

1 **Early Ipswichian (last interglacial) sea level rise in the Channel region: Stone Point Site of Special**  
2 **Scientific Interest, Hampshire, England**

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24  
25 **Abstract**

26 Constraining the speed of sea level rise at the start of an interglacial is important to understanding the size of  
27 the ‘window of opportunity’ available for hominin migration. This is particularly important during the last  
28 interglacial when there is no evidence for significant hominin occupation anywhere in Britain. There are very  
29 few finer grained fossiliferous sequences in the Channel region that can be used to constrain sea level rise and  
30 they are preserved only to the north of the Channel, in England. Of these, the sequence at Stone Point SSSI is  
31 by far the most complete. Data from this sequence has been previously reported, and discussed at a  
32 Quaternary Research Association Field Meeting, where a number of further questions were raised that  
33 necessitated further data generation. In this paper, we report new data from this sequence – thin section  
34 analysis, isotopic determinations on ostracod shells, new OSL ages and AAR analyses. These show early sea  
35 level rise in this sequence, starting during the pre-temperate vegetation zone IpI, but no early warming. The  
36 implications of this almost certainly last interglacial sequence for the human colonisation of Britain and our

37 understanding of the stratigraphic relationship of interglacial estuarine deposits with their related fluvial  
38 terrace sequences is explored.

39 **Keywords** AAR, OSL, interglacial sequence, sea level, estuary

40

## 41 **1. Introduction**

42

43 The last interglacial has been characterised as ‘deserted Britain’ (Ashton and Lewis, 2002), with no evidence  
44 of significant hominin occupation even after exhaustive review of multiple sequences (Lewis et al., 2011).  
45 Ashton and Lewis (2002) suggested that changes in hominin population density in Britain are controlled by  
46 two factors: the opening of the Dover Strait (and associated removal of a land bridge to the continent) and the  
47 rate of sea level rise at the start of an interglacial in relation to the rate of warming. Gupta et al. (2017)  
48 recently demonstrated that the opening of the Strait was a two-stage process, the second stage of which most  
49 likely occurred immediately prior to the last interglacial, although there is very little chronological control on  
50 this event. Once the land bridge had been removed, the rate of sea level rise becomes even more important,  
51 since hominins could not migrate once sea level had risen above the elevation of the sea floor (-40 m O.D. in  
52 the North Sea; -30 m O.D. at Dover; -60 m O.D. in the Channel). Therefore, to explain hominin absence from  
53 Britain during the last interglacial, when the Dover Strait had likely opened, constraining the rate of sea level  
54 rise is important to understand the size of the ‘window of opportunity’ available for hominin migration.

55 To constrain the rate of sea level rise at the start of the last interglacial, sedimentary sequences in the Channel  
56 region need to be investigated to complement the more northerly Dutch sequence (Long et al., 2015).  
57 However, shallow marine / coastal sequences in the Channel region are mostly clastic deposits that cannot be  
58 used to track sea level rise within the last interglacial (e.g. Bates et al., 2010, Pedoja et al., 2017). There are  
59 very few finer grained fossiliferous sequences that can be used to do this and they are preserved only to the  
60 north of the Channel, within the sheltered Solent seaway, peripheral to the main channel. (French sequences  
61 are more fragmentary and dated to earlier interglacials – e.g. Antoine et al., 2007). Of these, the sequence at  
62 Stone Point SSSI is the most complete (although of disputed age, which we discuss), and therefore the only  
63 sequence in the Channel region with the potential to constrain when sea level started to rise within the last  
64 interglacial, with associated impacts on hominin movement.

65 It is for this reason that this sequence was reinvestigated. Multiple fossil groups were analysed, from a much  
66 greater depth of sediments than previously recovered, with the aim of tracking sea level changes from the  
67 very start of the last interglacial. The Stone Point deposits comprise interbedded estuarine silts and peats  
68 exposed in the foreshore (Figure 1) and are associated with two gravel bodies (Figure 2). They have  
69 previously been assigned to both the last (Brown *et al.*, 1975) and the penultimate (Allen *et al.*, 1996)  
70 interglacial. Within the catchment of the former Solent river, interglacial deposits occur only at Stone Point  
71 (West and Sparks, 1960; Brown *et al.*, 1975); Pennington Marshes (Allen *et al.*, 1996); Bembridge Foreland  
72 (Preece et al., 1990) and St Leonards Farm (Briant *et al.*, 2013). These are all associated with the lower levels  
73 of the terrace sequence. At Pennington, St Leonard’s Farm and Bembridge Foreland, the deposits are of very  
74 limited depth ( $\leq 1.5$  m), compared with the sequences at Stone Point (9.5 m). Early investigations at the site  
75 only cored the thinner, more onshore part of the deposits (2.5 m depth). The data presented in this paper  
76 spans the full 9.5 m of the sequence, studied as part of the ‘Palaeolithic Archaeology of the Sussex /  
77 Hampshire Coastal Corridor’ (PASHCC) project. Results have previously been partially reported by Briant *et*  
78 *al.* (2006a,b & 2009) and the site was visited by the Quaternary Research Association in April 2009.  
79 Following field discussion at the site further work was undertaken to: more firmly establish the age of the  
80 sequence (a maximum age constraint using AAR on shell from the base of Unit 2 and OSL on Unit 5); the  
81 nature of the contact between the interglacial deposits and the gravel in Unit 3 (thin section analysis);  
82 quantify the palaeotemperature during the deposition of Unit 2 using the mutual climatic range (MCR)

83 method and provide a salinity signal from Unit 2 (isotopic analyses). This paper presents these new results in  
84 the context of the full palaeoenvironmental results previously published. These key issues and wider  
85 implications are discussed below.

## 86 2. History of previous research

87 West and Sparks (1960) observed estuarine silty clays from *c.* -0.2 to -2.7 m O.D., including two beds with  
88 freshwater affinities, near boreholes 9, 11 and 12 (Figure 1). They stated that these lay stratigraphically  
89 between the upper and lower gravels. Pollen and macroscopic plant remains suggest deposition during a  
90 temperate period, dominated by *Quercus*, *Pinus* and *Acer*. Molluscan assemblages were dominated by the  
91 brackish species *Hydrobia*.

92 Brown *et al.* (1975) sampled the deposit to the north-east of the West and Sparks borehole, near test pits 6a  
93 and 6b (Figure 1) from *c.* +1.0 to -1.5 m O.D. They also observed but did not investigate organic deposits in  
94 a further channel in the foreshore *c.* 2.6 m to the east, beyond an expanse of lower gravel. The interglacial  
95 silts thinned onshore and were not observed within the cliffs, but a finer-grained deposit separating two  
96 gravel successions in the cliff was thought to be a continuation of a 'pebbly clay' observed beneath the silts.  
97 Pollen spectra were similar to those of West and Sparks (1960), with the addition of *Phragmites* and higher  
98 *Alnus*. In the plant macrofossil assemblages, freshwater species such as *Carex*, *Menyanthes trifoliata* and  
99 *Sparganium* were in the peat beds and saltmarsh species including *Glaux maritima* and *Scirpus maritimus*  
100 were present throughout. All mollusca recorded were brackish (*Hydrobia*) and they found a single vertebrate  
101 remain of *Dama dama* (fallow deer).

102 Overlying the upper gravel is a 'brickearth' deposit (Unit 5, Figure 2, Table 1), described by Brown *et al.*  
103 (1975) as 1 m thick. This was studied in greater detail by Reynolds (1985, 1987) who described a lower  
104 brickearth 40 cm thick overlain by an 80 cm thick upper brickearth in which a Holocene soil had developed.  
105 The lower brickearth was silty (90-93% silt) and the upper brickearth more sandy (33-45% sand). Reynolds  
106 (1985, 1987) ascribed the lower brickearth to an interglacial warm period because thin section analysis  
107 showed a period of clay illuviation, followed by disruption of clay argillans, suggesting frost activity  
108 following soil formation. It was suggested that the lower brickearth predated the last interglacial  
109 (Ipswichian), and the upper dated from the end of the last glacial period (Late Devensian). Parks (1990) later  
110 sampled a section at Stone Point and thermoluminescence (TL) dated the upper brickearth to the Late  
111 Devensian (*c.* 20 ka), and the lower brickearth to an earlier event at approximately 120 ka (Parks, 1990) or 98  
112 ka (Parks and Rendell, 1992). This suggested that the palaeosol within the lower brickearth might have  
113 formed later, during interstadial conditions, although problems with zeroing the TL signal in sediments (see  
114 below) means that these ages are likely to be too old. Thus the age of these overlying silty sands (Unit 5)  
115 requires reinvestigation. The palaeosol is no longer exposed at the site, but Unit 5 is sufficiently thick to  
116 allow sampling for OSL dating.

117 West and Sparks (1960) and Brown *et al.* (1975) both attributed the Stone Point organic deposits to the  
118 Ipswichian (last interglacial, Marine Isotope Stage [MIS] 5e). Re-mapping of the Solent terrace deposits by  
119 Allen and Gibbard (1993) agreed with this age attribution. However, Keen (1995) reiterated the suggestion by  
120 Reynolds (1987) that it was likely the palaeosol separating the brickearth units is of Ipswichian (MIS 5e) age,  
121 implying the estuarine deposits must date to an earlier warm phase. This seemed to be reinforced by the  
122 identification of Ipswichian-age freshwater silts from -3.9 to -5.3 m O.D. at Pennington Marshes (Allen *et al.*,  
123 1996; Gibbard and Preece, 1999; Bridgland, 2001; Antoine *et al.*, 2003), within the Pennington Gravel  
124 which was thought to postdate the Lepe Gravel. A further reinterpretation of the terrace stratigraphy led  
125 Bridgland (2001) to suggest an age of MIS 7a. Bridgland and Schreve, (2001), however, put forward the view  
126 that the (albeit sparse) mammal remains might point to a date in the earlier part of the MIS 7 interglacial. The  
127 relationship between the Pennington Gravel and the Lepe Gravel has since been queried by Westaway *et al.*  
128 (2006) who suggest that in places both fall within an alternative gravel body called the St Leonards Farm

129 Gravel. The stratigraphy of these lower terraces was not, however, fully defined in this scheme. Hatch (2013,  
130 et al., submitted), on the basis of detailed borehole analysis, confirmed that the Pennington Gravel was a  
131 separate deposit, and correlated the Lepe gravels with the Milford on Sea Gravel.

### 132 **3. Materials and Methods**

133 Sections through the deposits were exposed using a combination of mechanically-cleared sections (sections 1  
134 and 5, 2003), mechanically-dug test pits (test pits 4-7, 2003), hand drilled boreholes (boreholes 8-13, 2004)  
135 and mechanically-recovered boreholes (boreholes 14-16, 2005). Samples were taken as bulk material, spot  
136 samples and as blocks of sediment for both fossil analysis and thin section investigation. Light-tight samples  
137 were also taken for OSL dating.

138 OSL dates from sections 1 and 5 and test pit 4a were published in Briant et al. (2006a); ostracods from test  
139 pits 4b, 4d, 7 and borehole 13 in Briant et al. (2006b) and full palaeoenvironmental data from all locations,  
140 including the newly drilled Borehole 16 in the QRA Field Guide (Briant et al., 2009). The age of the deposits  
141 (particularly Unit 5), nature of Unit 3 and salinity signal from Unit 2 were much debated at this meeting and  
142 so further analysis was undertaken to more firmly establish age (OSL from Unit 5, sampled in 2010, AAR  
143 from Unit 2), the nature of Unit 3 (thin section analyses) and salinity (isotopic analyses on ostracods).

144 Thin section analysis was undertaken on two samples from Unit 3 from Section 1 and Test pit 6a (Figure 2).  
145 Intact block samples were taken for thin section production. Thin sections were prepared using the methods  
146 outlined in van der Meer (1993). The thin sections were photographically recorded and features observed  
147 under a low power microscope.

148  
149 Pollen samples were analysed from eight levels within Borehole 16 (previously reported in Briant et al.,  
150 2009) and an additional sample from Unit 3 in March 2016, which proved to be barren. These were prepared  
151 using the standard hydrofluoric acid technique and counted for pollen using a high-power stereo microscope.  
152 Pollen preservation was relatively good, although some samples showed evidence of post-depositional  
153 oxidation. Main sums varied between 105 and 291, and pollen concentrations varied widely between 23412  
154 and 258966 grains per ml. It should be noted that for statistically reliable data, pollen sums of at least 300 are  
155 generally recommended. These counts rarely reach these levels, and care must therefore be taken during  
156 interpretation.

157  
158 Plant macrofossils were analysed from four samples from BH16 Table 2). They ranged in size from 100ml  
159 (740-746 and 750-755cm) to only 50 ml (761-768 and 772-777 cm). The sediment samples were soaked in  
160 water and then wet sieved through a nest of sieves (down to a 150 µm mesh size). Macroscopic plant remains  
161 were then picked from the resulting residues.

162 Molluscan analysis was undertaken on 7 samples from test pits 4d and 6a by Professor David H. Keen (Table  
163 3). Samples from Borehole 16 (drilled in September 2005) were not completed because of his death, although  
164 a brief scan of the samples was undertaken by Dr R.C. Preece, as discussed below. The samples were washed  
165 through sieves to 500µm aperture, dried and sorted under a 10-60x binocular microscope. Counting  
166 conventions follow Sparks (1961) in which each gastropod apex is recorded as a single individual, and each  
167 bivalve hinge line as half an individual. Taxonomic nomenclature follows the usage of Seaward (1990).

168 Coleopteran analysis was undertaken on 13 samples from test pits 4b, 4d, 6a, 6b and 7, borehole 16 and a  
169 small test sample collected in 1974 from the organic deposit exposed on the foreshore about three metres to  
170 the west of the southern end of the measured section AA of Figure 3 of Brown et al. (1975) (Table 4). Most  
171 of the samples come from Unit 2d, but one sample from the base of Borehole 16 fell within Unit 2b. The  
172 more organic horizons were intensely compressed and difficult to break down. Samples were therefore frozen  
173 for several hours, followed by washing in hot water and gentle manual splitting of the layers along the

174 bedding planes. The resultant slurry was then washed over a 0.25 mm mesh and the insects concentrated by  
175 paraffin flotation (Coope 1986). In many cases the insect fossils were flattened and appeared rather  
176 decomposed and pale. The nomenclature and taxonomic order follow that of Lucht (1987). The numbers  
177 opposite each species and in each sample column indicate the minimum numbers of the species in the sample.  
178 Non-British species are indicated by \*

179 Quantification of the climate signal from the coleopteran assemblages was undertaken using the Mutual  
180 Climatic Range (MCR) method (Atkinson et al. 1987). This was automated using the BugsMCR function of  
181 the BugsCEP database (Buckland & Buckland 2012). TMax (mean July air temperature) and TMin (mean  
182 January air temperature) were calculated for Units 2b and 2d separately. These temperature estimates are  
183 based on the thermal climate requirements of carnivorous and scavenging beetle species with food  
184 requirements that are independent of particular macrophytes or terrestrial plants.

185 Ostracod and foraminiferal analysis was carried out on 44 samples from test pits 4b, 4d and 7 and boreholes  
186 13 and 16 (Table 5). The samples were first placed in ceramic bowls and dried thoroughly in an oven. Each  
187 was then covered in boiling water (with a little sodium carbonate added to help release the clay fraction) and  
188 allowed to soak. They were washed through a 75 micron sieve with hot water. The remaining residue was  
189 then decanted back into the bowl which was placed in the oven again, to dry. When dry, the samples were  
190 stored in plastic bags. Each sample was then dry-sieved into various fractions and the residue little-by-little  
191 sprinkled onto a metal picking tray, a representative number of each species being picked out under a  
192 binocular microscope and placed in a 3x1" faunal slide. A semi-quantitative estimate of the abundance of  
193 each species was also noted. It was not possible to quantify palaeotemperatures from the ostracod  
194 assemblages because they contained exclusively brackish water species, and the Mutual Ostracod  
195 Temperature Range (MOTR) method is currently applicable only to non-marine/freshwater assemblages  
196 (Horne, 2007).

197 Diatom analysis was undertaken on 7 samples from borehole 16. Preparation followed standard techniques:  
198 the oxidation of organic sediment, removal of carbonate and clay, concentration of diatom valves and  
199 washing with distilled water (Battarbee 1988). Two coverslips, each of a different concentration of the  
200 cleaned solution, were prepared from each sample and fixed in a diatom mounting medium (Naphrax) of a  
201 suitable refractive index for microscopy. Slides were scanned and counted at magnifications of x400 and  
202 x1000 under phase contrast illumination. Diatom species' salinity preferences are discussed using the  
203 halobian groups of Hustedt (1953, 1957: 199), these salinity groups are summarised as follows:

- 204 1. Polyhalobian: >30 g l<sup>-1</sup>
- 205 2. Mesohalobian: 0.2-30 g l<sup>-1</sup>
- 206 3. Oligohalobian - Halophilous: optimum in slightly brackish water
- 207 4. Oligohalobian - Indifferent: optimum in freshwater but tolerant of slightly brackish water
- 208 5. Halophobous: exclusively freshwater
- 209 6. Unknown: taxa of unknown salinity preference.

210 Trace-element (Mg/Ca and Sr/Ca) and stable-isotope (<sup>18</sup>O/<sup>16</sup>O and <sup>13</sup>C/<sup>12</sup>C) determinations were undertaken  
211 on shells of the ostracod *Cyprideis torosa* from 11 samples from test pits 4b, 4d and 7 and borehole 13 (Table  
212 6). Unfortunately, by the time isotopic analyses were undertaken on these samples, samples from borehole 16  
213 were no longer available. Well-preserved shells of *C. torosa* lacking signs of calcite overgrowth or  
214 dissolution were chosen, brush-cleaned and air dried in preparation for trace-element and stable-isotope

215 analyses. All shells selected for analysis were smooth morphotypes and adults. Five single shells from each  
216 chosen level were placed in separate acid-washed 5 mL polyethylene tubes, dissolved in 2 mL of Aristar  
217 grade HCl acid and analysed for Ca, Mg and Sr using a JY Ultima 2C ICP-AES calibrated using BDH  
218 Spectrosol mono-element standards for ICP. Results were corrected for blank contamination and for  
219 instrumental drift using an external drift monitor and expressed as molar trace-metal to Ca ratios for plotting  
220 purposes. Instrumental precision was  $\pm 1.2\%$  and  $\pm 2.4\%$  RSD for Mg/Ca and Sr/Ca, respectively. Multiple-  
221 shell (4 adult shells per sample) samples were analysed for oxygen and carbon isotopes using a  
222 ThermoFinnigan Delta Plus XP mass spectrometer connected to a GasBench. Results were expressed in delta  
223 units relative to the VPDB standard. Typical precision was  $\pm 0.05\%$  for both  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$ . Methods used to  
224 estimate temperature and salinity from these results are discussed in the results section below.  
225

226 Four OSL samples from Unit 5 were prepared to quartz in the same way as those reported in Briant et al.  
227 (2006a). This involved separation of the modal size fraction by wet sieving and treatment with hydrochloric  
228 and hydrofluoric acids and removal of heavy minerals using sodium polytungstate. Samples with feldspar  
229 contamination (detected using infra-red (IR) light stimulation, Hütt et al., 1988) were subjected to further  
230 treatment in fluorosilicic acid. Palaeodose was determined in the Research Laboratory for Archaeology and  
231 the History of Art, Oxford, using automated Risø measurement systems with both blue diodes and green  
232 halogen light (Briant et al., 2006a). The Single Aliquot Regenerative (SAR) protocol of Murray and Wintle  
233 (2000) was used, with the addition of a post-IR blue OSL procedure (Banerjee et al., 2001) to further  
234 minimise feldspar contributions. Single aliquot luminescence measurements were made at  $125^\circ\text{C}$ , with  
235 preheat 1 (PH1) of  $260^\circ\text{C}$  for 10 s, preheat 2 (PH2) of  $220^\circ\text{C}$  (initial measurements) or  $240^\circ\text{C}$  (additional  
236 measurements) for 10 s and up to 6 regeneration dose points. Initial measurements on all four samples were  
237 on aliquots 6 mm in diameter and comprised grains in the 180 to 255  $\mu\text{m}$  fraction, meaning that c. 700-850  
238 grains were present on a disc, of which c. 35-45 are likely to be active (Duller, 2008). Additional  
239 measurements on X4103 and 4105 were on aliquots 3-4 mm in diameter and also the 180 to 255  $\mu\text{m}$  fraction,  
240 giving c. 150-500 grains on a disc, of which c. 7-25 are likely to be active (Duller, 2008). Equivalent dose  
241 (De) is a weighted mean of between 10 and 24 aliquots. Luminescence behaviour was very good, with low  
242 IRSL values suggesting minimal presence of feldspars and good recycling (Table 7).

243 Environmental dose rates for the Unit 5 ages were calculated on the basis of Inductively-Coupled Plasma  
244 Mass Spectrometry (ICP-MS). Radioisotope concentrations were converted to dose rates using the conversion  
245 factors of Adamiec and Aitken (1998) and grain-size attenuation factors of Mejdahl (1979). Cosmic dose  
246 rates were calculated using the equation of Prescott and Hutton (1994) and it was assumed that overburden  
247 accumulated soon after deposition and was negligible relative to the burial period. Interstitial water content  
248 attenuates dose rates, and this was corrected for using the absorption coefficient of Zimmerman (1971). It  
249 was assumed that present-day moisture content was representative of water contents throughout burial  
250 (percentage dry weight of sample) with a 5% error to reflect uncertainty in estimation. Ages were calculated  
251 by dividing the mean equivalent dose (De) by dose rate and presented as  $\pm$  one standard error (i.e. standard  
252 deviation /  $\sqrt{n}$ ).

253 AAR analyses were undertaken on two small individual *Bithynia tentaculata* opercula from Unit 2c within  
254 BH16 between 754 and 756 cm depth (NEaar 3312-3313). Samples were prepared using the procedures of  
255 Penkman et al. (2008) to isolate the intra-crystalline protein by bleaching. Two subsamples were then taken  
256 from each opercula; one fraction was directly demineralised and the free amino acids analysed (referred to as  
257 the 'Free' amino acids, FAA, F), and the second was treated to release the peptide-bound amino acids, thus  
258 yielding the 'total' amino acid concentration, referred to as the 'Total hydrolysable amino acid fraction  
259 (THAA, H\*)'. Samples were analysed in duplicate by RP-HPLC.

260 The revised technique of amino acid analysis developed for geochronological purposes (Penkman et al.,  
261 2008) combines a recent reverse-phase high-pressure liquid chromatography (RP-HPLC) method of analysis  
262 (Kaufman and Manley, 1998) with the isolation of an 'intra-crystalline' fraction of amino acids by bleach

263 treatment (Sykes et al., 1995). This combination of techniques results in the analysis of D/L values of  
264 multiple amino acids from the chemically protected (closed system) protein within the biomineral, thereby  
265 enabling both decreased sample sizes and increased reliability of the analysis. Amino acid data obtained from  
266 the intra-crystalline fraction of the calcitic *Bithynia opercula* indicate that this biomineral is a particularly  
267 robust repository for the original protein (Penkman et al., 2011) and therefore has been targeted in this study.

## 268 269 **4. Results**

### 270 271 **4.1 Description of sedimentary sequence**

272  
273 The lowest member of the Quaternary succession at Stone Point is an angular flint gravel (Unit 1 – Lepe  
274 Lower Gravel) whose lower contact was not observed in detail, representing a gravel aggradation of the  
275 former Solent River. It is a 2.5 m thick planar-cross-bedded gravel with thick sand bed, present both beneath  
276 the modern beach and in the lower part of the cliff succession up to a level of c. 3 m O.D. (Figure 2, Briant et  
277 al., 2009). West & Sparks (1960) suggested that the lower gravels and estuarine deposits pass beneath the  
278 upper gravels exposed in the cliff. Following a period of cliff erosion Brown *et al.* (1975) traced only the  
279 lower gravels into the cliff up to a level of about 2 m O.D., a metre lower than observed in 2003 (Briant et al.  
280 2009). Brown et al. (1975) suggested that this lower gravel was succeeded by a thin bed of inorganic pebbly  
281 clay about 25cm thick; also in some places a bleached sandy horizon and iron pan suggesting podsolisation of  
282 the upper part of the lower gravel. PASHCC excavations did not find this ‘pebbly clay’. Instead, a thin sand  
283 and silt bed (Unit 3) was observed both overlying the interglacial silts in Test pit 6b and between the two  
284 gravels (Units 1 and 4) in section 1 (Figure 2). Unit 3 was noticeably thicker (c. 10-15 cm) in exposures to the  
285 east of PASHCC section 5 observed by BB in March 2016. A sample from this thicker exposure was  
286 prepared for pollen analysis but proved to be barren.

287  
288 The full extent of Units 1 and 2 is unknown, but they are not present at Lepe Coastguard House, 0.6 km west  
289 of Stone Point (Reynolds, 1987), or at Cadland, 2 km to the north. At both these locations a low terrace  
290 gravel of the River Solent rests directly on Tertiary bedrock, its base at approximately the same level as the  
291 base of the upper gravel (Unit 4) at Stone Point. The estuarine deposits and lower gravel at Stone Point  
292 appear, therefore, to occupy a depression cut in Tertiary bedrock to altitudes below present sea level.

293  
294 Unit 2 comprises the Stone Point interglacial deposits. Units 2a to 2c are only recorded from the deeper  
295 interglacial sequence recovered by the PASHCC project from Borehole 16 (Figure 2). These yielded some  
296 fossils with freshwater affinities (Table 2). Unit 2a is a cemented fine sand and silt with frequent gravel  
297 including chalk, conformably overlain by Unit 2b which is characterised by dark brown, fine sandy organic  
298 clay and fibrous peat. This in turn is conformably overlain by Unit 2c which comprises an interbedded  
299 laminated brown organic clay and grey clay with lenses of fibrous peat and fine sand containing molluscs.

300 However, the bulk of the sequence is represented by Unit 2d - a stiff grey clay with shells, interbedded with  
301 thin discontinuous beds of compressed wood-peat, especially in the upper parts of the profile. These peat  
302 beds were labelled A to E by Brown *et al.* (1975) and noted to be between 2 and 24 cm thick and containing  
303 abundant *Phragmites* remains. These higher estuarine peats and clays are separated into two outcrops  
304 occupying depressions in the lower gravel separated by a gravel high. The uppermost clays show signs of  
305 weathering and attain an altitude of about 0.8 m O.D. The peat layers are highly compressed. West and  
306 Sparks (1960) described organic sediments from a site lower down on the foreshore, probably from a level  
307 lower in the succession than those described by Brown *et al.* (1975). The estuarine deposits of Unit 2d have  
308 yielded coccoliths, pollen, abundant plant macrofossils, molluscan remains, the partial tusk of a straight-  
309 tusked elephant (*Palaeoloxodon antiquus*) and a tibia of a fallow deer *Dama dama* (West and Sparks 1960;  
310 Brown *et al.*, 1975; Preece *et al.*, 1990; Briant et al., 2006b, 2009).

311 Unit 3 is a discontinuous 5–10 cm thick bed of laminated fine sand and silt, overlying a sharp contact at the  
312 top of Units 1 and 2 depending on location (Figure 2). Two samples were taken from this unit by PASHCC  
313 for thin section analysis (Figures 2 and 3). Structures observable in the field are fine laminae, distorted in  
314 places in Section 1. Thin section analysis also showed that this unit comprised interbedded sands and  
315 silts/clays, with some distortion of clays in Section 1 (Figure 3a). Neither thin section showed widespread  
316 evidence of soil formation, e.g. translocated clays or void filling. In Section 1 there was a single cross-section  
317 of an organic item (root or stem), surrounded by a void in which some clay had built up (Figure 3b). This is  
318 probably a modern intrusion into the section because gorse scrub was cleared from the section. The similarity  
319 between the samples from the two sections (Figures 3a, 3c) suggests that this unit is an effective stratigraphic  
320 marker placing the interglacial deposits between the two gravels. It is interpreted as a period of low-energy,  
321 fine-grained deposition, later distorted either by loading of saturated sediments or periglacial activity. A  
322 sample was prepared for pollen analysis in March 2016 but proved to be barren.

323  
324 The Lepe Upper Gravel (Unit 4) is 3 to 3.5 m of horizontally-bedded flint-dominated gravels with occasional  
325 thin sand lenses, erosionally overlying Unit 3. It is interpreted as a fluviially-deposited gravel of the former  
326 Solent river, partly due to the lithological composition (Allen and Gibbard, 1993). Cross bedding observed in  
327 some of the finer sandy material, indicated an easterly flow direction from approximately 280°N (Brown *et*  
328 *al.*, 1975). There is some evidence for periglacial modification of the upper gravel since involutions and stone  
329 erections are weakly developed in its upper levels. The surface of the gravel at Stone Point was considered by  
330 Brown *et al.* (1975) to equate with the terrace surface that is widespread at about 7-8m O.D. between Calshot  
331 and Lymington and mapped as Lepe Gravel by both Allen and Gibbard (1993) and Westaway *et al.* (2006).

332  
333 Unit 5 comprises 50 cm to 1 m of silty fine sand with dispersed fine pebbles gradationally overlying Unit 4.  
334 At present, this is exposed sporadically at the top of the sequence (Briant *et al.*, 2009, Figure 2), showing  
335 some modern soil development in places (Section 1) and bricks and roots in others (Section 5). Table 1  
336 compares this deposit in 2010 with descriptions by Reynolds (1985) and Parks (1990), both of whom  
337 described the cliffs before the brickearth was disturbed by construction on top of the cliff (Reynolds, 1985).  
338 They described a two part deposit, with a discontinuous lower brickearth up to 40 cm thick separated from an  
339 upper brickearth up to 80 cm thick by a line of flints. Both these deposits showed evidence of soil  
340 development with the palaeosol separating the two units perhaps representing an interglacial soil (Reynolds,  
341 1987). There is currently no evidence for palaeosol development within Unit 5, suggesting that the sequence  
342 that is currently exposed is likely to be truncated compared to what was exposed in the 1980's.

## 343 4.2 Palaeoenvironmental analyses

### 344 4.2.1 Pollen analysis

345  
346 Pollen analysis reported here (Figure 4) is from borehole 16 only, to capture the base of the sequence.  
347 Combination of this with the upper part of the sequence reported by West and Sparks (1960, Figure 12)  
348 enables the full vegetation succession to be discussed. Starting from the base of the sequence, the basal  
349 samples (7.46 m [base of Unit 2d], 7.57 m [Unit 2c] & 7.73 m [Unit 2b]) were dominated by grass (c.31.3-  
350 35.1%) and pine (c.13.2-18.3%) with sedges (Cyperaceae) (c.4.8-11.3%) and spruce (*Picea*) (1.8-3.5%).  
351 These samples also had elevated proportions of *Pteropsid* spores (c.9.5-18.4%) and pollen of the aquatic bur-  
352 reed (*Sparganium*) (c.7.3-24.9%). The sample from 7.46 m is interesting in that it represents something of a  
353 transition, with the first occurrence of oak, and an increase in the frequency of hazel, juniper (*Juniperus*) and  
354 birch (*Betula*). These lower samples record a boreal grass-pine phase and can be assigned to the pre-  
355 temperate stage (I) of the interglacial.

356  
357 Above this, in Unit 2d, there is a significant difference between those samples analysed from the lower part  
358 of the unit in borehole 16 and those analysed from the upper part of the unit by West and Sparks (1960).  
359 Those samples from borehole 16 had a relatively homogeneous assemblage dominated by grass (Poaceae),  
360 hazel (*Corylus*), oak (*Quercus*) and pine (*Pinus*). Subtle changes in the proportion of herbs such as buttercup

361 (*Ranunculus*) and strapwort plantain (*Plantago lanceolata*) can be seen, and the minor arboreal taxa present  
362 included elm (*Ulmus*), alder (*Alnus*), ash (*Fraxinus*), maple (*Acer*), willow (*Salix*) and holly (*Ilex*). This part  
363 of the sequence represents a temperate mixed-oak woodland environment that can be assigned to the early  
364 temperate stage (II) of the interglacial. The lower percentages of *Quercus* and *Corylus* compared to the West  
365 and Sparks (1960) sequence suggest assignment to substage IIa, since they assigned their sequence to  
366 substage IIb (Phillips, 1974). There may be some indication of estuarine sedimentation in that pollen of the  
367 fat hen family (Chenopodiaceae) appears to increase towards the top of the sequence. Emergent aquatic  
368 vegetation (bur-reed) appears to be present throughout.

369  
370 In the upper part of the sequence reported by West and Sparks (1960) and Brown et al. (1975), pollen  
371 analysis suggests the presence locally of mixed-oak woodland. These authors assigned the sequences that  
372 they observed to zone IIb of the Ipswichian with the presence of *Carpinus* indicating a position late in this  
373 zone. Herbaceous pollen mainly comprises Poaceae and Chenopodiaceae which reaches 54% AP in some  
374 peat beds, perhaps suggesting saltmarsh conditions during deposition of this upper organic layer (Brown et  
375 al., 1975). There is a gradual increase in hazel (*Corylus*) pollen upwards.

#### 376 4.2.2 Plant macrofossils (Michael H. Field & Rianne M. J. Simons)

377  
378  
379 The limited diversity and small size of the samples mean that it is difficult to identify any significant changes  
380 in the composition of the assemblages and the four samples from borehole 16 are therefore discussed together  
381 (Table 2). Waterside and damp ground taxa are dominant in all the assemblages, suggesting significant  
382 swamp vegetation at the margin of the water-body. Particularly common is *Typha* sp., but also present were  
383 *Eleocharis* cf. *palustris*, *Sparganium erectum*, *Juncus* sp. and *Carex* sp. Further away from the water-body,  
384 there is evidence of only two tree taxa. *Betula* probably grew in the drier areas surrounding the site, while  
385 *Alnus glutinosa* was present where conditions were damp.

386  
387 In contrast, aquatic taxa are not well represented in the assemblages, but do give some indication of salinity.  
388 The floating aquatic *Hydrocharis morsus-ranae* requires still, fresh-water conditions and is present in the two  
389 lower samples from Units 2b and 2c. However, the samples from Unit 2d yielded one fruit of *Ruppia* and  
390 *Scirpus maritimus* which both suggest a degree of salinity at the time of deposition. *Zannichellia palustris*  
391 also occurs in Unit 2d. This is a species that lives in fresh-water but can also tolerate a degree of salinity. It  
392 is unlikely that the fresh-water and brackish components of the assemblages inhabited the site at the same time,  
393 and indeed there is some evidence that the freshwater elements are concentrated in the lower parts of the  
394 sequence and the more saline elements in the higher parts. Where there is mixing, taphonomic processes may  
395 have washed the fresh-water component down into the tidal zone or a fresh water-body was occasionally  
396 inundated by saline water bringing with it the remains of salt tolerant plants.

#### 397 4.2.3. Molluscs (David H. Keen)

398  
399  
400 Molluscs are only described from Unit 2d (Test pits 4 and 6, Table 3), because of the untimely death of David  
401 Keen before analysis of borehole 16. The fauna from Unit 2d described here differs little to that reported from  
402 previous publications (West & Sparks, 1960; Brown et al., 1975). Preservation of shell was patchy and the  
403 fauna composed overwhelmingly of Hydrobiidae with fragments of *Scrobicularia plana*. The current study  
404 notes the occurrence of two further bivalve taxa, *Cerastoderma edule* and *Abra* spp, taking the total fauna to  
405 6 species. This fauna suggests brackish conditions in a lagoon or estuary. It is not certain whether the site of  
406 deposition was a lagoon or the mud banks of an estuary. The preference of *H. ventrosa* for sites sheltered  
407 from direct contact with estuarine waters and tides (Kerney, 1999) perhaps indicates a lagoon for the site of  
408 deposition. This possibility is reinforced by the total lack of any freshwater shells in Unit 2d. In the present  
409 and the two previous studies *H. ventrosa* is more numerous than *H. ulvae* at most levels, although West &  
410 Sparks (1960) record a majority of *H. ulvae* near the bottom of their borehole at depths below 92 cm. The  
411 mean salinity values from comparing the ranges of these species (after Peacock, 1993) are 20-25‰ (current

412 salinity tolerances of *H. ventrosa* are between 6 and 25 ‰; *H. ulvae* between 10 and 40 ‰; *S. plana* and most  
413 species of *Abra* no lower than 20 ‰). Whilst West and Sparks (1960) suggested that a change in salinity  
414 could be observed in their sequence, this is not observed in Unit 2d in this investigation or the research of  
415 Brown et al. (1975) and, given the small size of the samples used by Sparks, should be treated with caution.

416  
417 All of the taxa recorded live in British waters at present so the assemblage is clearly of interglacial character.  
418 The presence of *Ovatella myosotis* (*Phytia myosotis* in earlier studies) suggests conditions of some warmth as  
419 its modern range only extends as far north as Britain and Denmark (Kerney, 1999). None of the species in  
420 this small assemblage have any biostratigraphic significance and thus cannot give any indication of the age of  
421 the deposits.

422

#### 423 4.2.4 Coleoptera (G. Russell Coope & Nicola J. Whitehouse)

424  
425 The Unit 2b assemblage from sample BH16 7.74 – 7.79 m (Table 4) contains only ten taxa, including a group  
426 of phytophagous beetles that feed on reedy vegetation in a freshwater setting such as *Typha*, *Phragmites*,  
427 *Sparganium*, *Carex* and *Eriophorum*. This assemblage provides no evidence of open water or saline  
428 conditions. The Coleoptera therefore suggest that the local environment at this time was fen dominated by  
429 *Typha* and *Phragmites* which was probably visited by large herbivorous mammals, suggested by the dung  
430 beetle *Sphaeridium scarabaeoides / lunatum*.

431  
432 Only two of the species recorded from this samples from Unit 2b could be used for temperature  
433 reconstruction using the MCR database. They gave a very wide range of possible palaeotemperature values  
434 with 100% overlap of the climatic ranges of the species used. Mean July temperature (TMax) lay within the  
435 range +9°C and +26°C and mean January temperature (TMin) within the range –13°C and +13°C. The lowest  
436 values of this range and the absence of more thermophilous species may suggest that temperatures during  
437 deposition of Unit 2b were lower than those during deposition of Unit 2d.

438  
439 All the samples from Unit 2d (from Test pits 4, 6 and 7, the top of Borehole 16 and the 1974 sample, Table 4)  
440 are very similar. The predominant habitat was extensive reed swamp with *Phragmites*, *Carex*, *Scirpus* and  
441 *Typha* with open stationary water and occasional mud banks that were bare of vegetation. There is evidence  
442 of the presence of oak trees, ash and hazel bushes (e.g. *Rhynchaenus quercus*, *Curculio venusius*, *Hylesinus*  
443 *crenatus* and *H. oleiperda*). *Platypus cylindricus*) though probably at some distance from the marshy area.  
444 The stag beetle *Lucanus cervus* and the lesser stage beetle *Dorcus parallelipedus* indicate decaying and  
445 dying wood in the vicinity. *Scolytus carpini*, which is principally found on *Carpinus betulinus*, implies the  
446 presence of this tree (Koch 1992), a species that requires warm conditions. The presence of *Pinus sylvestris* is  
447 indicated by *Hylobius abietis* and *Hylastes angustatus*, whilst *Hylurgops palliatus* is found under the bark of  
448 all types of conifers including *Abies*, *Larix* and *Pinus* spp. (Bullock 1993).

449  
450 These assemblages differ from Unit 2b in providing clear evidence of saline habitats, including brackish  
451 water and salt marsh species such as *Bembidion normanum* and *Paracymus aeneus*. The assemblage is  
452 however dominated by more cosmopolitan species that can tolerate brackishness but do not actively prefer it,  
453 such as *Hydroporus*, *Noterus clavicornis*, *Cercyon tristis* and *Enochrus* sp. In summary, the Coleoptera from  
454 Unit 2d suggest a salt marsh with pools of eutrophic water in which were accumulations of decomposing  
455 plant material. A significant number of dung beetles associated with large grazing animals (e.g. *Caccobius*  
456 *schreberi*, *Onthophagus massai*, *O. verticocornis*, *O. fractorornis*, *Aphodius stictus* and  
457 *Aphodius* sp.) together with a diverse forest beetle community also indicates a climax woodland nearby with  
458 numerous animal grazers.

459  
460 There can be little doubt that the coleopteran assemblage from both subunits indicates fully temperate  
461 interglacial conditions. The non-British species (e.g. *Bembidion elongatum*, *Oodes gracilis*, *Cybister*  
462 *lateralimarginalis*, *Melanotus niger*, *Throscus cf exul*, *Oniticellus fulvus*, *Caccobius schreberi*, *Onthophagus*

463 *massai*, and *Heptaulacus* sp.) are all relatively southern with normal northern geographical limits that cross  
464 northern France and Germany. The British range of several others only reaches southern England and some  
465 of these are extraordinarily rare in this country today (*Bembidion octomaculatum*, *Chlaenius tristis*, *Dimetrius*  
466 *imperialis*, *Hydrovatus cuspidatus*, *Paracumus aeneus*, and *Hydrous caraboides*). The temperature during the  
467 summer months was thus a degree or two higher than that in southern England at the present day. Winters  
468 may have been no colder than now. Precipitation values cannot be estimated on the basis of this fauna since,  
469 though the marshy habitats remained throughout the summer months, the moisture may have been maintained  
470 to some extent by the adjacent marine water level. Biostratigraphically, the fauna resembles most closely  
471 those that have already been ascribed to the last interglacial (Coope, 2001), particularly in the non-British  
472 species described above, including the well-known indicators of this time period *Onthophagus massai* and  
473 *Caccobius schreberi*. It also includes a number of distinctive fragments of unidentified species which are not  
474 listed in Table 4 but have also been found exclusively in faunas of this age. There are also similarities to the  
475 fauna reported from the sequence at Hackney Downs that was initially dated to the last interglacial (Gibbard,  
476 1994) but more recently suggested to date from an interglacial that correlates with MIS 9 (Green et al., 2006).  
477 Key species that are present here at Stone Point, also at Hackney Downs (Green et al., 2006) and in many last  
478 interglacial sequences (Coope, 2001) include *Bembidion elongatum* and *Caccobius schreberi*. In addition  
479 *Onthophagus massai* is present, which is reported from only a few Ipswichian Interglacial deposits. Note that  
480 there is some taxonomic debate about this species, outlined in full in Langford et al. (2017), but we retain it  
481 here because it represents a specific morphotype that has biostratigraphic significance.

482  
483 Forty-four coleopteran species from all the samples from Unit 2d (Table 4) were used to obtain the  
484 temperature reconstruction using the MCR database, making it very robust. They give the following  
485 palaeotemperature values with 100% overlap of the climatic ranges of the species used: mean July  
486 temperature lay within the range +17°C and +18°C; mean January temperature lay within the range -2°C and  
487 0°C. Because several of the more southern species, which today live in central and southern Europe (e.g. *B.*  
488 *elongatum*, *O. massai*) are not present in the MCR database, this may be a conservative temperature estimate.  
489 These estimates are very similar to palaeotemperature estimates from Deeping St James (Keen et al., 1999 -  
490 TMax 17-18°C, TMin 0 to 4°C) and Itteringham (Beesley, 1988 - TMax 17-19°C, TMin 1 to -4°C).

#### 491 492 **4.2.5. Ostracods and foraminifera (John E. Whittaker)**

493  
494 Samples were taken from the full depth of the sequence from Test pits 4b and 4d, Test pit 7 and Boreholes 13  
495 and 16. No ostracods or foraminifera were preserved from Unit 2b. The foraminifera and ostracods from Unit  
496 2c (Table 5) are very low diversity brackish, inner estuarine assemblages; those of intertidal mudflats and  
497 creeks. There are no marine or even outer estuarine species present so the site must have been much too far  
498 from the then Solent Estuary mouth for them even to be brought in on the tide or in periods of storm. There  
499 are however a few freshwater ostracods, which suggest that the site was at that time close enough to  
500 freshwater ecosystems for fossils to be transported downstream from them.

501  
502 Unit 2d has a different assemblage from Unit 2c. The lower parts of test pit 7, borehole 13 and borehole 16  
503 contain a high number of intertidal foraminiferal species such as *Haynesina germanica* and *Elphidium*  
504 *williamsoni* in test pit 7, although not in borehole 13, which is dominated by *Ammonia aberdoveyensis* and  
505 *Elphidium waddense*. Also present in both is the euryhaline estuarine ostracod *Leptocythere castanea*,  
506 although the sequence is dominated by abundant *Cyprideis torosa* (all non-noded). This part of the sequence  
507 is therefore interpreted as a tidal (brackish) mudflat. There is no freshwater influence, neither is there  
508 indication of salt-marsh nearby. The salinity was also clearly above c. 6‰ as evidence by the exclusively  
509 non-noded populations of *Cyprideis torosa*.

510  
511 In the upper parts of Unit 2d (test pits 4b and 4d, top of test pit 7) the dominant foraminifera are *Ammonia*  
512 *aberdoveyensis*, *A. limnetes* and *Elphidium waddense*, all of which indicate brackish conditions, in a tidal  
513 river or estuary, with *E. waddense* and the agglutinating saltmarsh species, *Trochammina inflata* indicating

514 low saltmarsh. The dominant ostracod is *Cyprideis torosa*, which is represented by a full population age  
515 structure from adults to the smallest juveniles, so is definitely *in situ*. The populations are almost entirely  
516 smooth, although some of the specimens have small nodes which may indicate that the salinity is at or near a  
517 point where nodding (given other suitable ecological conditions being present) can develop; i.e. c. 5‰ (see  
518 Meisch, 2000). This species is indicative of sheltered creeks, as is *Leptocythere porcellanea*, whereas the  
519 rarer *Loxoconcha elliptica* is usually found in more open intertidal flats. Non-marine ostracods are rare, but  
520 present, although both *Candona* sp. and *Heterocypris salina* are able to tolerate low salinities in coastal pools.  
521 The environment represented in the upper parts of Unit 2d is interpreted as an area of low saltmarsh, cut by  
522 creeks.

523  
524 No indication of age or climatic significance can be deduced from the microfaunas, since all the species are  
525 still living in Britain and indeed could readily be collected from similar environments in the area today.  
526

527

#### 528 **4.2.6 Diatoms (Nigel G. Cameron)**

529

530 Diatoms from borehole 16 (Figures 5 and 6) are poorly preserved, with a high degree of diatom valve  
531 breakage and silica dissolution. In Unit 2b, the diatoms identifiable to species level (including *Diploneis*  
532 *didyma*, *Nitzschia granulate*, *Achnanthes brevipes* and *Paralia sulcata*) indicate that there were tidal  
533 conditions in the sedimentary environment. Overlying this in Unit 2c, dominant diatoms are marine (almost  
534 70% of the total are polyhalobous diatoms and the planktonic species *Paralia sulcata* is particularly  
535 common). Brackish water, mesohalobous diatoms comprise a further 20% of the assemblage, many of which  
536 (*Caloneis westii*, *Diploneis didyma*, *Nitzschia compressa* and *Nitzschia navicularis*) are found in mudflats.  
537 The diatom assemblage from Unit 2c thus represents full tidal conditions.

538

539 The diatom assemblage from the base of Unit 2d (745-746 cm) shows an increase in both diatom numbers  
540 and species diversity from Unit 2c. Mesohalobous diatoms increase to almost 75% of the total, including  
541 particularly commonly (c. 20%) the littoral species *Rhopalodia musculus*. A number of oligohalobous  
542 indifferent (freshwater) taxa are present including *Cocconeis placetula* and *Epithemia* spp. These changes  
543 reflect a decrease in salinity. This, however, is shortlived as higher in Unit 2d (529-530 cm) oligohalobous  
544 species drop again, with an assemblage comprising similar proportions of polyhalobous (over 40%) and  
545 mesohalobous diatoms (almost 45%) (Figures 5 and 6) and many marine taxa including *Paralia sulcata*. A  
546 few fragmented marine species are preserved from 215-216 cm depth showing continued brackish conditions.  
547 All samples above this were barren.

548

#### 549 **4.3. Trace-element and stable-isotope determinations of ostracod shells (Jonathan Holmes)**

550

551 It was clear from field discussions following the publication of Briant et al. (2009) that the salinity signal of  
552 this sequence was important and not yet comprehensively demonstrated. Therefore 11 isotopic determinations  
553 were undertaken on samples from test pits 4b, 4d and 7 and borehole 13. Mg/Ca and Sr/Ca in ostracod shells  
554 (Figure 7) are positively correlated with the trace-metal to Ca in the water in which the shells calcified and,  
555 for Mg, with water temperature. Trace-element partitioning between ostracod shell and water can be  
556 described using species- or genus-specific partition coefficients (KD[M] values, where  $KD[M] = M/Ca_{shell}/M/Ca_{water}$ , and M is either Mg or Sr). Whilst not without problems (e.g. Dettman and Dwyer, 2012),  
557 KD values can be used in some circumstances to reconstruct quantitatively the M/Ca of water. In marginal-  
558 marine waters, highly non-linear variations in water M/Ca and salinity arise from the mixing of sea-water  
559 with water from meteoric sources. This raises the possibility of using trace-element determinations to  
560 reconstruct both water composition and temperature (Holmes and De Deckker, 2012). This approach has  
561 been used successfully for trace-element determinations of *C. torosa* in marginal-marine settings (e.g.  
562 Holmes and De Deckker, 2015). De Deckker et al. (1999) have further shown that the Mg/Ca of *C. torosa*  
563 shells can be used to reconstruct water temperature using the equation  $T\text{ }^{\circ}\text{C} = 2.69 +$   
564

565 5230( $Mg/Ca_{shell}/Mg/Ca_{water}$ ). Clearly, this requires independent knowledge of  $Mg/Ca_{water}$ . For the material  
566 from Stone Point, we estimate the  $Mg/Ca$  of water using  $Sr/Ca_{water}$  estimates, derived from the  $Sr/Ca$  of each  
567 shell and assuming  $KD[Sr](Cypriideis)$  of 0.47 (Holmes and De Deckker, 2015), and a simple mixing model  
568 for Stone Point water based on seawater and chalk-derived groundwater (Figure 8). While somewhat  
569 oversimplified, this probably yields reasonable values.  
570

571 The  $\delta^{18}O$  value of ostracod shells is determined by water isotope composition and water temperature.  
572 Ostracod shells are generally offset from isotopic equilibrium: for *C. torosa*, the magnitude of the offset is  
573 poorly constrained, but probably around +0.8 ‰ (Holmes and De Deckker, 2015). The  $\delta^{18}O$  of water in  
574 marginal-marine waters is determined primarily by mixing of seawater and meteoric water, but unlike for  
575 trace-element to Ca ratios, the mixing line is linear. For carbon isotopes, the  $\delta^{13}C$  value of ostracod shells is  
576 determined primarily by the  $\delta^{13}C$  of dissolved inorganic carbon (DIC). Although this can be controlled by a  
577 number of factors, in marginal-marine waters it is often a function primarily of the relative balance of marine  
578 and non-marine water, since seawater and meteoric water usually have contrasting  $\delta^{13}C_{DIC}$  values. Carbon  
579 isotopes therefore provide a complementary line of evidence for mixing of different water types in such  
580 settings.  
581

582 Reconstructed  $Sr/Ca$  water values for Stone Point material range from 0.0051 to 0.0075 (Figure 7): although  
583 quite variable, these represent values that are likely to be lower than that for fully-marine water (assumed to  
584 be close to present-day values i.e. 0.0088) Use of the mixing model in Figure 8 suggests that this equates to  
585 around 7 to 13% seawater in the mixture, or a salinity of 2.5 to 4.6 psu, and  $Mg/Ca$  of between 4.62 and 4.73.  
586 We note that these reconstructions carry quite large uncertainties owing to uncertainties in the  $KD$  values and  
587 in the water mixing model: however, they probably provide a reasonable first order estimate of water  
588 composition. The reconstructed  $Sr/Ca_{water}$  and hence salinity values are likely to be minimum values –  
589  $Sr/Ca_{water}$ , and hence  $Sr/Ca_{ostracod}$ , becomes quite insensitive to further increases in salinity, as the mixing  
590 model (Figure 8) shows. However, salinity values below those quoted would lead to a dramatic reduction in  
591 the  $Sr/Ca_{water}$ , and hence  $Sr/Ca_{ostracod}$ . We note that reconstructed  $Sr/Ca$  and salinity values do not vary  
592 dramatically up sequence within Unit 2d and that the inferred water composition was always brackish, never  
593 fresh nor fully marine  
594

595 Weak positive correlation between  $Mg/Ca$  and  $Sr/Ca$  in the Stone Point ostracods suggests that some of the  
596 variability in  $Mg/Ca$  may be related to changes in water composition. We therefore use the inferred %  
597 seawater values and the mixing model in Figure 8 to infer water  $Mg/Ca$  in the  $Mg/Ca$  palaeotemperature  
598 equation in order to reconstruct water temperature. This yields average temperature values for individual  
599 stratigraphic levels at Stone Point sequence of 13.1 and 20.4°C (Figure 9). Given the life-history of *C. torosa*,  
600 these values likely represent spring or late summer/autumn temperature (Heip, 1976a, b). The estimates carry  
601 additional but un-quantified uncertainty from uncertainties in the  $Mg/Ca_{water}$  reconstructions and so must be  
602 viewed with caution.  
603

604 For oxygen isotopes, we have fewer determinations and it should be noted that these were not undertaken on  
605 the same shells as the trace-element measurements. Use of the  $Mg/Ca$ -inferred temperatures quoted above  
606 and a vital offset of +0.8 ‰ confirms the suggestion, based on trace elements, that the Stone Point water was  
607 a mixture of marine (assumed  $\delta^{18}O = 0$  ‰) and meteoric (assumed  $\delta^{18}O = -6.5$  ‰ based on modern values:  
608 Darling et al., 2003) sources although calculations suggest a rather greater proportion of non-marine water in  
609 the mixture. However, the calculations carry large uncertainties owing to uncertainties in the  $\delta^{18}O$  values of  
610 the endmembers, in the  $Mg/Ca$  temperature reconstructions (especially since these do not relate to the exact  
611 same shells as those used for isotope analysis) and in the vital offset, so differences may not actually be  
612 significant. Lower  $\delta^{18}O$  values in the lowermost three levels analysed at Stone Point are consistent with an  
613 increased freshwater input and hence lower salinity, although we note that these levels are not associated with  
614 lower  $M/Ca$  values, indicating that any reduction in salinity was not sufficient to lower the  $M/Ca$  ratios of the

615 water. The overall range of  $\delta^{18}\text{O}$  values (3 ‰) in *Cyprideis* is too large to be explained by temperature  
616 change alone (which would equate to about 12°C temperature range), however, and must in part be due to  
617 changes in freshwater input to the mixture. Weak positive correlation of  $\delta^{13}\text{C}$  with  $\delta^{18}\text{O}$  lends support to our  
618 suggestion that changes in the isotopes are related to variable freshwater input to the mixture.

619  
620 Overall, the ostracod geochemical determinations suggest that the environment represented by Unit 2d was  
621 brackish, with no evidence of fully marine or fully freshwater conditions and salinity that was closer to the  
622 freshwater rather than the marine end of the brackish range. There is some evidence for slightly fresher  
623 conditions nearer the base of the sequence analysed, although this is evident only in the stable isotope data,  
624 not the trace elements. We caution that the reconstructions carry large uncertainties.

### 625 626 **4.3 Geochronology (Jean-Luc Schwenninger and Kirsty E.H. Penkman)**

627  
628 Five optically-stimulated luminescence (OSL) samples from Units 1 and 4 have previously been reported in  
629 Briant *et al.* (2006). Age estimates from Unit 1 (Lepe Lower Gravel) (LEPE03-01, 02, 03, 04) span 230 to  
630 130 ka (MIS 7d-5e, Table 3), broadly coincident with the cold stage immediately preceding the last  
631 interglacial (i.e. MIS 6). Error bars for these age estimates are relatively small, however, meaning that these  
632 age estimates do not overlap. These differences are discussed in Briant *et al.* (2006) and probably reflect both  
633 inter-aliquot variability and difficulties in estimating long-term water content and overburden history because  
634 of proximity to present-day sea level. It was only possible to take one sample from Unit 4 (LEPE03-05)  
635 because this unit is less sand-rich than Unit 1. The OSL age of this is between 72 and 58 ka (MIS 4-3), post-  
636 dating the deposition of Unit 1. It should be noted that age estimates from Unit 1 overlap MIS 7d, which  
637 might suggest that Unit 2 could date from the penultimate interglacial, particularly if the terrestrial expression  
638 of the MIS 7 interglacial is correlated with one of the later substages (i.e. MIS 7a or 7c). This age for Unit 2  
639 is less likely if the terrestrial interglacial correlated with either or both of MIS 7c or 7e, as suggested by  
640 Candy and Schreve (2007). Furthermore, two of the four OSL ages post-date MIS 7. For these reasons, we  
641 consider a penultimate interglacial (MIS 7) age less likely and suggest instead that the Stone Point organic  
642 deposits are more likely to date from the last interglacial (Ipswichian, MIS 5e) than from MIS 7.

643 These previously-reported OSL ages conflict with previous interpretations of the timing of deposition of the  
644 overlying Unit 5. The TL dates of c. 20 ka and 98/120 ka reported by Parks (1990; Parks and Rendell, 1992)  
645 are older than the OSL age from Unit 4. However, TL dates on sediment are problematic because of the  
646 almost certainty of partial bleaching of this light insensitive signal. Because of this uncertainty about the age  
647 of Unit 5 following discussion in the field after publication of Briant *et al.* (2009), a further four OSL samples  
648 were taken from Section 1 in 2010. As can be seen from Table 7, two of the samples from Unit 5 (LEP10-02,  
649 -04; X4103, X4105) yielded ages in MIS 4-3, centred around 40-50 ka, only a little younger and partially  
650 overlapping the age estimate from Unit 4. The other two samples (LEP10-01,-03; X4102, X4104) yielded  
651 anomalously young ages. For this reason, after measurement of an initial 12 aliquots for each sample, a  
652 further 12 aliquots were measured only for LEP10-02 and -04 (X4103, X4105) since these seemed to be more  
653 tightly clustered.

654 Figure 10 shows the  $D_e$  distributions for single aliquot measurements on each sample, including a value for  
655 skewness to aid detection of bioturbation (Bateman *et al.*, 2007). Whilst skewness values are relatively low,  
656 only X4103 has an approximately normal distribution, and even this has a significant tail of older dates. Most  
657 striking is the large number of very low  $D_e$ 's in X4102 and 4104. The most likely explanation is that these  
658 samples, so close to the ground surface, have been affected by bioturbation. This could have occurred during  
659 either soil formation or burrowing by sand wasps or bees (Sphecidae) (see Table 1). The very young ages  
660 suggest incorporation of almost zero-age material. Although care was taken during sampling to avoid fresh  
661 burrows, it is possible that older burrows will have collapsed and therefore have incorporated very recently  
662 bleached material into the samples. Bee bioturbation may have also caused older material to be incorporated  
663 from the underlying gravel. This evidence further suggests that previous TL ages from this unit should be

664 disregarded, as these were produced using a multiple aliquot protocol which produced a single age estimate  
665 from results from multiple aliquots that does not allow scatter to be determined. Given the scatter between  
666 aliquots observed here, the previous TL dates are even less likely to reflect a true age estimate.

667 These difficulties mean that it is hard to assign an age to Unit 5. However, on the basis of the clustering of  
668 De's around 100 Gy in X4103 and (to a lesser extent) X4105, it seems likely that it either dates from or  
669 postdates MIS 4-3. This strengthens the single age estimate previously reported from Unit 4 and thus the  
670 suggestion that the interglacial deposits date from MIS 5e.

671 Because the OSL dating was unable to provide an age estimate for the interglacial silts directly, we sought an  
672 alternative method to provide such an age estimate, as part of the process of seeking to reconstruct the full  
673 record of sea level at this location. As discussed above, multiple fossil groups show evidence for freshwater  
674 influence from Units 2b and 2c. Therefore when *Bithynia tentaculata* opercula were found from a sample  
675 within Unit 2c, it seemed likely that this was also part of the evidence for freshwater influence in this part of  
676 the sequence, even if not directly *in situ*. (As discussed below, it seems likely that none of the freshwater  
677 fossils represent individuals that were living at this exact location, since they are a minority of the assemblage  
678 in every case). As such, it seemed likely that these opercula could provide a robust age for the base of this  
679 sequence. Even if they had been reworked from earlier deposits, they would provide a maximum age estimate  
680 for comparison with OSL age estimates.

681 For this reason, AAR analyses were undertaken on two small individual *Bithynia tentaculata* opercula from  
682 Unit 2c within borehole 16 between 754 and 756 cm depth (NEar 3312-3313, Figure 12). The sample size  
683 for 3313 was very small, with concentrations similar to the analytical level of detection, so the data from this  
684 sample (Table 8) should be considered with caution, although comparison of free and total hydrolysed  
685 fractions for both samples suggested closed system behaviour. The range of data for British sites has been  
686 compared to the Lepe dataset (Figure 11), and the Lepe samples have Ala amino acid ratios that are similar to  
687 sites correlated with the penultimate interglacial (MIS 7) (Penkman *et al.*, 2011), although the small sample  
688 size precludes further resolution at this stage.

689 There is no analytical evidence for error in the AAR data. Therefore the conflicting age estimates from the  
690 AAR and OSL must have a different cause. It should firstly be noted that the OSL samples from Unit 1 were  
691 taken beneath a thinner part of the Unit 2 sequence, further onshore, so cannot be directly compared with the  
692 AAR from the base of borehole 16. Although the multiple boreholes shown in Figure 2 and the continuity of  
693 the vegetation succession in the pollen record both strongly suggest that the sediments in borehole 16 are a  
694 continuous sequence and contemporary with thinner sequences further onshore, there is a small possibility  
695 that the Unit 2c sediments sampled for AAR represent a remnant of older deposits. The full sequence cannot  
696 plausibly be assigned to the penultimate interglacial (MIS 7) because of both the OSL age estimates from  
697 Unit 1 and the implausibility of a full climatic cycle hiatus between the top of Unit 2 / Unit 3 and Unit 4. We  
698 therefore suggest that the AAR results provide a maximum age estimate for this sequence, firmly  
699 constraining it to the more recent part of the Pleistocene. In this interpretation, instead of transport  
700 downstream within the contemporary estuary as with freshwater evidence from other fossil groups, these  
701 samples must have been reworked from an earlier deposit. Indeed, they are very small and found within a  
702 sand lens rather than in the finer-grained material, which further supports the reworking interpretation.

## 703 **5. Discussion**

### 704 **5.1 Age of the sequence**

705

706 Biostratigraphic indications of age from the pollen assemblages are limited, although the presence of  
707 *Carpinus* might indicate an Ipswichian (last) interglacial age. More conclusive are the Coleoptera, which  
708 resemble most closely those assemblages that have already been ascribed to the last interglacial (Coope,  
709 2001). This resemblance includes several significant “non-British” species (e.g. *Bembidion elongatum*,

710 *Caccobius schreberi* and *Onthophagus massai*) none of which have yet been found in penultimate interglacial  
711 assemblages. It also includes distinctive fragments of unidentified species found exclusively in last  
712 interglacial faunas (Coope, 2001) and rare southern English species including *Bembidion octomaculatum*,  
713 *Paracumus aeneus* and *Hydrous caraboides*.

714  
715 As discussed above, the dating is not conclusive from this sequence and the AAR and OSL conflict.  
716 However, the balance of probability is that the most likely age for this sequence is the Ipswichian (last)  
717 interglacial, particularly given the biostratigraphic evidence above. Treating the age estimate from AAR  
718 analyses (penultimate interglacial) as a maximum also suggests that the sequence is relatively young.  
719 Freshwater species such as the opercula used for AAR analysis are likely to have been transported into the  
720 sequence from upstream, but this result suggests that there was also scouring of previously deposited material  
721 during transgression. It might also indicate an erosional discontinuity within the interglacial sequence that is  
722 undetectable because of both the limited exposure inherent in borehole-based investigations and the  
723 sedimentological and faunal similarity of most estuarine interglacial material. This latter explanation seems  
724 less likely because of the OSL age from underlying gravels. It therefore seems most likely that this sequence  
725 is of Ipswichian (last interglacial, MIS 5e) age and that the AAR correlation represents a maximum age.

## 726 **5.2 Timing of sea level rise during the Ipswichian (last) interglacial**

727  
728 The combination of fossil groups present in this sequence enables determination of the timing of sea level rise  
729 within the last interglacial in relation to the establishment of forest. A clear interglacial development is seen  
730 in the vegetation, with Units 2b and 2c dominated by grass and pine (IpI). Oak and birch then occur from the  
731 very base of Unit 2d upwards, with changing percentages of other species indicative of a development from  
732 IpIIa to IpIIb. The assemblages throughout this unit show mixed-oak woodland, as also reported by West and  
733 Sparks (1960) and Brown *et al.* (1975). Determining the timing of sea level rise recorded in this sequence is  
734 more complicated. Figure 12 summarises the salinity signal from the full sequence, integrating records from  
735 all the test pit and boreholes investigated by PASHCC and the West and Sparks (1960) sequence.

736  
737 It is clear from the summary in Figure 12 that even the lower parts of the sequence have a strong brackish  
738 signal. Freshwater species are slightly more significant in Units 2b and 2c. For example, fossil coleopteran  
739 assemblages from Unit 2b are interpreted as representing a freshwater fen and two opercula of the species  
740 *Bithynia tentaculata* used for AAR analysis from Unit 2c (755 cm, borehole 16) are the only freshwater  
741 evidence in the mollusc sequence from borehole 16 (Dr Richard Preece, *personal communication*). In Unit  
742 2d, the sequence is again predominantly brackish, although here too some freshwater elements occur. For  
743 example, terrestrial plant macrofossils include wood, buds, cupules and fruit of *Quercus robur*, and fruit of  
744 *Acer* reported by Brown *et al.* (1975). In the peat beds near the top of Unit 2d, saltmarsh and freshwater plant  
745 macrofossils are equally frequent, with freshwater species including *Carex cf. riparia*, *Carex cf. rostrata*,  
746 *Hydrocotyle vulgaris*, *Lemna* sp., *Lycopus europaeus*, *Menyanthes trifoliata*, *Ranunculus sceleratus* and  
747 *Sparganium* sp. (Brown *et al.*, 1975).

748  
749 The new isotopic determinations reported in this paper enable us to quantify the salinity during formation of  
750 Unit 2d. The ostracod trace-element data support the existence of brackish water, with a slight trend towards  
751 lower Mg/Ca and Sr/Ca values up sequence (Figure 7), although within-level variability is always relatively  
752 high. Calculations with a simple mixing model (Figure 8) suggest that the water contained up to about 13%  
753 seawater, giving a salinity value of up to about 4.6 psu. The overall picture gained here therefore is one of  
754 early sea level rise. Units 2b and 2bc (IpI) are defined as mixed and 2d (IpIIa and IpIIb) as brackish (Figure  
755 13). The mixing of species in this sequence suggest that the site occupied a position mid-estuary where  
756 transport of individuals from both up and downstream was common. Whilst it is possible that this, and the  
757 switching between minerogenic and organic sediment accumulation seen in Unit 2d can be associated with  
758 fluctuating sea levels, as in the Holocene (Long *et al.*, 2000), it is also possible that local sediment budgets  
759 are more important in this case (e.g. Bates and Whittaker, 2004). Given the proximity of the site to the edge

760 of the likely floodplain, local factors will have played significant roles in sediment accumulation, and input  
761 from freshwater and brackish sources will have varied as channels switched across the inundated area.  
762 Differences in interpretation between the different fossil groups may reflect different taphonomic pathways or  
763 difficulties in sampling directly comparable material from boreholes. It is possible that the final slight  
764 freshening towards the top of Unit 2d (peat beds) is a response to a decrease in accommodation space, as in  
765 sedimentary sequences infilling many of our estuaries at the present time (e.g. Devoy, 1979).

766  
767 The evidence from this sequence is important, as discussed above, because it is the longest fossiliferous  
768 record of sea level change for the last interglacial in the Channel region (sequences in France are more  
769 fragmentary and also dated to previous interglacials – e.g. Antoine et al., 2007). Placing it in the context of  
770 other relevant but shorter sequences along the Solent seaway confirms the interpretation that Lepe is in a mid-  
771 estuary position (Figure 13), as they show a west to east transition from freshwater to brackish. To the far  
772 west, early interglacial (birch-pine, IpI) deposits with freshwater affinities occur at –3.9 to –5.3 m O.D. depth  
773 c. 17 km upstream at Pennington Marshes (Allen *et al.*, 1996). Closer, c. 5 km upstream, a slightly older  
774 interglacial vegetation sequence (IpII/IpIII) is preserved at St Leonards Farm at c. 0.1-1.8 m O.D. (Briant *et*  
775 *al.*, 2013). This sequence contains both freshwater and marine fossils. In addition, to the far east, c. 25 km  
776 downstream is a fully brackish sequence at Bembridge Foreland from c. 4-6 m O.D. (Preece et al., 1990).

777  
778 A rapid and early rise in sea level is also seen in global sea level records (e.g. Siddell et al., 2005) and in the  
779 well-dated Dutch record where the initial rise is observed in E2, equivalent to IpIb (e.g. Long et al., 2015).  
780 This is likely to be due to rapid retreat of the Saalian ice sheet, possibly in response to early peak warmth in  
781 the last interglacial, as reported by Langford et al. (2017), although all other British sequences report peak  
782 warmth in IpIb (as far as can be determined given how fragmentary they are – Candy et al., 2016). MCR  
783 temperature reconstructions from this sequence suggest summer temperatures of c. 9-26°C during deposition  
784 of Unit 2b (IpI) and c. 17-18°C during deposition of Unit 2d (IpIIa to IpIb). Water temperature  
785 reconstructions from the Stone Point organic deposits from Mg/Ca in shells of the ostracod *Cyprideis torosa*  
786 are  $17 \pm 3^\circ\text{C}$  for the upper parts of the sequence. There is some suggestion of higher temperatures in the  
787 lower part of the sequence (-3 to -5 m OD:  $18 \pm 3^\circ\text{C}$ ) and lower temperatures in the upper part (above -2.22 m  
788 OD:  $15 \pm 2^\circ\text{C}$ ). However, the uncertainties in the temperature reconstructions are poorly constrained and so  
789 the apparent trend may not be real, although we note that the increase in  $\delta^{18}\text{O}$  values in the upper part of the  
790 sequence with no accompanying trace-element data to support an increase in salinity is consistent with lower  
791 water temperature. These are similar to mean July air temperatures reconstructed from most Ipswichian  
792 sequences of 18°C (Candy et al., 2016), but lower than the mean July temperatures reported from Trafalgar  
793 Square (c. 20-21°C) and Whittlesey (c.19-23°C, Langford et al., 2017).

794  
795 This rapid sea level rise has implications for hominin movement from the continent to Britain. Ashton and  
796 Lewis (2002) talk about the presence of ‘windows of opportunity’ for immigration to Britain between ice  
797 melting and sea level rising. The early sea level rise recorded here makes the window small for the last  
798 interglacial, exacerbated further by the likely final breaching of the Straits of Dover (Gupta et al., 2017). Our  
799 findings therefore strengthen this proposed explanation for hominin absence in the last interglacial. However,  
800 it should be noted that last interglacial deposits, whilst lacking in hominins, do contain an abundance of warm  
801 climate taxa (i.e. hippo, straight-tusked elephant etc. – Sutcliffe, 1995). Therefore sea level rise did not occur  
802 so fast that it prevented these animals from reaching Britain. There is tantalising evidence further east,  
803 adjacent to the North Sea basin (Langford et al., 2017) that Britain was already very warm by IpI. It is  
804 possible that the presence of a warm climate fauna is a response to this early warming, since the ‘windows of  
805 opportunity’ suggested by Ashton and Lewis (2002) also relate to warming. If so, a plausible explanation for  
806 the different migration patterns of these fauna and hominins would be required. Ashton and Lewis (2002)  
807 note that sparse hominin sites from the whole of northwest Europe in the last interglacial might suggest that  
808 humans were present further east, having adapted to hunting on the mammoth-steppe. This might explain  
809 why a diverse range of warm climate fauna that are not known to have been hunted extensively by hominins  
810 arrived in Britain but hominins did not.

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### 5.3 Stratigraphic implications of interglacial sedimentation in estuaries

The deposition of Transgressive Systems Tract deposits over a significantly time transgressive erosional surface caused by previous incision during base level fall is a central part of sequence stratigraphic principles (e.g. Posamentier and Vail, 1988; Posamentier et al., 1988). There has been significant debate about how far up-valley this relationship should be expected to be observed (e.g. Leeder and Stewart, 1996; Blum and Törnqvist, 2000). However, the Lepe site is so close to past shorelines that this conceptual model can usefully be used here.

Gibbard (1994) has argued that the Lower Thames estuarine interglacial sequences show this onlapping onto older terrace deposits. In this model, as transgression progressed, sediment was progressively deposited over altitudinally higher and higher deposits. Gibbard (1994) argues that sedimentation would have been controlled by sea level, with its rate controlled by the volume of sediment supplied by the river. This model conflicts with vertebrate-based biostratigraphic models (Schreve, 2001) that ascribe sequences at various locations on the terrace level above that which contains the last interglacial deposits of Trafalgar Square to the penultimate interglacial. The Gibbard (1994) model instead assigns interglacial deposits overlying both terrace levels (and indeed several higher ones) all to the last interglacial. The Gibbard (1994) model has conceptual appeal and does make sense of the fact that frequently these extensive estuarine deposits are not overlain by further fluvial deposits. Furthermore, the Holocene deposits in the Lower Thames demonstrably do overlie two different gravel aggradations – the Shepperton Gravel throughout and the higher East Mucking / Kempton Park Gravel in places.

Such an onlapping model is harder to apply in the Solent, however, because two of the four sequences summarised in Figure 13 (Pennington and Lepe / Stone Point) are overlain by fluvial gravels at significantly different elevations. These were mapped by Allen and Gibbard (1993) as separate gravel bodies. Westaway et al. (2006) failed to either confirm or deny this difference, concentrating instead on the higher and more extensive deposits. Hatch (2013; et al., submitted) tackled the many disparities between these two stratigraphic schemes by a comprehensive re-examination of boreholes in the region and additional geophysical data using modern borehole comparison software. He reassigned the gravels of Units 1 and 4 of this study (previously Lepe Lower and Upper Gravels) to the Milford on Sea Gravel and confirmed the gravels above and below the Pennington interglacial deposits as a separate aggradation, extremely geographically confined. It is therefore possible that last interglacial deposits in the Solent were deposited over a time transgressive surface. If this were so, then at the start of the interglacial the river channel was at the altitude of the Pennington Lower Gravel, later overlapping the lower gravel (Unit 1) at Lepe. At Pennington, deposition occurred in a freshwater environment, at least during IpI, which is the only part of the interglacial from which we have evidence preserved. Further downstream, at Lepe, the Stone Point organic deposits were laid down in a mid-estuary situation. The valley continued to fill, onlapping Unit 1 and reaching a maximum altitude of c. 1 m O.D. in Ip IIb. No later deposition is recorded here, but upstream at St Leonards Farm the Ip II/III transition is possibly preserved in a proto-Beaulieu River, which did not then deposit further gravel over the deposits. It is also recorded downstream in the more open setting of Bembridge Foreland, adjacent to a raised beach deposit (Preece et al., 1990; Figure 13). Once sea levels fell again, incision took place at both Pennington and Lepe. The fluvial deposition following this incision is the part of the sequence that fits this model least well, because deposits at noticeably different elevations contain OSL age estimates that are very similar, particularly LEPE03-05 at  $66\pm 7$  ka and PENN03-06 at  $53\pm 6$  ka (Briant et al., 2006a). There is no obvious mechanism for this at a time of stable, low sea level. Nonetheless, it is clear from the discussion above that there is significant potential for interglacial estuarine deposits to have a confusing or problematic relationship to their associated stratigraphy. Therefore they should be used with caution to provide tie-points for terrace sequences.

## 6. Conclusion

862  
863 We have reported new data from the longest fossiliferous last interglacial sequence in the Channel region –  
864 thin section analysis of Unit 3, new MCR analysis from coleoptera, isotopic determinations on ostracod shells  
865 from Unit 2d, new OSL ages on Unit 5 and AAR analyses on Unit 2c. These show early sea level rise,  
866 although no early warming, starting during the pre-temperate vegetation zone IpI which is characterised by  
867 birch-pine assemblages. This agrees with patterns observed in the Netherlands and suggests that the ‘window  
868 of opportunity’ for human colonisation of Britain at the start of the last interglacial may indeed have been  
869 very small (cf Ashton and Lewis, 2002), particularly given the likely final breach of the Straits of Dover at  
870 this time (Gupta et al., 2017).

871 The stratigraphic linkage of the last interglacial deposits in the Solent seaway to fluvial terrace deposits at  
872 two different altitudes requires us to rethink our understanding of such relationships. It is clear that when  
873 interglacial deposits are estuarine in affinity, they may overlap older deposits and have a time transgressive  
874 lower contact. Thus we should be cautious about using them as tie-points on which to build a terrace  
875 chronology.

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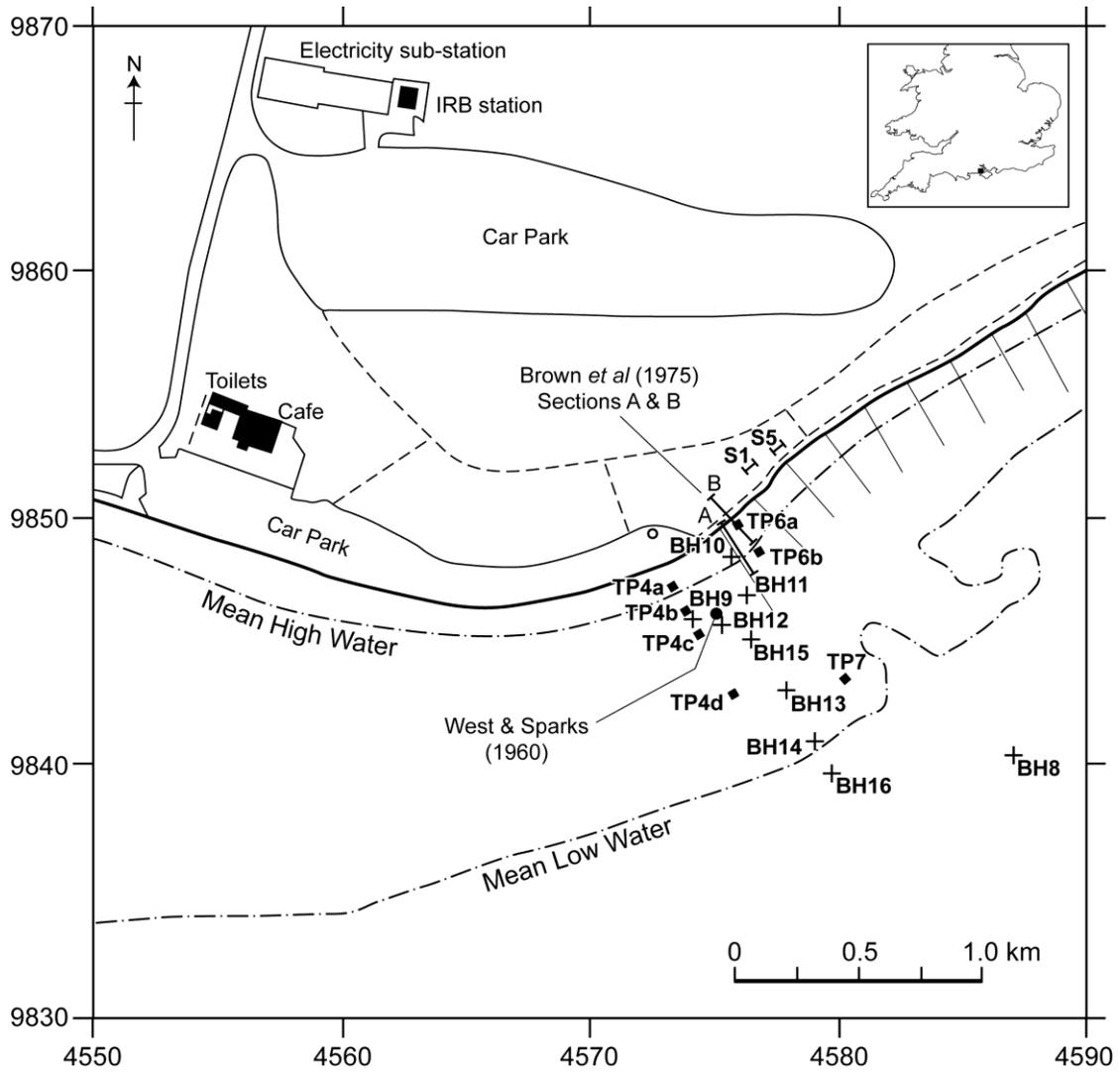
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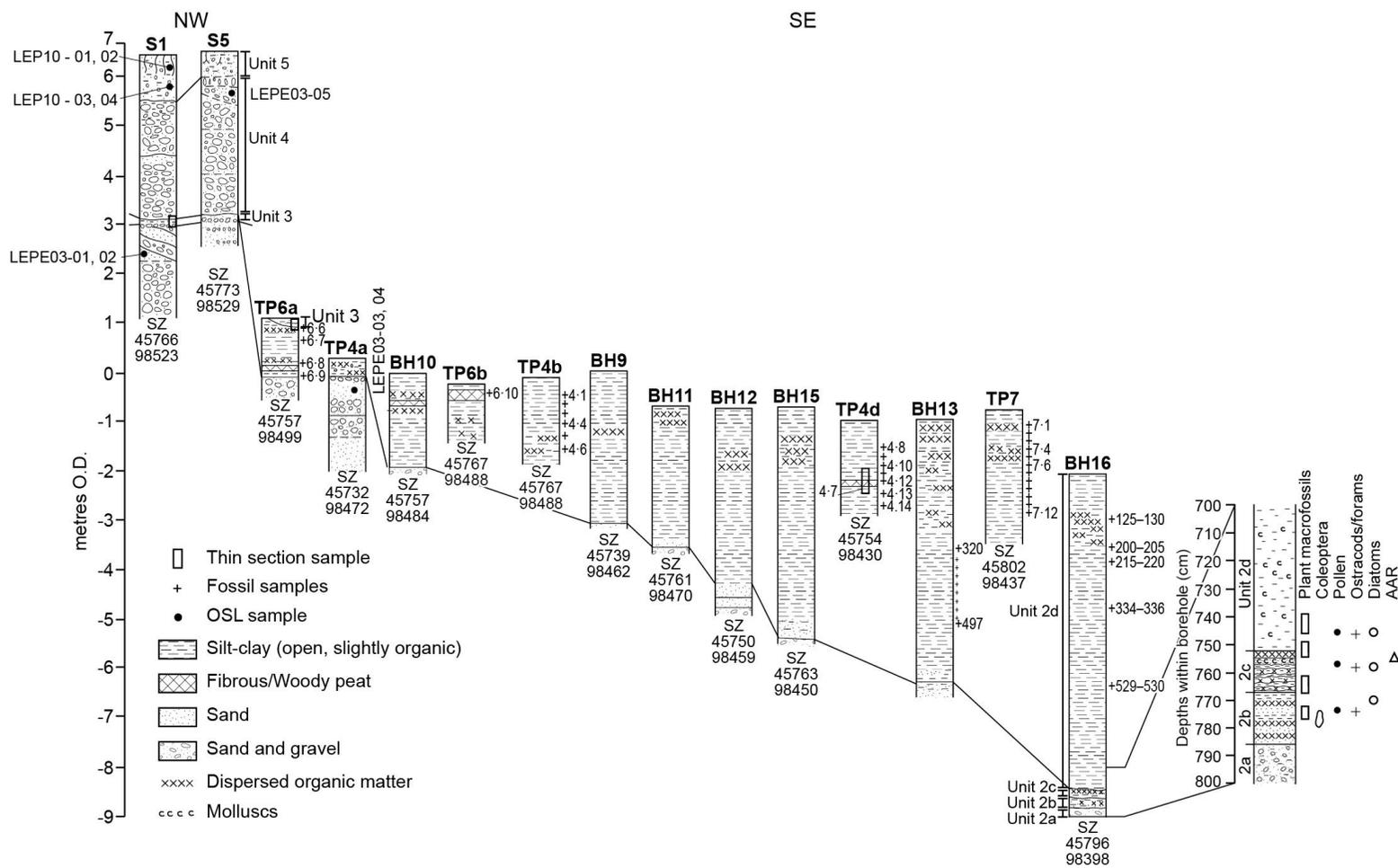
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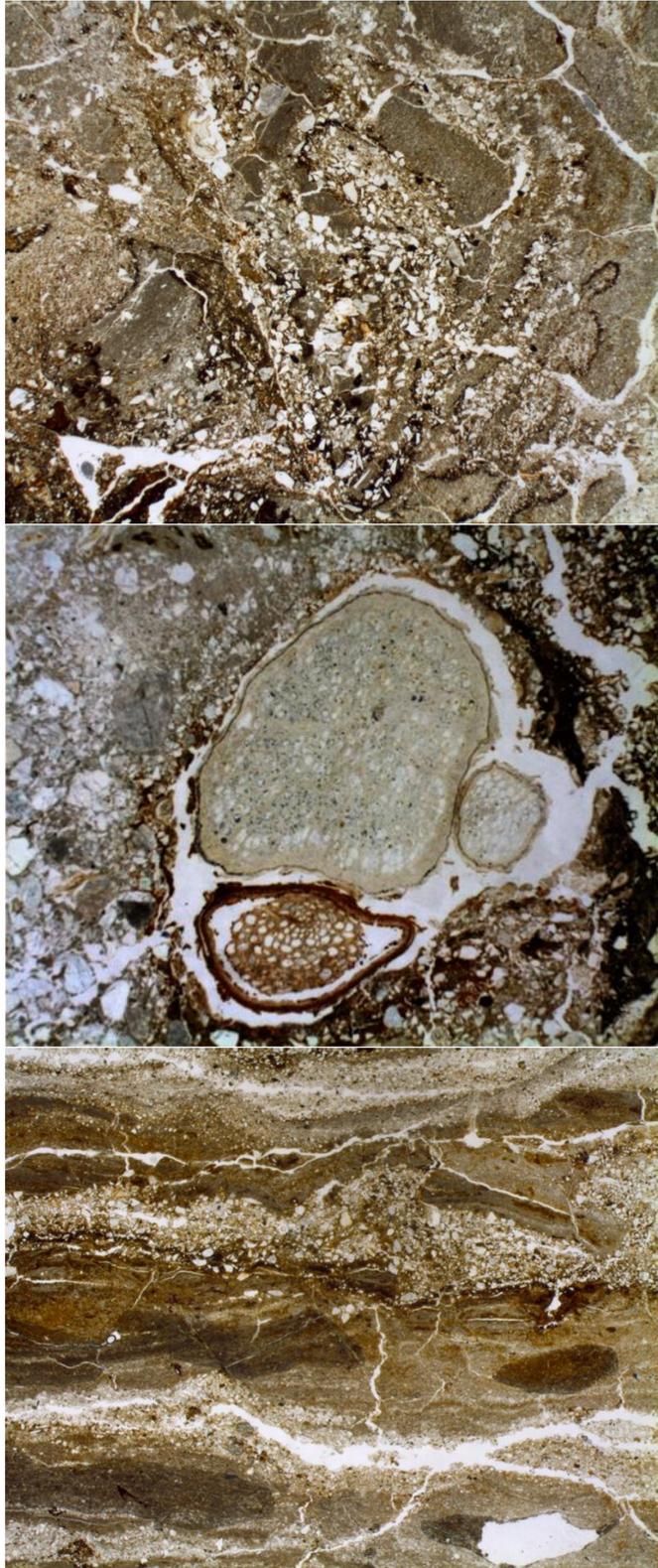
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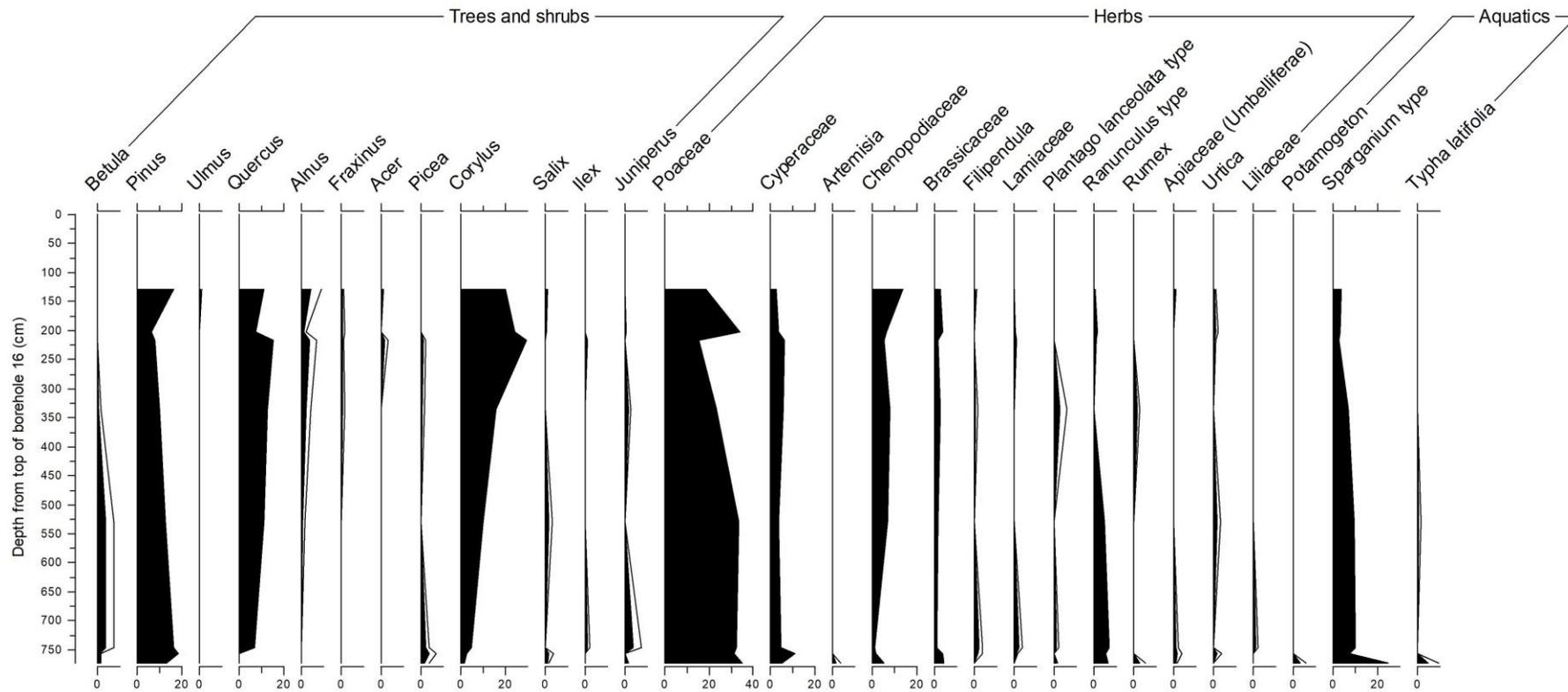
**Figure 1.** Maps showing the location of Lepe Country Park, Hampshire, England and sections, boreholes and test pits within it from all previous authors.



**Figure 2.** Key sections and boreholes from Lepe Country Park investigated by the PASHCC project between 2003 and 2005. All cores have been previously presented (Briant et al., 2006a,b, 2009) but thin section, AAR, OSL from Unit 5 and isotopic analyses are new (see text in section 3 for details).



**Figure 3. Photographs from thin sections from Unit 3 (63 x magnification); a) general view of LEPE03 KUB 1 (section 1); b) organic material in LEPE03 KUB 1 (section 1); c) LEPE03 monolith 6.5 (test pit 6b).**



**Figure 4. Pollen from Unit 2 in borehole 16. Main sum includes all terrestrial plants, including spores. Counts are low due to variable preservation.**

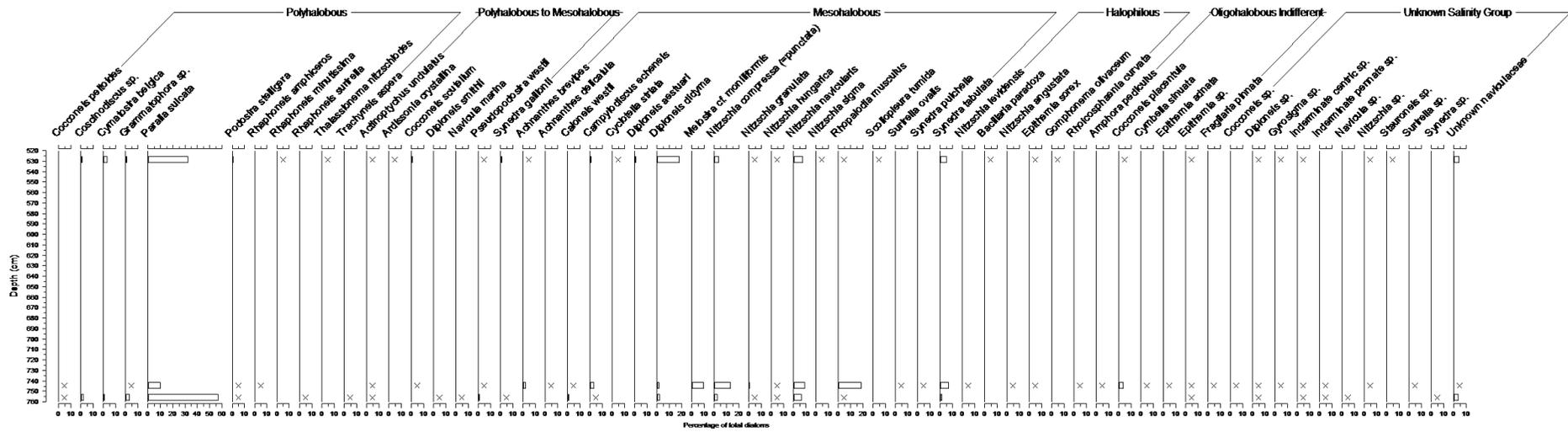


Figure 5. Diatom species abundances from Borehole 16.

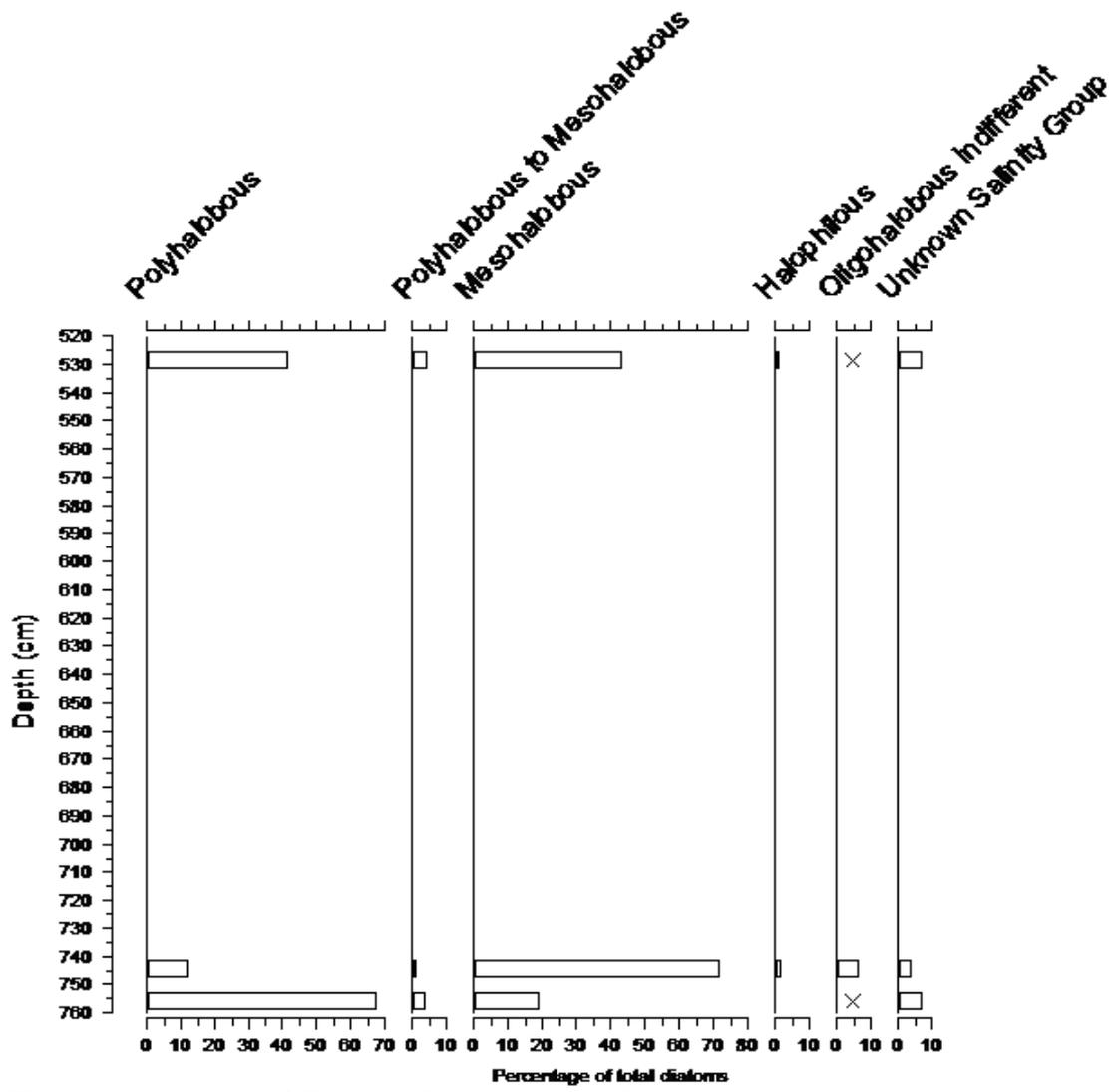
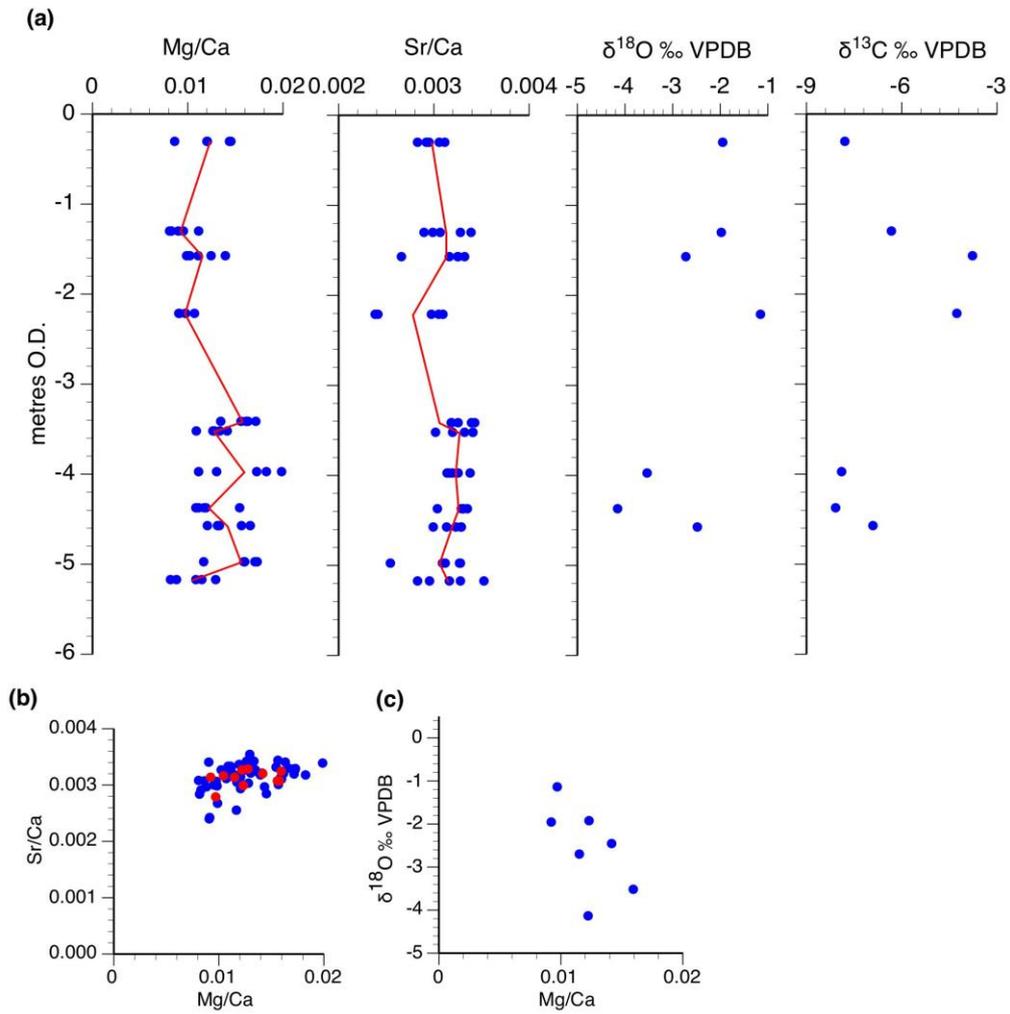
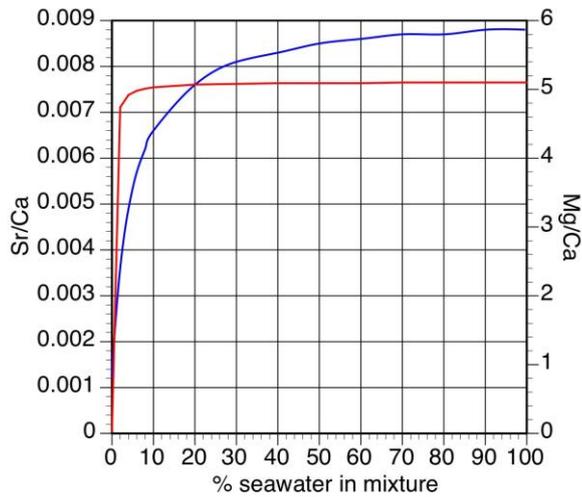


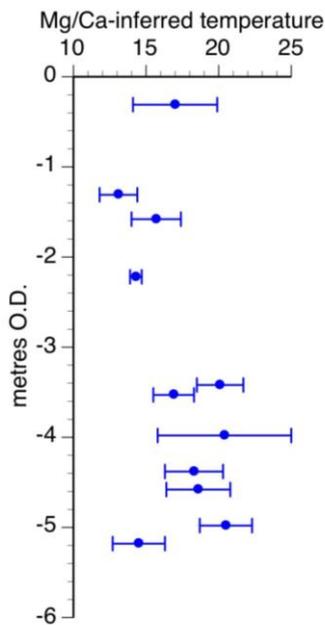
Figure 6. Abundances of diatoms in Borehole 16 by salinity group.



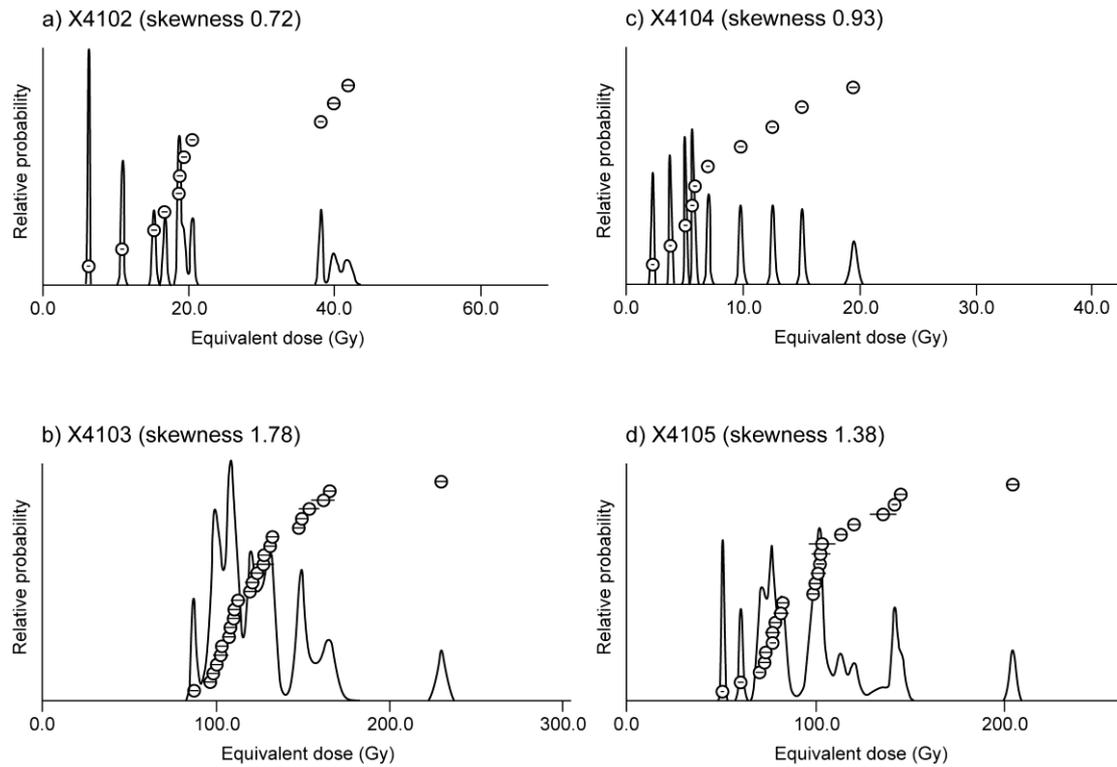
**Figure 7. (a) Stratigraphic plot of Mg/Ca, Sr/Ca,  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  from the Stone Point sequence (b) Mg/Ca vs Sr/Ca (red = average values for each stratigraphic interval; blue = all data), (c)  $\delta^{18}\text{O}$  vs Mg/Ca.**



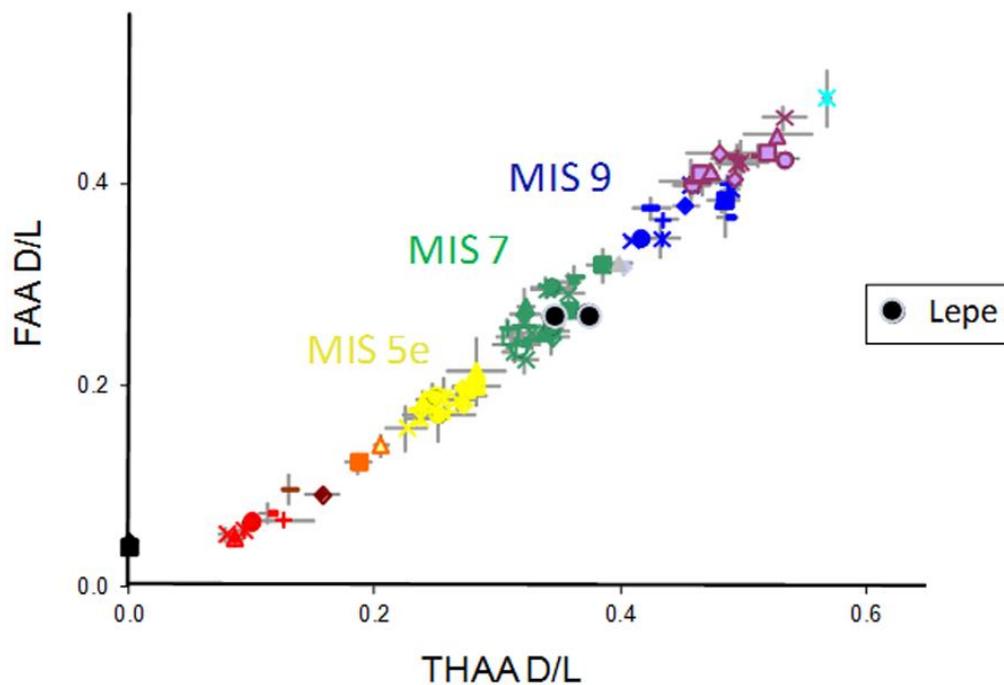
**Figure 8. Mixing model to show change in Mg/Ca (red line) and Sr/Ca (blue line) of marginal-marine water with varying proportions of seawater in a seawater – meteoric water mixture. Seawater: [Mg] = 29.45 meqL<sup>-1</sup> and Mg/ Ca = 5.1; [Sr] = 0.1758 meqL<sup>-1</sup> and Sr/Ca = 0.0088) and chalk-derived groundwater: [Mg] = 0.028 meqL<sup>-1</sup> and Mg/ Ca = 5.1; [Sr] = 0.0079 meqL<sup>-1</sup> and Sr/Ca = 0.0012).**



**Figure 9. Reconstructed temperatures. Uncertainties are 1sd of the single shell; measurements at each level but do not attempt to include uncertainties in the Mg/Ca water estimates, which are an element in the palaeotemperature equation, nor of uncertainties in the equations itself. See text for further information.**



**Figure 10.** Equivalent dose ( $D_e$ ) distributions for single aliquot measurements of samples a) LEP10-01 (X4102, 11 aliquots), b) LEP10-02 (X4103, 24 aliquots), c) LEP10-03 (X4104, 10 aliquots) and d) LEP10-04 (X4105, 22 aliquots). Skewness values for each are shown.



**Figure 11.** Free amino acid (FAA) vs Total (THAA) D/L values of Ala from bleached *Bithynia tentaculata* opercula from Lepe, compared with shells from UK sites (Penkman *et al.*, 2011) correlated with MIS 5e (yellow), MIS 7 (green) and MIS 9 (blue).

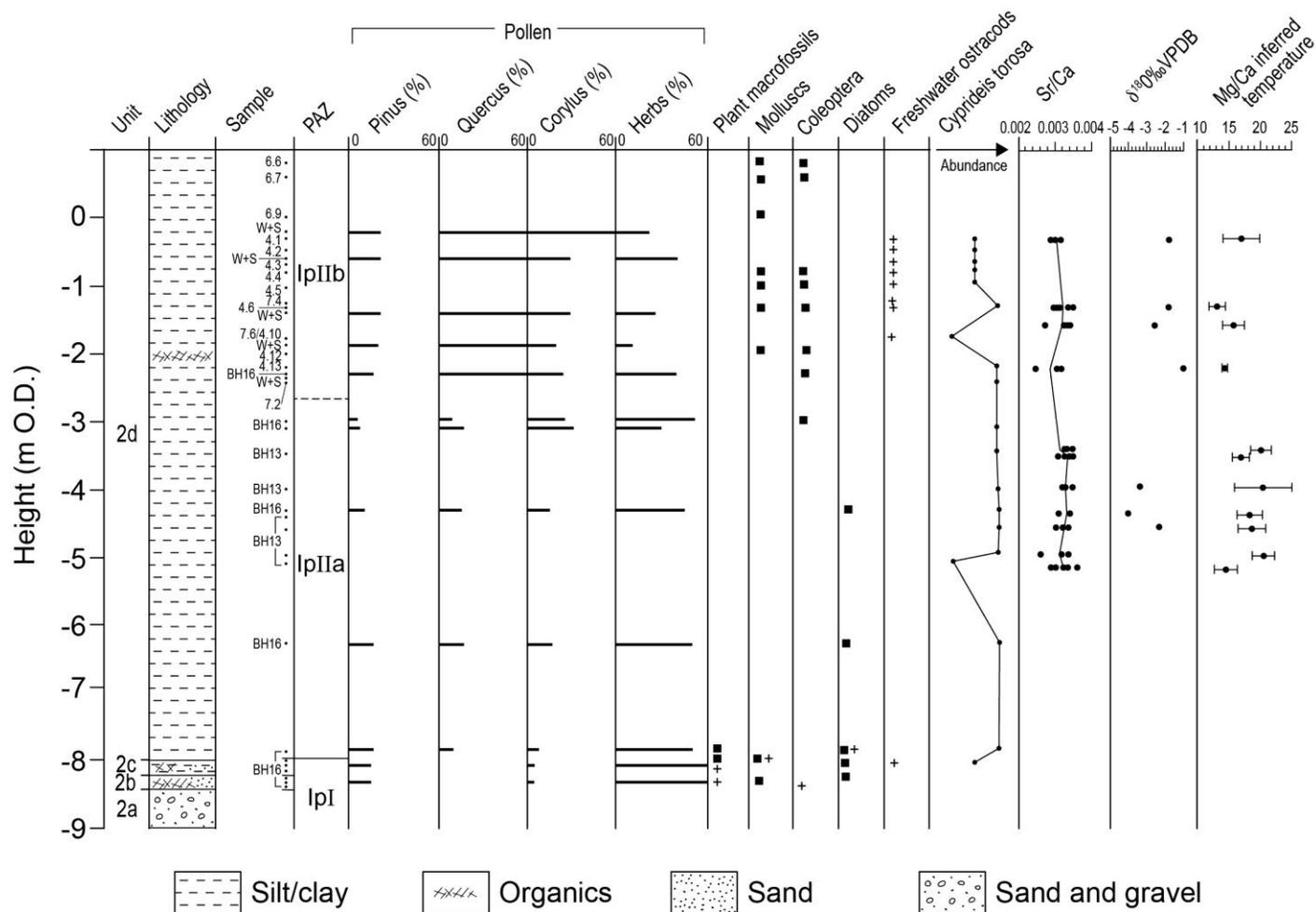


Figure 12. Summary of palaeoenvironmental and isotopic data from the Stone Point organic deposits. Data has been collated from West and Sparks (1960) – W+S, test pits 4a, 4b, 4d, 6a, 6b, 7 and boreholes 13 and 16. Filled squares denote brackish conditions and crosses freshwater conditions or presence of freshwater ostracods.

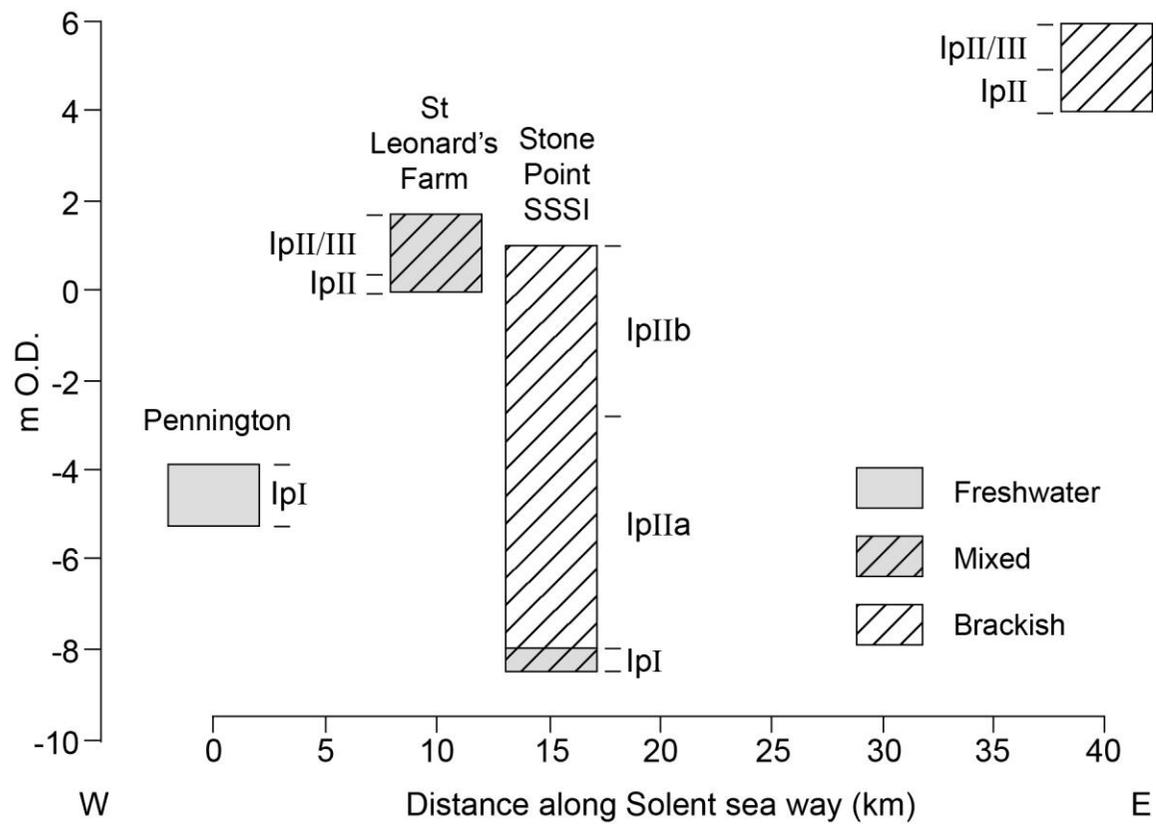


Figure 13. Comparison of key fossiliferous sequences along the Solent seaway: Pennington (Allen et al., 1996); St Leonard's Farm (Briant et al., 2013); Stone Point SSSI (this paper and references therein) and Bembridge Foreland (Preece et al., 1990).

	Reynolds (1985)				Parks (1990)			Section 1 (Briant et al, 2009)		
	Thickness (m)	Description	Particle size	Thin section features	Thickness (m)	Description	Particle size	Thickness (m)	Description	Particle size
'Upper brickearth'	Ah horizon 0.3 (0-0.3 m depth) Particle size sample 0.15-0.25 m depth	Dark greyish brown (10YR 4/2) very slightly stony sandy silt loam with fine gravel; roots and earthworm channels.	Modal size fraction 4-3 phi; 33% sand.	Yellowish brown (Holocene) clay illuviation, 75% as undisturbed argillans.	0.9 – 1.1 (c. 0.5-1.5 m depth - contacts irregular) LPI/2 at a depth of 1.1 m below ground surface	Reddish yellow (7.5 YR 6/6) medium silt / loess	Median particle size 25.5 microns	0.51 (0-0.51 m depth) LEP10-01,02 at 0.38 m depth below ground surface	Fine sand / silt, becoming slightly clayey below c. 35 cm; occasional wasp/bee burrow and roots; occasional flint clasts; pale yellow (2.5 Y 7/4).	LEP10-01/X4102: modal size fraction 125-175 microns / 2.5-3 phi; median particle size 120 microns / 3 phi  LEP10-02/X4103: modal size fraction 88-125 microns / 3-3.5 phi; median particle size 67 microns / 3.9 phi
	Eb horizon 0.18 (0.3-0.48 m depth)	Dark yellowish brown (10 YR 4/4) very slightly stony sandy silt loam; roots and earthworm channels.	-	-						
	Bt horizon 0.3 (0.48-0.78 m depth) Particle size sample 0.5-0.68 m depth Thin section sample 0.63-0.75 m depth	Strong brown (7.5 YR 4/6) very slightly stony clay loam; roots.	Modal size fraction 4-3 phi; 45% sand.	-						
'Lower brickearth'	2Bt horizon 0.4 (0.78-1.18 m depth) Particle size sample 0.8-0.9 m depth Thin section sample 1-1.08 m depth	Strong brown (7.5 YR 5/8) with yellowish brown (10YR 5/6) very slightly stony silty clay with very rare dark red (2.5 YR 3/6) mottles. Few roots and earthworm channels. Thin irregular stone lines of fine to medium gravel at 0.78 and 0.96 m depth.	Bimodal – main peak at 7-6 phi (silt fraction), secondary at 2-1 phi (sand). Total silt 90.3%; sand 9.7%.	74% egg-yellow illuvial clay, of which only 57% is undisturbed. 26% yellowish-brown illuvial clay (Holocene), of which 90% is undisturbed.	0.6 – 0.8 (c. 1.5-2.2 m depth - contacts irregular) LP3/4 at a depth of 1.75 m below ground surface	Reddish yellow (7.5 YR 6/8) medium silt / loess	Median particle size 7.5 microns	0.45 (0.51-0.96 m depth) LEP10-03,04 at 0.76 m depth below ground surface	As above, but yellowish red (5YR 5/8).	LEP10-03/X4104: modal size fraction 31-44 microns / 4.5-5 phi; median particle size 31 microns / 5 phi  LEP10-04/X4105: modal size fraction 31-44 microns / 4.5-5 phi; median particle size 30 microns / 5 phi

**Table 1. Summary of descriptions of Unit 5 at Stone Point SSSI from various studies. Note that in Briant et al. (2009), descriptions are simply of two overlying units – it was not clear which were equivalent to the previously defined upper and lower brickearths, although the Munsell colours described are similar for the lower unit only.**

Taxon	Plant part	Sample (depth cm, Borehole 16)			
		740 - 746	750 - 755	761 - 768	772 - 777
		100 ml	100 ml	50 ml	50 ml
<i>Woodland &amp; shade tolerant</i>					
<i>Alnus glutinosa</i>	fruit	-	1	2	1
<i>Betula</i> sp.	fruit (without wings)	-	-	-	1
<i>Cenococcum geophilum</i>	sclerotium	-	-	present	-
<i>Rubus idaeus</i>	seed	3	-	-	-
<i>Waterside &amp; damp ground</i>					
Alismataceae sp.	fruit	-	-	-	1
<i>Bidens</i> sp.	barbed spine	-	-	-	1
<i>Eleocharis</i> cf. <i>palustris</i>	nutlet	-	-	-	3
<i>Epilobium</i> cf. <i>hirsutum</i>	seed	-	-	1	-
<i>Hypericum tetrapterum</i>	seed	-	1	-	-
<i>Lycopus europaeus</i>	nutlet	-	-	1	-
<i>Ranunculus</i> subgenus <i>Ranunculus</i> sp(p).	achene	-	-	1	5
<i>Scirpus maritimus</i>	nutlet	4	14	-	-
<i>Scirpus</i> sp(p).	nutlet	-	7	-	-
<i>Sparganium erectum</i>	fruitstone	-	-	3	1
<i>Typha</i> sp(p).	fruit	8	30	390	335
<i>Aquatic</i>					
Characeae sp(p).	oospore	2	2	12	8
<i>Hydrocharis morsus-ranae</i>	seed	-	-	1	2
<i>Potamogeton</i> sp.	fruit	1	-	-	-
<i>Ruppia</i> sp.	fruit	-	1	-	-
<i>Ruppia</i> sp.	fruit	-	1	-	-
<i>Zannichellia palustris</i>	fruit	-	1	-	-
<i>Unclassified</i>					
<i>Carex</i> sp(p).	biconvex nutlet	-	-	4	2
<i>Carex</i> sp(p).	trigonus nutlet	-	-	2	-
<i>Carex</i> sp(p).	nutlet and utricle	-	-	5	-
<i>Juncus</i> sp(p).	seed	-	6	33	63
Laminaceae sp.	nutlet	-	-	1	-
<i>Mentha</i> cf. <i>aquatica</i>	nutlet	-	-	2	2
<i>Urtica dioica</i>	achene	-	-	-	3
<i>Undetermined taxon</i>	bud scales	-	-	1	-
Total number of remains (excluding oospores)		18	64	458	428
Total number of taxa		5	9	13	14

**Table 2. Plant macrofossil analysis from samples from Borehole 16.**

Sample	TP4d	TP4b			TP6a		
	4.12	4.4	4.5	4.6	6.6	6.7	6.9
<i>Hydrobia ventrosa</i> (Montagu, 1803)	7	2	1	128			
<i>Hydrobia ulvae</i> (Pennant, 1777)	1			39			
<i>Hydrobia</i> spp.	45	30	10	1132			1
<i>Ovatella myosotis</i> (Draparnaud, 1801)		2	1	17			
<i>Cerastoderma edule</i> (Linné, 1758)		2		1			
<i>Scrobicularia plana</i> (da Costa, 1778)		11	4	35			
<i>Abra</i> spp.		1		4			
<i>Total</i> (6 species)	53	48	16	1356	0	0	1

**Table 3. Molluscs from the upper part of Unit 2d (test pits 4b, 4d and 6a)**

	Unit 2d										Unit 2b
	1974 sample	TP7	TP6b	TP6a		TP4d	TP4b		BH16		BH16
	7.5	6.10	6.8	6.7	6.6	4.12	4.6	4.5	4.4	125 – 127 cm 200 cm	774 – 779 cm
Carabidae											
<i>Elaphrus riparius</i> (L.)		1									
<i>Dyschirius salinus</i> Schaum	1		2	3					1		
<i>Dyschirius aeneus</i> (Dej.)	1		1	1				1	1		
<i>Paratachys bistratus</i> (Duft.)			1					2	1		
* <i>Porotachys bisulcatus</i> (Nicol.)									2	1	
<i>Bembidion obliquum</i> Sturm	1	3	1						1	1	
<i>Bembidion varium</i> (Ol.)	1		2	1	3	1	2	2	2	2	1
<i>Bembidion nitidulum</i> (Marsh.)									1	1	
* <i>Bembidion elongatum</i> Dej.	1										
<i>Bembidion assimile</i> Gyll.	5	2	1	1	2	1	2	2	2	2	
<i>Bembidion fumigatum</i> (Duft.)									1		
<i>Bembidion normanum</i> Dej.			2		1		1	1	2	2	1
<i>Bembidion minimum</i> (F.)	1	1	2	1	2	1	1		1	2	
<i>Bembidion articulatum</i> (Panz.)		1	1						2		
<i>Bembidion octomaculatum</i> (Goeze)						1			1		
<i>Bembidion iricolor</i> Bedel,									1		
<i>Bembidion guttula</i> (F.)			1								
<i>Pogonus litoralis</i> (Duft.)	1				1		1	1	1		
<i>Acupalpus</i> sp.					1						
<i>Poecilus</i> sp.	1								1		
<i>Pterostichus vernalis</i> (Panz.)	2							1		1	
<i>Pterostichus nigrata</i> (Payk.)	1		1								
<i>Pterostichus minor</i> (Gyll.)		1								1	
<i>Pterostichus atterimus</i> (Hbst.)			1						1		
<i>Agonum muelleri</i> (Hbst.)	1									1	
<i>Agonum thoreyi</i> Dej.	1	1	2								
<i>Amara convexiuscula</i> (Marsh.)	1										
<i>Chlaenius tristis</i> (Schall.)		1					1			1	
<i>Oodes helopioides</i> (F.)								1			
* <i>Oodes gracilis</i> Villa	2	2	1				1	3	1	1	
<i>Odacantha melanura</i> (L.)	3	14	5	2	1	1	5	1	1	2	
<i>Demetrias monostigma</i> Sam.		2									
<i>Demetrias imperialis</i> (Germ.)		2		1							
<i>Paradromius longiceps</i> Dej.							4	1	1	1	
Halipidae											
<i>Peltodytes caesus</i> (Duft.)								1	1		
Dytiscidae											
* <i>Hydroglyphus pusillus</i> (F.)	1	1				2		1	2	3	
<i>Hydrovatus cuspidatus</i> (Kunze)	2	16		1			2	3	6	13	
<i>Coelambus impressopunctatus</i> (Schall.)		1									
<i>Coelambus parallelogrammus</i> (Abr.)		1								1	
<i>Hygrotus inaequalis</i> (F.)		1	1				2			1	
<i>Hydroporus</i> spp.		2	2			1	5	1	1	1	1
<i>Graptodytes bilineatus</i> (Sturm)										1	
<i>Noterus clavicornis</i> (Geer)	1	6	1			1	1	1	2	2	1

<i>Noterus crassicornis</i> (Müll.)		2							2					
<i>Agabus bipustulatus</i> (L.)								1						
<i>Agabus</i> sp.		1					1	1						
<i>Ilybius</i> sp.							1							
<i>Rhantus</i> sp.	1							1	1					
<i>Colymbetes fuscus</i> (L.)	1	1						1	1	1				
<i>Graphoderus</i> sp.	1	1						1	1	1				
* <i>Cybister lateralimarginalis</i> (Geer)										1				
Gyrinidae														
<i>Gyrinus caspius</i> Mènètr.	1	5	1	1	1	1	1	5	2	5				
Hydraenidae														
<i>Hydraena gracilis</i> Germ.				1										
<i>Hydraena cf riparia</i> Kug.								1						
<i>Ochthebius dilatatus</i> Steph.								1						
<i>Ochthebius minimus</i> (F.)	4	1	1	1	1				2	1				
* <i>Ochthebius foveolatus</i> Germ.	1													
<i>Ochthebius marinus</i> (Payk.)			1	5				1	1					
<i>Ochthebius viridis</i> Peyrhhf. / <i>pusillus</i> Steph.	1	1						1	1	2				
<i>Ochthebius</i> sp.	6	18	10	1	4	1	3	3	10	14	1	1		
<i>Limnebius aluta</i> Bedel	2	2	5		1			5		1	1			
<i>Hydrochus carinatus</i> Germ.										1				
<i>Helophorus</i> misc.small spp.	1		1	1	1			1	1	1				
Hydrophilidae														
<i>Coelostoma orbiculare</i> (F.)	2	3	2	1	2			3	2	4	8			
<i>Sphaeridium scarabaeoides</i> (L.) / <i>lunatum</i> F.														1
<i>Sphaeridium</i> sp.	1									1	1			
<i>Cercyon ustulatus</i> (Preysl.)										1	1			
<i>Cercyon melanocephalus</i> (L.)										1				
<i>Cercyon marinus</i> Thoms.											1			
<i>Cercyon pygmaeus</i> (Illiger)										1				
<i>Cercyon tristis</i> (Illiger)		1											1	
<i>Cercyon convexiusculus</i> Steph.	1	1						2	1	1	3			
<i>Cercyon sternalis</i> Shp.	4	5	3	3					5	11	6			
<i>Cercyon analis</i> (Payk.)	1	1	1	2	3				1		3			
<i>Cercyon</i> sp.														1
<i>Megasternum obscurum</i> (Marsh.)														1
<i>Paracymus aeneus</i> (Germ.)	7	28	21	11	17	8	36	17	27	28	2	2		
<i>Hydrobius fuscipes</i> (L.)	1	1	1						1	1	1			
<i>Limnoxenus niger</i> (Zschach)	1	2	1	1			1	1	2	1		1		
<i>Laccobius</i> sp.	1	1	1		1									
<i>Helochaeres</i> sp									1					
<i>Enochrus affinis</i> (Thunb.)												1		
<i>Enochrus</i> sp.	8	34	17	2	5	4	10	15	15	25		2		
<i>Cymbiodyta marginella</i> (F.)	3	7	1	1	2	2	1		2	3				
<i>Hydrochara caraboides</i> (L.)						1			1	1				
<i>Hydrophilus piceus</i> (L.)										1	1			
<i>Berosus luridus</i> (L.)		1		1	1				1	2	1			
Histeridae														
<i>Acritus homoeopathicus</i> Woll.				1				1						
<i>Hister</i> ( <i>sensu lato</i> ) sp.		1		1					1	1				
Silphidae														
<i>Phosphuga atrata</i> (L.)			1											
Ophthoperidae														
<i>Corylophus crassidoides</i> (Marsh.)	6	2	2	1	2	3	1	1	1	1				

<i>Orthoperus</i> sp.	4	37	8	15	25	9	14	14	12	16	1	5	
Sphaeiidae													
<i>Microsporus acaroides</i> Walth	2				1		2		3	5	1	1	
Ptiliidae													
<i>Ptenidium</i> sp.	1	1			1			1					
Staphylinidae													
<i>Micropeplus staphylinoides</i> (Marsh.)					1								
<i>Acrolocha sulcata</i> (Steph.)								1		1			
<i>Lesteva punctata</i> Er.						1							
<i>Lesteva heeri</i> Fauv.		1							1				
<i>Geodromicus nigrita</i> (Müll.)	1												
<i>Trogophloeus</i> sp.	1	4	6	1	5	1	5	11	10	1			
<i>Anotylus rugosus</i> (F.)									1	1			
<i>Oxytelus laqueatus</i> (Marsh.)		1											
<i>Anotylus complanatus</i> Er.								1					
<i>Platystethus arenarius</i> (Fourcr)								1					
<i>Platystethus nodifrons</i> Mannh.						1							
<i>Bledius</i> sp.	1						1	1					
<i>Stenus juno</i> (Payk.)	1	1	1		1			1	1				1
<i>Stenus</i> spp.	8	8	9	3	5	3	2	3	9	12	1		
<i>Euaesthetus ruficapilus</i> Boisd.Lacord.						1							
<i>Paederus riparius</i> (L.)		1					1			1			
<i>Stilicus</i> sp.	1									1			
<i>Lathrobium</i> sp.								1	1	1			
<i>Philonthus</i> sp.		1	1			1							
<i>Ocypus fuscatus</i> (Grav.)										1			
<i>Tachinus corticinus</i> Grav.										1			
<i>Tachinus</i> sp.	1						1						
<i>Xantholinus</i> sp.													1
Alaeocharinae Gen. et sp. indet.	9	6	16	1	5	1	3	3	9	7	2	2	
Pselaphidae													
<i>Bryaxis</i> sp.				1									
<i>Pselaphaulax dresdensis</i> (Hbst.)	1		1	1				1					
Cantharidae													
<i>Rhagonycha</i> sp.								1					
<i>Silis ruficollis</i> (F.)					1								
Elateridae													
<i>Agriotes</i> sp.										1			
<i>Melanotus punctolineatus</i> (F.)									1	1			
<i>Agrypnus murina</i> (L.)					1				1				
<i>Prosternon tessalatum</i> (L.)									1				
<i>Athous</i> sp.									1				
Throscidae													
* <i>Throscus</i> v. small sp. ? exul Bonv.	2	7	1	2	1	1	1	1	1	2			
Helodidae													
Gen et sp. indet.	41	43	19	5	7	2	16	4	17	18		3	
Dryopidae													
<i>Pomatinus substriatus</i> (Müll.)								1					
<i>Oulimnius</i> sp.								2		1			
Cucujidae													

* <i>Airaphilus elongatus</i> (Gyll.)				1	1	1		1					
Heteroceridae													
<i>Heterocerus</i> sp.		4			2			1	2	3	4		
Byrrhidae													
* <i>Pelochares versicolor</i> (Waltl)									1				
<i>Byrrhus</i> sp.											1		
Nitidulidae													
<i>Meligethes</i> sp.		1									1		
<i>Epuria</i> sp.		1	1		1	1		1	1				
Phalacridae													
<i>Stilbus oblongus</i> (Er.)	2	25	6	3	8	3		3	5	10	9	1	
Lathridiidae													
<i>Corticarina</i> sp.		3	1	1					1	2	4		
Mycetophagidae													
* <i>Berginus tamariski</i> Woll.					1								
Coccinellidae													
<i>Coccidula rufa</i> (Hbst.)											1		
<i>Anisosticta novemdecimpunctata</i> (L.)					1								
<i>Coccinella undecimpunctata</i> L.								1	1		1	1	
Bostrichidae													
<i>Bostrychus capucinus</i> (L.)									1				
Anobiidae													
<i>Anobium</i> sp.	1								1				
Anthicidae													
<i>Anthicus antherinus</i> (L.)			1										
* <i>Cordicomus gracilis</i> (Panz.)		2	1					1					
<i>Cordicomus</i> sp.	1	4		2	1			1	1	2	2	1	
Tenebrionidae													
<i>Opatrum sabulosum</i> (L.)									1				
<i>Eledona agaricola</i> (Hbst.)						1							
Scarabaeidae													
* <i>Euoniticellus fulvus</i> (Goeze)						1							
<i>Copris lunaris</i> (L.)									1				
* <i>Caccobius schreberi</i> (L.)	1	1									1		
* <i>Onthophagus massai</i> Barraud	1	2	1	1	1	?	?		1	2	2		
<i>Onthophagus verticornis</i> (Laich.)											1		
<i>Onthophagus fracticornis</i> (Preysl.)										1			
* <i>Aphodius cf carpetanus</i> Graëlls	1			1				1					
<i>Aphodius sticticus</i> (Panz.)		1											
* <i>Aphodius</i> sp.										1			
<i>Aphodius</i> sp.	2	1	2	2	2	3		3		3	1		
* <i>Heptaulacus</i> sp.			1										
<i>Melolontha melolontha</i> (L.)											1		
<i>Cetonia aurata</i> (L.)	1								1		1		
Lucanidae													
<i>Lucanus cervus</i> (L.)									1				
<i>Dorcus parallelipedus</i> (L.)				1							1		



		FORAMINIFERA							OSTRACODA						
		<i>Ammonia aberdoveyensis</i>	<i>Ammonia limnetes</i>	<i>Elphidium waddense</i>	<i>Elphidium williamsoni</i>	<i>Haynesina germanica</i>	<i>Quinqueloculina</i> sp. (brown)	<i>Trochammina inflata</i>	Freshwater ostracods	<i>Cyprideis torosa</i>	<i>Loxococoncha elliptica</i>	<i>Leptocythere porcellanea</i>	<i>Leptocythere castanea</i>	<i>Cytherois</i> sp.	<i>Elofsonia baltica</i>
2d	TP 4b	4.1*	x	x	x				o	xx					
		4.2	x	x	x				x	xx	x	x			
		4.3	x	x	x				x	xx	x	x			
		4.4	x	x	x				x	xx	x				
		4.5	xx	xx	x	x	x		x	xx					
		4.6*	xx	x	xx	x	x		x	xxx	x				
		TP 4d	4.8	x	xx	x	o			x			x		
			4.9	x	x					x			x		
			4.10	x	x	x				o	x	x	xx		
			4.11	x	x	x					x	x	x		
			4.13*	xxx	xx	x	x	x			xxx	x			
			4.14	xx		x	x	x			x				
		TP 7	7.1												
			7.2	xx	xx										
			7.3	xx	xx										
			7.4	x	x	x				x	x				
			7.5												
			7.6*	xx	x	x				x					
			7.7	x	xx	x					x				
			7.8	xxx	xx	xx	xx	xx			x		xx		
			7.9	xx	xx	x	xx	x		xx					
			7.10	xx	xx	xx	x	x		x			x		
			7.11	xx	x	xx	x	x			x		x	o	
			7.12*	x	xx	x					xxx		xx	xx	
		BH 13	320 cm*	xx		x		x			xxx	xx	x	x	
			345 cm	xxx		x		x			xxx	xx	xx	xx	x
			365 cm*	xxx		xx		x			xxxx	xx	x	x	
			385 cm	xx		xx		x			xxx	x	xx	x	
			405 cm*	xx		xx		o			xxxx	x	xx		
			425 cm*	xx		x		x			xxxx	xx	x		o
			445 cm	xx		x		x			xxx	x	xx		o
			465 cm*	xx		x					xxx	x	x		
			475 cm	xx		x					xxx	x	x		
			485 cm*	x		x					xx	o			
			491 cm	x							x		x		
			497 cm												
		BH16	127 cm												
			201 cm	x	x	x		x							
		218 cm	xxx	xxx	xxx					xxx					
		336 cm	xxx		xx		x			xxx	xxx	x	x		
		530 cm	xxx		xx		x			xxx	xx	x			
		747 cm	xxx		xxx					xxx	xx	x			
	2c	758 cm	xx		x				x	xx	x	x			
	2b	773 cm													

Table 5. Ostracoda and foraminifera from Units 2b to 2d. o - one specimen; x - present (several specimens); xx - common; xxx – abundant. Starred samples are those from which isotope measurements are reported in Table S6.

Section/borehole	Level	HEIGHT m OD	Mg/Ca C. torosa	Sr/Ca C. torosa	Mg/Ca average	Mg/Ca 1sd	Sr/Ca average	Sr/Ca 1sd	d <sup>13</sup> C C. torosa	d <sup>18</sup> O C. torosa	Sr/Ca water (Kd[Sr]=0.47 Kd[Sr]=0.47	Sr/Ca (water) average	Sr/Ca (water) 1sd	Inferred temperature		Inferred temperature	
														Mg/Ca <sub>(water)</sub> calculated from Sr/Ca	T °C	average T °C	1sd
Lepe Borehole 13	480/490cm	-5.18	0.01089	0.00328							0.00698			4.7	14.7		
		-5.18	0.00820	0.00283							0.00602			4.4	12.4		
		-5.18	0.01151	0.00317							0.00674			4.7	15.6		
		-5.18	0.00883	0.00295							0.00629			4.5	12.9		
		-5.18	0.01296	0.00353	0.01048	0.00195	0.00315	0.00027				0.00751	0.00671	0.00058	4.8	16.7	
Lepe Borehole 13	460/470cm	-4.98	0.01732	0.00328							0.00698			4.7	21.9		
		-4.98	0.01599	0.00309							0.00658			4.6	20.8		
		-4.98	0.01705	0.00327							0.00696			4.7	21.6		
		-4.98	0.01593	0.00312							0.00664			4.6	20.7		
		-4.98	0.01170	0.00255	0.01560	0.00227	0.00306	0.00030				0.00542	0.00651	0.00064	4.2	17.3	20.5
Lepe Borehole 13	420/430cm	-4.58	0.01659	0.00329							0.00700			4.7	21.0		
		-4.58	0.01315	0.00329							0.00699			4.7	17.2		
		-4.58	0.01211	0.00313							0.00667			4.6	16.3		
		-4.58	0.01569	0.00300							0.00638			4.5	20.7		
		-4.58	0.01336	0.00323	0.01418	0.00188	0.00319	0.00012	-6.90	-2.47		0.00688	0.00678	0.00026	4.7	17.6	18.6
Lepe Borehole 13	400/410cm	-4.38	0.01118	0.00331							0.00705			4.7	15.0		
		-4.38	0.01548	0.00331							0.00704			4.7	19.8		
		-4.38	0.01174	0.00304							0.00646			4.6	16.1		
		-4.38	0.01195	0.00335							0.00713			4.8	15.8		
		-4.38	0.01085	0.00329	0.01224	0.00187	0.00326	0.00013	-8.07	-4.15		0.00700	0.00694	0.00027	4.7	14.7	18.3
Lepe Borehole 13	360/370cm	-3.98	0.01829	0.00317							0.00673			4.7	23.2		
		-3.98	0.01989	0.00338							0.00719			4.8	24.5		
		-3.98	0.01307	0.00320							0.00680			4.7	17.3		
		-3.98	0.01115	0.00314							0.00668			4.6	15.3		
		-3.98	0.01727	0.00326	0.01594	0.00368	0.00323	0.00010	-7.89	-3.53		0.00693	0.00687	0.00020	4.7	21.9	20.4
Lepe Borehole 13	315/325cm	-3.53	0.01091	0.00332							0.00707			4.7	14.7		
		-3.53	0.01282	0.00302							0.00643			4.6	17.4		
		-3.53	0.01338	0.00341							0.00726			4.8	17.3		
		-3.53	0.01268	0.00341							0.00726			4.8	16.5		
		-3.53	0.01416	0.00320	0.01279	0.00120	0.00327	0.00017				0.00681	0.00696	0.00035	4.7	18.5	16.9
Lepe Trench 7	7.12	-3.42	0.01350	0.00325							0.00692			4.7	17.7		
		-3.42	0.01717	0.00318							0.00677			4.7	21.9		
		-3.42	0.01563	0.00343							0.00730			4.8	19.7		
		-3.42	0.01617	0.00319							0.00679			4.7	20.8		
		-3.42	0.01635	0.00340	0.01576	0.00138	0.00330	0.00010				0.00723	0.00700	0.00025	4.8	20.6	20.1
Lepe Trench 7	7.6	-2.22	0.00909	0.00239							0.00508			4.0	14.5		
		-2.22	0.00978	0.00305							0.00650			4.6	13.8		
		-2.22	0.00983	0.00298							0.00633			4.5	14.0		
		-2.22	0.00915	0.00241							0.00513			4.1	14.5		

		-2.22	0.01075	0.00310	0.00972	0.00067	0.00278	0.00036	-4.26	-1.15	0.00659	0.00593	0.00076	4.6	14.9	14.3	0.4
Lepe Trench 4	4.13	-1.58	0.01111	0.00332							0.00707			4.7	14.9		
		-1.58	0.00989	0.00266							0.00566			4.3	14.8		
		-1.58	0.01025	0.00325							0.00693			4.7	14.1		
		-1.58	0.01249	0.00325							0.00692			4.7	16.6		
		-1.58	0.01397	0.00317	0.01154	0.00169	0.00313	0.00027	-3.76	-2.72	0.00674	0.00666	0.00057	4.7	18.4	15.7	1.7
Lepe Trench 4	4.6	-1.31	0.00811	0.00307							0.00653			4.6	11.9		
		-1.31	0.01117	0.00328							0.00698			4.7	15.1		
		-1.31	0.00957	0.00299							0.00636			4.5	13.7		
		-1.31	0.00831	0.00290							0.00616			4.5	12.4		
		-1.31	0.00905	0.00339	0.00924	0.00123	0.00313	0.00021	-6.32	-1.97	0.00722	0.00665	0.00044	4.8	12.6	13.1	1.3
Lepe Trench 4	4.1	-0.31	0.00864	0.00306							0.00651			4.6	12.5		
		-0.31	0.01438	0.00295							0.00628			4.5	19.3		
		-0.31	0.01208	0.00292							0.00622			4.5	16.7		
		-0.31	0.01455	0.00283							0.00602			4.4	19.9		
		-0.31	0.01203	0.00312	0.01234	0.00239	0.00298	0.00011	-7.79	-1.94	0.00663	0.00633	0.00024	4.6	16.3	17.0	2.9

**Table 6. Isotope measurements from ostracods from Unit 2d.**

Section / test pit / borehole	Field code	Laboratory code	Field moisture (%)	K conc. (%)	Th conc. (% o)	U conc. (% o)	Overburden thickness (m)	Cosmic dose rate (Gy/ka)	Total dose rate (Gy/ka)	Mean recycling ratio (all aq)	Mean D <sub>e</sub> (Gy) (all accepted aq)	Age estimate (ka)	Age range (ka)	MIS attribution
Unit 5 (Brickearth)														
S1	LEP10-01	X4102	6.0	1.19±0.06	6.9±0.345	2.2±0.11	0.41	0.20±0.05	2.19±0.15	1.07	10.6±8.16	4.8 ± 3.7	1.1-8.5	1
S1	LEP10-02 (replicate of -01)	X4103	6.0	1.16±0.06	7.1±0.36	2.1±0.1	0.38	0.20±0.06	2.16±0.11	1.00	116.5±27.6	54 ± 13.1	41-67	4-3
S1	LEP10-03	X4104	14.0	1.24±0.06	11.4±0.57	2.6±0.13	0.79	0.19±0.03	2.36±0.16	1.08	5.2±3.06	2.2 ± 1.3	0.9-3.5	1
S1	LEP10-04 (replicate of -03)	X4105	14.0	1.24±0.06	11.4±0.57	2.6±0.13	0.76	0.19±0.03	2.24±0.11	1.01	73.7±35.2	32.9 ± 15.8	17-49	3-2
Unit 4 (Lepe Upper Gravel / St Leonards Farm Gravel [upper] – see Briant <i>et al.</i> , 2006a)														
S5	LEPE03-05	X1729	2.0	0.54±0.027	<0.300 (0.200±0.100)	1.25±0.063	2.00	0.16±0.04	0.68±0.06	1.04	38.9±2.7	57± 6	63-51	4–3
Unit 1 (Lepe Lower Gravel/St Leonards Farm Gravel [lower] – see Briant <i>et al.</i> , 2006a)														
S1	LEPE03-01	X1725	9.2	0.348±0.017	0.340±0.017	2.610±0.131	4.27	0.12 ±0.02	0.61 ±0.03	0.99	121.9 ± 6.3	198 ± 15	213-184	7–6
S1	LEPE03-02 (replicate of -01)	X1726	9.2	0.240±0.012	1.900±0.095	0.500±0.025	4.27	0.12 ±0.02	0.68 ±0.03	1.05	98.9 ± 3.4	146 ± 10	156-136	6
TP4a	LEPE03-03	X1727	17.9	0.138±0.007	0.420±0.021	1.16±0.058	5.00	0.11±0.01	0.36±0.02	1.02	50.7±2.30	141±11	152-130	6–5e
TP4a	LEPE03-04 (replicate of -03)	X1728	17.9	0.160±0.008	0.900±0.045	0.300±0.015	5.00	0.11±0.01	0.34±0.02	1.03	56.2±2.9	165±14	179-151	6

**Table 7. OSL dosimetry, equivalent dose and age estimates for samples from the Stone Point SSSI sequence, Hampshire, England by PASHCC (Briant *et al.*, 2006a, 2009, Supplementary Information). Gy = Grays, ka = thousands of years. Dose rate estimate for Units 1 and 4 based on neutron activation analysis (NAA) and gamma spectrometry where feasible (LEPE03-01, 02, 05) and NAA alone where this was not possible (LEPE03-03, 04). Dose rate estimate for Unit 5 based on Inductively-Coupled Plasma Mass Spectrometry (ICP-MS). Age calculated by dividing mean D<sub>e</sub> by total dose rate. Error quoted as one standard error (standard deviation /  $\sqrt{n}$ ). MIS boundaries are taken from Shackleton *et al.* (1990) and Bassinot *et al.* (1994).**

NEaar no.	Sample name	Asx D/L	Glx D/L	Ser D/L	Ala D/L	Val D/L	[Ser]/[Ala]
3312bF	LeBto1bF	0.680 ± 0.001	0.186 ± 0.001	0.987 ± 0.007	0.345 ± 0.001	0.214 ± 0.006	0.565 ± 0.002
3312bH*	LeBto1bH*	0.580 ± 0.000	0.180 ± 0.000	0.671 ± 0.013	0.267 ± 0.000	0.144 ± 0.002	0.489 ± 0.020
3313bF	LeBto2bF	0.680 ± 0.032	ND	0.749 ± 0.018	0.373 ± 0.003	ND	0.461 ± 0.005
3313bH*	LeBto2bH*	0.568 ± 0.003	0.168 ± 0.001	0.615 ± 0.122	0.268 ± 0.013	0.152 ± 0.005	0.316 ± 0.146

**Table 8. Amino acid data on opercula of *Bithynia tentaculata* from Lepe. Error terms represent one standard deviation about the mean for the duplicate analyses for an individual sample. Each sample was bleached (b), with the free amino acid fraction signified by 'F' and the total hydrolysable fraction by 'H\*'. The sample size for 3313bF was very small, with concentrations similar to the level of detection, and therefore should be treated with caution.**