

# Relative sea-level variability during the late Middle Pleistocene: New evidence from eastern England

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#### 28 Abstract

29 Unravelling patterns of relative sea-level change during previous interglacials enhances our 30 understanding of ice sheet response to changing climate. Temperate-latitude estuarine environments 31 have the potential to preserve continuous records of relative sea level from previous interglacial (warm) periods. This is important because, currently, we typically only have snapshots of sea-level 32 33 highstands from low-latitude corals and raised palaeoshoreline indicators while the (continuous) 34 deep-sea oxygen isotope record only provides indirect evidence of sea-level changes. Here, we focus 35 on the Nar Valley in eastern England, in which is preserved evidence of a late middle-Pleistocene marine transgression more than 20 vertical metres in extent. By applying a model of coastal 36 37 succession and sea-level tendencies, as used in Holocene sea-level studies, we assess the mode 38 (abrupt versus gradual) of sea-level change recorded by the interglacial Nar Valley sequences. 39 Compiled palaeo-stratigraphic evidence comprising foraminifera, pollen and amino acid racemization 40 dating, suggests that the mode of sea-level change in the Nar Valley interglacial sequence was gradual, 41 with potentially two phases of regional transgression and relative sea-level rise occurring at two 42 separate times. The first phase occurred during the latter part of marine oxygen isotope stage (MIS) 43 11 from ~8 to 18 m OD; and, the second phase potentially occurred during early MIS 9 from ~-3 to 3 44 m OD (with long-term tectonic uplift included in these estimates). We cannot conclusively preclude 45 an alternative MIS 11 age for these lower sediments. The lack of indicators for rapid sea-level 46 oscillations in the Nar Valley adds weight to an argument for steady melt of the ice sheets during both 47 MIS 9 and 11.

## 48 **1. Introduction**

49 To achieve an improved understanding of the relationship between climate, ice-sheet behaviour and 50 sea level, we need to examine geological archives. Previous interglacials are often used to assess 51 changes in past sea level during warm-climate episodes (Dutton et al., 2015) and inform predictions 52 of future sea-level change (Church et al., 2013; Lowe et al., 2009). A key component of this work is 53 understanding how the ice sheets may respond to future climate change, which presents the largest 54 uncertainty in future predictions (Grinsted et al., 2015). Reconstructing direct evidence of ice-sheet 55 behaviour during previous interglacials is challenging, with many archives (e.g., proximal marine 56 sediments and geomorphological features) removed by subsequent glaciations. Ice cores provide the 57 best insight into past ice sheet accumulation (e.g., Dansgaard et al., 1993; Petit et al., 1999), but are 58 typically drilled on stable ice domes in order to provide the most complete records, whereas the 59 peripheries of ice sheets are the regions where mass is potentially lost during interglacial warming. As 60 a result, observations of changes in past sea level are the most commonly used method to infer past 61 ice-sheet changes (e.g., Dutton et al., 2015).

62 Evidence for modes of sea-level variability during MIS 11 and 9 is relative sparse, although they are 63 interglacials of particular interest. MIS 11 is the longest interglacial of the late Quaternary (27 ka, 64 <u>Tzedakis et al., 2012</u>) with global atmospheric  $CO_2$  at 286 ppm, and is considered a potential analogue 65 of the current interglacial due to similarities in orbital configuration (McManus et al., 2013). MIS 9, 66 although comparatively short in duration (11.6 ka), is the warmest interglacial recorded in Antarctica, 67 with global atmospheric CO<sub>2</sub> at 300 ppm (Past Interglacials working group of PAGES, 2016). Yin and 68 Berger (2012) demonstrate that MIS 11c, MIS 9e and MIS 5e are the warmest interglacials of the last 69 800,000 years.

70 Evidence of MIS 11 and 9 sea level in low-latitude regions includes relict shorelines, marine terraces, 71 tidal notches and coral reefs (e.g., Blakemore et al., 2015; Chen et al., 2014; Hearty and Kindler, 1995; 72 Murray-Wallace, 2002; Raymo and Mitrovica, 2012; Schellmann and Radtke, 2004; Vezina et al., 1999). 73 These features typically provide evidence for the elevation of the interglacial sea-level highstand at, 74 or above present, although the calculated elevation is dependent on the assumed long-term uplift 75 rate (e.g., Schellmann and Radtke, 2004). Based upon these relative sea-level (RSL) data, terrestrial ice extent during MIS 11 is assumed to be less than at present (Raymo and Mitrovica, 2012). However, 76 77 little is known about stage MIS 9.

78 Marine oxygen isotope data can act as proxy for past sea level in the absence of coastal 79 geomorphological features and the near-continuous time series may highlight any notable sea-level 80 fluctuations (e.g., Siddall et al., 2007; Spratt and Lisiecki, 2016) (Figure 1). These datasets suggest MIS 81 11 is typified by a single, long (~30 ka) duration highstand (Siddall et al., 2007). MIS 9 has a dominant 82 single peak in sea level during the earliest substage (MIS 9e, Railsback et al., 2015), with a much smaller 83 (~8-10 m lower) secondary peak during the next substage (MIS 9c) (Siddall et al., 2007). One or more 84 sea-level oscillations during a highstand suggests dynamic behaviour of the ice sheets during the peak 85 warm period with episodes of significant mass loss and gain, often in relatively short time intervals (a few thousand years or less), as has been reconstructed in MIS 5e (Kopp et al., 2009). The marine 86 87 isotope records from MIS 11 and MIS 9 provide no evidence for abrupt, large scale oscillations in sea 88 level that might be comparable to those seen in some MIS 5e records.

89 To achieve better understanding of the behaviour of ice sheets during MIS 11 and 9, there is a need 90 for continuous records of RSL as found in temperate-latitude estuarine environments, similar to 91 detailed study of the MIS 5e Netherlands record (Long et al., 2015; Zagwijn, 1983). There is evidence 92 for marine inundation in northwest Europe in MIS 11 and 9, for example within the Thames, and along 93 the south and east coasts of England (Bridgland et al., 1999; Bridgland et al., 2013; Roe et al., 2009; 94 Roe et al., 2011; Roe and Preece, 2011; Schreve et al., 2002; White et al., 2013). Flexure of the North 95 Sea Basin, tectonic uplift/subsidence, sediment compaction and glacial-isostatic adjustment (GIA) 96 during repeated glacial-interglacial cycles (Busschers et al., 2008; Lambeck et al., 2012; Rose, 2009) 97 mean that the elevations at which sea-level positions are observed may be different from their 98 elevations at the time of formation. Notwithstanding, these records are important because they are 99 often continuous for all or part of the interglacial highstand(s), and, therefore, offer the potential to 100 reconstruct the mode (gradual versus abrupt) of sea-level change with a high degree of precision, 101 especially if microfossil analyses - as developed and applied in Holocene sea-level studies (e.g., Barlow 102 et al., 2013) - can be applied.

The study area for this paper, the Nar Valley in eastern England (Figure 2) has evidence of Pleistocene interglacial marine transgression(s), preserved over ~20 vertical metres (<u>Stevens, 1959</u>). By applying methodological insight gained from Holocene sea-level reconstructions in estuarine settings, similar to that discussed by <u>Long et al. (2015)</u>, this paper aims to assess the mode of sea-level change during the interglacial Nar Valley record, which we demonstrate as recording marine inundation during MIS 11 and 9. This archive from a temperate-latitude location may increase our knowledge of ice-sheet behaviour during warm periods and aid predictions of future responses.

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## 111 **2.** Identifying modes of sea-level change in estuarine sediments

- 112 Assessing the mode of sea-level change in estuarine sediments requires consideration of three main
- lines of evidence which have been applied extensively in temperate-latitude, estuarine-based studiesof Holocene sea level:
- 115 1. The tendency of the sea-level indicator;
- 116 2. The nature of the transgressive or regressive contact, i.e., abrupt or gradual;
- The lateral extent of the transgressive or regressive contact and its representation in adjacent
   vertically stacked sequences.

The tendency of a sea-level indicator describes the stratigraphic or morphological evidence for an increase (positive sea-level tendency) or decrease (negative sea-level tendency) in marine influence (Shennan et al., 2015; van de Plassche, 1986). This is a useful means of analysis as it goes beyond simply identifying the elevation of past sea level (as recorded by geomorphological indicators such as raised marine terraces or drowned shorelines), by also objectively describing changes in the height and salinity of the water table, which are in turn, related to the proximity of marine conditions and the elevation of the sample site with respect to defined tidal datums.

126 Tendency analysis requires litho-, bio- and chrono-stratigraphic data through a sequence of 127 sediments, both laterally and vertically. Marine-brackish to brackish-freshwater vegetation 128 successions in coastal lowlands of northwest Europe are typified by five coastal zones (Figure 3), which 129 reflect the tolerance of different species to the frequency of tidal inundation and groundwater salinity 130 (after Waller et al., 1999). Gradual vertical changes in groundwater cause adjacent coastal vegetation 131 zones to migrate up or down the environmental gradient. For example, when saline groundwaters rise, the coastal zones migrate landward so that salt marsh species (zone 3 in Figure 3A) colonise 132 133 former reed swamps (freshwater swamps colonised by the common reed) (zone 2). Microflora and fauna such as diatoms and foraminifera also exhibit zonation in the coastal zone (Figure 3). 134 135 Foraminifera are absent above the highest astronomical tides (HAT), but below this, specific assemblages dominate each coastal zone; for example Jadammina macrescens in the upper salt 136 137 marsh, Miliammina fusca in the low marsh and tidal flats and Elphidium excavatum in sub-tidal 138 environments (Murray, 2006). The zonation and succession of flora and fauna thus aid interpretation 139 of the positive and negative tendencies of sea level within palaeo-estuarine sequences.

Litho- and biostratigraphical analysis of estuarine sequences may be also used to assess whether the transgressive or regressive contact, which records the up-core transition from fresh or brackish-water to marine conditions (or *vice versa*), is abrupt or gradual (e.g., Long and Shennan, 1994). Abrupt changes in groundwater levels result in one vegetation/coastal zone being replaced by a non-adjacent vegetation type; for example a rapid sea-level rise may mean subtidal environments (zone 5 in Figure 3A) replacing a freshwater swamp (zones 1 or 2), missing out the intervening salt marsh and tidal flat zones (zones 3 and 4). Figure 3B shows two hypothetical stratigraphic sequences that would indicate a positive tendency, but with the second profile highlighting a potential jump in sea level with the typical pathway of coastal succession abruptly interrupted. This analysis is first done in a single core (as in Figure 3B), and then may be considered together in a series of cores from across a site or region.

150 By tracing the timing and lateral and vertical extent of any transgressive or regressive contacts, it is 151 possible to assess whether they record site-specific processes or are part of system-wide (i.e., estuary-152 scale) changes. Transgressive contacts from the same time period, which are recorded in multiple 153 sites within one or more systems, may suggest a regional change in tendency, most likely caused by a 154 rise in regional sea level, as opposed to local shifts in shoreline position caused by, for example, 155 changes in sediment supply or tidal channel position (e.g., Shennan, 1982; Shennan et al., 2015; 156 <u>Tooley, 1982</u>). Similarly, a salt marsh to intertidal mud transgressive contact recorded in one core 157 may also be replicated in an adjacent vertically deeper sequence by subtidal sediments replacing 158 intertidal muds. If a core does not record a switch from one environment to another, and simply 159 contains either freshwater or marine sediments, it cannot record a change in tendency, but it may be 160 used as a freshwater or marine limiting point, indicating that sea level must either have been below 161 or above this elevation, respectively. Long and Shennan (1994) applied the tendency framework and 162 models of vegetation and coastal succession to test for abrupt versus gradual positive and negative 163 sea-level tendencies in both tectonically active and stable Holocene coastal settings. Here, we apply 164 this approach to previous interglacial estuarine sequences, found in the Nar Valley.

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## 3. The Nar Valley, eastern England

The Nar Valley (in Norfolk, eastern England) is an asymmetrical valley cut into underlying Mesozoic 167 168 rocks (Figure 4). The Pleistocene valley-fill is characterized by a glacial diamicton overlain by pro-169 glacial lake laminated clays (Gibbard et al., 1992; Ventris, 1996), most likely formed following retreat 170 of the Anglian (MIS 12) ice sheet (Pawley et al., 2008). The clay facies are overlain by sands that fine 171 upwards into clays that are, in turn, capped by a dense, lignitic bed of wood peat (Ventris, 1996). The 172 sequence is collectively known as the Nar Valley Freshwater Beds (Stevens, 1959). Above these 173 freshwater sediments in several locations is the Nar Valley Clay, often containing visible remains of marine fauna including foraminifera (Baden-Powell, 1967; Rose, 1835; Stevens, 1959). This paper 174 175 focuses on the nature of this flooding surface, where marine sediments of the Nar Valley Clay

transgress the lower freshwater deposits. In many locations the Nar Valley Clay is overlain by coldstage outwash (the Tottenhill Sands and Gravels), with Holocene alluvial sediments filling the modern
River Nar valley. Between the outwash fan formed by the Tottenhill Sands and Gravels (<u>Gibbard et</u>
<u>al., 2009</u>; <u>Gibbard et al., 1992</u>; <u>Lewis and Rose, 1991</u>) and the modern Nar valley floor is a staircase of
Middle-Late Pleistocene river terraces that testify to long-term land uplift (Boreham et al., 2010).

181 Previous pollen analyses through the Nar Valley Freshwater Beds clearly show affinities with the 182 British Hoxnian interglacial pollen assemblage (Table 1), based upon the presence of the palynomorph 183 'Type X', high presence of *Hippophae* and the occurrence of significant frequencies of *Tilia* and *Taxus*, 184 with the marine transgression proposed to occur through early to late-temperate pollen stages Holic 185 to Hollib (Stevens, 1959; Ventris, 1996). However, northwest European 'Hoxnian' profiles are thought 186 to characterise both MIS 11 and 9 (Thomas, 2001). Numerical and relative dating of the Hoxnian 187 stratotype at Hoxne, Suffolk (Ashton et al., 2008) and the most complete Hoxnian pollen record at 188 Marks Tey (Rowe et al., 1999; Turner, 1970) correlate the Hoxnian sensu stricto with the first warm 189 period after MIS 12, therefore MIS 11 (Candy et al., 2014). However, the evident similarities between 190 the MIS 11 and 9 pollen assemblages means that separating sequences solely based upon pollen 191 spectra is a challenge (Roe et al., 2009), and no single vegetation zone can be considered sufficiently 192 diagnostic to be applied for dating interglacial periods. Numerical dating of the freshwater peat at 193 Tottenhill by <sup>230</sup>Th/<sup>238</sup>U produced a mean age of 317±14 ka (Rowe et al., 1997), whilst multiple 194 isoleucine epimerization determinations of Ammonia beccarii and Aubignyna perlucida foraminifera 195 within the Nar Valley Clay yield mean A/I values of 0.135 and 0.111 respectively (Scourse et al., 1999), 196 all of which suggested that the Nar Valley Clay correlated with MIS 9. By comparison, similar 197 aminostratigraphic dating of a Hoxnian-type sequence in the Inner Silver Pit area of the southern 198 North Sea produced ages which suggest its deposition during MIS 11 (Scourse et al., 1998), highlighting 199 the challenge of ascribing a definitive MIS age for Hoxnian pollen-type sequences within the same 200 region (Scourse et al., 1999).

201 Numerical dating of the Nar Valley has not been applied outside of the Tottenhill site. We therefore 202 we use amino acid racemization dating (AAR) of Bithynia tentaculata opercula collected from the Nar 203 Valley Freshwater Beds with comparison to the established British Quaternary chronological 204 framework (Penkman et al., 2011, 2013), in an effort to constrain the marine oxygen isotope stage(s) 205 during which the freshwater deposits were emplaced. However, the current absence of an AAR 206 chronological framework for late-Quaternary marine sediments in Britain means we cannot 207 independently date the Nar Valley Clay itself, and are therefore reliant on correlation with the Hoxnian 208 pollen assemblages in Table 1.

Zone name	Pollen stage	Fossil pollen assemblage characteristics at Marks Tey and			
Zone name	r onen stage	Hoxne			
Post tomporato	HolV	The Early-Glacial. Arctic/Sub-Arctic conditions. Non-arboreal			
Post temperate		pollen (NAP) increases.			
	Holll a&b	Masked by Alnus at Hoxne, Azolla filiculoides present.			
		Gradual increase in <i>Pinus</i> and <i>Picea</i> , followed by increases in			
Late Temperate		Abies and Carpinus in IIIa at Marks Tey, which is particularly			
		dominant in HoIIIb (with Alnus). Declines of Quercus and			
		Ulmus in IIIa while Corylus remains. Ilex, Hedera and Taxus			
		present.			
	Holld	Alnus-Qurcus-Ulmus-Tilia. Mixed oak forest with expansion of			
		Ulmus and decline of Tilia. Fraxinus also present.			
Early Tomporato	Hollc	Alnus-Quercus-Betula-Tilia. Rapid expansion of Alnus.			
	Hollb	Betula-Quercus-Pinus. Quercus became dominant. Ulmus			
		incoming with sparse Tilia, Alnus and Picea later			
	Holla	Betula-Pinus colonising. Evidence of Quercus arriving.			
Pre-temperate/		Hinnonhao scrub, somo Potula			
late glacial					

Table 1 - Summary of Hoxnian-type pollen assemblage characteristics and stages at Hoxne and Marks
 Tey (Turner, 1970; West, 1956).

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- 212

# 213 **4. Methods**

# 214 4.1 Field methods

Our field strategy was guided by previous work (<u>Gibbard et al., 1992</u>; <u>Stevens, 1959</u>; <u>Ventris, 1996</u>), with resampling near to known Nar Valley Clay sequences where access was available. We aimed to sample material across a range of elevations to provide as much information as possible regarding the lateral and vertical extent of the marine sediments.

219 Material was collected from five locations (Figures 5 and 6, grid references provided in the results, 220 section 5): (1) at the lowest part of the working Blackborough End Quarry, near to the Blackborough 221 End sequence described by Stevens (1959); (2) a newly exposed section at the southern end of 222 Tottenhill Quarry south of the previously described sections (Gibbard et al., 1992; Ventris, 1996); (3) 223 Horse Fen, aiming to replicate the work by Stevens (1959); (4) Railway Cottage, east of East Winch 224 near to Stevens' (1959) boreholes 1-3; and (5) Bradmoor Hill at Little Long Plantation ~1 km east of 225 Summer End Farm (Stevens, 1959). Cores at Blackborough End Quarry, Horse Fen, Railway Cottage 226 and Bradmoor Hill were collected in 2012 using a Percussion drilling kit and window sampler. At Horse 227 Fen a second deeper core was collected in 2013 using a shell and auger drilling rig, ~50 m north of the 228 first core to collect material below the wood peat. A newly opened face (2014) at Tottenhill Quarry, 229 where the overburden Tottenhill Sands and Gravels had been excavated, provided access to the Nar

Valley Freshwater beds and overlying clay for monolith sampling. All boreholes were levelled to metres Ordnance Datum (m OD) using local benchmarks (with the exception of Tottenhill Quarry where the elevation had to be estimated from Ventris, 1996) with the latitude and longitude taken using a handheld GPS. The attitudinally lowest occurrence of Nar Valley Clay is found at Manor Farm (Figure 6), but we were unable to resample this site due to access restrictions, and therefore are reliant on the results of <u>Mitlehner (1992)</u>.

236

#### 237 4.2 Laboratory methods

Following fieldwork, the collected sediment was wrapped in plastic and stored in a fridge (~4°C) at Durham University and sampled for further analysis. The sampling interval of the cores varied according to the stratigraphy and avoided core breaks, with a higher resolution sampling interval across the peat-clay contacts. Organic content was measured across the peat-clay contact in the six cores, as percentage loss on ignition (LOI), by burning ~2-5 g of dried sediment at 550°C for four hours.

243 All cores were subjected to spot-sampling to establish in the first instance, the absence or presence 244 of foraminifera. Where foraminifera were found, full counts and identification of taxa were carried 245 out and absolute concentrations calculated. Samples (0.4-7 cc) were wet-sieved and the fraction 63-246  $500 \,\mu\text{m}$  retained. The samples were divided into four at least once and, a fraction expected to yield at 247 least 100 specimens of the sample was picked. Some samples had too few foraminifera to provide a 248 useful count. On average, ~140 specimens were counted per sample. The foraminifera were identified 249 to species level based on the taxonomy according to Loeblich and Tappan (1987), Murray (1979); 250 Murray et al. (2000) and Walton and Sloan (1990). We follow Walton and Sloan (1990) for the genus 251 Ammonia because we recognise their forms in our samples, but we are aware of the genetic debate 252 and different nomenclature (Hayward et al., 2004). Diatom samples were also prepared across each 253 peat-clay contact, but no diatoms were preserved.

254 Pollen analysis was undertaken on 2 cm<sup>3</sup> sub-samples at 16, 8, 2 or 1 cm resolution from the five cores 255 (due to limited material for analysis the analysed depths are not the same as for foraminifera samples). 256 Higher resolution sampling focussed on the peat sections of the cores and transitions from peat to 257 clay. Standard pollen extraction techniques were used (Moore et al., 1991). Because pollen was sparse 258 in many samples, micromesh sieving (10  $\mu$ m) was used to remove the clay and finest silt fraction prior 259 to extraction. For Blackborough End Quarry, Tottenhill and Railway Cottage, samples were then 260 combined with heavy liquid (LST Fasfloat) prepared to a density of 1.9 g/ml, and centrifuged for 20 261 minutes at 1800 rpm (Nakagawa et al., 1998). The retained pollen was, in all cases, mounted on 262 microscope slides in glycerol jelly. Where the density separation process was used, all residues were 263 examined and found to contain no discernible pollen grains. The pollen sum counted was dependent 264 upon pollen preservation between sites and within site. In general, a minimum sum of 300 land pollen 265 grains was aimed for. Pollen taxa were were identified using the keys in Moore et al. (1991) and an 266 extensive comparative collection was available to aid identification of critical taxa. In general, the 267 taxonomy of Moore et al. (1991) modified by Bennett (1994) has been used. Percentage calculations were based on the sum of the dry land pollen with pollen marsh and aquatic pollen as a percentage 268 269 of the sum plus this category. This also applies to fern spores and to the miscellaneous (pre-270 Quaternary palynomorphs, Dinoflagellates and Pediastrum).

271 The current technique of amino acid analysis developed for geochronological purposes (Penkman et 272 al., 2008) combines a reverse-phase high-pressure liquid chromatography (RP-HPLC) method of 273 analysis (Kaufman and Manley, 1998) with the isolation of an 'intra-crystalline' fraction of amino acids 274 by bleach treatment (Sykes et al., 1995). This combination of techniques results in the analysis of D/L 275 values of multiple amino acids from the chemically protected (closed system) protein within the 276 biomineral, thereby enabling both decreased sample sizes and increased reliability of the analysis. 277 Amino acid data obtained from the intra-crystalline fraction of the calcitic Bithynia opercula indicate 278 that this biomineral is a particularly robust repository for the original protein (Penkman et al., 2011, 279 2013) and therefore has been targeted in this study.

Amino acid racemization (AAR) analyses were undertaken on samples detailed below (supplementary
 information for results). Opercula were not found in the freshwater sediments in any other cores.

- 3 individual *Bithynia tentaculata* opercula from Nar Valley Freshwater Beds, from a grab
   sample of peat near to the Tottenhill analysed section (as in Figure 6), that had undergone
   mineral diagenesis, appearing chalky (NEaar 9786 9788; THBto1-3).
- 3 individual *Bithynia tentaculata* opercula, from the same grab sample of peat as the chalky
   opercula near to the Tottenhill section, that had not undergone mineral diagenesis (NEaar
   9789 9791; THBto4-6);
- 6 individual *Bithynia tentaculata* opercula from the shelly peat at the base of the analysed
   Tottenhill section (NEaar 10337-10342; Tott3Bto1-6) (see results, location given on Figure 9);
- 1 incomplete fragment of *Bithynia tentaculata* operculum from Horse Fen, HF13, 1058-9
   (NEaar 10344; HF13Bo1) (see results, location given on Figure 7).

All samples were prepared using the procedures of <u>Penkman et al. (2008)</u> to isolate the intracrystalline protein by bleaching. Two subsamples were then taken from each shell; one fraction was 294 directly demineralised and the free amino acids analysed (referred to as the 'free' amino acids, FAA, 295 F), and the second was treated to release the peptide-bound amino acids, thus yielding the 'total' 296 amino acid concentration, referred to as the 'total hydrolysable amino acid fraction (THAA, H\*). 297 Samples were analysed in duplicate by RP-HPLC, with standards and blanks run alongside samples. 298 During preparative hydrolysis, both asparagine and glutamine undergo rapid irreversible deamination 299 to aspartic acid and glutamic acid respectively (Hill, 1965). It is, therefore, not possible to distinguish 300 between the acidic amino acids and their derivatives and they are reported together as Asx and Glx 301 respectively.

302

# 303 **5. Results**

Six new boreholes and one quarry face section in the Nar Valley reveal shell-bearing clay (containing 304 305 Hydrobia, Littorina and Ostrea edulis) up to +18 m OD. At Horse Fen, Blackborough Quarry and 306 Tottenhill (the lower sites) the clay overlies a lignitic peat from ~-2.5 to + 3 m OD (Figure 6). In 307 comparison, in the upper sites, Railway Cottage and Bradmoor Hill, the shell-bearing clay overlies a 308 dense, chalk-rich clay and medium to coarse sand rather than lignitic peat. Despite extensive coring 309 using a hand gouge and auger at a number of test sites in the modern elevation range between the 310 lower and upper sites, we found no evidence of sediments resembling the Nar Valley Clay or Nar Valley 311 Freshwater Beds between +4 and +8 m OD, typically encountering bedrock Carstone under the shallow 312 Holocene/Lateglacial substrate. It must be noted that Stevens (1959) documented Nar Valley Clay at 313 ~5 m OD at a former brickyard near East Winch, so it is not clear whether the absence of these 314 sediments within this vertical range is real or an artefact of the field sampling. We summarise the 315 lithological and biostratigraphical results from each location in turn, from the lowest occurrence of 316 the marine clay (Horse Fen 13-1) to the highest (Bradmoor Hill) (Figure 6), with full biostratigraphy 317 given in the supplementary information.

318

#### 319 5.1 Horse Fen 13-1

Drilling at Horse Fen (52.70038, 0.50385), ~50 m north of the original Stevens (<u>1959</u>) investigations, revealed an organic-rich brown sandy silt from 11.00-11.50 m (Figure 6), above which, is a dense, black, lignitic peat to 9.98 m, with occasional (up to ~0.05 m thick) layers of marl. The peat-clay boundary with the overlying stiff grey silty-clay at 9.98 m (-2.28 m OD) is visually sharp (<5 mm), with a decrease in organic content from ~80% at 10.05 m to ~5% at 9.90 m (Figure 7). Due to water saturation, it was not possible to collect material for analysis from 8.44-9.89 m. The stiff grey clay
contains occasional shells of *Littorina* and is overlain by yellow-orange sand from ~5 m to ~0.5 m below
the surface.

328 Foraminifera were not found in the dense black peat, with the first occurrences in low numbers at 329 9.99 m. The first 0.04 m above the peat-clay contact is dominated by forms of Ammonia beccarii, 330 Aubignyna perlucida, Elphidium williamsoni and Haynesina germanica (Figure 7). E. williamsoni and E. incertum decrease by 9.80 m, with A. beccarii f. beccarii, H. germanica, Aubignyna perlucida and 331 332 Elphidium incertum dominant to 7.70 m with no marked changes in the assemblage. Samples at 6.70 m and 5.70 m show a decrease in forms of A. beccarii and an increase in Elphidium gerthi 333 334 (supplementary information). These assemblages suggest an increase in water depth, as lower down 335 it is dominated by intertidal species (e.g., forms of A. beccarii, E. williamsoni) which at the top of the 336 sampled interval, is replaced by E. gerthi, which is found in fully marine environments (e.g., Knudsen, 337 <u>1984</u>).

There are a number of significant changes in the Horse Fen 13-1 pollen profile which are, in part, 338 339 related to the changing stratigraphy of the site. Pollen preservation in the differing sediment facies is 340 poor and especially in the lignitic peat from above 10.58 m. The basal zone (to 10.90 m) is dominated by Betula with few other trees and shrubs although, Juniperus and possible Tsuga are present. During 341 342 this earliest phase, Poaceae and Cyperaceae are the dominant herbs and are probably autochthonous 343 with other marsh taxa recorded (Typha latifolia, Typha angustifolia/Sparganium and Menyanthes 344 trifoliata). At 10.91-10.93 m, there is clear evidence of a stratigraphic hiatus between the basal sandy 345 silts and overlying peat. In the humic silt above the basal peat (10.90-10.70 m), Pinus becomes the 346 dominant taxon with largely reduced values of Betula, Poaceae, Cyperaceae and pre-Quaternary 347 palynomorphs. Subsequently, with change to the lignified peat, Pinus remains important but also with 348 marked increases of thermophiles, that include Ulmus, Quercus, Tilia, Fraxinus, Alnus and Corylus 349 avellana type. Values of these latter taxa become increasingly important towards the top of the 350 profile, especially after the change to humic silt above 10.1 m. Throughout this period, levels of 351 Poaceae and Cyperaceae remain low. Spores of Pteropsida (Dryopteris type) attain high levels, which 352 reflect the drier ground flora of the site and also their differential preservation in the humified peat.

It is clear that the depositional habitat during peat formation was variable. Initially fluvial conditions pertained, manifested by substantial numbers of reworked pre-Quaternary palynomorphs, and the autochthonous vegetation was probably grass and sedge fen. There is a hiatus in the stratigraphy which may be due to erosion of sediment or cessation of accumulation (perhaps due to groundwater lowering), after which the depositional environment was of lower energy with deposition of humic silt 358 again under fen vegetation. This progressed through to a drier alder carr habitat under which the 359 lignified wood peat accumulated. There was a subsequent reversal to wetter, fluvial/alluvial 360 conditions. The pollen sequence obtained is, unsurprisingly, similar to that obtained by Stevens (1959) 361 and may be compared with the Hoxnian profile at Marks Tey (Turner, 1970). The base to 10.90 m may 362 be correlated with pollen sub-zone Holla due to the importance of Betula and a diverse range of herb 363 pollen. Hippophae rhamnoides, as with Stevens (1959), is not found. The subsequent arboreal development with expansion of Pinus above the hiatus, with the following increase of thermophiles, 364 365 suggests a successional sequence of Holla (10.90-10.70 m), Hollb for 10.70-10.50 m and Hollc from 366 10.50-10.14 m. The top may also be Hollc or possibly, the early part of Holll, although this is not clear. 367 The AAR result from a single operculum fragment from Horse Fen (at 10.58 m) is discussed in the 368 chronology results section below, though the sample size is too small to be reliable.

369

## 370 5.2 Blackborough End Quarry

371 The Blackborough End Quarry borehole (52.70565, 0.48763) is the lowest elevation site sampled in 372 the modern Nar Valley, although the peat-clay contact is 1.18 m higher than at Horse Fen 13-1. A 373 hard, black, lignitic peat with organic content of ~85% (Figure 8) extends from the base of our core at 374 7.15 to 7.06 m (upper peat contact at -1.1 m OD), with a visually sharp contact to the overlying silt-375 clay (Figure 6). At 0.08 m above the peat-clay contact is a silty-clay with detrital peat and unidentified 376 shell fragments. Above this the organic content decreases to ~10% and the dark grey sandy silt, with 377 occasional Littorina and a shell bed of Ostrea edulis at 6.05-6.15 m, extends up to 3.35 m below the 378 surface. Iron-stained grey-brown silty sand overtops the sequence.

379 Foraminiferal preservation in the Blackborough End Quarry core is variable. No tests were found 380 below 7.00 m; at this level, the assemblage is dominated by forms of A. beccarii, A. perlucida, E. 381 williamsoni and H. germanica (Figure 8). Counts then remain low until 6.92 m where the silt-clay to 382 6.10 m primarily contains forms of A. beccarii, E. excavatum f. clavata and H. germanica. Above this, 383 to 3.70 m, preservation is again poor, albeit with an assemblage of forms of A. beccarii, Elphidium spp 384 and H. germanica. This fairly homogeneous, subtidal assemblage, contains two samples containing 385 foraminifera indicative of deeper water; at 6.10 m a number of Eggerelloides scaber are found 386 (although only 4%, so in the "rare and unknown" category), and a few Gavelinopsis praegeri at 5.30 387 m. The presence of these sub-tidal species (e.g., Alejo et al., 1999; Alve and Murray, 1999; Mendes et 388 al., 2004) in discreet intervals may indicate storm events.

389 The pollen sequence from Blackborough End Quarry represents an early-temperate woodland with 390 thermophiles including Ulmus, Quercus, Tilia, Fraxinus, Ilex and Hedera which are present to the base 391 of the profile (Figure 8), potentially correlating with HoII. These taxa then decline over the peat-clay 392 transition with an increase in coniferales (Pinus, Picea) which may be viewed as transition to early 393 Holll. It must be noted that diagnostic Hoxnian-type taxa such as Type X, Taxus, Vitis, low levels of 394 Carpinus and the lack of Abies (typical of mid HoIII) are not evident which means that the correlation 395 with the Hoxnian pollen stages (Table 1) is tentative. The fluctuating nature of the pollen assemblages 396 across the peat-clay transition at ~7 m may be partly taphonomic due to poor pollen preservation 397 (indicated by very damaged pollen, low pollen concentration and, in particular, by substantial numbers 398 of Pteropsida spores), or may indicate a hiatus in the record and may also explain the lack of diagnostic 399 Hoxnian taxa. It is also possible that the peat deposits may have accumulated over a long period of 400 time, whilst the clay above represents a much more rapidly accumulating sediment.

401

#### 402 5.3 Tottenhill

403 A newly-opened section at the south-west corner of Tottenhill Quarry (52.66985, 0.40428), ~0.8 km 404 south of locations Ta-Tf of Ventris (1996), provided an opportunity to observe the lateral extent of the 405 Nar Valley peat and its stratigraphic relationship to the overlying sediment. Coarse-to-fine sands and 406 gravels had been excavated from above the section, leaving a truncated surface over the underlying 407 ~1.6 m section. The basal unit at the sampled section is a light-grey silty sand with occasional shells (below which, in some other locations, a sticky light-grey silty clay with chalk clasts was observed). 408 409 The silty-sand is replaced by 0.21 m of grey-brown organic enriched clay-silt which then grades into a 410 brown-black, dense woody peat for another 0.21 m (Figure 6). The peat has a reasonably sharp (<1-5 411 mm) upper contact (estimated elevation 2.4 m OD, based upon the Ventris (1996) stratigraphic 412 sections Ta-Tf) with the overlying ~0.5 m of brown-grey silty clay, which contains many visible shells, 413 sometimes in laminated bands. The organic content decreases across the peat-clay contact from ~85% 414 to 14% (Figure 9). No foraminifera were found in the peat and overlying clay.

The Tottenhill Quarry pollen sequence (Figure 9) presented in this study is truncated by the recent quarry excavations and, therefore, we also consider the profile from Ventris (<u>1996</u>) for a more complete picture. The sequence represents a temperate wooded environment dominated by deciduous taxa such as *Alnus*, *Quercus* and *Ulmus*; that is, diagnostic of an early temperate interglacial phase. Thermophiles present include, *Alnus*, *Tilia* and *Hedera*, as well as Type X (<u>Phillips</u>, <u>1974</u>; <u>Turner</u>, <u>1970</u>) and are typical of this phase and, the pollen sequence corresponds most closely with Hollb, moving into Hollc (West, 1980). The high Alnus values followed by a rise and fall in Corylus values, as
well as a rise and fall in Ulmus levels, are characteristic of this transition. The results of the AAR
analysis of the opercula found at Tottenhill are presented in section 5.7.

424

#### 425 5.4 Horse Fen 12-2 and 12-4

426 Cores 12-2 and 12-4 at Horse Fen (Figure 6) were collected to provide foraminiferal data in association 427 with the Stevens (1959) pollen diagram obtained from this site. Core 12-2 (52.69946, 0.50387) is 428 located in a small clay pit where the overburden material had been removed; core 12-4 (52.69959, 429 0.50388) is ~10 m north on a track above the pit. We include 12-2 in Figure 6 for completeness as it 430 is geographically closest to Stevens' Horse Fen pollen diagram. We are, however, cautious of potential 431 erosion/disturbance of the peat-clay transition (see below) and therefore focus our investigations on 432 borehole 12-4 where there is a greater thickness of clay for analysis. The base of core 12-4 contains a 433 grey-black, very compacted peat from 4.69-4.52 m, with an upper contact (at 2.64 m OD) to the 434 overlying grey sandy silt with occasional shells and a particularly shell-rich layer containing fragments 435 of Ostrea edulis at 4.27-4.35 m. The organic content decreases from ~80% at 4.54 m to ~4% at 4.50 436 m (Figure 10). The grey sandy silt extends to 3.40 m, above which is ~0.80 m of light brown clay with 437 some organics, overtopped by orange-grey silty sand from 2.60 to 0.20 m.

438 Foraminifera occur between 4.54 and 2.25 m in Horse Fen 12-4, with forms of A. beccarii being 439 dominant, and associated with H. germanica, A. perlucida, E. excavatum f. clavata, E. macellum, and 440 E. williamsoni (Figure 10). There is a subtle assemblage change from an intertidal assemblage with 441 Ammonia spp. at 4.54 m, to a shallow sub-tidal assemblage with E. macellum (e.g., Li et al., 2000) 442 between 4.41 and 2.65 m, reinforced by a peak in E. gerthi at 3.05 m. Between 3.05 m and 2.25 m 443 this trend reverses. A similar assemblage of forms of A. beccarii, A. perlucida and H. germanica is found above the peat in core 12-2. (Foraminifera counts from 12-2 are presented in the 444 445 supplementary information).

Stevens (<u>1959</u>) divides her Horse Fen peat pollen profile into two parts: a lower non-arboreal pollen zone dominated by Cyperaceae with small quantities of *Betula* and *Pinus*, followed by gradual arrival of a mixed oak forest, though heavily dominated by *Alnus*. Stevens suggests the profile likely records a sedge fen around a lake (a fen is a minerotrophic peatland common in modern Eastern England) that was later overgrown by an alder carr, most likely equivalent to successions from Holla/b to Holld (West, <u>1980</u>). Above the peat-clay contact *Pinus* dominates with low levels of *Picea*, although the original Stevens profile is truncated ~0.2 m above the top of the peat, which fits with our boreholeinvestigations at core 12-2.

454

#### 455 5.5 Railway Cottage

The Railway Cottage borehole (52.71964, 0.54043) is ~200 m west of Stevens' (<u>1959</u>) boreholes 1-3 where she shows the Nar Valley Clay thinning out along a ridge, at ~15-16.5 m OD. The base of our borehole (6.51 m) stopped in flints/stones (Figure 6) which we also observed in the base of a drainage pit on the other side of the road to our core. From the base (8.51 m OD) to ~4.9 m is a black-grey silty clay containing remains of shells, including a visible band at 5.81-5.86 m, most likely *Ostrea edulis*. The organic content of the clay is low (<9%). Above the clay is ~4.9 m of coarse sand with occasional flints that extend to the surface.

Foraminifera are present from the base of the sample core (6.46 m) to 5.30 m, above which, no tests occur (Figure 11). A relatively homogeneous assemblage, dominated by forms of *A. beccarii*, *A. perlucida*, *H. germanica* and *E. incertum*, characterises this lower ~1.2 m of the silty clay. The only notable change in this assemblage is a shift from *A. beccarii f. tepida* to *A. beccarii f. parkensoniana* towards the top of the clay, which may be indicative of higher salinities (Debenay et al., 1998; Walton and Sloan, 1990).

The pollen sequence at Railway Cottage (Figure 11) represents a late-temperate interglacial stage attributed to HoIII, possible the very end of HoIIIa to HoIIIb (<u>West, 1980</u>). Thermophilous taxa and components of the deciduous, oak-dominated woodland (*Quercus, Ulmus, Hedera* and *Ilex*) decline or, are absent, above 6.00 m, suggesting climatic deterioration. The rapid expansion of *Abies* pollen above 6.10 m has supressed the within sum percentages of the other pollen as well as indicating the increasing ecological importance of fir growing in proximity to the site.

475

## 476 5.6 Bradmoor Hill

477 Stevens (<u>1959</u>) reports the highest occurrence of the Nar Valley Clay at Narford Hall at ~19 m OD, 478 although without a sediment description. Our borehole at Bradmoor Hill (52.70314, 0.60444) is ~1.3 479 km north of this site, in a small pit on the edge of Bradmoor Plantation. At the base of our borehole 480 at 8.87 m (9.24 m OD) to 8.15 m, there is a silty sand with occasional chalk fragments (Figure 6). 481 Overlying this to 6.41 m is a grey silty clay with small chalk fragments and thin laminae of fine sand, 482 with occasional traces of detrital organic material. From 6.15 to 4.38 m (6.15-6.41 m was not recorded) is a laminated coarse-fine silty sand with occasional fine chalk fragments. Above 4.38 m the silt-clay
content of the sand increases to 2.8 m from where clay-silt containing many shells of *Ostrea edulis*, *Hydrobia* and *Littorina* extends to ~0.50 m below the ground surface (organic content of the clay-silt
is typically less than 10%).

The deepest occurrence of foraminifera at Bradmoor Hill is at 3.80 m (Figure 12), with samples at approximately 1 m intervals below this level barren of tests. From 3.80 to 2.55 m forms of A. *beccarii* and *H. germanica* dominate with some A. *perlucida*. Above 2.80 to 0.20 m A. *perlucida* decrease with an increase in *E. williamsoni*. This is a gradual change with no rapid switches in assemblage, except for a spike in an unknown *Elphidium* sp. at 2.55 m. This entire assemblage is indicative of a stable intertidal environment.

493 The pollen spectra from Bradmoor Hill are largely homogeneous throughout, although there are some 494 changes between the lower clay and the upper sandy-silt facies (Figure 12). The sequence is 495 dominated by Abies, which attains high values (to 90%) with smaller numbers of other coniferales, 496 including, especially Pinus and Picea. Both are consistent at low levels through most of the profile and 497 expand in the upper sandy-silt from c. 0.4 m. Other coniferales include sporadic occurrences of Taxus 498 and Cuppressaceae indet. Deciduous trees include small but consistent levels of Quercus (to 4%) and 499 Alnus (peak to 8%). Thermophiles occur sporadically with Carpinus, Tilia, Fraxinus, Ilex and notably 500 Pterocarya in the upper levels. Type X is noted and small numbers of Vitaceae are present in the lower 501 clay-silt. Ericales show some increase from 0.4 m. Although not present in quantity, there is a diverse 502 range of herb pollen. Poaceae and Cyperaceae become more important in the uppermost sample. 503 There are substantial numbers of Dinoflagellates.

504 This pollen sequence clearly shows the dominance of Abies on, or in very close proximity to the site 505 (Figure 12). The importance of Abies and the presence of Type X, Pterocarya and Vitaceae (West 1956), 506 when compared with Marks Tey (Turner, 1970), suggests an immediate post-temperate phase (HoIV). 507 Thermophiles are more frequent in the lower part of the profile (below ~1.80 m) and this suggests the 508 remaining vegetation of the late temperate (HoIII), which fits with Stevens (1959) assessment of the 509 nearby Summer End Farm borehole. It should be noted that the dominance of Abies, which was 510 growing in close proximity and with high pollen values, will have suppressed the importance of other taxa. Changes in the upper levels of the profile (the sandy-silt from ~0.4 m) may indicate further 511 512 climatic change or increasing soil acidity in response to pedogenic change caused by the dominance of Abies. More acidophilous taxa include Pinus, Picea and Ericales. 513

514

#### 515 5.7 Chronology

The pollen results demonstrate the correlation of the Nar Valley sequences with the known Hoxnian pollen-assemblages (Table 1), but as discussed above, relating this to the marine oxygen isotope framework to compare the results on a broader scale is a challenge (<u>Thomas, 2001</u>). As result, we applied an independent chronological control for the timing of the deposition of the freshwater deposits found at the lower sites. Material collected in this project did not yield many *Bithynia* opercula (material was only found at Tottenhill and one fragment from Horse Fen), which have been successfully used elsewhere in relative AAR dating of the British Quaternary (<u>Penkman et al., 2013</u>).

523 We compare the Tottenhill and Horse Fen opercula dataset (Figure 13 and supplementary 524 information) to the range of data for British sites (Penkman et al., 2011, 2013). The preparation 525 technique of sample bleaching removes the leachable, open-system matrix of shell protein, leaving a 526 component that exhibits closed-system behaviour (the 'intra-crystalline' fraction). The protein 527 degradation in this intra-crystalline fraction is therefore dependent only on time and temperature 528 (Penkman et al., 2008), enabling aminostratigraphic correlation between sites sharing an equivalent integrated temperature history (Wehmiller et al., 2000; Wehmiller et al., 1992). The DL ratios of 529 530 aspartic acid/asparagine, glutamic acid/glutamine, serine, alanine and valine (D/L Asx, Glx, Ser, Ala, 531 Val) as well as the [Ser]/[Ala] value are assessed to provide an overall estimate of intra-crystalline 532 protein decomposition (IcPD). In a closed system, the amino acid ratios of the FAA and the THAA 533 subsamples should be highly correlated, enabling the recognition of compromised samples (e.g., Preece and Penkman, 2005). The D/L of an amino acid will increase with increasing time, but each 534 535 amino acid racemises at a different rate (e.g., Kaufman, 2006), due to differing side chains as well as 536 stabilities in peptide bonds. This means that they are useful over different timescales, with fast 537 racemisers such as Asx allowing better temporal resolution at young sites (less than ~130 ka in the UK; 538 Penkman et al., 2013), but at older sites, where its values approach equilibrium, the extent of natural 539 variability within the data precludes further age discrimination. Conversely, Val allows only relatively 540 poor age resolution in young contexts but provides much better temporal resolution at older ones, 541 back to the Pliocene (Penkman et al., 2011). Serine is one of the most geochemically unstable amino 542 acids, producing alanine as one of its decomposition products (Bada et al., 1978). The ratio of the 543 concentration of serine ([Ser]) to the concentration of alanine ([Ala]) therefore gives a useful indication of the extent of protein decomposition within a closed-system, with [Ser]/[Ala] decreasing 544 545 with time. The D/L of Ser is less useful as a geochronological tool for samples of this age, but is 546 presented here as aberrant values are useful indications of contamination.

547 Many attempts have been made to refine the temporal resolution of AAR and generate numerical 548 dates from kinetic experimental data (see <u>Clarke and Murray-Wallace (2006)</u> for a review), but recent 549 studies have shown that high temperature kinetic experiments may not accurately mimic low 550 temperature protein diagenesis in some biominerals (Demarchi et al., 2013; Tomiak et al., 2013). This 551 'calibration' approach has therefore not been attempted in this study, but the data has been 552 compared to the range of data for British sites (Penkman et al., 2011, 2013), which (ignoring urban 553 heat effects) span a narrow range of mean annual temperature (MAT) of 9-10°C (Penkman et al., 554 2013), so it is assumed that the samples will have experienced similar integrated thermal histories. As 555 amino acid racemisation rates within biominerals are dependent on the underlying protein sequence 556 (the ordering of the amino acids in the peptide chain), significant differences are observed in the rates and extent of racemisation between different species, the so-called "species effect" (Lajoie et al., 557 558 1980; Miller and Hare, 1975; Penkman et al., 2007). This can be ignored in this study, as all the 559 analyses and comparator material are undertaken on Bithynia opercula which have been shown to 560 show only minimal differences in racemisation within the genus (Penkman et al., 2013).

561 The "chalky" opercula, which appear to have undergone mineral diagenesis, show greater variability 562 than the normal opercula from the same horizon, and are therefore not included in the results in 563 Figure 13 for the age estimation. The Tottenhill samples show levels of protein breakdown consistent 564 with either a mid-late MIS 11 age, or possibly, early MIS 9. As so little decomposition occurs in the 565 cold stages and because of the extent of natural variability in biological samples, it can be difficult to 566 discriminate the end of one warm stage from the beginning of the next (Penkman et al., 2013). The 567 operculum AAR sample from Horse Fen 13-1 shows lower levels of protein breakdown than at 568 Tottenhill (Figure 13) but, as this is based on a fragmentary sample with low concentrations, this 569 should be treated with caution.

In an attempt to refine the age further, the AAR data can be examined for relevant sites plotted in
order of the pollen succession where the data is available from the relevant horizons (Figure 13).
Within MIS 9: Cudmore Grove, late temperate (Roe et al., 2009); Shoeburyness, early temperate Hol/II
(Roe et al., 2011); Barling early pre-temperate (Bridgland et al., 2001); within MIS 11: Hoxne Stratum
E (Hol-Hollc) (Ashton et al., 2008); Clacton early interglacial (Bridgland et al., 1999). Based solely on
these comparisons, the Tottenhill samples are consistent with an MIS 11 age, and less likely to
correlate with MIS 9, but this cannot be excluded.

577 The lack of further material for AAR dating and a lack of independent dating of the marine sediments 578 means we are reliant on correlation with published sites of known ages and additional stratigraphic 579 evidence. Both Bradmoor Hill and Railway Cottage, which do not have evidence of the Nar Valley

580 Freshwater Beds, as well as Stevens (1959) Summer End Farm site at a similar elevation, are typified 581 by very high percentage of Abies, diagnostic of HoIII. In <u>Stevens (1959)</u> East Winch borehole, the Abies 582 content is lower (<10%), suggesting its deposition during early Holla. The dominance of fir is also 583 found at Marks Tey (Turner, 1970), Inner Silver Pit (Scourse et al., 1998), Hoxne (West, 1956), Clacton 584 (Pike and Godwin, 1952) and East Hyde, Tillingham (Roe, 2001), which through independent means 585 have all been correlated with MIS 11 (Ashton et al., 2008; Bridgland et al., 1999; Rowe et al., 1999; 586 Scourse et al., 1998; White et al., 2013). Together, these sites account for most of the Hoxnian sites 587 at which the late part of the interglacial is represented palynologically. The exception is the fluvial-588 estuarine record at Woodston, Peterborough which, with low Abies values, has been correlated to 589 Hollc (Horton et al., 1992) but independently dated using AAR to MIS 11 (Penkman et al., 2013). 590 However, the presence of marine clay overlying glacial sediments at Bradmoor Hill and expected to 591 be at the base of Stevens' (1959) East Winch and Summer End Farm sites and our Railway Cottage 592 borehole, which are most likely from the extensive MIS 12 Anglian glaciation (Pawley et al., 2008), 593 leads us to conclude that the marine sedimentation in the higher-level Nar Valley interglacial sites 594 relates to a MIS 11 transgression during the late-temperate phase of the interglacial, most probably 595 the warm MIS 11c substage (<u>Candy et al., 2014</u>).

596 The apparent of the Nar Valley Freshwater Beds above ~4 m OD and the difference in relative timing 597 (c. Holl versus Holll) of the marine phases between the lower and upper sites, raises the question of 598 whether there are two separate phases of marine sedimentation recorded in the Nar Valley. Previous 599 dating of both the Nar Valley Freshwater Beds and Nar Valley Clay at Tottenhill suggested correlation 600 with MIS 9 (Rowe et al., 1997; Scourse et al., 1999). Our new AAR results from freshwater Bithynia 601 opercula at Tottenhill point to late MIS 11 age, but cannot also exclude an early MIS 9 age (Figure 13), 602 with the pre- and early-temperate (HoI-II) pollen assemblage for the Freshwater Beds at Tottenhill 603 (Ventris, 1996) potentially favouring the early MIS 9 age, with the pollen not suggesting late 604 interglacial conditions. The absence or relatively low abundance of Abies at Horse Fen, Tottenhill and 605 Blackborough leads to the suggestion of a difference in the regional pollen assemblage in comparison 606 with MIS 11 sites in eastern England where Abies is dominant. The absence of 'classic' Hoxnian pollen 607 indicators for the early and late temperate phases: Pterocarya, Vitis, Buxus, Azolla filiculoides and the 608 low levels of Taxus at Horse Fen and Tottenhill, (albeit with the presence of Type X demonstrably 609 present in both the MIS 11 and MIS 9 interglacials (Roe et al., 2009)), also highlights that these sites 610 may have been deposited during a different, post-Hoxnian interglacial stage. These species, as well 611 as Type X, are also absent at Blackborough Quarry (potentially due to poor pollen preservation) and 612 mean that it is not possible to designate with any certainty the interglacial stage to which this 613 particular sequence might belong. These lower-level Nar Valley profiles show similarity with estuarine 614 sites from the Thames and Essex with low Abies, high Pinus and occasional Type X, including Barling 615 (Bridgland et al., 2001), Purfleet (Bridgland et al., 2013; Schreve et al., 2002), Cudmore Grove (Roe et 616 al., 2009), Shoeburyness (Roe et al., 2011), Rochford and Burnham-on-Crouch (Roe and Preece, 2011) 617 all of which have been attributed to MIS 9. In the absence of absolute dating, it is therefore not 618 possible to reject a MIS 9 age for the lower Nar Valley sites, as also dated by Scourse et al. (1999) at 619 Tottenhill. This contracts the more definitive attribution of the upper sites to MIS 11. Therefore, the 620 Nar Valley Clay, previously recorded as being a single unit (Stevens, 1959; Ventris, 1996), most likely 621 represents two separate periods of marine inundation, during two different interglacials.

622

## 623 6. Discussion

# 624 6.1 Modes of sea-level change in the Nar Valley

625 The results presented above provide details of a lower freshwater peat, transgressed by a marine clay, 626 most likely deposited during MIS 9. In the uppermost sites (Railway Cottage and Bradmoor Hill) the 627 peat is absent (Figure 6), with the marine clay overlying a silty clay with sand and chalk fragments, 628 devoid of foraminifera. It is most likely that the underlying sandy-silt is glacially derived, probably 629 correlating with the Anglian (MIS 12) deposits found along the East Anglian coast (Pawley et al., 2008; 630 Jim Rose, personal communication), which means the upper Nar Valley Clay was most likely deposited 631 earlier (during MIS 11) than that found in the lower sites. We summarise the palaeo-environments 632 of peat and clay recorded in our new boreholes in Table 2, and synthesize the results to assess the 633 mode of sea-level change through the sequences: gradual versus abrupt.

## 634 Change in tendency

635 The tendency of a sea-level indicator describes the increase or decrease in marine influence (Shennan 636 et al., 2015; van de Plassche, 1986). Foraminifera are absent above the limit of the highest 637 astronomical tides, but occur throughout the marine environment (Figure 3). The replacement of 638 freshwater peats, devoid of foraminifera, by clay containing taxa such as forms of Ammonia beccarii, 639 Haynesina germanica and Elphidium species at Horse Fen and Blackborough End Quarry records a 640 positive tendency across the peat-clay (transgressive) contact. Our new section at Tottenhill Quarry 641 does not extend into the marine shell-bearing clay recorded by Ventris (1996), with the sequence 642 truncated by the quarry excavations and only extending into the freshwater lake marl above the peat. 643 The composite section of Ventris (1996) from the northern half of the quarry suggests that the 644 freshwater lake was replaced by brackish conditions (as indicated by the presence of Hydrobia

molluscs), followed by fully marine conditions (indicated by the occurrence of oysters). This site also
 records an increase in marine influence and, therefore, a positive sea-level tendency.

647 At Railway Cottage, the foraminifera-containing clay overlies gravel clasts, mainly flints (of unknown 648 origin) suggesting a stable marine environment but no indication of a change in tendency. At Bradmoor Hill, the first occurrence of foraminifera (at ~3.8 m) occurs in clay in association with 649 650 occasional fragments of chalk and flint, although these clasts disappear with the slight increase in 651 organic content above ~3.0 m. There is then some reworking between the glacial sediments and the 652 bottom of the overlying marine clay. Therefore, it is not possible to ascribe a change in tendency 653 based on the coastal succession model in Figure 3 for the upper sites, although it appears marine 654 conditions replaces non-marine glacial sediments. Evidence of negative sea-level tendencies within 655 the Nar Valley interglacial sequences is absent as there are no intercalated peats within the Nar Valley 656 Clay recorded by this and previous work (Stevens, 1959; Ventris, 1996).

#### 657 The nature of the transgressive contact: abrupt or gradual?

The lower sites (Horse Fen, Blackborough End Quarry and Tottenhill Quarry) all provide evidence of a positive sea-level tendency. As discussed above, there is no direct evidence for a change in tendency over a transgressive contact at Bradmoor Hill or Railway Cottage. In both cases, however, the relatively homogenous foraminiferal assemblages of forms of *A. beccarii f.*, *H. germanica* and species of *Elphidium* suggest a stable intertidal to subtidal environment with no evidence for rapid change in water depth. The occurrence of beds of molluscs such as *Hydrobia*, *Littorina* and oysters also suggests no rapid changes in environment.

665 Previous work in the Nar Valley has not focused on the nature of the peat-clay transition and our 666 detailed laboratory analysis allows assessment of the character of the transgressive contact using the 667 coastal succession model in Figure 3. We found very low numbers of typical salt-marsh foraminifera 668 such as Jadammina macrescens and Trochammina inflata within the analysed Nar Valley sequences, 669 nor are there transitional salt-marsh pollen taxa. The transgressive overlaps at Horse Fen, 670 Blackborough End Quarry and Tottenhill Quarry record a freshwater peat replaced by low intertidal 671 facies, representative of a fen being replaced by a tidal flat. Salt-marsh facies are absent, so the 672 transgression can arguably be interpreted as a 'moderate' drowning, a transition from zone 2 to zone 4 in Figure 3. Using modern analogues this represents a minimum RSL rise of about half the tidal range, 673 674 as peat forms above the highest tide level and the salt marsh to mudflat transition is found around mean tide level in the UK (e.g., Horton and Edwards, 2006). Is this evidence for a rapid rise in sea level? 675

676 We compare our lower Nar Valley stratigraphies with similar sequences from Holocene estuarine 677 deposits from this region. This is potentially a useful exercise, because we know that during the 678 Holocene, very rapid sea-level oscillations (on the order of metres per century) did not occur (with the 679 exception of the 8.2 ka BP event (Lawrence et al., 2016)). If the transgressive sequences we find in 680 the Nar Valley also occur in the Holocene, then we may reject the hypothesis that they are due to 681 rapid sea-level rise and ice-sheet instability. Holocene transgressive sequences in eastern England 682 that include the same, non-erosive, transition from fen to tidal flat include several deep cores along 683 the Norfolk coast, where basal peats are overlain by mudflat sediments (Andrews et al., 2000). Dates 684 on these contacts range between 5000 and 7000 cal. yr BP when relative sea level rose at average 685 rates of ca. 3-5 mm/yr (Shennan et al., 2000).

686 The Fenland arguably represents the nearest Holocene analogue to the estuary of the Nar Valley 687 during MIS 11 and 9. In the Fenland, several basal peat sequences representing a freshwater swamp 688 environment are overlain by either salt-marsh or mudflat sediments. Examples of the latter are 689 described by Waller (1994) at Welney Washes (ca. 6200 <sup>14</sup>C yr BP), Feltwell Common (ca. 4200 <sup>14</sup>C yr BP), and Farcet Fen (ca. 3800 <sup>14</sup>C yr BP). Relative sea-level rise during the formation of these contacts 690 691 was on average ca. 3 mm/yr (Shennan, 1994). Rapid compaction of peat following marine inundation 692 can also create accommodation space that results in widespread inundation and the rapid deposition 693 of thick intertidal sediments (Long et al., 2006).

694 In summary, several examples exist from Holocene coastal sequences in eastern England that include 695 similar stratigraphic signatures of the drowning of basal peat as found in the lower Nar Valley. These 696 transitions were not due to rapid rates of sea-level rise caused by abrupt ice-sheet collapse. Instead, 697 they can be formed by gradual changes in RSL due to long-term subsidence, or to various coastal 698 processes, including coastal barrier shifts, changes in basin morphology and local tidal range, basal 699 peat compaction, and sedimentation (Shennan, 1994). Our model of rapid sea-level rise (Figure 3B) 700 does not apply to the Nar Valley sequences, but rather suggests the sea-level rise recorded in the 701 lower (MIS 9) sites was gradual.

Site	Peat-clay contact elevation (m OD)	Foraminifera palaeo- environment	Pollen palaeo- environment	Relative timing of marine conditions (Hoxnian pollen stage)	Change in tendency	Change in coastal zone (from Fig 3)	AAR result	Suggested MIS age correlation
Bradmoor Hill	13.9 (first occurrence of foraminifera)	Stable intertidal	Succession from late- temperate to post- temperate woodland	HoIIIb potentially to start of HoIV	None	Zone 4/5 Stable marine conditions	n/a	11
Railway Cottage	6.5 (onto hard substrate)	Stable subtidal	Succession from deciduous woodland to late-temperate woodland	End of Hollla to Holllb	None	Zone 4/5 Stable marine conditions	n/a	11
Horse Fen (12-4)	2.8	Intertidal, deepening to shallow subtidal	Succession from fen to alder carr and aboreal woodland (from Stevens, 1959)	Holld (from Stevens, 1959)	+	Change from zone 2 to 4 (RSL rise = half the tidal range)	n/a	9 (11)*
Tottenhill Quarry	~2.6 m (from Ventris, 1996)	No foraminifera present in this study	Late early-temperate woodland	Hollc (from Ventris, 1996)	None in this study + in Ventris (1996)	Gradual (from Ventris, 1996)	Late MIS 11 or early MIS 9 ( <i>Bithynia</i> opercula)	9 (11)*
Blackborough End Quarry	-1.1	Intertidal/ shallow subtidal	Succession from early temperate to temperate woodland	Holla-c ?	+	Change from zone 2 to 4 (RSL rise = half the tidal range)	n/a	9 (11)* ?
Horse Fen (13-1)	-2.3	Intertidal, deepening to subtidal	Succession from fen to alder carr and aboreal woodland	Hollc or Holll	+	Change from zone 2 to 4 (RSL rise = half the tidal range)	Mid- Pleistocene (Bithynia opercula)	9 (11)*

702 **Table 2** – Summary of palaeoenvironments and estimate of age at each core location in the Nar Valley from this study, along with an estimate of the change

recorded with respect to the coastal succession model in Figure 3. \*The balance of evidence points to a MIS 9 age for these sites, but a MIS 11 age can also

not be rejected outright.

706 Lateral extent of the transgressive contact and its representation in adjacent sequences

707 The occurrence of a transgressive contact over a wide area of the Nar Valley (Figure 6) suggests the 708 marine sedimentation was not simply a consequence of site-specific processes. Transgressive 709 contacts from the same time period which are recorded in multiple cores may suggest a regional 710 tendency (Shennan et al., 2015). Based upon the Hoxnian-type pollen zones (Table 1), the 711 transgression at Horse Fen and Tottenhill Quarry occurred within Holl, most likely Hollc at Horse Fen 712 13-1 and Tottenhill, and Holld at the upper Horse Fen sites, suggesting a system-wide positive 713 tendency. The difference in Hoxnian pollen-zone between Horse Fen 13-1 (Hollc) and 12-4 (Holld) 714 may be a consequence of the ~5 m difference in elevation, suggesting that the sea-level rise was 715 gradual during this phase of climatic succession. The pollen assemblage at Blackborough End Quarry 716 similarly suggests that the transgression occurred during the latter part of the Early Temperate phase, 717 as in Horse Fen and Tottenhill, but with the absence of diagnostic Hoxnian taxa as found at the other 718 sites, correlation remains tentative.

The relative timing of the marine conditions at the higher sites of Railway Cottage and Bradmoor Hill differs from the lower transgressive contacts, with both containing HoIII (and potentially early HoIV at Bradmoor Hill) pollen assemblages. This fits with the <u>Ventris (1996)</u> summary of HoIIIb marine conditions at East Winch (~8.5 m OD) and Summer End Farm (<u>Stevens, 1959</u>) (~12.8-10.5 m OD). The absence of marine conditions during HoIII in the lower-level sites, based upon the absence of *Abies* in these sequences, adds further support to our argument that the two phases of marine sedimentation occurred during two separate interglacials.

726 The representation of a positive tendency across a peat-clay contact may also be replicated in adjacent 727 vertically deeper sequences as a deepening, for example from an intertidal to subtidal foraminiferal 728 assemblage. The transgressive contact at Blackborough End Quarry (~1.1 m OD) and the marine clay 729 of Horse Fen 13-1 are the only instance from the cores we collected where there an elevation overlap 730 of this nature. At this elevation of the Blackborough End Quarry flooding surface, the Horse Fen clay 731 contains a homogenous foraminiferal assemblage dominated by forms of A. beccarii and Aubignyna 732 perlucida, suggesting stable shallow subtidal conditions, with no evidence for rapid deepening. The 733 transgressive contact at Horse Fen 13-1 (~2.3 m OD) overlaps with diatom samples analysed in the 734 upper part of the Manor Farm borehole by Mitlehner (1992), which also show no rapid changes in 735 water depth, but instead a gradual shift in current turbidity in a shallow marine setting.

Consideration of the palaeo-stratigraphic evidence from the Nar Valley against the three main criteria
leads us to conclude that the mode of sea-level change during the Nar Valley interglacial sequence
was gradual (Figure 14), in line with similar Holocene changes, with potentially regional transgression
occurring during both MIS 11 and 9.

740

#### 741 6.2 Sea-level change in the Nar Valley

742 Pollen data from the Nar Valley sequences correlate with the British Hoxnian interglacial pollen 743 assemblage sensu lato (Table 1), which have been demonstrated to have affinities to both MIS 11 and 744 9 (Thomas, 2001), although the stratotype site of Hoxne and the full Hoxnian para-type succession at 745 Marks Tey are now correlated with MIS 11, probably substage 11c (Ashton et al., 2008; Candy et al., 746 2014; Rowe et al., 1999). The balance of evidence (discussed above) leads us to suggest the Nar Valley 747 Clay was deposited during both MIS 11 and 9, with long-term uplift (Westaway, 2009) separating their 748 local elevation (Figure 14), and not during a single interglacial as previously thought (Stevens, 1959; 749 Ventris, 1996). The two-interglacial model further supports evidence for the mode of sea-level change 750 in the Nar Valley being gradual, with rising sea level during MIS 9, and a stable highstand recorded 751 during both MIS 11 and 9 (Figure 14), rather than the elevation difference between the lower and 752 upper sites being explained by a sea-level jump. However, we cannot preclude erosion by subsequent 753 glacial sedimentation of the upper part of the marine sediments in the lower sites (Horse Fen, 754 Tottenhill and Blackborough) where Holll pollen is absent. This means it is also not possible to reject outright a MIS 11 age for the whole Nar Valley sequence based upon correlation with the Hoxnian 755 756 succession at Marks Tey (Rowe et al., 1999; Turner, 1970). Nonetheless, even within a single 757 interglacial framework there is a lack of indicators for rapid sea-level oscillations in the Nar Valley.

758

#### 759 **6.3 MIS 11 and MIS 9 sea-level highstands around the world**

760 Evidence for two late-Middle Pleistocene marine transgressions (MIS 11 and 9) have been found 761 elsewhere in eastern England, most notably in the channel-fill deposits of the Thames and its tributaries in eastern Essex (Roe and Preece, 2011). Determining maximum water heights at any of 762 763 these sites, or in the Nar Valley, is difficult as ascribing absolute water depths from the foraminiferal 764 assemblages is not possible and the upper surfaces of the marine units have been eroded. 765 Furthermore, regional uplift and cycles of glacial isostatic adjustment have modified the elevation of 766 the sediments from that at the time of deposition (Westaway, 2009). Due to the issues of dating 767 'Hoxnian' sediments, as discussed here, correlation with other sites in northwest Europe is challenging

and beyond the scope of this study. However, the absence of intercalated peats within the interglacial
marine sediments, or any change in tendency (beyond the initial recorded transgression at both MIS
11 and 9 sites in eastern England such as Cudmore Grove, Tillingham, Shoeburyness and Barling
(Bridgland et al., 2001; Roe et al., 2009; Roe et al., 2011; Roe and Preece, 2011)), suggests that neither

highstand was typified by markedly rapid RSL changes.

773 Geomorphological evidence of MIS 11 and 9 sea level found in low-latitude regions provide a snapshot 774 of the interglacial sea-level highstand at, or above, present sea level (Blakemore et al., 2015; Chen et 775 al., 2014; Hearty and Kindler, 1995; Murray-Wallace, 2002; Raymo and Mitrovica, 2012; Schellmann 776 and Radtke, 2004; Vezina et al., 1999). A stack of ocean sediment core-based reconstructions of Late 777 Pleistocene sea level identifies the highstands in sea level during MIS 11 and 9, but is unable to resolve 778 millennial-scale structure (Spratt and Lisiecki, 2016). The only 'continuous' sea-level record that might 779 provide further insight into the mode of sea-level change during the MIS 11 and 9 highstands is 780 currently from the Red Sea which, within the sample resolution, does not suggest any rapid 781 fluctuations when sea level is above present (<u>Rohling et al., 2010; Rohling et al., 2009</u>), unlike the MIS 782 5e record in the same location (Rohling et al., 2008).

783 Ice extent during MIS 9 has received little attention (Past Interglacials working group of PAGES, 2016) 784 and, a mean highstand of 9±23 m based upon a range of ocean-core records (Spratt and Lisiecki, 2016), 785 suggests the potential for either greater, the same or reduced total ice volume relative to present. 786 Data for MIS 11 is a little more comprehensive. Ice core and oceanographic records from Greenland 787 during MIS 11 suggest that although ice was probably present at the centre of the present ice sheet 788 (Yau et al., 2016), it was much smaller in overall extent, potentially losing up to 6 m sea-level-789 equivalent volume (de Vernal and Hillaire-Marcel, 2008; Reyes et al., 2014). After correcting for GIA, 790 Raymo and Mitrovica (2012) calculate that global mean sea level during MIS 11 was 6-13 m above 791 present and infer melt of the Greenland and West Antarctic ice sheets towards the end of the 792 interglacial, but relative stability of the East Antarctic Ice Sheet, although the rate of mass loss is 793 unknown (Alley et al., 2010). Delayed melting of the ice sheets within MIS 11 fits with our pollen 794 records from Bradmoor Hill and Railway Cottage, which suggest marine sediment deposition during 795 the Late Temperate phase of the interglacial. Although there is clear evidence for sea-level highstands 796 above present during MIS 11, and potentially also during MIS 9, in both the low latitudes and 797 northwest Europe, the absence of indicators for one or more sea-level oscillations, in our albeit 798 spatially limited datasets implies steady melt of the ice sheets during the interglacial phases.

799

## 800 **7. Conclusions**

801 MIS 11, 9 and 5e have been shown to be the warmest interglacials of the last 800,000 years (Past 802 Interglacials working group of PAGES, 2016; Yin and Berger, 2012), and therefore hold insights into 803 ice-sheet behaviour in warm climates and provide potential analogues for the future. Evidence for 804 the mode of sea-level change during MIS 11 and 9 is sparse compared to that from MIS 5e (Dutton et 805 al., 2015). We present new detailed analysis of a 'Hoxnian' sequence from the Nar Valley and apply 806 multi-proxy methods of reconstruction which have been widely applied to similar Holocene 807 temperate-latitude estuarine sequences. Such records are valuable as they have the potential to 808 provide more continuous archives of RSL change and therefore identify millennial-scale changes in sea 809 level that large-scale geomorphological features, such as raised beaches, may not record. The 810 application of methodologies developed in Holocene settings to previous interglacial deposits may be 811 restricted by the preservation of material across a range of elevations, sampling resolution and 812 limitations of dating. Notwithstanding these challenges, we apply the tendency methodology to 813 marine sediments from over a ~20 m modern elevation range in the Nar Valley, with pollen analysis 814 and AAR dating suggesting that there may be two periods of marine sediment deposition: one during 815 MIS 11 (Hoxnian Late Temperate phase) from ~8 to 18 m OD; and a second phase potentially during 816 MIS 9 (Hoxnian Early Temperate phase) from ~-3 to 3 m OD, although we cannot conclusively preclude 817 an alternative MIS 11 age for these lower sediments. It must be noted that these modern elevations 818 likely bear very little resemblance to their elevation at the time of deposition due to glacial isostatic 819 adjustment and long-term tectonic uplift. We do not find any compelling evidence for abrupt changes 820 in sea level either in the Nar Valley or nearby similar sequences in eastern England during these times 821 and no difference in the nature of the MIS 9/11 transgression when compared to similar Holocene 822 sequences, where there is no evidence for abrupt (multi-meter) sea-level jumps. These results add 823 weight to similar analysis of the MIS 5e record from the Netherlands (Long et al., 2015), which suggest 824 gradual, rather than rapid, melt of the ice sheets persisted in these interglacials when sea level was at 825 or above present-day levels, although much more data is needed to test these hypotheses.

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837

#### 838 Figure captions

Figure 1: MIS 9 and 11 global sea level highstands recorded by the Spratt and Lisiecki (2016) ocean core sea level stack (PC1) relative to present (0 m at 0 ka). Only vertical uncertainties shown, for clarity.

**Figure 2:** Map of eastern England showing location of the Nar Valley and key locations given in text.

Figure 3: A: Model of northwest European coastal succession (after Waller et al., 1999). B: Models of gradual (left) and abrupt (right) sea level rise as recorded by a coastal sequence (adapted after Long and Shennan, 1994). Note: the length of panel B is not indicative of the amount of sedimentation and both models assume the same total RSL rise.

Figure 4: Stratigraphy of the Nar Valley and locations of former boreholes. Cross section adapted from
Ventris (1996)

Figure 5: Map of the Nar Valley showing locations of new boreholes and key settlements. Topography
from NEXTMap British Digital Terrain Model Dataset Produced by Intermap with tickmarks in degrees,
minutes and second. White contours show location of Nar Valley Clay as mapped by British Geological
Survey (BGS).

Figure 6: Nar Valley borehole lithology, collected as part of this work, with additional boreholes from
the literature at sites we were unable to resample. Elevation of Tottenhill section estimated from
Ventris (1996).

Figure 7: Horse Fen 13-1 litho- and bio-stratigraphy. Foraminifera >5% of total tests counted (grey
line n=50). Selected pollen taxa shown. Lithology key same as Figure 6.

Figure 8: Blackborough End Quarry litho- and bio-stratigraphy. Foraminifera >5% of total tests
counted (grey line n=50). Selected pollen taxa shown. Lithology key same as Figure 6.

Figure 9: Tottenhill litho- and biostratigraphy. Selected pollen taxa shown. Lithology key same as
Figure 6. No foraminifera were found at this location.

Figure 10: Horse Fen 12-4 litho- and bio-stratigraphy. Foraminifera >5% of total tests counted (grey
line n=50). Lithology key same as Figure 6. Pollen for this location in Stevens (1959) though exact
elevations do not match.

Figure 11: Railway Cottage litho- and bio-stratigraphy. Foraminifera >5% of total tests counted (grey
line n=50). Selected pollen taxa shown. Lithology key same as Figure 6.

Figure 12: Bradmoor Hill litho- and bio-stratigraphy. Foraminifera >5% of total tests counted (grey
line n=50). Selected pollen taxa shown. Lithology key same as Figure 6.

869 Figure 13: D/L values of glutamic acid/glutamine (Glx) and alanine (Ala) for the total hydrolysable 870 amino acid (THAA;H) fractions of bleached Bithynia tentaculata opercula from Horse Fen (HF) and 871 Tottenhill (TH and Tott3) (light blue) compared with opercula from UK sites correlated with MIS 9 872 (grouped in darker blue) and MIS 11 (grouped in purple). Selected relevant sites are plotted in the 873 order in which they are presumed to occur based on the pollen succession (CG = Cudmore Grove, Pu 874 = Purfleet, Sh = Shoeburyness, Ba = Barling, Ho = Hoxne, Wo = Woodston, Cl = Clacton) by which to 875 compare the results from this study. For each group, the base of the box indicates the 25th percentile, 876 the line within the box plots the median, and the top of the box indicates the 75th percentile. Where 877 more than nine data points are available, the 10th and 90th percentiles can be calculated (shown by 878 lines at the bottom and the top of the boxes, respectively). The results of each duplicate analysis are 879 included in order to provide statistically significant sample sizes.

Figure 14: Summary figure as to the mode of sea-level change in Nar Valley assuming the two sequences (upper and lower) were deposited during differing interglacials. The alternative hypothesis is that the lower sites (shown as MIS 9 here) were also deposited during MIS 11, but during a differing sub-stage. Elevation correction is for illustration assuming uplift between MIS 11 and 9 (Westaway (2009) estimates ~3.3-5 m uplift during the two interglacials in this location).

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#### B: Models of gradual and abrupt relative sea-level rise



North



South











Horse Fen			Foraminifera															
<b>12-4</b> ((0 m) (m) (m) (m) (m) (m) (m) (m) (m) (m)	Lithology	Loss on ignition	<sup>6</sup>	□ T	☐ ➡ ■ • • • • • • • • - • • • • • • • • • •	¬ ■	☐ T I I I I I I I I I I I I I I I I I I	☐ The set of the s	Elphidium gerthi		Elphidium margaritaceum	The second secon	□ Elphidium sp.	☐ The set of the s	□			
		%							% To	otal								









### Horse Fen

### Horse Fen Cont.







### Blackborough Fen

Blacborough Fen Cont.





Bradmoor Hill



## AAR results Supplementary information

# Relative sea-level variability during the late Middle Pleistocene: new evidence from eastern England

Barlow, N.L.M., Long, A.J., Gehrels, W.R., Saher, M.H., Scaife, R.G., Davies, H.J., Penkman, K.E.H., Bridgland, D.R., Sparkes, A., Smart, C.W., Taylor, S.

**Quaternary Science Reviews** 

Colours as per Figure 13 in main paper


















# Supplementary information Data files for the pollen, foraminifera and AAR results collected as part of the Barlow et al. Nar

# Citation:

Barlow, N.L.M., Long, A.J., Gehrels, W.R., Saher, M.H., Scaife, R., Davies, H., Penkman, K., Bridglan Relative sea-level variability during the late Middle Pleistocene: new evidence from eastern England Quaternary Science Reviews

Dataset	Analysis completed by	
Pollen		
Horse Fen 13-1 pollen Blackborough pollen Tottenhill pollen Railway Cottage pollen Bradmoor Hill pollen	Rob Scaife Heather Davies Heather Davies Heather Davies Rob Scaife	
Foraminifera		
Horse Fen 13-1 foraminifera Blackborough foraminifera Horse Fen 12-4 foraminifera Horse Fen 12-2 foraminifera Railway Cottage foraminifera Bradmoor Hill foraminifera	Margot Saher Margot Saher/Amy Sparkes Margot Saher/Amy Sparkes Margot Saher Margot Saher/Amy Sparkes Margot Saher/Amy Sparkes	Not shown in paper due to potenti
Horse Fen 13-1 AAR Tottenhill AAR	Kirsty Penkman/Sheila Taylor Kirsty Penkman/Sheila Taylor	
LOI data	,	
Horse Fen 13-1 LOI Blackborough LOI Tottenhill LOI Horse Fen 12-4 LOI Railway Cottage LOI Bradmoor Hill LOI	Natasha Barlow Natasha Barlow Natasha Barlow Natasha Barlow Natasha Barlow Natasha Barlow	

# Valley study

nd, D.R., Taylor, S., Sparkes, A., Smart, C.W.

al for erosion, but included here for completeness

### Horse Fen

Depth metres	8.36	8.44	9.92	9.96	10	10.04
ABIES	1	4	2	0	0	0
PINUS	76	42	70	56	60	19
PICEA	23	18	10	10	15	5
JUNIPERUS	0	0	0	0	0	0
CUPPRESSACEAE	2	0	2	0	1	0
cf TSUGA	1	0	0	0	0	0
BETULA	1	1	10	15	2	3
ULMUS	16	13	29	25	17	39
QUERCUS	25	40	29	37	21	9
cf POPULUS	0	0	0	0	0	0
TILIA	1	1	6	1	0	3
FRAXINUS EXCELSIOR	1	2	0	0	0	0
ILEX	0	0	0	0	0	0
ALNUS	39	25	41	36	33	49
SORBUS TYPE	0	1	0	0	0	0
PRUNUS TYPE	0	0	0	0	0	0
CORNUS	0	0	0	0	0	0
CORYLUS AVELLANA TYPE	82	115	85	107	46	73
SALIX	0	0	0	0	0	0
ERICA	0	0	1	0	0	0
EMPETRUM	0	0	0	0	0	0
HEDERA	0	0	0	0	0	0
RETIC. INDET. (incl TYPE X)	8	16	6	8	0	2
cf TYPE X	3	0	1	0	1	0
RANUNCULACEAE UNDIFF.	0	0	0	0	0	0
RANUNCULUS TYPE	0	0	0	0	0	0
THALICTRUM	0	0	0	0	0	0
BRASSICACEAE UNDIFF.	0	0	0	0	0	0
POLYGALA	0	0	0	0	0	0
cf HYPERICUM	0	0	0	0	0	0
DIANTHUS TYPE	0	0	0	0	0	0
STELLARIA TYPE	0	0	0	0	0	0
CHENOPODIACEAE	1	3	1	2	0	0
GERANIACEAE	0	0	0	0	0	0
FABACEAE UNDIFF.	0	0	0	0	0	0
MEDICAGO TYPE	0	0	0	0	0	0
TRIFOLIUM TYPE	0	0	0	0	0	0
ONONIS TYPE	0	0	0	0	0	0
LOTUS TYPE	0	0	0	0	0	0
VICIA TYPE	0	0	0	0	0	0
LATHYRUS TYPE	0	0	0	0	0	0
ROSACEAE UNDIFF.	0	0	0	0	0	0
GEUM TYPE	0	0	0	0	0	0
APIACEAE	0	0	0	0	0	0
MYRRHIS TYPE	0	0	0	0	0	0
OENANTHE TYPE	0	0	0	0	0	0
RUMEX	0	0	0	0	0	0
PRIMULACEAE INDET.	0	0	0	0	0	0
LYSIMACHIA	0	0	0	0	0	0

CONVOLVULUS	0	0	1	0	0	0
SCROPHULARIACEAE UNDIFF.	0	0	0	0	0	0
PLANTAGINACEAE	0	0	0	0	0	0
VALERIANA	0	0	0	0	0	0
SUCCISA TYPE	0	0	0	0	0	0
BIDENS TYPE	0	1	0	0	0	0
ASTER TYPE	0	1	0	0	0	0
ANTHEMIS TYPE	0	0	0	0	0	0
SENECIO TYPE	0	0	0	0	0	0
ARTEMISIA	0	0	0	0	0	0
CIRSIUM TYPE	0	0	0	0	0	0
CENTAUREA NIGRA TYPE	0	0	0	0	0	0
SERRATULA TYPE	0	0	0	0	0	0
LACTUCOIDEAE	0	0	0	0	0	0
POACEAE	21	15	13	8	0	1
LARGE POACEAE	0	0	0	0	0	0
UNIDENTIFIED/DEGRADED	0	2	0	1	1	0
MENYANTHES TRIFOLIATA	0	0	0	0	0	0
TYPHA LATIFOLIA TYPE	0	1	0	0	0	0
TYPHA ANGUSTIFOLIA TYPE	2	0	1	2	1	1
CYPERACEAE	6	1	0	5	2	3
PHYLLITES TYPE	0	0	0	0	0	0
BLECHNUM TYPE	0	0	0	0	0	0
EQUISETUM	0	0	0	0	0	0
PTERIDIUM AQUILINUM	0	0	0	1	0	0
DRYOPTERIS TYPE	132	141	104	176	68	104
THELYPTERIS PALUSTRIS TYPE	0	0	0	0	0	0
POLYPODIUM VULGARE	0	1	0	4	3	1
cf. BOTRYCHIUM LUNARIA	0	0	0	0	0	0
SPHAGNUM	2	3	2	1	0	1
LIVERWORTS	0	0	0	0	0	0
PEDIASTRUM	0	0	0	0	0	0
PRE-QUATERNARY	945	510	492	45	1	0
PODOCARPIDITES	0	2	2	0	0	0
PICEAPOLLENITES	0	2	1	0	0	0
CLASSOPOLIS/EUCOMMIADITES	0	0	0	0	0	0
CARYA	0	0	0	0	0	0
DINOFLAGELLATES	30	17	17	7	0	0

Depth metres	10.64	10.68	10.72	10.76	10.8	10.84
ABIES	0	0	0	0	0	0
PINUS	90	210	69	259	153	87
PICEA	0	0	0	0	0	0
JUNIPERUS	0	0	1	0	1	0
CUPPRESSACEAE	0	0	0	0	0	0
cf TSUGA	0	0	0	0	0	0
BETULA	107	31	286	18	37	3
ULMUS	11	0	3	0	0	0
QUERCUS	92	12	1	0	0	0

cf POPULUS TILIA FRAXINUS EXCELSIOR ILEX ALNUS SORBUS TYPE PRUNUS TYPE CORNUS CORYLUS AVELLANA TYPE SALIX	0 0 0 3 0 0 1 21 0	0 0 0 0 0 0 0 1	0 0 0 0 0 1 2 1	0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 1 0	0 0 0 1 0 0 0 2 0
ERICA	0	0	1	0	0	0
EMPEIRUM	0	0	1	0	0	0
	2	0	0	0	0	0
cf TYPE X	0	0	0	0	0	0
RANUNCULACEAE UNDIFF.	0	0	0	0	0	0
RANUNCULUS TYPE	3	0	0	0	0	0
THALICTRUM	0	0	0	0	0	0
BRASSICACEAE UNDIFF.	0	0	0	0	0	0
POLYGALA	0	0	0	0	0	0
cf HYPERICUM	0	0	0	0	0	0
DIANTHUS TYPE	1	0	0	0	0	0
	1	0	0	0	0	0
	0	0	0	0	0	1
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
ONONIS TYPE	0 0	0	0	0	0	0
LOTUS TYPE	0	0	0	0	0	0
VICIA TYPE	0	0	0	0	0	0
LATHYRUS TYPE	0	0	0	0	0	0
ROSACEAE UNDIFF.	0	0	0	0	0	0
GEUM TYPE	0	0	0	0	0	0
APIACEAE	0	0	0	0	0	0
MYRRHIS TYPE	0	0	0	0	0	0
OENANTHE TYPE	0	0	0	0	0	0
RUMEX	0	0	0	0	0	0
PRIMULACEAE INDET.	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
SCROPHULARIAGEAE UNDIFF.	0	0	0	0	0	0
	1	0	0	0	0	0
	0	0	0	1	0	0
BIDENS TYPE	0	0	7	0	1	0
ASTER TYPE	0	0	0	0	0	0
ANTHEMIS TYPE	0	0	0	0	0	1
SENECIO TYPE	0	0	0	0	0	0
ARTEMISIA	0	0	0	0	0	0
CIRSIUM TYPE	0	0	0	1	2	1
CENTAUREA NIGRA TYPE	1	0	1	0	0	0
SERRATULA TYPE	0	0	0	0	0	0

LACTUCOIDEAE	0	0	0	1	0	0
POACEAE	34	15	113	20	43	2
LARGE POACEAE	0	0	0	0	0	0
UNIDENTIFIED/DEGRADED	6	0	1	2	1	0
MENYANTHES TRIFOLIATA	0	0	0	0	0	0
TYPHA LATIFOLIA TYPE	1	0	0	0	0	1
TYPHA ANGUSTIFOLIA TYPE	23	0	0	0	0	0
CYPERACEAE	19	34	9	6	41	1
PHYLLITES TYPE	3	0	5	0	0	0
BLECHNUM TYPE	0	0	0	0	0	0
EQUISETUM	0	0	0	0	0	0
PTERIDIUM AQUILINUM	0	1	0	0	0	0
DRYOPTERIS TYPE	63	85	18	53	59	965
THELYPTERIS PALUSTRIS TYPE	1	2	2	0	0	0
POLYPODIUM VULGARE	0	0	0	0	0	0
cf. BOTRYCHIUM LUNARIA	0	0	0	0	0	0
SPHAGNUM	1	0	15	12	3	1
LIVERWORTS	0	1	0	1	1	0
PEDIASTRUM	0	0	0	0	0	0
PRE-QUATERNARY	1	0	0	0	2	0
PODOCARPIDITES	0	0	0	0	0	0
PICEAPOLLENITES	0	0	0	0	0	0
CLASSOPOLIS/EUCOMMIIDITES	0	0	0	0	0	0
CARYA	0	0	0	0	0	0
DINOFLAGELLATES	0	0	0	0	0	0

$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	10.08	10.12	10.16	10.2	10.24	10.28	10.32	10.56	10.6	10.64
56 $88$ $52$ $45$ $61$ $68$ $142$ $179$ $212$ $90$ 2 $8$ $3$ $1$ $11$ $4$ $1$ $3$ $2$ $0$ 0000000 $0$ $0$ $0$ 000000 $0$ $0$ $0$ 0000 $0$ $0$ $0$ $0$ $0$ 11295 $20$ $17$ $13$ $8$ $53$ $6$ $111$ 12 $41$ $27$ $20$ $14$ $24$ $29$ $81$ $34$ $92$ 0000000 $0$ $0$ $0$ $0$ 1202 $4$ $1$ $0$ $1$ $0$ $0$ $0$ 0100 $0$ $0$ $0$ $0$ $0$ $0$ 0100 $0$ $0$ $0$ $0$ $0$ $0$ 01 $0$ $0$ $0$ $0$ $0$ $0$ $0$ 0 $0$ <td>0</td> <td>0</td> <td>0</td> <td></td> <td>0</td> <td>1</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td>	0	0	0		0	1	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	56	88	52	45	61	68	142	179	212	90
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	2	8	3	1	11	4	1	3	2	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	1	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	1	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	1	1	0	1	0	13	8	33	36	107
12   41   27   20   14   24   29   81   34   92     0	11	29	5	20	17	13	8	5	6	11
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	12	41	27	20	14	24	29	81	34	92
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	1	2	0	2	4	1	0	1	0	0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	0	1	0	0	0	0	1	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	1	0	0	1	0	0	0	0	0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	35	78	46	66	73	220	92	19	0	3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
64 $43$ $5$ $15$ $7$ $41$ $3$ $7$ $3$ $21$ 0002300<	0	0	0	0	0	0	0	0	0	1
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	64	43	5	15	7	41	3	7	3	21
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	1	0	1	0	2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     33       0	2	3	0	0	0	2	1	0	4	0
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	0	0	0	0	0	0	0	0	0	0
0     0	0	0	1	0	0	0	1	0	1	3
0     0     1     1     0     0     0     1     0     0       0     1     0	0	0	0	0	0	0	0	0	0	0
0     1     0     0     0     1     0     0     0     1     0     0     0     1     0     0     1     0     0     1     0     0     1     0     0     1     0	0	0	1	1	0	0	0	1	0	0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     1     0     0     0     1     0     0     0     1     0     0     0     1     0     0     0     1     1     0     0     0     1     1     0     0     0     1     1     0     0     0     1     1     0     0     0     1     1     0     0     0     1     1     0     0     0     1     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     0     1     1     1     1     1     1     1     1     1     1     1	0	0	0	0	0	0	0	0	0	0
0     0     0     1     0     0     1       0     0     0     0     0     0     0     1       0     0     0     0     0     0     0     0     1       0     0     0     0     0     0     0     0     1       0     0     0     0     0     0     0     0     0     0     0     0       0	0	0	0	0	0	0	0	0	0	0
0     0     0     0     0     0     0     0     1       0	0	0	0	0	0	1	0	0	0	1
0     0	0	0	0	0	0	0	0	0	0	1
0     0	0	0	0	0	0	0	0	0	0	0
0     0	0	0	0	0	0	0	0	0	0	0
0     0	0	0	0	0	0	0	0	0	0	0
0     0	0	0	0	0	0	0	0	0	0	0
0     0	0	0	0	0	0	0	0	0	0	0
0     0	0	0	0	0	0	0	0	0	0	0
0     0	0	0	0	0	0	0	0	0	0	0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	U	0	0	U	U	0	U	0	1	0
	U	0	0	U 4	U 4	0	U	0	U	0
	0	0	0	1	1	0	U	0	U	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	1	0

0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0	0 0 0 0 1 0 0 0	0 0 4 0 0 0 0 0	0 0 1 0 0 0 0 0	0 0 1 2 0 0 0 0	0 0 1 0 1 0 0 0	0 1 0 1 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0	0 0 1 0 0 0 0 0
0 0 0 0 16 0 0	0 0 0 0 1 0 1	0 0 0 0 3 0 0	0 4 0 0 0 1 0 3	0 1 0 0 3 0 3	0 0 1 0 1 0 3	0 2 0 0 0 1 0 1	0 0 0 0 17 0 3	0 0 0 0 1 0 1	0 0 1 0 34 0 6
0 0 0 1	0 1 1 2	0 0 0 5	0 0 1 12	0 0 2 11	0 0 0 5	0 0 0 10	0 0 7 8	0 0 3 9	0 1 23 19
0 2 0 441 0 0 0	1 0 1 1482 0 0 0	0 0 0 1395 0 1 0	1 0 0 1064 0 0 0	0 0 0 2243 0 0 0	3 0 0 992 0 2 1	0 0 5 672 1 0 0	7 0 1 476 0 0 0	0 2 0 2 92 2 1 0	3 0 0 63 1 0 0
1 0 4 0 0 0 0 0	4 0 0 0 0 0 0 0	1 0 0 0 0 0 0 0	1 440 0 0 0 0 0 0	1 73 0 0 0 0 0 0	3 20 0 0 0 0 0 0	1 0 0 0 0 0 0 0	0 1 26 0 2 0 0 0	0 0 0 0 0 0 0 0	1 0 1 0 0 0 0
10.88	10.92	11.04	11.12	11.2	11.28	11.36	11.4		
0 57 0 0 0 0 25 0 0	0 23 1 1 0 0 56 0 0	0 10 0 0 0 0 110 0 0	0 5 0 0 0 0 85 0 1	0 3 0 1 0 0 85 0 1	0 9 0 1 0 1 80 0 0	0 4 0 0 0 0 83 0 0	0 8 0 0 0 0 120 0 0		

0 0 0 0 0 0 0 0 0 0	0 0 1 0 0 0 0 1	1 0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 0 0 3	0 0 0 0 0 0 0 1	1 0 0 0 0 0 0 4 2	0 0 1 0 1 0 12 12
0 0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	1 0 0 0 0	0 0 0 0	0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	$\begin{array}{c} 0 \\ 2 \\ 0 \\ 0 \\ 0 \\ 1 \\ 3 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0$	$\begin{array}{c} 0 \\ 3 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0$	$ \begin{array}{c}   1 \\   1 \\   0 \\   0 \\   0 \\   1 \\   1 \\   0 \\ $	$\begin{array}{c} 0 \\ 4 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0$	$\begin{array}{c} 0 \\ 6 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 3 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0$	$\begin{array}{c} 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0$	$\begin{array}{c} 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 2 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0$

0	1	0	0	0	1	2	0	
9	90	163	171	204	188	236	137	
0	2	10	5	5	10	11	6	
0	3	0	0	4	4	0	5	
0	0	0	1	0	0	0	0	
0	0	3	5	1	1	1	1	
0	5	11	3	3	4	3	17	
27	109	85	114	82	75	184	57	
0	0	0	0	0	0	0	0	
0	0	0	0	0	0	1	0	
0	1	2	3	1	1	1	2	
0	4	2	1	0	1	1	6	
18	31	19	37	42	42	19	21	
0	0	0	0	0	0	0	0	
0	0	0	0	0	1	1	0	
0	0	0	0	0	0	0	0	
0	0	3	0	0	1	0	0	
0	0	1	2	1	1	1	1	
0	1	1	3	0	0	0	0	
0	171	54	32	56	21	144	37	
0	0	0	0	0	0	0	0	
0	3	4	1	0	1	3	0	
0	8	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	
0	0	1	0	0	0	0	0	

10.68	10.72	10.76	10.8	10.84	10.88	10.92	11.04	11.12	11.2
0	0	0	0	0	0	0	0	0	0
210	69	259	153	87	57	23	10	5	3
0	0	0	0	0	0	1	0	0	0
0	1	0	1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
31	286	18	37	3	25	56	110	85	85
0	3	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
1	2	1	1	2	0	0	0	0	0
0	1	0	0	0	0	1	0	1	3
0	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	2	3	1	4
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	1	0	1	0
0	0	0	0	0	0	3	1	1	1
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0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	1	0	0
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0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0
0	U	0	U	U	U	U	U	0	U
0	U	0	0	U	U	U	U 4	0	U
0	U	0	U	U	U	U	1	U 4	1
0	U	0	0	0	U 1	о 0			
0	0	0	0	0		0	0	0	U 4
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0
0	7	0	1	0	0	1	1	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	2	1	1	1	2	5	3
0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0	0	0
15	113	20	43	2	9	90	163	171	204
0	0	0	0	0	0	2	10	5	5
0	1	2	1	0	0	3	0	0	4
0	0	0	0	0	0	0	0	1	0
0	0	0	0	1	0	0	3	5	1
0	0	0	0	0	0	5	11	3	3
34	9	6	41	1	27	109	85	114	82
0	5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	2	3	1
1	0	0	0	0	0	4	2	1	0
85	18	53	59	965	18	31	19	37	42
2	2	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	15	12	3	1	0	0	3	0	0
1	0	1	1	0	0	0	1	2	1
0	0	0	0	0	0	1	1	3	0
0	0	0	2	0	0	171	54	32	56
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	3	4	1	0
0	0	0	0	0	0	8	0	0	0
0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	1	0	0

11.28	11.36	11.4
11.28  0 9 0 1 0 1 80 0 0 0 0 0 0 0 0 0 0 0 0 0	11.36  0 4 0 0 0 0 0 0 0 0 0 0 0 0 0	11.4 0 8 0 0 0 120 0 0 0 0 0 0 0 0 1 0 1 0 1 0 12 1 1 1
1 0 0 0 0	0 0 0 0 0	0 0 0 0 0
0 6 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0	0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 0 0 0	0 1 1 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 1 0 0 1 188 10 4	0 0 1 0 4 0 0 0 0 1 0 0 2 236 11 0	0 0 0 1 0 0 0 7 0 0 0 7 0 0 137 6 5
0 1 4 75	0 1 3 184	0 1 17 57
0 0 1 42 0 1 0	0 1 1 19 0 1 0	0 2 6 21 0 0
1 0 21 0 1 0 0 0	0 1 044 0 3 0 0 0	0 1 0 37 0 0 0 0 0

# BLACKBOROUGH

Depth m	3.36	3.44	3.52	3.6	3.68	3.76	3.84	3.92
BETULA	2	0	0	6	4	2	4	6
PINUS	234	300	174	290	102	182	146	126
PICEA	20	14	8	26	2	16	6	10
ULMUS	0	0	0	0	0	2	0	0
QUERCUS	6	4	12	14	8	14	20	22
TILIA	0	0	0	0	0	0	2	0
FRAXINUS EXCELSIOR	0	0	0	0	0	0	10	2
FAGUS SYLVATICA	0	0	0	0	0	0	0	0
ILEX AQUIFOLIUM	0	0	0	0	2	2	0	0
CORYLUS AVELLANA TYPE	20	0	24	26	4	48	46	26
PRUNUS/MALUS	0	0	0	0	0	4	2	0
EUONYMUS EUROPAEUS	0	0	0	0	0	0	0	0
HEDERA HELIX	0	0	0	0	0	0	0	0
ERICA	2	2	0	0	0	2	0	0
EMPETRUM	0	0	0	0	0	0	0	0
CALTHA TYPE	0	0	0	0	0	0	0	0
RANUNCULUS TYPE	0	0	0	0	0	0	0	0
BRASSICACEAE UNDIFF.	0	2	0	0	0	1	0	0
CARYOPHYLLACEAE	0	0	0	0	0	0	0	0
CHENOPODIACEAE	2	0	0	0	0	2	4	4
ROSACEAE UNDIFF.	0	0	4	4	0	2	8	6
FILIPENDULA	0	0	0	2	0	0	0	0
SANGUISORBA MINOR	0	0	0	0	0	0	2	0
CIRCAEA TYPE	0	0	0	0	0	0	0	0
CHAMAENERION TYPE	0	0	0	0	0	0	0	0
POLYGONACEAE UNDIFF.	0	0	0	0	0	0	0	0
OXYRIA TYPE	0	0	0	0	0	0	0	0
RUMEX ACETOSA TYPE	0	0	0	0	0	0	2	1
MERCURIALIS	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
APIACEAE	0	0	0	4	0	0	2	0
PRIMULA VERIS TYPE	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
GENTIANA CAMPESTRIS TYPE	0	0	0	0	0	0	0	0
CONVOLVULUS	0	0	0	0	0	0	0	0
ATROPA BELLADONNA	0	0	0	0	0	0	0	0
SCROPHULARIA TYPE	0	0	0	0	0	2	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	1	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	4	0
	U	0	0	U	U	U	U	U
	2	0	2	0	U	U	0	0
	U	0	U	0	U	U	0	0
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	U	0	U	U 40	U	U	0	U
	0	14 0	∠4 ∩	10 0	4	~ ~ ~	21	04 0
	0	0	U	0	0	0	0	0

UNIDENTIFIED/DEGRADED	0	0	0	0	0	0	0	0
ALNUS	2	0	8	18	12	30	24	10
SALIX	0	0	0	0	4	2	4	0
NYMPHAEA	0	0	0	0	0	0	0	0
MYRIOPHYLLUM	0	0	0	0	0	0	0	0
CALLITRICHE	0	0	0	0	0	0	0	0
POTAMOGETON TYPE	0	0	0	0	0	0	0	0
TYPHA LATIFOLIA TYPE	0	0	0	0	0	0	0	0
TYPHA ANGUSTIFOLIA TYPE	0	0	0	0	0	0	0	0
CYPERACEAE	19	34	20	20	18	16	14	20
ADIANTUM TYPE	0	0	0	0	0	0	0	0
CRYPTOGRAMMA	0	10	0	2	0	2	0	0
LYCOPODIUM INUNDATA	2	0	0	0	0	0	0	0
PTERIDIUM AQUILINUM	54	108	86	78	40	42	48	26
DRYOPTERIS TYPE	0	0	0	2	0	6	3	0
THELYPTERIS PALUSTRIS TYPE	0	0	0	0	0	0	0	0
POLYPODIUM VULGARE	0	0	0	0	0	0	0	0
PHAEOCEROS	0	0	0	0	0	0	0	0
SPHAGNUM	0	0	0	4	0	10	2	2

4	4.08	4.14	4.24	4.32	4.4	4.48	4.56	4.64	4.72	4.8	4.88
0	8	6	4	10	22	4	0	0	0	2	4
96	122	52	176	104	144	44	228	40	178	220	72
10	14	2	6	6	4	0	16	0	14	20	2
0	2	2	0	0	4	2	0 16	0	0	2	4 24
4	20	22	20	0	22	4	0	4	2	0	0 0
2	+ 6	0	0	0	4	0	0	0	0	0	8
0	0	2	0	0	0	0	0	0	0	0	0
4	2	0	0	0	0	0	0	0 0	Õ	Õ	2
4	52	38	52	16	84	8	6	2	12	20	28
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	4	0	0	0	0	0	0	0	0	0	2
0	0	0	0	0	4	2	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	2 4	0	2	0	0	0	0	0	0
0	2	0	6	0	2	0	2	2	0	1	2
0	4	0	4	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	2	0	1	0	2	0	0	0	0	0	0
1	0	0	0	0	1	0	2	0	0	0	0
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0	0	0	0	0	0	0	2	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0
0	4	0	0	2	2	0	2	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
20	30	21	20	14	44	8	38	12	31	28	12
0	0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0	0	0
4	22	18	26	6	52	4	14	15	16	17	18
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
2	12	13	16	8	10	6	26	4	10	10	14
4	0	0	0	0	0	0	0	0	0	0	0
0	4	0	0	0	0	0	0	0	0	0	0
4	2	6	10	6	0	2	6	0	10	6	0
20	34	22	498	20	42	31	50	12	26	31	24
0	6	4	8	1	4	4	8	0	0	6	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	10	6	0	2	0	4	2	0	5	0

4.96	5.04	5.11	5.2	5.28	5.36	5.44	5.52	5.6	5.68	5.76	5.84
 8 42	12 122	0 20	2 40	6 88	2 36	0 48	6 52	 4 84	4 39	1 30	1 42
4	14	6	6	10	2	2	0	10	5	3	2
2	4	2	2	4	0	2	2	22	9	8	1
12	45	6	10	14	6	16	14	28	56	28	42
0	8	0	0	2	0	0	2	2	3	2	4
0	0	0	0	4	0	2	0	20	25	8	5
2	0	0	0	0	0	2	0	0	0	0	0
0	1	0	0	2	0	0	0	4	2	4	2
6	90	16	24	32	10	22	8	68	102	147	88
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	6	0	0	0	2	0	0	0	3	3	4
0	0	0	0	2	0	0	0	0	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	4	0	0	0	0	0	0	4	3	3	2
0	0	0	0	0	0	0	0	0	0	0	1
1	4	0	2	1	0	0	2	0	1	2	1
0	8	0	2	0	0	0	0	4	0	3	5
0	0	0	0	0	0	0	0	2	2	0	0
0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	2	0	4	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	4	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0
12	U	U	0	U	U	U	0	0	U	T O	U
0	0	0	0	0	0	0	0	0	0	0	0
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1/	U 1 Q	17	20	28	10	6	18	0	7	10	10
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0	0	0	0	0	0	0	0	0	0	0	0
19	20	21	22	8	2	4	8	30	41	42	13
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	2	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	2	0
6	12	6	12	17	1	0	10	20	6	9	10
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	2	0	2	8	0	2	2	0	5	0	4
24	32	6	18	26	10	22	16	30	20	20	12
0	4	0	4	10	8	4	2	2	2	5	12
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0	4	0	0	0	0	0	4	0	1	0	0
0	2	0	0	0	4	0	0	0	0	0	0
2	0	0	0	4	0	0	0	6	0	3	5

5.92	6	6.08	6.14	6.24	6.32	6.4	6.56	6.66	6.72	6.8	6.84
0	8	3	7	0	2	0	6	5	2	0	4
68	90	35	70	48	74	82	106	28	39	70	162
6	4	6	3	6	10	16	12	1	4	0	0
16	6	19	6	20	4	0	4	8	9	10	4
36	86	35	48	60	58	54	46	48	32	4	8
2	2	6	3	0	4	2	2	2	4	18	30
4	28	22	19	20	36	10	18	14	25	0	0
0	0	0	0	2	0	0	0	0	0	0	0
0	4	1	7	2	4	0	8	2	2	0	0
50	112	111	70	50	86	32	96	107	90	82	40
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	6	1	1	0	2	0	0	2	0	0	0
0	0	0	0	0	2	0	0	1	2	0	2
0	0	0	1	0	0	6	0	0	0	0	0
0	0	0	0	0	2	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	2	2	3	0	0	4
0	0	0	0	4	0	0	0	0	0	0	0
4	3	3	8	0	8	2	8	5	6	2	2
6	4	3	4	8	2	2	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	2	0	4	2	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	4	0	2	0	0	0	0	2	0	0	0
2	0	0	0	10	0	0	0	0	0	0	0
0	0	1	0	0	0	4	0	1	0	0	0
2	0	0	0	0	2	0	0	0	0	0	0
0	0	0	0	0	0	6	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	2	0	0	0	0	0	0	0	0	0	0
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2	0	Õ	0	0	0	Õ	Õ	0	4	0	Ő
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0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	4
0	0	0	0	0	0	0	0	0	0	2	0
0	0	0	0	0	0	0	0	0	0	0	0
0	2	0	0	2	0	2	6	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
14	2	14	2	55	14	18	20	11	14	10	22
0	0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0	0	0
18	46	28	29	14	44	14	36	63	66	32	22
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	2	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	4
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	12
6	12	9	8	45	10	6	18	5	4	2	6
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
2	2	3	3	0	0	2	4	0	2	2	4
2	12	25	21	34	20	12	20	3	11	20	26
12	24	5	9	2	20	0	26	8	18	86	520
0	0	0	2	0	0	0	0	0	0	0	0
6	0	0	0	0	2	0	4	0	0	4	2
0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	5	4	0	12	16	1	0	4	36

6.88	6.89	6.91	6.93	6.95	6.97	6.97	7.01	7.03	7.055	7.07
10	0	0	3	2	2	2	8	0	2	4
34	136	20	30	140	14	14	78	32	20	6
2	0	2	9	2	0	0	2	16	2	0
4	0	6	15	0	8	8	16	38	16	20
42	6	12	34	12	14	14	64	50	44	30
0	0	6	7	2	8	8	12	2	22	6
20	4	0	31	2	0	0	16	44	14	10
0	0	0	0	2	0	0	0	0	0	0
4	0	0	0	0	4	4	6	2	2	0
64	6	62	84	12	24	24	44	120	72	42
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	2	8	8	0	4	2	0
0	0	0	0	0	0	0	4	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
2	0	0	2	2	0	0	0	0	0	0
0	0	0	0	0	0	0	0	12	2	0
0	0	0	0	0	0	0	2	0	0	0
0	0	4	14	2	2	2	0	0	2	0
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0	2	2	0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	0	0	0	0
0	0	2	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	4	0	0	0
0	0	0	0	0	0	0 0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	2	0	0	2	2	2	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	0	0	2	0	0	0
8	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2	0	0	0
0	2	0	0	0	0	0	0	0	0	0
10	18	12	18	28	12	12	34	20	12	16
0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0	0
48	14	26	46	8	6	6	56	90	58	40
0	0	0	0	0	0	0	2	2	0	2
0	0	0	0	0	0	0	2	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	0	0	0	2	0	2
0	0	0	0	0	2	2	0	6	0	8
10	6	2	6	0	0	0	2	12	22	14
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	6	0	0	2	4	4	2	0	0	0
10	48	6	2	62	6	6	24	6	222	0
42	356	34	34	1510	232	232	286	22	116	36
0	0	0	0	0	0	0	0	0	0	4
0	14	2	0	14	0	0	2	0	0	2
0	0	0	0	0	0	0	0	0	0	0
6	4	2	1	14	0	0	0	2	2	2

7.105	7.14	
2 24 0 16 34 30 4 0 0 30 0 0 4	0 46 0 12 36 40 2 0 0 22 0 0 0 6	
0 0	0 0	
0 0 0 0 14 0	0 0 0 0 12 0	

0	0	
70	80	
0	0	
0	0	
0	0	
0	0	
0	0	
0	0	
2	0	
40	68	
0	0	
0	0	
0	0	
2	2	
200	284	
0	0	
0	0	
0	0	
2	6	

#### TOTTENHILL

Depth cm	0.36	0.38	0.4	0.42	0.44	0.46	0.48	0.5	0.52
BETULA	1	0	2	0	1	1	1	0	4
PINUS	39	18	37	40	21	24	20	22	21
PICEA	2	0	2	7	2	2	0	5	2
ULMUS	8	9	6	10	8	9	11	10	19
QUERCUS	68	40	39	79	49	35	33	37	54
TILIA	0	1	7	1	2	3	2	1	1
FRAXINUS EXCELSIOR	19	13	12	21	10	13	10	11	8
FAGUS SYLVATICA	0	0	0	0	0	0	0	0	1
ILEX AQUIFOLIUM	1	2	2	1	0	2	1	1	0
FRANGULA ALNUS	1	1	0	0	0	0	0	0	0
SORBUS/CRATAEGUS TYPE	0	0	0	0	0	0	0	0	0
CORYLUS AVELLANA TYPE	63	116	81	76	130	115	111	176	116
MYRICA GALE	3	1	0	1	0	0	0	0	0
TYPE X	4	5	2	2	1	2	6	4	6
HEDERA HELIX	0	0	1	0	0	1	0	1	0
ERICACEAE	0	0	0	0	0	2	0	1	0
EMPETRUM	0	1	0	0	3	0	1	0	0
CALTHA TYPE	1	0	0	0	0	1	0	0	0
BRASSICACEAE UNDIFF.	3	0	0	0	0	1	1	1	0
TRIFOLIUM TYPE	0	0	0	0	0	0	0	0	0
LOTUS TYPE	1	0	0	0	0	0	0	0	0
CARYOPHYLLACEAE UNDIFF.	0	0	0	0	0	0	0	0	0
CHENOPODIACEAE	1	1	1	2	0	1	0	0	2
ROSACEAE UNDIFF.	1	1	0	1	0	3	1	0	0
FILIPENDULA	0	0	0	0	0	0	0	1	1
SAXIFRAGA GRANULATA TYPE	0	0	1	0	0	0	0	0	0
APIACEAE UNDIFF.	0	1	1	0	1	0	0	0	0
FALLOPIA CONVOLVULUS TYPE	0	0	0	0	0	0	0	0	0
RUMEX ACETOSA TYPE	0	1	0	0	1	0	0	0	0
PRIMULA	0	0	0	0	0	0	0	0	1
LYSIMACHIA VULGARIS TYPE	0	0	0	0	0	0	0	0	0
ANAGALLIS	0	0	0	0	0	0	0	0	0
GENTIANELLA CAMPESTRIS TYPE	0	0	0	0	0	0	0	0	0
SCROPHULARIA TYPE	0	0	0	0	0	0	0	0	0
DIGITALIS PURPUREA TYPE	2	0	0	0	0	0	0	0	0
ASTERACEAE UNDIFF.	2	3	3	0	1	0	0	1	0
CARDUEAE	0	0	0	0	0	0	0	0	0
ARTEMISIA	0	0	0	0	0	0	0	0	0
LACTUCOIDEAE	1	0	0	0	0	0	0	0	0
POACEAE	21	14	17	10	10	13	14	4	7
ALNUS	61	69	88	53	66	69	92	71	83
SALIX	0	0	0	0	0	0	0	0	2
MYRIOPHYLLUM	0	0	0	0	0	0	0	0	0
POTAMOGETON TYPE	1	0	0	0	0	0	0	0	0
IRIS PSEUDACORUS	0	0	0	0	0	0	0	0	0
TYPHA LATIFOLIA	0	0	0	0	0	0	0	0	0
TYPHA ANGUSTIFOLIA TYPE	0	5	2	0	0	3	0	1	0
CYPERACEAE	14	4	7	11	1	6	6	4	0

OSMUNDA REGALIS	0	0	0	0	0	0	0	0	0
PTERIDIUM AQUILINUM	2	5	2	1	2	3	0	0	3
DRYOPTERIS TYPE	61	34	40	36	28	15	18	22	10
THELYPTERIS PALUSTRIS	0	1	1	3	1	2	5	0	0
POLYPODIUM VULGARE	0	1	0	0	0	0	0	0	0
SPHAGNUM	12	3	6	11	7	8	12	4	5

	0.54	0.56	0.57	0.58	0.59	0.62	0.65	0.68	0.71	0.74	0.77	0.8	0.82	0.84
-	2	0	0	0	0	0	0	0	0	1	0	0	 1	1
	7	18	9	34	26	28	30	21	3	11	17	24	15	20
	2	2	0	5	0	1	4	2	0	1	0	0	1	0
	18	35	28	19	22	23	18	5	0	1	3	4	6	6
	43	54	54	41	25	73	78	50	14	38	26	33	17	35
	5	10	6	11	0	0	4	3	3	6	4	7	5	3
	10	2	9	9	6	13	16	20	8	13	15	23	16	25
	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	0	0	2	3	0	0	2	1	0	1
	0	0	0	0	0	0	0	2	0	1	0	1	0	0
	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	118	94	90	76	49	49	52	27	8	16	18	12	27	9
	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	5	ວ ວ	3	3	4	3	0	4	5 1	ן כ	1	9	ວ ວ	0
	0	2	Z	I	I	2	U	9	I	3	I	Z	2	4
	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	1	0	0	0	0	0	1	0	0	0	1	0
	0	1	0	0	0	0	0	0	0	0	1	0	1	5
	0	0	0	0	0	0	0	0	0	2	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	0	0	0	1	0	0	0	0	1	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	1	1	3	2	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	1	0	5	0	4	3	0
	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	0	0	0	0	0	0	2	1	0	0	0	0	0	0
	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	0	0	0	0	0	1	0	0	0	1	0	1	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	2 1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	1	3	3	4	9	6	8	5	5	6	12	8	11
	00	0.0	00	01	40	01	66	110	050	400	400	272	100	474
	0 90	o∠ ∩	99	91 0	40 0	91	00	0	200 ∩	103 0	40∠ ∩	3/3 N	190	1/4
	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	0	n	0	0	2	1	0	1	0	n
	0 0	0	0	0	n	ñ	0	2	ñ	0	0 0	0	0 0	0
	õ	0	Ő	0	0 0	1	0	2	0 0	0	Ő	0 0	ñ	0 0
	0	4	5	8	18	10	26	0	9	12	10	14	9	13

0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	1	5	0	0	0	2	0	4	0
11	3	3	3	8	9	82	41	4	6	15	22	21	13
0	0	0	0	0	0	4	0	0	0	0	0	0	0
0	0	0	0	0	0	2	1	0	0	0	2	0	0
3	0	0	0	0	0	2	0	0	0	1	3	1	1

0.86	0.88	0.9	0.92	0.94	0.96	0.98
1 24	0 40	0 27	0 9	0 21	0 15	2 15
0 3	6	2 5	7	0 5	0 3	0 3
29 11	49 1	39 7	22 1	45 7	35 12	44 4
9	12	13	10	14	15	11
2	2	1	1	1	0	1
0 0	0 0	0	0 0	0 0	0 0	0 0
17	18	15	17	15	12	20
0 5	0 6	0 8	0 3	0 10	0 5	0
4	2	1	3	5	11	2
0 0	0 0	0 0	0 0	0 0	0 0	0 0
0	0	1	0	0	0	0
2 0	4 0	0 0	0 0	0 0	1 0	1 0
1	2	0	1	0	0	0
0	0	0	0	0	0	0
0 0	1 0	1 0	0 0	0 0	0 0	3 0
0	0	0	0	0 5	0	0
0	1	0	0	0	0	0
0	0	0	0	0	0	1 0
0 0	0 0	0 0	0 0	0 0	1 0	0 1
0	0	0	0	0	0	0
0	0	0	0	0	1	0
0 0	0 0	0 0	2 0	0 0	0 0	0 0
0	1	0	0	0	0	0
10	12	16	7	5	9	12
181	132	187	208	238	183	173
0 0	1 0	0 0	0 0	0 0	1 0	0 0
0	0	0	0	0	0	0
0	0	0	0	1	0	0
1 15	0 15	0 12	0 15	0 16	0 17	1 14

0	0	0	0	0	0	0	
2	6	0	1	0	3	1	
16	25	33	12	8	17	24	
0	0	0	0	0	0	0	
0	2	0	0	0	1	1	
0	2	2	0	0	0	0	

Railway Cottage						
Depth m	4.96	5.12	5.28	5.44	5.61	5.76
BETULA	0	0		0	1	0
ABIES	296	236	242	219	235	193
PINUS	30	14	23	29	30	47
PICEA	0	0	0	0	0	0
ULMUS	0	0	0	0	0	0
QUERCUS	3	2	5	12	6	15
TILIA	0	0	0	0	0	0
FRAXINUS EXCELSIOR	0	1	0	0	0	1
FAGUS SYLVATICA	1	1	0	0	0	0
ILEX	1	0	0	0	0	1
HIPPOPHAE RHAMNOIDES	0	0	0	0	0	0
FRANGULA ALNUS	0	0	0	0	0	0
CORYLUS AVELLANA TYPE	4	8	18	15	13	18
TYPE X	0	0	0	1	0	0
HEDERA HELIX	0	1	1	0	1	1
ERICACEAE UNDIFF.	0	2	1	3	4	3
EMPETRUM	0	0	0	0	0	1
CALTHA TYPE	0	1	0	0	0	1
BRASSICACEAE UNDIFF.	0	0	0	1	0	0
CARYOPHYLLACEAE UNDIFF.	0	0	1	0	1	0
CHENOPODIACEAE	2	4	5	2	1	7
ROSACEAE UNDIFF.	2	1	1	0	0	2
SAXIFRAGA GRANULATA TYPE	0	0	0	1	2	0
APIACEAE UNDIFF.	0	0	0	1	0	0
RUMEX ACETOSA TYPE	0	0	0	1	1	2
LYSIMACHIA VULGARIS TYPE	0	0	0	0	0	0
GENTIANELLA CAMPESTRIS TYPE	0	0	0	0	0	0
STACHYS TYPE	0	0	0	0	0	0
PLANTAGO MAJOR TYPE	0	0	0	0	0	0
RUBIACEAE	0	0	0	1	0	0
ASTERACEAE UNDIFF.	0	0	0	0	0	0
ARTEMISIA	0	0	1	0	0	0
POACEAE	2	1	0	1	0	1
ALNUS	17	31	25	17	29	32
	0	0	0	0	1	0
CYPERACEAE	2	2	0	2	0	0
LYCOPODIELLA INUNDATA	0	0	0	0	0	0
OSMUNDA REGALIS	0	0	0	0	0	0
	0	2	4	8	12	8
	0	0	0	3	3	4
POLYPODIUM VULGARE	0	0	3	6	2	0
SPHAGNUM	0	0	0	0	0	0
5.92	6.08	6.24	6.42			
--	---	--	--			
0 226 40 0 13 0 0 1 0 0 1 0 0 8 0 0	3 73 61 1 0 40 3 5 0 3 0 2 65 0 1	2 22 59 1 1 37 1 7 1 3 1 0 100 0 0	1 12 63 2 5 37 0 17 0 3 0 1 95 0 0			
0	1	2	0			
0 0 4 5 0 0 0 0 0 0 0 0 1	0 0 9 4 0 0 0 0 0 1 1 0 1 0 9	0 0 4 2 0 1 2 2 1 1 0 0 0 0 9	0 0 0 5 0 0 1 0 1 0 1 0 0 0 5			
23 0 0	15 0 2	36 0 10	35 0 14			
0 0 4 3 0	0 0 14 8 1 0	1 23 4 0	0 0 24 7 4 1			

Bradmoor

Depth metres	0.2	0.4	0.6	0.9	1.2	1.4	1.6	1.8	2	2.6	2.8
ABIES	204	124	256	213	293	313	415	374	425	365	281
PINUS	52	52	14	11	24	23	26	21	25	37	33
PICEA	15	15	3	1	2	3	0	1	2	1	1
TAXUS	0	0	0	0	0	1	0	0	1	0	2
CUPPRESSACEAE	0	1	0	0	2	0	0	0	1	0	3
BETULA	1	0	0	0	0	3	1	0	1	4	2
PTEROCARYA	0	3	1	0	1	0	0	0	0	0	0
CARPINUS	1	0	3	2	6	3	0	0	2	0	1
UNID P3	0	0	0	0	0	0	2	2	0	0	0
ULMUS	1	0	0	0	0	0	0	1	0	2	3
QUERCUS	6	2	5	4	6	10	8	8	5	15	20
TILIA	0	0	1	0	0	0	0	0	1	2	2
FRAXINUS	0	0	0	0	0	0	0	0	2	1	0
ILEX	0	0	0	0	0	0	0	0	0	1	1
ALNUS	5	3	17	26	15	30	11	8	21	33	22
PRUNUS/MALUS TYPE	0	0	1	0	0	0	0	1	1	1	1
CORYLUS AVELLANA TYPE	2	2	2	6	6	14	3	1	4	28	72
ERICA	16	13	3	1	1	0	2	0	1	1	1
CALLUNA	1	2	0	0	0	0	0	0	1	0	0
LONICERA	0	0	0	0	0	0	1	0	0	0	0
HEDERA	0	0	0	0	0	2	0	0	0	0	0
VITACEAE	0	0	0	0	0	0	0	0	0	1	1
RETIC, INDET, (incl TYPE X)	0	0	0	0	0	0	0	0	0	1	0
cf TYPE X	1	0	0	0	0	1	2	0	0	2	5
CALTHA TYPE	0	0	0	0	1	0	0	0	0	1	0
DIANTHUS TYPE	1	0	0	0	0	0	0	0	0	0	0
STELLARIA TYPE	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	1
CHENOPODIACEAE	0	0	0	0	0	0	2	3	0	0	0
ROSACEAE UNDIFE.	0	0	0	0	0	1	0	0	1	0	1
PRIMULACEAE INDET.	0	0	0	0	0	0 0	0	0	1	0	0
cf I YSIMACHIA	Õ	Õ	1	Õ	0	Õ	2	0	0	1	0
	Õ	Õ	0	Õ	0	Õ	0	0	1	0	0
PLANTAGO MEDIA/MAJOR TYPE	Õ	Ő	Ő	Õ	0 0	Õ	Ő	Õ	1	Ő	0
	Õ	Õ	Õ	Õ	0	Õ	Õ	Õ	0	Õ	Õ
VALERIANA	Õ	1	Õ	Õ	0	Õ	Õ	Õ	Õ	Õ	Õ
BIDENS TYPE	Õ	0	Ő	Õ	1	Õ	Ő	1	Ő	1	1
	1	0	0	1	1	0	Ő	0	0	0	1
SENECIO TYPE	0	0	0	0	0	1	1	Ő	Ő	0	0
	0	1	0	0	0 0	0	0	1	0	0	0
	54	à	0	1	1	2	0	1	1	0	1
UNIDENTIFIED/DEGRADED	0	0	1	0	1	0	0	0	1	0	1
	1	Ω	Ω	0	0	Ο	Ο	0	0	0	0
	0	1	0	1	0	0	n N	0	0	2	0
CYPERACEAE	63	7	1	0	0	0	0	0	1	1	0
	1	2	0	0	Ο	1	1	0	2	1	2
DRYOPTERIS TYPE	4	5	2	5	4	2	5	3	4	2	3

POLYPODIUM VULGARE cf AZOLLA	2 0	0 0	0 0	1 1	0 0	1 0	2 0	2 0	1 0	2 0	1 0
SPHAGNUM	15	11	0	0	0	1	0	0	0	0	0
LIVERWORTS	0	1	0	0	1	0	0	0	0	0	0
PEDIASTRUM	14	1	0	0	1	0	0	0	0	0	0
PRE-QUATERNARY	19	1	0	0	0	2	2	0	0	0	18
DINOFLAGELLATES	1	0	7	4	33	14	240	93	27	270	90

3.2	
284 35 14 0 3 0 0 0 6 22 2 1 0 8 0 58	
0 0 0 0 5	
0 0 0 0 0 0 0 0 1 0 0 0 0 3 4 4	
0 0 1	
0 5	

			Ammonia	Ammonia	Ammonia		
Depth	Volume		beccarii forma	beccarii forma	beccarii forma	Haynesina	Aubignyna
(m)	(cc)	split	beccarii	parkensoniana	tepida	germanica	perlucida
5.70	) 2	. 1/4	7	0	0	21	5
6.70	) 2	. 1/4	8	0	2	35	7
7.70	) 2	. 1/4	47	0	10	16	28
8.30	) 2	: 1	115	0	9	30	31
8.40	) 2	: 1	69	0	0	12	50
8.50	) 2	. 1/4	83	0	5	27	46
8.70	) 2	. 1/4	63	0	10	9	39
9.80	) 2	. 1/4	41	0	0	2	12
9.90	) 2	. 1/4	77	8	4	28	28
9.95	5 3	1/4	42	24	8	60	34
9.97	7 5	5 1	56	24	0	98	25
9.99	9 5	5 1	16	2	0	5	0
10.01	1 5	5 1	0	0	0	0	0
10.05	5 3	5 1	0	0	0	0	0
10.79	9 2	. 1/4	0	0	0	0	0
10.8´	1 2	. 1/4	0	0	0	0	0
10.83	3 2	. 1/4	0	0	0	0	0
10.85	5 2	. 1/4	0	0	0	0	0
10.87	7 2	! 1	0	0	0	0	0
10.89	9 2	. 1/4	0	0	0	0	0
10.9 <sup>-</sup>	1 2	: 1	0	0	0	0	0
10.92	2 2	: 1	0	0	0	0	0
11.00	) 2	. 1/4	0	0	0	0	0
11.40	) 2	. 1/4	0	0	0	0	0
11.80	) 2	: 1	0	0	0	0	0

Elphidium	۱							
excavatu	m				Elphidium			
forma		Elphidium	Elphidium	Elphidium	margaritaceu	Elphidium		
clavata		gerthi	incertum	macellum	m	williamsoni	Elphidium sp	Bolivina spp
	13	98	0	13	1	1	36	5
	12	19	0	5	1	0	3	1
	9	15	0	0	0	0	1	3
	13	5	0	0	0	0	1	0
	17	0	0	0	2	0	0	2
	18	23	1	0	4	2	1	3
	13	0	4	0	1	0	0	0
	4	1	3	0	4	1	2	0
	2	0	10	0	8	14	0	0
	0	0	14	1	4	26	4	0
	0	0	25	20	0	16	13	0
	0	0	0	0	0	12	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0

Vaginulinopsis		Lenticulina	Buliminella		Parafissurina		
spp		spp	elegantissima	Globulina spp	sp.	Trifarina sp	Unknown
	1	0	1	1	1	0	2
	1	1	0	0	2	0	0
	0	0	0	1	1	0	0
	0	0	0	2	0	0	0
	0	0	0	0	1	1	3
	0	0	0	2	0	0	0
	0	0	0	0	0	0	1
	0	0	0	0	0	0	4
	0	0	0	0	0	0	1
	0	0	0	0	0	0	2
	0	0	0	0	0	0	4
	0	0	0	0	0	0	
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
	0	0	0	0	0	0	0

Total	#/cc
206	412
97	194
131	262
206	103
157	78.5
215	430
140	280
74	148
180	360
219	292
281	56.2
35	7
barren	0

			Ammonia	Ammonia	Ammonia		
Depth	Volume		beccarii forma	beccarii forma	beccarii forma	Ammonia	Haynesina
(m)	(cc)	split	beccarii	parkensoniana	tepida	sp	germanica
290	) 1	1/1	0	0	0	0	0
370	) 1	1/4	0	0	0	0	0
390	2	1	25	15	8	0	86
410	2	1	11	1	5	0	42
430	2	1	4	0	3	0	16
447	' 1	1/1	1	0	0	0	19
470	2	1	0	0	0	0	
490	2	1	0	0	0	0	
510	2	1	17	0	0	0	9
530	1	1/4	0	0	0	1	2
550	2	1	14	2	1	0	24
570	2	1/4	0	0	0	0	
570	0.5	1	1	0	0	0	
590	2	1	9	0	0	0	3
610	) 1	1/1	71	27	13	19	109
630	2	1	26	0	1	0	9
650	2	169/512	57	0	9	0	85
670	2	1/8	82	15	16	0	29
690	2	7/16	9	2	8	2	68
691	2	1/4	7	3	8	3	39
692	2	1	22	1	11	0	44
694	- 2	1/4	0	0	0	0	1
696	2	1	5	0	1	3	7
698	5 1	1/4	0	0	0	0	0
699	1.6	1/16	0	0	0	0	0
700	2	11/64	11	1	18	2	40
701-703	3 1.6	1/4	0	0	0	0	0

	Elphidium excavatum						
Aubignyna perlucida	forma clavata	Elphidium aerthi	Elphidium incertum	Elphidium macellum	Elphidium margaritaceum	Elphidium williamsoni	Elphidium sp
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
2	2	5	0	21	0	10	0
	3	2	0	2	0	0	3
	2	1	0	2	0	0	1
3		1	0	9	0	0	2
	1		0	1	0	0	0
	4		0	0	0	1	0
1	9		0	0	0	0	1
		1	0	1	0	0	0
	3	2	0	4	0	0	1
			0	0	0	0	0
			0	0	0	0	0
1	1	4	0	0	0	0	0
38	82	29	0	6	0	7	0
	4	2	0	1	0	0	0
16	58	1	0	0	14	2	8
13	7	0	0	1	4	11	10
32		0	0	2	2	18	0
27	2	0	0	1	8	20	0
45	5	0	0	0	13	22	2
		0	0	0	0	0	0
4	1	0	0	0	3	8	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
17	7	0	0	1	1	5	4
0	0	0	0	0	0	0	0

Bolivina	Vaginulinopsis	Lenticulina	Stainforthia	Quinqueloculina	Buliminella	Globulina	
spp	spp	spp	spp	spp	elegantissima	spp	
0	0	0	0	0	0 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	3	1	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
3	0	0	3	4	2	1	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	1	0	) 0	0	
0	0	0	0	0	) 0	0	
0	1	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	) 0	0	
0	0	0	0	0	0	0	
0	0	0	0	0	0	0	

Cornuspira	Eggerella	Haplophragmo	organic			
sp	scaber	ides sp	lining	Unknown	Total	#/cc
0	0	0	0	0	barren	0
0	0	0	0	0	barren	0
0	0	0	0	0	174	87
0	0	0	0	0	69	35
0	0	0	0	0	29	15
0	0	0	0	2	37	37
0	0	0	0	0	2	1
0	0	0	0	0	5	3
0	0	0	0	0	37	19
0	0	0	0	1	10	40
0	0	0	0	0	51	102
0	0	0	0	0	barren	0
0	0	0	0	0	1	2
0	0	0	0	0	18	9
1	21	0	1	21	458	458
0	0	0	0	0	43	22
0	0	1	0	0	251	380
0	0	0	0	0	188	752
0	0	0	3	4	151	172.571
0	0	0	2	1	121	242
0	0	0	0	6	172	86
0	0	0	0	0	1	2
0	0	0	0	0	32	16
0	0	0	1	0	1	4
0	0	0	0	0	barren	0
0	0	0	0	0	107	311.273
0	0	0	0	0	barren	0

		Ammonia	Ammonia	Ammonia	
		beccarii forma	beccarii forma	beccarii forma	
Volume (cc)	split	beccarii	parkensoniana	tepida	Ammonia sp
2	1	43	12	6	0
2	1	10	0	1	0
2	1	28	3	4	0
1	1	5	0	0	0
1	1/4	0	0	1	0
2	1	6	0	1	0
2	15/64	32	0	2	0
2	1	3	2	2	0
1	11/128	5	0	8	6
2	1	7	2	8	0
1	1/4	0	0	27	0
2	1/16	3	1	44	4
2	1/16	58	7	23	0
1	1/16	45	3	32	0
1	1/16	91	1	22	3
1	7/256	45	5	15	1
1	7/256	48	6	1	2
2	83/1024	29	12	4	9
2	1/4	4	0	0	1
1.2	1	5	6	0	5
	Volume (cc) 2 2 1 1 2 2 2 2 2 1 2 1 2 1 2 1 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 2 2 1 2	Volume (cc) split 2 1 2 1 2 1 1 1 1 1/4 2 1 2 15/64 2 1 1 11/128 2 1 1 1/4 2 1/16 2 1/16 1 1/16 1 1/16 1 1/16 1 7/256 2 83/1024 2 1/4 1.2 1	Ammonia beccarii forma Volume (cc) split beccarii 2 1 43 2 1 10 2 1 28 1 1 5 1 1/4 0 2 1 6 2 15/64 32 2 1 6 2 15/64 32 2 1 3 1 11/128 5 2 1 7 1 1/4 0 2 1/16 3 2 1/16 3 2 1/16 58 1 1/16 45 1 1/16 91 1 7/256 45 1 7/256 48 2 83/1024 29 2 1/4 4 1.2 1 5	Ammonia beccarii forma Ammonia beccarii forma parkensoniana   2 1 43 12   2 1 43 12   2 1 10 0   2 1 28 3   1 1 5 0   1 1/4 0 0   2 1 3 2   1 1/4 0 0   2 1 3 2   1 1/4 0 0   2 1 3 2   1 1/1/128 5 0   2 1 7 2   1 1/16 3 1   2 1/16 58 7   1 1/16 91 1   1 7/256 45 5   1 7/256 48 6   2 83/1024 29 12   2 1/4 4 <td< td=""><td>Ammonia beccarii forma beccarii Ammonia beccarii forma parkensoniana Ammonia beccarii forma tepida   2 1 43 12 6   2 1 43 12 6   2 1 10 0 1   2 1 28 3 4   1 1 5 0 0   1 1/4 0 0 1   2 1 3 2 2   1 1/4 0 0 1   2 1 3 2 2   1 1/4 0 0 2   2 1 3 2 2   1 1/128 5 0 8   2 1 7 2 8   1 1/4 0 0 27   2 1/16 3 1 44   2 1/16 5 3 32   1 1/16 91 1 22   1 7/256 48 6 1   2 83/1024 29 12 4</td></td<>	Ammonia beccarii forma beccarii Ammonia beccarii forma parkensoniana Ammonia beccarii forma tepida   2 1 43 12 6   2 1 43 12 6   2 1 10 0 1   2 1 28 3 4   1 1 5 0 0   1 1/4 0 0 1   2 1 3 2 2   1 1/4 0 0 1   2 1 3 2 2   1 1/4 0 0 2   2 1 3 2 2   1 1/128 5 0 8   2 1 7 2 8   1 1/4 0 0 27   2 1/16 3 1 44   2 1/16 5 3 32   1 1/16 91 1 22   1 7/256 48 6 1   2 83/1024 29 12 4

		Elphidium					
Haynesina germanica	Aubignyna perlucida	forma clavata	Elphidium gerthi	Elphidium macellum	Elphidium margaritaceum	Elphidium williamsoni	Elphidium sp
15	2	3	0	1	0	9	4
8	2	4	1	2	0	6	2
17	8	36	0	26	0	9	5
12	25	17	6	20	1	2	13
16	11	1	71	36	5	9	5
8	2	2	0	9	2	10	10
16	1	10	0	9	2	40	3
13	0	4	0	17	0	9	2
15	11	3	19	36	0	1	13
11	5	15	0	21	0	20	2
19	24	11	26	26	1	1	6
44	17	18	14	25	2	19	18
22	20	13	1	5	2	3	0
37	14	16	3	1	1	2	6
54	32	27	5	2	1	11	4
28	15	10	2	3	4	4	0
23	1	4	0	0	0	6	3
16	10	6	0	0	1	1	1
1	0	0	0	0	0	0	0
2	1	2	0	0	1	2	0

	Vaginulinopsis			Jadammina	Parafissurina	
Bolivina spp	spp	Lenticulina spp	Lagena sp	macrescens	s sp.	organic lining
0	) (	0	0 (	)	0	0 0
0	) .	1	0 (	)	0	0 0
0	) (	0	0 (	)	0	0 0
0	) (	0	0 (	)	1	0 0
2	2	3	4 (	)	0	0 1
0	) (	0	0 (	)	0	0 0
0	) (	0	0 (	)	0	0 0
0	) (	0	0 (	)	0	0 0
2	2	2	1 1	1	1	0 0
0	) (	0	0 (	)	0	0 0
0	) 2	2	0 (	)	0	0 0
1	2	4	0 (	)	0	0 4
0	) (	0	0 (	)	0	0 0
2	2 (	0	0 (	)	0	1 2
3	6 (	0	0 (	)	0	0 2
0	) (	0	0 (	)	0	0 0
0	) (	0	0 (	)	0	0 0
0	) (	0	0 (	)	0	0 2
0	) (	0	0 (	)	0	0 1
0	) (	0	0 0	)	0	0 0

Unknown	Total	#/cc
0	95	48
0	37	19
0	136	68
0	102	102
1	166	664
0	50	25
0	115	245
0	52	26
4	128	1489
0	91	46
0	143	572
1	219	1752
5	159	1272
2	167	2672
9	267	4272
1	133	4864
7	101	3694
10	101	623
0	7	14
1	25	21

				Ammonia	Ammonia	Ammonia		
1	Volume	2		beccarii forma	beccarii forma	beccarii forma		Haynesina
	(cc)		split	beccarii	parkensoniana	tepida	Ammonia sp	germanica
1.08		1	158/2048	10	15	15	2	16
1.09	0	.4	1/16	8	13	0	6	22
1.1	1	.2	1/16	21	28	6	21	29
1.11		1	7/16	19	8	18	19	5
1.12		1	1	0	0	0	0	0
1.14		1	1	0	0	0	0	0
1.16		1	1	0	0	0	0	0
2.84		2	1/4	0	0	0	0	0
	.08  .09  .11  .11  .12  .14  .16 2.84	Volume (cc) 1.08 1.09 0 1.1 1 1.11 1.12 1.14 1.16 2.84	Volume (cc)1.0811.090.41.11.21.1111.1211.1211.1411.1612.842	Volume (cc)split1.081158/20481.090.41/161.11.21/161.1117/161.12111.14111.16112.8421/4	Ammonia beccarii forma (cc)Ammonia beccarii forma beccarii1.081158/2048101.090.41/1681.11.21/16211.1117/16191.121101.141101.161102.8421/40	Ammonia beccarii forma (cc)Ammonia beccarii forma parkensoniana1.081158/204810151.090.41/168131.11.21/1621281.1117/161981.1211001.1411001.1411002.8421/400	Volume (cc)Ammonia beccarii forma beccarii forma beccarii forma parkensonianaAmmonia beccarii forma parkensonianaAmmonia beccarii forma tepida1.081158/20481015151.090.41/1681301.11.21/16212861.1117/16198181.12110001.14110002.8421/4000	Volume (cc)Ammonia beccarii forma beccarii forma parkensonianaAmmonia beccarii forma parkensonianaAmmonia beccarii forma tepidaAmmonia beccarii forma tepida1.081158/204810151521.090.41/16813061.11.21/1621286211.1117/1619818191.121100001.141100001.161100002.8421/40000

	Elphidium excavatum						
Aubignyna perlucida	forma clavata	Elphidium macellum	Elphidium margaritaceum	Elphidium williamsoni	Bolivina spp	Trochammina inflata	Jadammina macrescens
36	20	2	0	2	0	0	0
27	5	0	1	1	0	0	0
26	7	0	1	1	0	0	0
34	5	0	0	3	1	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1

Unknown	Total	#/cc
19	137	1775.8
15	98	3920
0	140	1866.67
17	129	294.857
0	barren	0
0	barren	0
0	barren	0
0	2	4

			Ammonia	Ammonia beccarii	Ammonia		
	Volume		beccarii forma	forma	beccarii forma		Haynesina
Depth (m)	(cc)	split	beccarii	parkensoniana	tepida	Ammonia sp	germanica
4.9	1	1/1	0	0	0	0	0
5.3	1	1/4	222	8	0	67	81
5.4	2	169/512	92	107	4	0	52
5.5	2	1/8	187	17	9	0	64
5.6	2	1/8	137	44	0	0	30
5.7	2	1/8	65	16	0	0	78
5.8	2	1/8	132	0	24	0	48
5.9	2	1/8	127	1	20	0	43
6	2	1/8	69	0	11	0	6
6.1	1	1/16	60	0	0	0	22
6.2	1	1	81	0	22	0	37
6.3	2	1	85	0	61	0	45
6.38	2	1	103	0	30	0	33
6.46	2	1	15	0	3	0	9

Elphidium						
excavatum			Elphidium			
forma	Elphidium	Elphidium	margaritaceu	Elphidium		
clavata	gerthi	incertum	m	williamsoni	Elphidium sp	Bolivina spp
0	0	0	0	0	0	0
15	0	0	0	2	0	1
14	0	0	0	3	0	0
0	0	26	2	26	1	0
0	0	40	0	16	0	0
0	0	18	0	0	0	0
0	0	54	0	19	4	0
0	6	36	1	4	27	1
0	1	24	0	3	0	0
0	4	5	0	2	0	0
0	0	48	0	0	0	0
0	0	20	0	0	0	0
0	0	33	0	0	0	0
0	0	13	0	0	1	0
	Elphidium excavatum forma clavata 0 15 14 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Elphidium excavatum forma Elphidium clavata gerthi 0 0 15 0 14 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Elphidium Elphidium Elphidium Elphidium Iphidium	Elphidium Elphidium Elphidium margaritaceu   forma Elphidium Elphidium margaritaceu   0 0 0 0   15 0 0 0   14 0 0 0   0 0 40 0   0 0 18 0   0 0 54 0   0 1 24 0   0 0 48 0   0 0 20 0   0 0 33 0   0 0 33 0	Elphidium Elphidium Elphidium Elphidium margaritaceu Elphidium   forma Elphidium Elphidium margaritaceu Elphidium williamsoni   0 <td>Elphidium Elphidium Elphidium margaritaceu Elphidium margaritaceu Elphidium Elphidium Elphidium Margaritaceu Elphidium Margaritaceu Elphidium Margaritaceu Elphidium Margaritaceu Margaritac</td>	Elphidium Elphidium Elphidium margaritaceu Elphidium margaritaceu Elphidium Elphidium Elphidium Margaritaceu Elphidium Margaritaceu Elphidium Margaritaceu Elphidium Margaritaceu Margaritac

Vaginulinopsis	Lenticulina	Stainforthia	Trochammina			
spp	spp	spp	inflata	Unknown	Total	#/cc
0	0	0	0	0	barren	0
1	1	0	0	17	474	1896
0	0	0	0	0	282	427
0	0	0	0	0	351	1404
0	0	0	0	0	273	1092
0	0	0	0	0	181	724
0	0	0	0	0	290	1160
0	0	0	0	0	285	1140
0	0	0	0	0	124	496
0	0	1	0	13	157	2512
0	0	0	0	0	206	206
0	0	0	0	0	217	109
0	0	0	1	0	207	104
0	0	0	0	0	41	21

			Ammonia	Ammonia	Ammonia	
			beccarii forma	beccarii forma	beccarii forma	
Depth (m) Volume	(CC)	split	beccarii	parkensoniana	tepida	Ammonia sp
0.2	2	15/64	28	15	0	0
0.4	1	15/64	65	4	5	0
0.65	1	1	7	1	1	1
0.8	2	1	30	3	0	0
1.2	1	5/128	62	2	0	0
1.4	2	15/64	206	7	6	0
1.6	1	1/64	26	1	10	5
1.8	1	1/8	97	3	13	0
2	2	1/8	114	7	11	0
2.55	1	18/64	6	0	0	0
2.55	2	1	8	0	2	0
2.77	2	1/8	142	8	25	0
3.11	1	11/128	69	30	44	1
3.4	21	695/4096	142	10	9	0
3.6	2	13/16	19	27	20	5
3.8	2	1	2	0	0	0
4.6	2	1/16	0	0	0	0
5.6	2	1/16	0	0	0	0
6.8	2	1/4	0	0	0	0
7.98	2	1/4	0	0	0	0
8.8	2	1/4	0	0	0	0

	A	Elphidium excavatu					
dermanica	perlucida	m torma clavata	aerthi	incertum	Elphidium	Elphidium	williamsoni
85	1	1	0	3	0	0	22
71	2	0	0	0	0	0	56
11	1	2	0	0	0	0	34
24	0	2	0	0	1	0	21
30	15	2	0	1	1	0	15
116	3	25	0	0	0	0	26
25	4	19	0	0	0	2	20
51	8	21	0	0	0	0	12
58	8	6	5	0	13	2	53
7	0	1	0	0	0	1	5
1	0	0	3	0	2	0	7
40	15	26	3	0	1	0	10
37	44	7	5	0	0	1	1
32	15	12	2	0	0	3	2
15	19	6	1	0	1	0	1
3	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

		Jadammina	Valvulina			
Elphidium sp	Bolivina spp	macrescens	conica	Unknown	Total	#/cc
С	0	0	0	4	159	339
C	0	0	0	6	209	892
C	0	0	0	1	59	59
C	0	0	0	1	82	41
C	0	0	0	16	144	3686
4	- 0	0	0	3	396	845
4	. 1	0	0	1	118	7552
46	i 0	0	0	6	257	2056
31	0	0	0	1	309	1236
95	i 0	0	0	1	116	412
79	0	0	0	0	102	51
2	2 0	0	0	1	273	1092
1	0	0	1	2	243	2828
C	0	0	0	1	228	275
1	2	1	0	4	122	75
C	0	0	0	0	6	3
C	0	0	0	0	barren	0
C	0	0	0	0	barren	0
C	0	0	0	0	barren	0
C	0	0	0	0	barren	0
C	0	0	0	0	barren	0

Extent of amino acid racemization (D/L) for aspartic acid (Asx), glutamic acid (Glx), serine (Ser), alanine FAA = free amino acid fraction

THAA = total hydrolysable amino acid fraction

LAB	LAB NUMBER	SAMPLE NAME	COUNTR Y	SITE NAME	PROVEN ANCE / SAMPLE I.D.	UK National Grid Reference	Latitude	Longitude
NEaar	10344	HF13Bo1	England	Horse Fen	HF13, 105	8-9	52.7004	0.50385

SAMPLE	GENUS	SPECIES n (number							
ITEE			of	FAA Asx	FAA Asx	FAA GIx	FAA Glx	FAA Ser	
			injections)	D/L x	D/L σ	D/L x	D/L σ	D/L x	
opercula	Bithynia	sp.	2	0.78	0.00	0.22	0.05	0.92	

							n (number
FAA Ser	FAA Ala	FAA Ala	FAA Val	FAA Val	FAA	FAA	of
D/L σ	D/L x	D/L σ	D/L x	D/L σ	[S]/[A] x	[S]/[A] σ	injections)
0.03	0.51	0.00	0.28	0.00	0.27	0.01	1

THAA Asx	THAA Asx	THAA GIX	THAA GIx	THAA Ser	THAA Ser	THAA Ala	THAA Ala	THAA Val
D/L x	D/L σ	D/L x						
0.61		0.19		0.54		0.37		0.18

THAA Val	THAA	THAA	Additional
D/L σ	[S]/[A] x	[S]/[A] σ	information
	0.34		second injection failed

Extent of amino acid racemization (D/L) for aspartic acid (Asx), glutamic acid (Glx), serine (Ser), alanine (Ala), valir FAA = free amino acid fraction

THAA = total hydrolysable amino acid fraction

LAB	LAB NUMBER	Sample Name	COUNTR Y	SITE NAME	PROVEN ANCE / SAMPLE I.D.	UK National Grid Reference	Latitude	Longitude	SAMPLE TYPE
NEaar	9786	THBto1	England	Tottenhill	Nar Valley	Freshwater	52.670	0.408	opercula
NEaar	9787	THBto2	England	Tottenhill	Nar Valley	Freshwater	52.670	0.408	opercula
NEaar	9788	THBto3	England	Tottenhill	Nar Valley	Freshwater	52.670	0.408	opercula
NEaar	9789	THBto4	England	Tottenhill	Nar Valley	Freshwater	52.670	0.408	opercula
NEaar	9790	THBto5	England	Tottenhill	Nar Valley	Freshwater	52.670	0.408	opercula
NEaar	9791	THBto6	England	Tottenhill	Nar Valley	Freshwater	52.670	0.408	opercula
NEaar	10337	Tott3Bto1	England	Tottenhill	shelly peat	at base of T	52.670	0.407	opercula
NEaar	10338	Tott3Bto2	England	Tottenhill	shelly peat	at base of T	52.670	0.407	opercula
NEaar	10339	Tott3Bto3	England	Tottenhill	shelly peat	at base of T	52.670	0.407	opercula
NEaar	10340	Tott3Bto4	England	Tottenhill	shelly peat	at base of T	52.670	0.407	opercula
NEaar	10341	Tott3Bto5	England	Tottenhill	shelly peat	at base of T	52.670	0.407	opercula
NEaar	10342	Tott3Bto6	England	Tottenhill	shelly peat	at base of ⊺	52.670	0.407	opercula

Note: lat long estimated from Goog

GENUS	SPECIES	n (number							
		of	FAA Asx	FAA Asx	FAA Glx	FAA Glx	FAA Ser	FAA Ser	FAA Ala
		injections)	D/L x	D/L σ	D/L x	D/L σ	D/L x	D/L σ	D/L x
Bithynia	tentaculata	2	0.76	0.01	0.31	0.00	0.98	0.02	0.50
Bithynia	tentaculata	2	0.77	0.00	0.33	0.01	0.97	0.02	0.50
Bithynia	tentaculata	2	0.75	0.01	ND		0.83	0.02	0.50
Bithynia	tentaculata	2	0.77	0.00	0.32	0.02	1.07	0.01	0.51
Bithynia	tentaculata	2	0.77	0.00	0.32	0.01	0.98	0.04	0.51
Bithynia	tentaculata	2	0.78	0.00	0.32	0.01	1.00	0.00	0.52
Bithynia	tentaculata	2	0.77	0.00	0.35	0.02	1.01	0.01	0.52
Bithynia	tentaculata	2	0.77	0.00	0.35	0.01	1.00	0.01	0.51
Bithynia	tentaculata	2	0.77	0.00	0.32	0.01	1.03	0.01	0.50
Bithynia	tentaculata	2	0.79	0.00	0.34	0.00	1.03	0.01	0.52
Bithynia	tentaculata	2	0.77	0.00	0.31	0.00	1.02	0.02	0.52
Bithynia	tentaculata	2	0.77	0.00	0.31	0.01	1.01	0.02	0.51

gle Earth as no GPS in field

					n (number			
FAA Ala	FAA Val	FAA Val	FAA	FAA	of	THAA Asx	THAA Asx	THAA GIx
D/L σ	D/L x	D/L σ	[S]/[A] x	[S]/[A] σ	injections)	D/L x	D/L σ	D/L x
0.01	0.27	0.00	0.30	0.00	2	0.63	0.00	0.27
0.00	0.29	0.00	0.28	0.00	2	0.61	0.00	0.26
0.01	ND		0.37	0.04	2	0.60	0.05	0.31
0.00	0.28	0.01	0.29	0.01	2	0.67	0.00	0.30
0.00	0.28	0.01	0.29	0.00	2	0.68	0.01	0.29
0.00	0.28	0.00	0.28	0.00	2	0.67	0.01	0.28
0.00	0.29	0.00	0.28	0.00	2	0.66	0.00	0.29
0.00	0.29	0.00	0.29	0.00	2	0.65	0.00	0.29
0.00	0.28	0.00	0.29	0.00	2	0.66	0.00	0.28
0.00	0.29	0.00	0.26	0.00	2	0.68	0.00	0.31
0.00	0.29	0.00	0.31	0.00	2	0.64	0.00	0.26
0.00	0.29	0.00	0.30	0.00	2	0.66	0.00	0.27

THAA GIx	THAA Ser	THAA Ser	THAA Ala	THAA Ala	THAA Val	THAA Val	THAA	THAA	
D/L σ	D/L x	D/L σ	D/L x	D/L σ	D/L x	D/L σ	[S]/[A] x	[S]/[A] σ	
0.00	0.67	0.00	0.40	0.00	0.21	0.00	0.32	0.00	
0.00	0.64	0.02	0.38	0.00	0.21	0.00	0.31	0.01	
0.05	0.44	0.09	0.41	0.01	ND		0.73	0.25	
0.00	0.72	0.01	0.44	0.00	0.23	0.00	0.31	0.00	
0.00	0.71	0.00	0.43	0.00	0.23	0.00	0.30	0.00	
0.00	0.64	0.00	0.43	0.00	0.22	0.00	0.33	0.00	
0.00	0.71	0.01	0.42	0.00	0.23	0.00	0.30	0.00	
0.00	0.67	0.01	0.42	0.00	0.22	0.00	0.30	0.00	
0.00	0.71	0.00	0.42	0.00	0.23	0.00	0.30	0.00	
0.00	0.73	0.02	0.43	0.00	0.23	0.00	0.27	0.00	
0.00	0.67	0.00	0.41	0.00	0.21	0.00	0.32	0.00	
0.00	0.69	0.00	0.41	0.00	0.22	0.01	0.29	0.00	

Additional informatio n
Depth (m)	Moisture	LOI	Ash
7.7	21.3	4.7	95.3
8	23.4	5.1	94.9
8.2	22.6	5.9	94.1
8.3	21.9	5.8	94.2
8.4	20.4	5.3	94.7
8.5	20.0	5.3	94.7
9.9	25.8	6.5	93.5
9.92	29.5	7.6	92.4
9.95	30.5	10.7	89.3
9.96	44.3	29.0	71.0
9.97	37.2	22.3	77.7
9.98	48.4	63.2	36.8
9.99	49.9	64.1	35.9
10	47.8	79.6	20.4
10.05	48.3	81.3	18.7
10.1	46.3	76.3	23.7
10.15	52.3	78.2	21.8
10.2	50.7	81.7	18.3
10.25	45.1	83.0	17.0
10.3	50.5	83.8	16.2
10.55	54.9	62.1	37.9
10.6	53.5	40.9	59.1
10.65	52.9	49.4	50.6
10.7	49.0	60.1	39.9
10.75	51.0	59.9	40.1
10.8	43.3	17.3	82.7
10.85	42.9	17.7	82.3
10.9	49.3	65.9	34.1
11	25.3	20.9	79.1
11.1	27.5	5.0	95.0
11.2	24.8	4.2	95.8
11.3	26.9	4.6	95.4
11.4	25.8	4.7	95.3

Depth (m)	Moisture	LOI	Ash
2.9	17.6	0.5	99.5
3.3	17.8	1.6	98.4
3.7	17.4	3.9	96.1
4.1	17.1	2.9	97.1
4.47	14.8	4.1	95.9
4.9	17.4	3.8	96.2
5.3	20.9	4.3	95.7
5.7	20.8	5.7	94.3
6.1	22.1	4.9	95.1
6.5	19.0	4.3	95.7
6.7	23.6	5.5	94.5
6.82	22.4	6.0	94.0
6.9	26.3	8.2	91.8
6.91	28.6	9.4	90.6
6.92	28.6	10.4	89.6
6.93	30.3	10.5	89.5
6.94	28.7	9.8	90.2
6.95	30.5	11.2	88.8
6.96	34.3	14.9	85.1
6.97	34.4	18.3	81.7
6.98	35.6	21.7	78.3
6.99	34.4	23.6	76.4
7.02	35.7	37.9	62.1
7.035	49.3	67.6	32.4
7.047	57.2	89.5	10.5
7.062	62.1	83.5	16.5
7.087	57.6	84.5	15.5
7.125	61.3	79.3	20.7

Depth (m)	Moisture % LOI	%	Ash %
0.08	32.3	12.3	87.7
0.12	29.7	8.4	91.6
0.16	35.7	15.2	84.8
0.2	24.7	8.2	91.8
0.24	36.5	22.0	78.0
0.28	33.9	18.7	81.3
0.32	40.2	21.9	78.1
0.36	34.3	15.7	84.3
0.38	33.6	14.2	85.8
0.4	34.9	13.7	86.3
0.42	35.8	15.0	85.0
0.44	31.8	12.0	88.0
0.46	33.7	12.7	87.3
0.48	34.3	18.2	81.8
0.5	36.7	22.8	77.2
0.52	40.2	30.6	69.4
0.54	57.6	67.9	32.1
0.56	52.5	82.8	17.2
0.58	50.3	86.9	13.1
0.605	49.8	85.5	14.5
0.635	53.7	87.1	12.9
	50.3	84.5	15.5
0.695	56.5	81.7	18.3
0.725	36.3	21.8	78.2
0.755	40.8	31.6	68.4
0.785	40.2	30.9	69.1
0.8	31.5	21.2	78.8
0.82	36.7	23.3	76.7
0.84	23.8	11.1	88.9
0.88	36.6	23.4	76.6
0.96	40.5	28.8	71.2
1	14.8	2.9	97.1
1.04	14.2	1.8	98.2

Depth (m)	Moisture	LOI	Ash
2.25	20.7	4.4	95.6
2.65	21.5	4.5	95.5
3.05	20.6	4.1	95.9
3.45	21.1	6.2	93.8
3.85	21.2	5.5	94.5
4.25	24.2	6.7	93.3
4.41	35.0	4.0	96.0
4.45	25.1	4.9	95.1
4.47	23.7	4.6	95.4
4.49	24.1	4.2	95.8
4.5	24.0	4.2	95.8
4.51	26.2	6.9	93.1
4.52	28.5	13.3	86.7
4.53	38.6	74.9	25.1
4.54	40.2	84.9	15.1
4.63	51.3	73.4	26.6

Depth (m)	Moisture	LOI	Ash
4.9	15.0	0.9	99.1
5.1	28.0	9.7	90.3
5.3	24.6	5.5	94.5
5.7	16.3	3.6	96.4
6.1	20.7	4.5	95.5
6.46	20.5	4.2	95.8

Depth (m)	Moisture	% LOI	%	Ash %	
0.65	35	.0	10.9	89	9.1
0.85	36	.0	12.3	87	7.7
1.2	31	.3	7.3	92	2.7
1.6	29	.0	4.7	95	5.3
2	18	.8	20.2	79	9.8
2.55	38	.0	6.8	93	3.2
2.77	18	.4	2.6	97	7.4