Holocene sequences and archaeology from the Crabble Paper Mill site, Dover, UK and their regional significance

M. R. Bates[1], A. J. Barham[2], S. Jones[1], K. Parfitt[3], S. Parfitt[4], M. Pedley[5], R. C. Preece[6], M. J. C. Walker[1] & J. E. Whittaker[7]

BATES, M. R., BARHAM, A. J., JONES, S., PARFITT, K., PARFITT, S., PEDLEY, M., PREECE, R. C., WALKER, M. J. C. & WHITTAKER, J. E. 2008. Holocene sequences and archaeology from the Crabble Paper Mill site, Dover, UK and their regional significance. *Proceedings of the Geologists' Association*, **119**, 299–327. The results of multidisciplinary investigations of the Quaternary sediments of the Dour valley, extending inland from Dover, Kent, are reported. The oldest sediments are unfossiliferous coarse gravels and silts of probable Late Devensian age. These are overlain by a complex series of peats and tufaceous sediments of early to mid-Holocene age. Pollen, mollusc, ostracod and vertebrate fossils (including the earliest British Holocene record of hazel dormouse) enable detailed reconstructions of the local environments and the vegetational and faunal history. A chronology is provided by a number of radiocarbon dates. The sequence is mantled by colluvial hillwash. The younger sediments have produced evidence for the presence of early humans (marine shells and flint artefacts) during the Bronze Age.

Key words: Holocene, tufa, archaeology, palaeoenvironment, radiocarbon

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1. INTRODUCTION

The Dour Valley in Kent, with the town of Dover at its mouth, has received little attention from scientists attempting to understand the Late Quaternary history of southeast England. This is surprising, given the proximity to the adjacent continent and the possibility that evidence for the earliest stages of recolonization of the British Isles by plant and animal species following the Last Glacial Maximum may exist in the valley. In addition, relatively little is known about the earliest Holocene human occupation of this part of southeastern Britain. However, recent investigations linked to site-specific archaeological projects have begun to shed some light on these issues. This paper describes the results of work carried out over the course of the past fifteen years at one of these sites, Crabble Paper Mill, which is located just over 2 km inland from the present coast at Dover (Figs 1 and 2; Table 1).

The site was first investigated in 1990 when the geoarchaeological potential was evaluated (Barham & Bates, 1990). Of particular interest was the discovery of tufas of early, mid- and late Holocene age, some of which were found to contain flint artefacts (Bates & Barham, 1993a). In addition to the tufa deposits, however, other sedimentary units – peats, fluvial gravels and colluvial accumulations – were recorded, the palaeoenvironmental potential of which has been highlighted more recently in an archaeological evaluation carried out in advance of the construction of a housing estate (Parfitt, 2002, 2006). To date, however, there has been no systematic exploration or documentation of these often complex depositional sequences.

This paper presents the first detailed multidisciplinary study of the Crabble Mill deposits. New pollen, molluscan and ostracod data are combined with the results of earlier sedimentological and archaeological investigation (Parfitt, 2006) and these results are placed in a time-stratigraphic framework based on fifteen radiocarbon dates. The various data sources provide the basis for a reconstruction of the environment of the Dour Valley region of southeast

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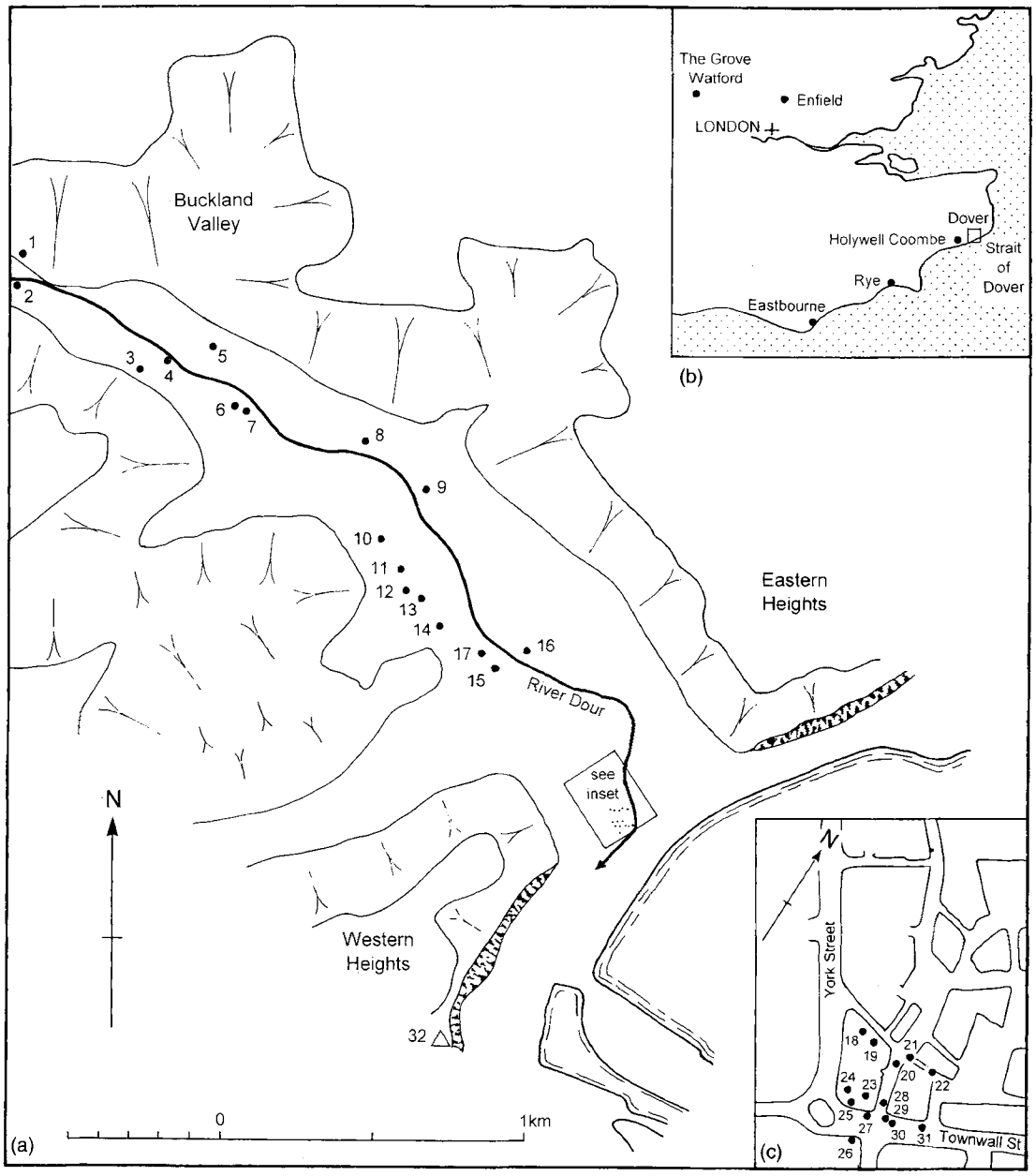

Fig. 1. Site location plan showing (**a**) regional geomorphology, location of Crabble Paper Mill and other key sites (1–31 as listed in Table 1); (**b**) comparable sites in southeast England; and (**c**) detailed location plan for Dover town centre area.

England from the end of the Late glacial around 11 500 calibrated years before present (cal. yr BP) through to the late Holocene. This reveals a complex history of landscape development, involving fluctuations in fluvial regime, changes in the nature and distribution of the vegetation cover and, above all, the increasing impact of human activity on the landscape. While there may be a human record at the site dating back to the Mesolithic, anthropogenic impact on the landscape became most pronounced during the Bronze Age and is reflected initially in reduction of the woodland cover and, subsequently, in enhanced valley-side colluviation, a process that may have continued through into the post-Saxon period.

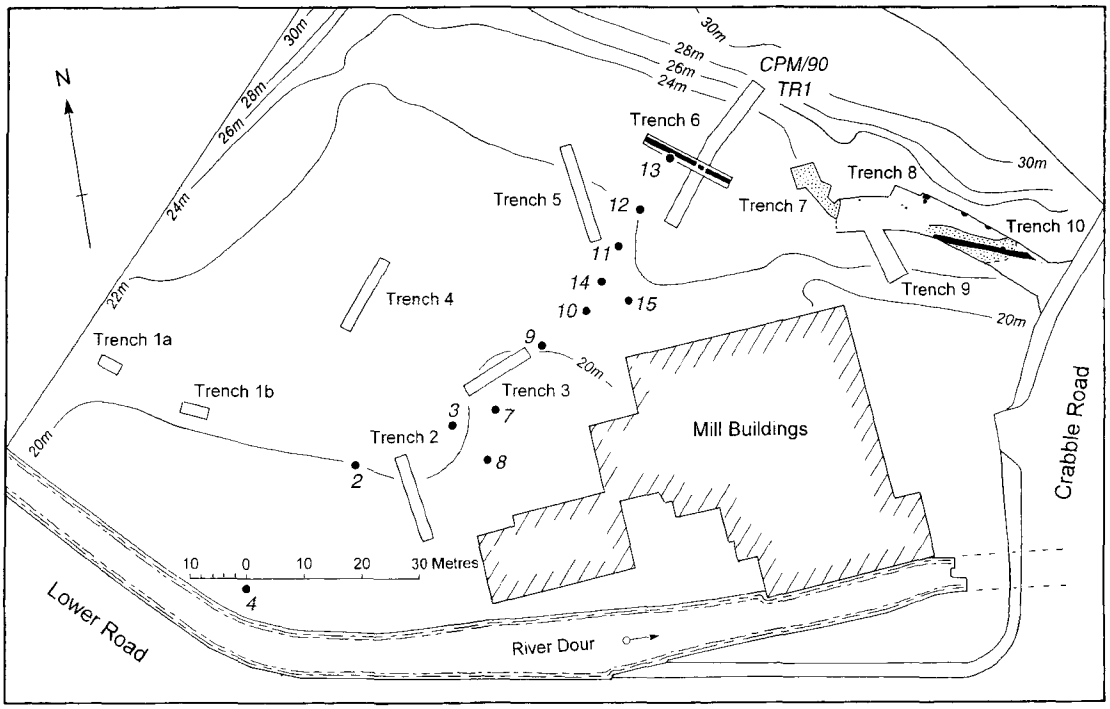

Fig. 2. Trench (1–10) and borehole (1–15) location plan for both phases of investigation works at Crabble Paper Mill.

2. GEOLOGY AND GEOMORPHOLOGY

The River Dour (Fig. 1) lies in a deeply incised valley cut into Middle and Upper Chalk (Shephard-Thorn, 1988). Sediments infilling the valley have been mapped by the British Geological Survey (BGS) as Alluvium, Estuarine Alluvium, Dry Valley and Nailbourne deposits, Head and Head Brickearth (Shephard-Thorn, 1988). Recent work (Barham & Bates, 1990) has demonstrated that, within the lower Dour Valley, the simple mapping categories adopted by the BGS require modification. In particular, the nature and patterns of sediment distribution are more complex (Table 2). Typically these sequences are laterally discontinuous and have been replaced in places by 'made ground' that has completely removed any sediment overlying the basal flint gravels. Of particular significance at Crabble are the Angular flint gravels (Ia), Tufa and peat units (II) and the Fine-grained (inorganic) silts (III).

Angular flint gravels (Ia)

These sediments, up to 6 m in thickness, consist predominantly of poorly sorted, sub-angular to angular flint gravels with a variable sandy matrix. Borehole records indicate that these sediments are found throughout the lower and middle Dour Valley downstream of Crabble (Fig. 3). To the southwest, they have been identified beneath the Western Docks Train Ferry Terminal and the Admiralty Pier (McDakin, 1900). These deposits outcrop at +14 m OD to 16.0 m OD at Crabble and decline to elevations of −1.0 m OD (upper surface) to >−10.0 m OD (lower surface) in Dover town centre. A mammoth tooth (*Mammuthus primigenius*) was discovered in the gravels during excavations in Market Square, and further mammoth teeth were recovered from them during the extension works to the Admiralty Pier in 1890 and 1898. These teeth are fresh and unrolled and are unlikely to have been extensively reworked (McDakin, 1900). No archaeological material is known from these deposits in the Dour Valley.

Sequences similar to those in the Dour Valley occur in valleys throughout SE England and are thought to have been laid down by fluvial processes under periglacial conditions during or following the Last Glacial Maximum (Ballantyne & Harris, 1994). These deposits are probably lateral equivalents of the chalk-rich gravels and silts (Head brickearth *sensu* Shephard-Thorn, 1988) found at the valley margins and which probably also have a cold climate origin. Similar sediments occur to the southwest of the Western Docks at Archcliffe Fort, where a buried soil and associated late-glacial mollusc fauna is present (Bates & Barham, 1993b).

Table 1. List of all known sites producing tufa deposits in the Dour Valley, Kent.

	Location	Grid reference (TR)	Ground surface height (m OD)	Thickness of sequences	Sediment fabric	Associated material	Overlies	Age estimates (yr BP)
1	Crabble Paper Mill	2998 4311	20–24	1.5 m	Medium to coarse oncoidal tufa clasts, in places cemented together or hard cemented phytoclastic mass. Elsewhere varies to fine micritic tufa	Peat and organic silts interbedded in places with tufa. Struck flake within fine micritic tufa in ponds. Burnt flakes resting on surface of infilled tufa ponds and cut into tufa ponds	Angular flint gravels or 'brickearth'	Seven radiocarbon dates ranging from 9480 ± 60 to 3870 ± 40
2	South of Crabble Mill	2998 4296	21.28			Clay-with-flints		
3	Buckland Churchyard	3046 4274	17.17	0.15 m	Medium to fine tufa pellet gravel (oncoids) with occasional shell fragments and patches of organic material	Peat	Angular flint gravel	9240+100
4	Buckland Paper Mill	3060 4275	17					
5	Whitfield Avenue	3073 4279	17.6					
6	Buckland School	3074 6063	13.19	1.83 m	Well-bedded, predominantly horizontal but some cross-bedded units of tufa oncoliths of various sizes from 0.05–0.45 m	Molluscs within tufa, including *Arianta arbustorum* (L), *Lymnaea* sp., *Planorbis* sp. A single struck flake also present	Angular flint gravel	
7	197 London Road	3078 4259	14					
8	Barton Road School	3117 4251	12					
9	Beaconsfield Avenue	3137 4234	11					
10	Beaconsfield Road Chapel	3123 4218	11	0.91 m				
11	15 London Road	3129 4209	7.32	Thin		Peat. Both peat and tufa deposits thicken towards river	Clay-with-flints	

Table 1. *Continued.*

	Location	Grid reference (TR)	Ground surface height (m OD)	Thickness of sequences	Sediment fabric	Associated material	Overlies	Age estimates (yr BP)
12	9 London Road	3132 4202	7.3	Thin		Peat. Sharpened stakes (0.45 m long) and blue patinated flint flakes found in peat	Clay-with-flints	
13	Bridge Street/ High Street junction	3136 4199	7.6					
14	95 High Street	3142 4191	9					
15	Ladywell	3160 4178	7					
16	Police Station	3171 4183	6	0.76 m				
17	Royal Victoria Hospital	3156 4182	7	1.5 m	Stratified hard, cemented compact phytoclastic tufa and coarse to fine concoidal tufa gravels. Oncoids from <1 cm to >6 cm			
18	BH QS-1	31939 41433	0.59	3.1 m	Well sorted tufa pellet gravel and occasional patches of cemented phytoclastic tufa	Flint	Chalk rubble	
19	BH QS-2	31941 41432	0.72	1.25 m	Tufa pellet gravel – loose and unconsolidated	Shell and angular flint clasts	Chalk rubble	
20	BH DBS-4	31980 41437	0.29	1.75 m	Tufa pellet gravel with shell and flint inclusions and occasional fragments of wood	Interstratified with peat and containing shell, wood and plant macrofossils	Angular flint gravels	
21	BH DSI-2	32012 41443	−0.86	0.4 m	Tufa pellet gravel	Wood and plant macrofossils	Angular flint gravels	
22	BH DSI-1	32222 41280	−0.24	1 m	Lime mud	Wood and other organics	Angular flint gravel	
23	BH DSC-1	31974 41369	−0.85	0.1 m	Tufa pellet gravel	Interstratified with peat	Angular flint gravels	

Table 1. *Continued.*

	Location	Grid reference (TR)	Ground surface height (m OD)	Thickness of sequences	Sediment fabric	Associated material	Overlies	Age estimates (yr BP)
24	BH DSC-2	31962 41357	−1.96	0.15 m	Tufa pellet gravel	Interstratified with peat containing molluscs and plant macrofossils	Angular flint gravels	One radiocarbon date. 4810 ± 95
25	BH DSC-5	31970 41353	−0.54	0.6 m	Tufa pellet gravel	Interstratified with peat containing molluscs and plant macrofossils	Angular flint gravels	
26	BH TWS-6	31994 41337	−0.9	1.3 m	Well-sorted oncoidal tufa pellet gravel	Interstratified with peat containing roots, shells and plant macrofossils	Angular flint gravels	
27	BH TWS-3	31997 41362	−0.24	1.6 m	Medium to coarse oncoidal tufa pellet gravel that is generally loose and unconsolidated	Interstratified peat and freshwater molluscs	Angular flint gravels	
29	Bench Street/ Townwall Street junction – Dover Boat trench	32012 41266	0.00	0.5 m	Well-stratified fine to medium tufa oncoidal gravel. Oncoids 1–4 cm and well rounded. Individual beds exhibit cross-bedding, fining-upwards sequences. *In situ* rooting common	Interstratified with peat and organic silts. Freshwater and terrestrial molluscs present. Wood, plant macrofossils, insects, animal bones, ostracods present	Angular flint gravels	
30	BH TWS-5	32018 41372	0.13	2.29 m	Well-sorted medium to coarse oncoidal pellet gravel.	Interstratified with peat containing roots, shells and plant macrofossils	Angular flint gravels	Four radiocarbon dates from 8380 ± 110 to 5120 ± 65
31	BH TWS-4	32046 41388	−2.14	0.1 m	Medium oncoidal tufa pellet gravel	Silts and flint gravel	Angular flint gravels	

Table 2. Stratigraphic groups, locations, inferred palaeoenvironmental conditions and age estimates (^{14}C yr BP) for key deposits in the Dour Valley.

Stratigraphic group number	Stratigraphic group	Location in valley	Inferred palaeoenvironmental conditions	Age ascriptions
VII	Anthropogenic sediments	Town centre		Medieval to post-Medieval
VI	Rounded flint gravels	Town centre		Medieval to post-Medieval
V	Sands	Town centre	Littoral and aeolian sand infilling harbour basin	late Saxon
IV	Organic sands and silts	Town centre	Freshwater wetland growth on infilled harbour	late Roman to early Saxon
IIIb	Bedded fine-grained silts containing angular flint clasts	Valley sides		Bronze Age to Roman
IIIa	Laminated fine-grained silts	Town centre		Bronze Age to Roman
II	Tufa/peat units	Crabble to town centre	Carbonate-rich fluvial systems with damp ground, open and closed vegetation. Stable system	<3300 BP
				>9240 BP
Ic	Chalk rubble beds within fine-grained silts	Valley sides, Archcliffe Fort		
Ib	Fine-grained silts	Valley sides, Archcliffe Fort		
Ia	Angular flint gravels	Crabble to Western Docks	Periglacial, braided channel systems	>10 000 BP

Tufa/Peat units (IIa–d)

These deposits rest on angular flint gravels (Unit Ia) and comprise interbedded tufa and compact, firm humified peats. Tufa commonly consists of well-stratified gravels of sub-rounded to near-spherical oncoids (Ordóñez & Garcia del Cura, 1983) (IIb), stromatolitic-like growths (Buccino *et al.*, 1978) (IIc) or very fine micritic silts (Schafer, 1973) (IId). Typically, sequences are between 1.0 m and 2.5 m in thickness and, where oncoliths or detrital material are present, well-bedded. Cross-bedded, fining-upwards sequences and *in situ* tufa growth have been reported (such as in the coffer dam excavated for the removal of the Dover Bronze Age Boat (Keeley *et al.*, 2004). Cemented tufas exist in Queen Street (Sites 18/19). The maximum extent of the tufa (both cemented and oncoidal) is shown on Figure 1 (inset). Peats (IIa) are humified, compact and occasionally interstratified with tufa. A range of palaeoenvironmental evidence has been recovered from both the tufa and peats, including well-preserved plant macrofossils, pollen, diatoms, molluscs, ostracods and mammalian remains (Clark & Keeley, 1997; Keeley *et al.*, 2004).

Associations of tufa and peat have been found in numerous locations throughout the lower and middle Dour Valley (Bates & Barham, 1993a, c; Table 1). These deposits typically outcrop between 0.0 m OD and −2.0 m OD in the town centre, rising to elevations of 16.0 m OD to 20.0 m OD in the middle Dour valley at Crabble. Tufa is not known to occur upstream of Crabble Mill.

The sequences appear to have formed in carbonate-rich floodplain or channel marginal environments that do not exist in the Dour Valley today. The tufa associations appear similar to those described by Pedley (1990), which form in, and infill, braided fluvial systems, suggesting the presence of shallow, clear moving water bodies. The peats, which may have accumulated in areas of damp ground, contain evidence for wetland environments, grassland and wooded situations. Similar stratigraphies were described at Raper Lodge in the Lathkill Valley, Derbyshire (Pedley, 1993).

Prehistoric artefacts (predominantly ascribed to the later Bronze Age) were recorded from a number of locations associated with the tufa deposits. These include the well-preserved boat discovered beneath the Bench Street Underpass (Parfitt, 1993a, b; Parfitt & Bates, 1993; Clark, 2004), and stakes and struck flakes from No. 9 London Road [NGR TR 3132 4202] reported by a Mr Amos in an unpublished manuscript held at the archive of the British Geological Survey at Keyworth.

Fine-grained silts (IIIa–b)

The sediments range from thin well-sorted, bedded organic silts (Unit IIIa), which overlie the prehistoric

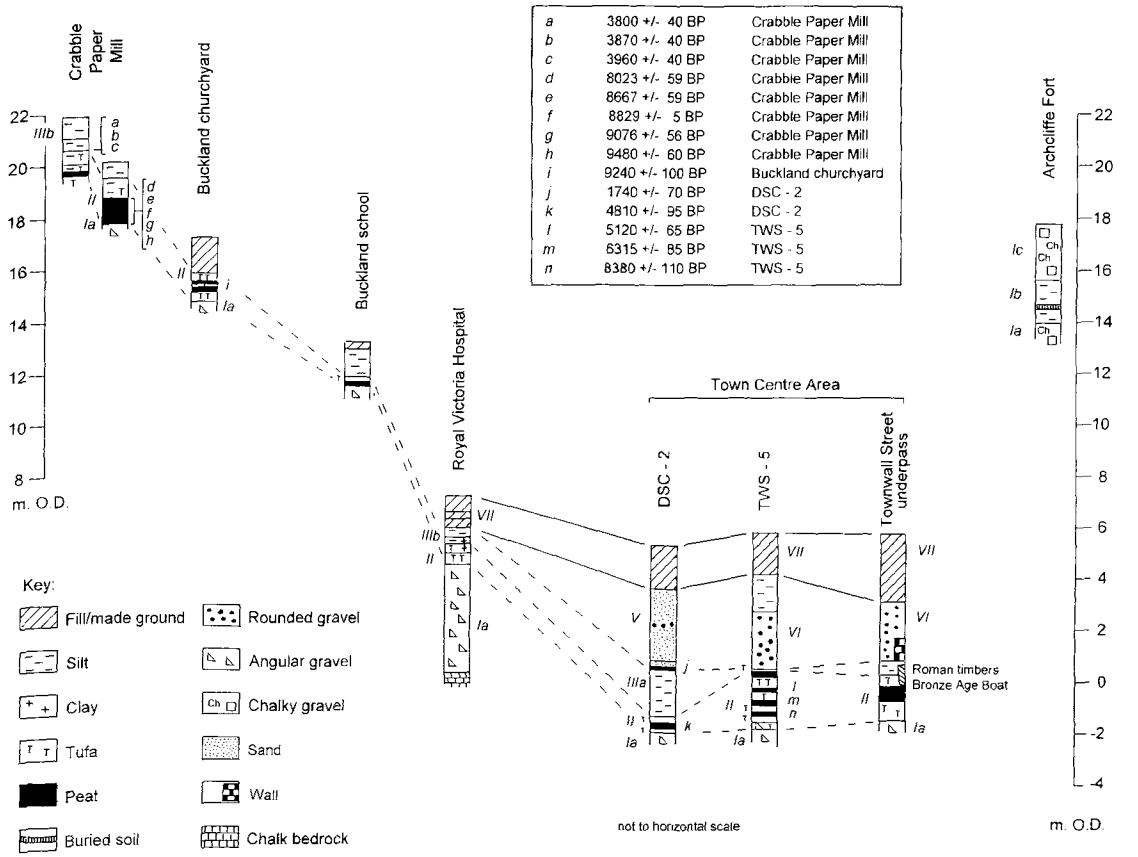

Fig. 3. Summarized stratigraphic sequences for key sites in lower Dour Valley. Units identified by Roman numerals as defined in Table 2. Location of key radiocarbon dates (^{14}C yr BP) shown.

boat in the Bench Street Underpass (Bates & Barham, 1993b, c; Keeley *et al.*, 2004) to structureless clay-silts with a high clast content (diamictons, IIIb) at sites such as Crabble (Barham & Bates, 1990: Bates & Barham, 1993b) and the Royal Victoria Hospital (Bates, 1993) (IIIb). Commonly the diamictons are present as decalcified sediment wedges thinning upslope, but locally they may contain pockets of molluscs or, more commonly, bone, but rarely plant material. These deposits occur at a number of locations in the valley, in places forming a wedge thinning against the lower valley slopes (IIIb), where they seal the peat/tufa sediments (Figs 4 and 5). The diversity in location, geomorphological aspect and structure/content indicates that these deposits were laid down in a variety of environments. Sediments, such as those recorded at Crabble and the Royal Victoria Hospital (Bates, unpublished data), are similar to those described elsewhere in SE England as colluvial 'hill-wash' (Bell, 1983; Bell & Boardman, 1992; Preece, 1992, 1998). Sediments found sealing the boat contexts (Keeley *et al.*, 2004) indicate possible deposition in water, perhaps as a consequence of overbank flooding, the incursion of brackish-water or estuarine conditions.

3. SEDIMENTARY SEQUENCES AT CRABBLE PAPER MILL

The site at Crabble (Fig. 2) has maximum dimensions of 160 m × 130 m. The elevation of the ground ranges from 30 m OD along the northeast side to 19 m OD adjacent to the river. Until recently, the site was occupied by a large, brick mill complex, where the buildings were largely confined to the lower, southern half of the site, adjacent to the river, leaving the remainder of the area essentially undisturbed.

Thick and extensive sequences of tufa and peat were first identified at the site during a survey carried out in 1990. This survey, which was designed to establish the main sedimentary sequences and to recover samples, involved a combination of boreholes and trenches (Bates & Barham, 1993a, b). More recently, samples

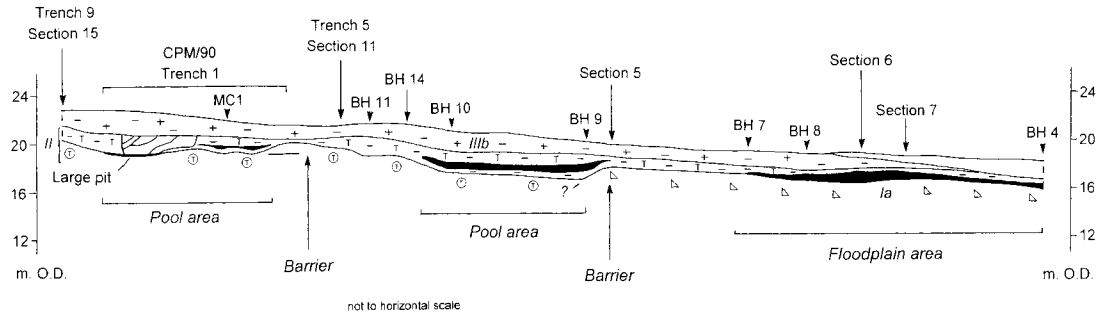

Fig. 4. NE–SW composite lithological transect through the Crabble site using borehole and trench excavation data. Note the intermittent distribution of peat in 'pool-like' features beneath the valley side. Key as for Figure 3.

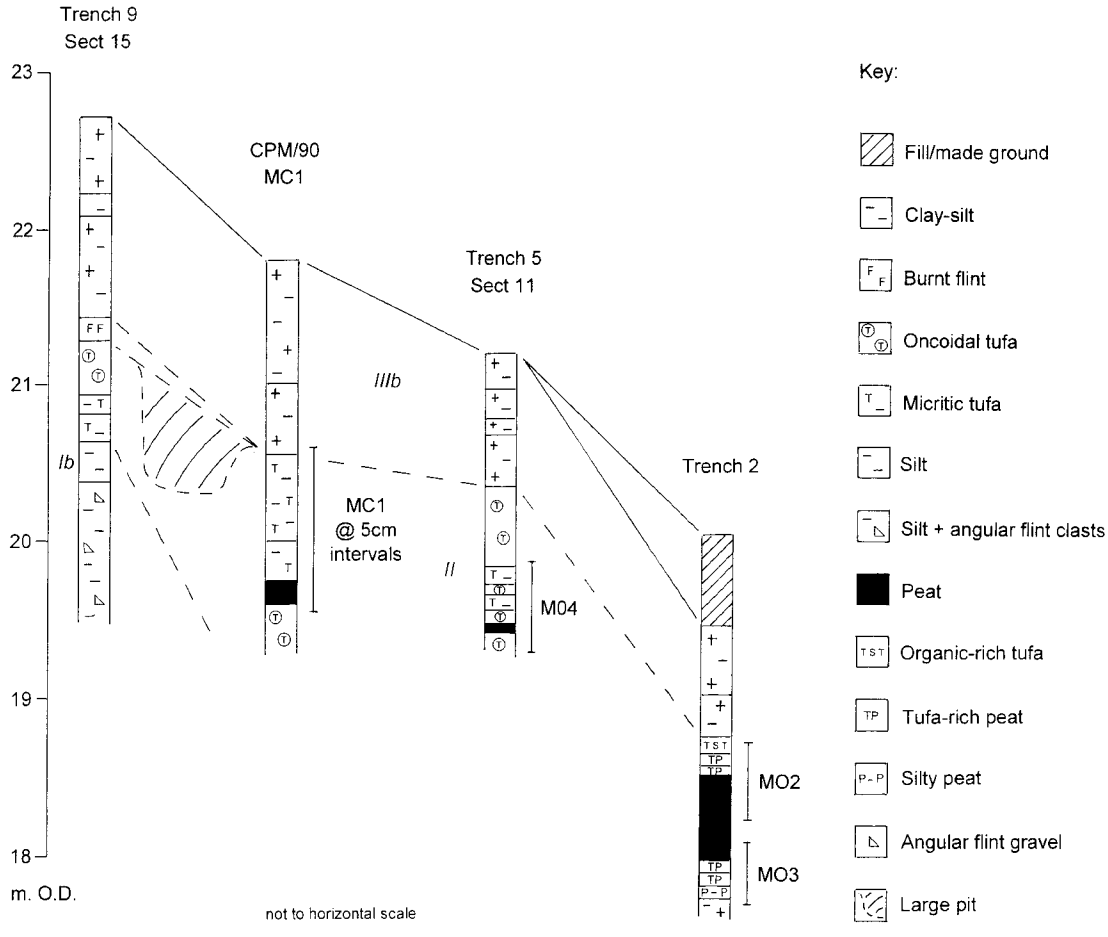

Fig. 5. Detailed lithologies from Trench 9, section 15; MC 1 from CPM/90 works; Trench 5, section 11; and Trench 2. Position of monoliths (M02/03) analysed for pollen content shown in Trench 2. Distribution of samples taken for mollusc analysis from MC 1, CPM/90 works and ostracods from Trench 5 also shown.

Table 3. Tufa oncoid characteristics from key sites compared to the Crabble data.

Site	Size (mm)	Situation
River Lathkill, Derbyshire	80 × 60 × 50	Main channel oncoids in full flow (>1 m s^{-})
River Bradford, Derbyshire	18 × 12 × 5	Sluggish flow in a straight section of a tributary to the Lathkill
Crabble Mill	40 × 35 × 30	

were taken from a series of trenches excavated as part of the Canterbury Archaeological Trust (CAT) investigations in advance of development of the site. The main trench and borehole locations are shown on Figure 2.

Six lithological units, which can be traced across the site, are representative of the regional sedimentary sequence described above:

Ia. Angular flint gravels (Fig. 4);
Ib. Fine-grained silt (brickearth) (Fig. 5);
IIb/c. Coarse oncoidal tufa gravels and cemented stromatolitic-like growths (Fig. 5);
IIa. Humified peats and peaty silts (with occasional thin beds of tufa) (Fig. 5);
IId. Fine calcareous muds and thin beds of small tufa oncoliths (Fig. 5);
IIIb. Decalcified clay-silts with common flint clasts (Fig. 5).

Angular flint gravels (Ia) were identified at the base of a number of boreholes and trenches at the site (Fig. 4, floodplain area). Typically, these consist of poorly-sorted clast-supported flint gravels with heavy red-brown staining. In places, a light brown clay-silt (Ib) was present (e.g. in Trench 9, Section 15; Fig. 5) at the base of the trench (Head Brickearth *sensu* Shephard-Thorn, 1988).

The overlying sequence of tufa and organic-dominated facies forms a set of three distinct groups of deposits (Fig. 5):

(1) Basal coarse tufa oncoidal gravel (IIb);
(2) Peats (IIa);
(3) Fine-grained calcareous muds (IId).

Basal coarse tufa oncoidal gravel (IIb). Very coarse tufa oncoliths, cemented together, exist in places, but elsewhere are found mixed with organic clays and silts. The largest oncoids are found typically towards the base of the unit (IIb). These deposits are best developed in the upslope direction, particularly within Trench CPM/90, Trench 1 (Fig. 4). The nuclei of some oncoids are gastropods and tufa intraclasts; there is little flint and other clastic material. The upper surface of these deposits undulates and appears to describe fluvial bar bedforms along the base of the valley. The oncoidal lower levels represent deposition in an active flow setting, but with much lower velocities than are needed to mobilize the underlying siliclastic clasts. A similar situation was documented in the Wye and Lathkill valleys in Derbyshire (Bakewell to Matlock), where thick siliclastic fluvial braidplain gravels directly underlie oncoid-rich beds (Pedley, 1993). The typical mix of oncoids and organic clay suggests that flow velocities fluctuated seasonally. The rarity of flint and other clastic material suggests that spate conditions were rare (not unusual in tufa streams containing oncoids).

The maximum diameter of the oncoids falls mid-range in comparison with active sites in Britain (Table 3). Thin-section examination shows that the principal constructor was the cyanobacterium *Phormidium* sp. This is one of the most common cyanobacteria in European tufas, especially oncoids (Pentecost, 2005). Concentric layering suggests that typical oncoids grew over seven seasons (a season might be a year, but not necessarily so). Each concentric layer consists of a dense basal (probably spring–early summer) layer and a late summer to winter thrombolitic layer. The high sphericity and concentric internal banding indicates that the oncoids were overturned frequently, probably by current action. Certainly, there was free flow at times within fluvial channels to produce such large, highly spherical oncoids. The absence of cylindrical oncoids is interesting and suggests little marginal semi-aquatic macrophytic vegetation (e.g. reeds or sedge). There is also only minimal evidence of tufa framestone development (if this was a typical paludal tufa deposit, fragments of phytoherm cushions should be present).

Peats (IIa). Some channelling into the top of the oncoid beds occurred before the accumulation of finer tufa silts and calcareous mud drapes (IId) and organics (IIa), which is a reflection of slower flow rates. The situation appears to reflect the development of paludal conditions with small standing water bodies in an organic-rich marsh setting. In such situations, tufa silts may be developed locally in floodplain areas and interfinger with peaty and sapropel-like deposits. Detrital peats (IIa) occur within the undulating channels cut into the underlying oncoidal gravels (Fig. 4) and a thin spread of peat can be traced downslope towards the modern river. These peats are often dense, compact and humified and have probably been subjected to drying and post-depositional compaction. Organic content of the peat varies (Fig. 6) and there appears to be an increase in minerogenic content in the middle and top, suggesting that episodes of inwash of inorganic material punctuated the accumulation of organic

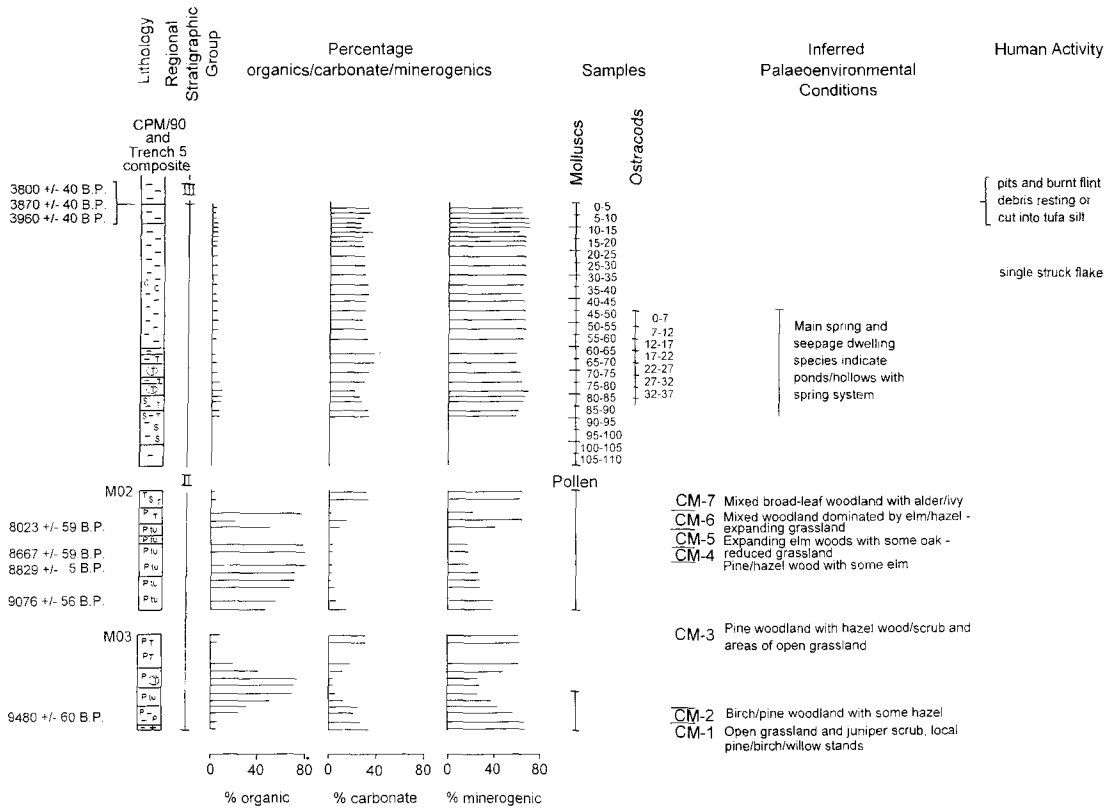

Fig. 6. Integrated composite stratigraphic sequence summarized from the site showing the relationship of samples and inferred palaeoenvironmental conditions and phases of human activity.

detritus. The upper surface of the peat is mottled with orange staining, possibly indicative of a weathering horizon forming after cessation of peat formation and prior to inundation by the overlying lime muds (IId).

Fine-grained calcareous muds (IId). The uppermost part of the sequence (IId; Fig. 6) is dominated by calcareous muds with occasional thin bands of small oncoids. Small oncoids are developed locally where sluggish channel flow occurs but generally are subordinate to silt and mud-grade tufa. This would suggest that resurgence flow rates have declined progressively through time. The upper levels of the sequence contain some reworked oncoids, as well as minerogenic sediments (clays and silts), charcoal and fragments of marine molluscs. This may be an indication of the onset of colluviation in the valley associated with human activity. Similar patterns were noted in the Derbyshire examples.

The entire site is sealed by a series of clay-silts rich in clastic flint (IIIb, Figs 4 and 5). These deposits consist of a number of discrete units that dip downslope parallel to the modern ground surface rather than the underlying sediments. The clay-silts thicken upslope and thin towards the river. Typically, the clastic material present consists of flint that exhibits an angular appearance. Flint-tempered pottery, struck flakes and flint tools were recovered.

The sequences, therefore, reflect the development of the valley floor from the Late-glacial period associated with the deposition of the basal siliciclastic braidplain gravels (Ia) into tufa-dominated early Holocene braided channel environments characterized by oncoidal tufa gravels (IIb). Abandonment of the channel network resulted in the accumulation of organic debris (IIa) in the channel beds, followed by the accumulation of calcareous muds (IId). All deposits were buried by the final depositional event, which produced the colluvial clay-silts (IIIb).

Nowhere at the site were all stratigraphic units observed in a single section and, consequently, a composite stratigraphic section is presented (Fig. 6). This illustrates the distribution of the key samples taken for palaeoenvironmental reconstruction (Sections 5–8), as well as the position of the samples taken for dating.

Table 4. Radiocarbon age estimates from the Crabble site and other relevant sequences in the Dour Valley.

Site code	Laboratory sample number	Material type	Sediment unit	$\delta^{13}C$ (‰)	Radiocarbon age (yr BP)	Calibrated age (95.4% probability)
MO2, 17–18 cm	Wk-14477	Peat	Peat	−27.8 ± 0.2	8023 ± 59	8657–9029 (1.000)
MO2, 25–26 cm	Wk-14478	Peat	Peat	−27.8 ± 0.2	8667 ± 59	9530–9792 (97.5)
MO2, 31–32 cm	Wk-14479	Peat	Peat	−27.6 ± 0.2	8829 ± 58	9686–10166 (1.000)
MO2, 47–48 cm	Wk-14480	Peat	Peat	−28.3 ± 0.2	9076 ± 56	10166–10404 (1.000)
MO3, 35–36 cm	Wk-14481	Peat	Peat	−28.2 ± 0.2	9480 ± 60	10572–10878 (74.3)
CPM/90, MC1, 95–100 cm	Wk-15413	Shell (*Arianta arbustorum*)	Lime mud	−10.1 ± 0.2	7198 ± 52	7935–8074 (81.7)
CPMD-55	Beta-181796	Charcoal	Apron dump		3870 ± 40	4223–4416 (88.9)
CPMD-101 (F. 102)	Beta-181797	Charcoal	Pit		3800 ± 40	4081–4299 (93.1)
CPMD-132 (F. 133)	Beta-181798	Charcoal	Pit		3960 ± 40	4290–4524 (1.000)
DSC-2, 7.09–7.11 m	OxA-4186	Peat	Peat/Tufa		4810 ± 95	5319–5725 (1.000)
TWS-5, 6.39–6.41 m	GU-5323	Wood (*Quercus* sp.)	Peat/Tufa		5120 ± 65	5710–5996 (99.2)
TWS-5, 6.72–6.74 m	OxA-4187	Peat	Peat/Tufa		4340 ± 85	4808–5093 (78.4)
TWS-5, 6.80–6.82 m	OxA-4188	Peat	Peat/Tufa		6315 ± 85	7146–7422 (84.9)
TWS-5, 6.90–6.92 m	OxA-4189	Peat	Peat/Tufa		8380 ± 110	9090–9542 (99.8)
Buckland Churchyard, BC-90/27b, 1.78–1.87 m	Beta-38216	Peat	Peat/Tufa		9240 ± 100	10229–10664 (1.000)

4. RADIOCARBON DATES

Five samples of peat, four from MO2 and one from MO3, were taken from the monoliths for AMS radiocarbon dating. These measured approximately 1 cm^3 and were hand-picked carefully to avoid tufa or other obvious carbonate material. The samples were oven dried and despatched to the Radiocarbon Laboratory at the University of Waikato, New Zealand. The radiocarbon ages (Table 4) were calibrated using INTCAL04 (Reimer *et al.*, 2004). A sample of shell from the land snail *Arianta arbustorum* was also submitted from the basal levels of the overlying fine-grained lime muds. Additional dates are available from areas with archaeological remains (Clark, 2004), as well as from other deposits in the Dour Valley (Fig. 3).

5. POLLEN

Pollen analysis was carried out on two monolith columns, MO2 and MO3, obtained from Trench 2 (Figs 4–6). MO2 occurred higher in the sequence and contained a thicker accumulation of organic material. Monoliths were sub-sampled in the laboratory at 2 cm intervals, initially using a sample size of *c.* 0.5 cm^2. These were prepared using standard techniques (Moore *et al.*, 1991), mounted in safranin-stained glycerine jelly and counted using a Leitz microscope at × 400 and × 630 magnification, with critical identifications under oil at × 1000. Pollen and spores were categorized on the basis of Bennett *et al.* (1994); nomenclature follows Stace (1997).

Pollen preservation varied considerably throughout, but initial analysis showed the pollen content of the deposits to be low. An alternative approach was therefore adopted in which the sub-sample size was doubled (*c.* 1 cm^2 sub-samples) and the material was microsieved (mesh size 10 μm) following deflocculation in KOH. Although this method had the effect of improving the concentration of pollen on the slides, the occurrence of grains was still relatively sparse and a sum of 300 land pollen was not always attained. In MO2, the pollen sum ranged from 112 to 322 total land pollen (TLP), the 300 TLP sum being achieved in 14 of the 23 levels. In MO3, the pollen sum varied from 116 to 340 TLP, with a count of 300 land pollen grains being achieved in half of the eight levels. The pollen diagrams (Figs 7 and 8) were produced using Tilia and Tilia*Graph (Grimm, 1991).

During pollen counting, a record was also kept of fragments of microscopic charcoal. None was found in the samples from MO3, but several levels in MO2 yielded charcoal, and these are expressed as percentages of total land pollen towards the right-hand side of the diagram (Fig. 8). Pollen assemblage zones and vegetation reconstructions are described in Table 5.

Although not dated directly, the earliest pollen record from the sequence (CM-1) is from the very early Holocene and records a phase of vegetational history pre-dating the establishment of *Betula* and *Pinus* woodland in this part of southeast England. Evidence from the nearby site of Holywell Coombe, Folkestone suggests that while *Betula* may have been present in this area during the cold phase of the Loch Lomond Stadial, *Pinus* was not, and that the latter appeared in the early Holocene between *c.*9800 ^{14}C yr BP and 9500 ^{14}C yr BP (*c.* 10 800 cal. yr BP and 10 500 cal. yr BP) where it expanded into a landscape of *Juniperus* scrub

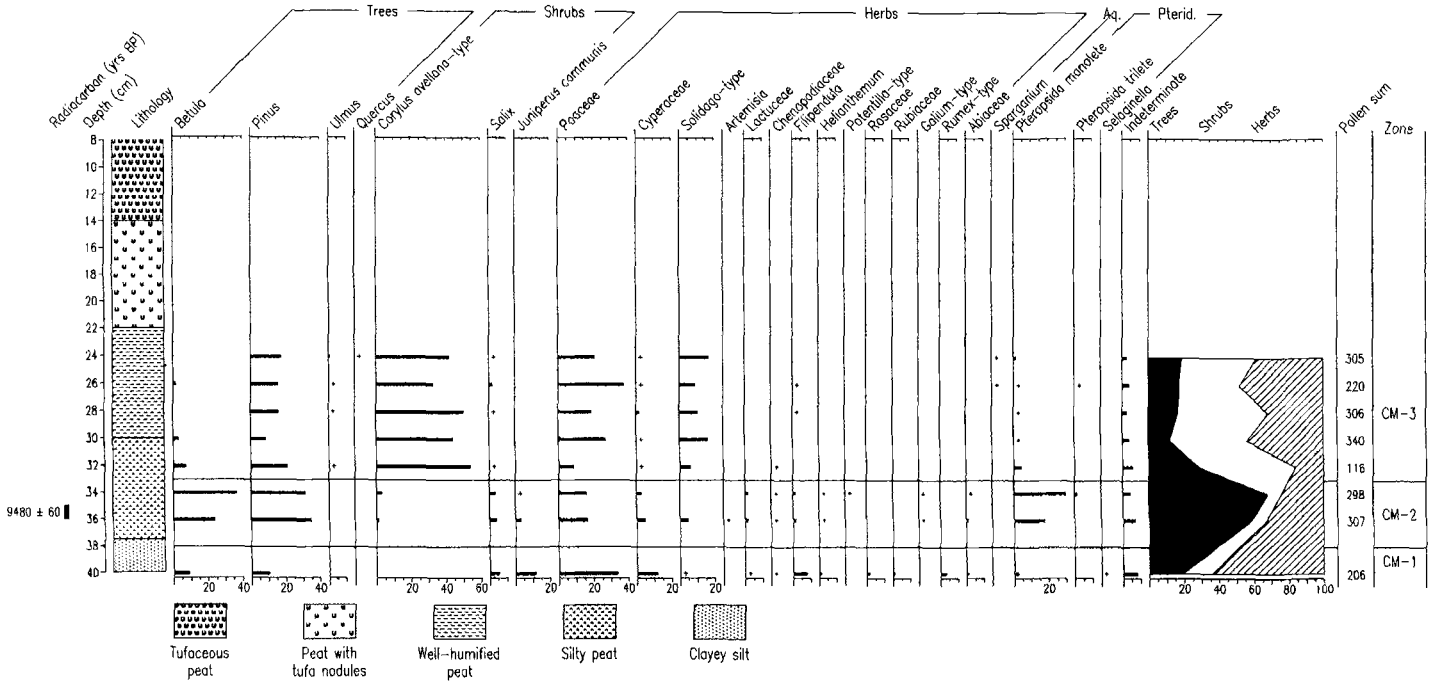

Fig. 7. Percentage pollen diagram from Trench 2, Monolith MO3.

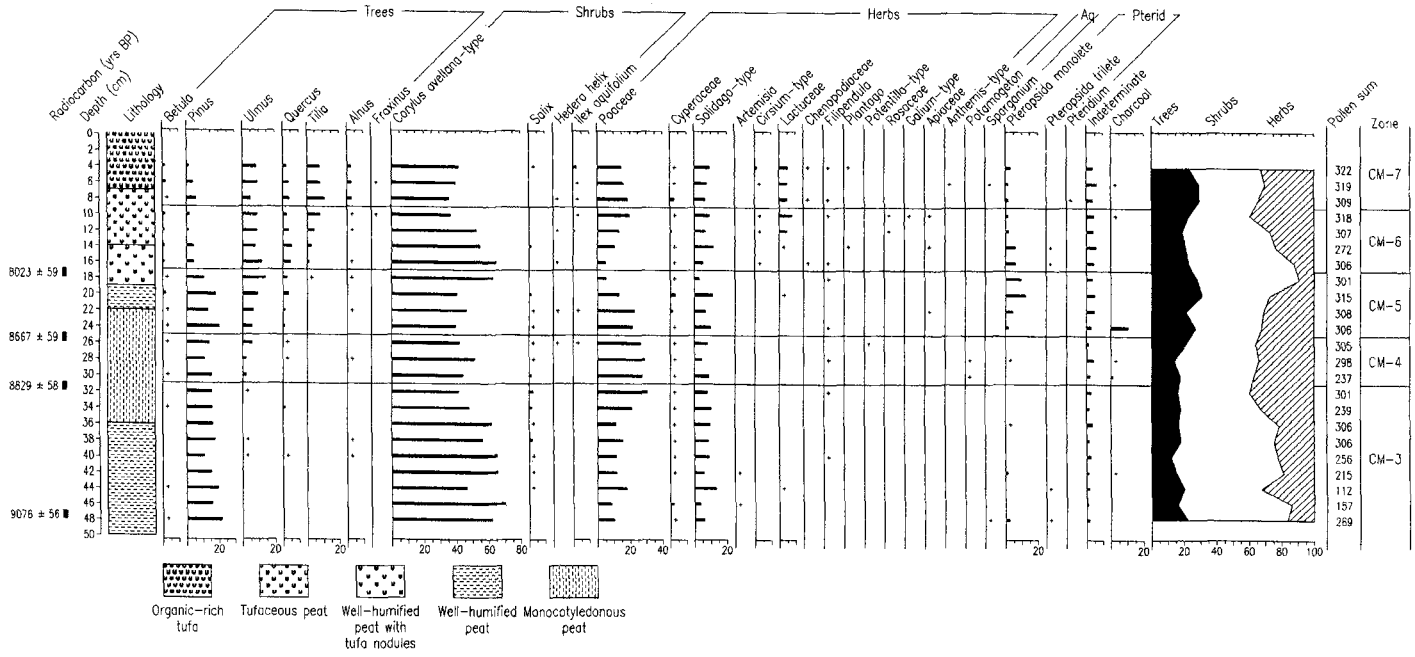

Fig. 8. Percentage pollen diagram from Trench 2, Monolith MO2.

Table 5. The Crabble Mill pollen assemblage zones and vegetation reconstructions.

Pollen assemblage zone (paz)	Monolith	Depth (cm)	Palynological characteristics and vegetational reconstruction
CM-7	MO2	0–9	High counts for *Corylus*; *Ulmus* and *Tilia* are strongly represented; *Quercus*, *Pinus* and *Ilex* are also recorded; the first continuous record for *Alnus*; relatively high counts for Poaceae. *Interpretation*: Mixed broad-leaved woodland, but with alder now a component, and an understorey of holly (*Ilex*). Areas of open woodland are indicated by the higher counts for grass pollen.
CM-6	MO2	9–17	The first continuous record for *Tilia*, initially high, but declining counts for *Corylus* and a strong representation of *Ulmus*. *Pinus* counts are significantly lower, while there is a steady increase in Poaceae. *Interpretation*: Mixed woodland, dominated by elm and hazel, in which lime is becoming an increasing component; oak is also well represented, but pine is now less abundant. The rise in the Poaceae curve reflects the gradual expansion of grassland.
CM-5	MO2	17–25	High counts for *Corylus* and *Pinus*, and the rising curve for *Ulmus* are the principal features of this paz. The first continuous record for *Quercus* but Poaceae declines. *Interpretation*: The expansion of elm woodland and the establishment of oak within a landscape of pinewoods and hazel wood/scrub. The progressive reduction in Poaceae suggests closing of the forest canopy.
CM-4	MO2	25–31	*Corylus*, *Pinus* and Poaceae predominate, but the principal palynological feature is the gradual increase in *Ulmus*. *Interpretation*: The arrival of elm in the area and its gradual expansion into a landscape of open pine and hazel wood/scrubland
CM-3	MO2/MO3	31–50 (MO2), 24–33 (MO3)	Very high counts for *Corylus* (in some levels in excess of 60% TLP); *Pinus* is also a major component of the pollen spectra, as are Poaceae and *Solidago*-type pollen. *Interpretation*: a landscape of pine woodland and hazel wood/scrub, with areas of grassland.
CM-2	MO3	33–*c.* 38	*Betula* and *Pinus* are the principal arboreal taxa; *Corylus* appears towards the top of the zone; *Salix* and *Juniperus* are present in both levels. Poaceae is also abundant and there are high counts for Pteropsida spores. *Interpretation*: Birch and pine woodland, with willow, juniper and areas of grassland into which hazel is beginning to expand. Local damp habitats may be indicated by the fern spores.
CM-1	MO3	38–41	Poaceae is the principal pollen taxon in this zone, although *Juniperus*, *Betula*, *Pinus*, *Salix* and Cyperaceae are all well represented. *Interpretation*: A largely open landscape of grassland and juniper scrub, with localized stands of pine, birch and willow.

and herbaceous plant communities (Bennett & Preece, 1998). A similar date for early Holocene *Pinus* expansion was obtained from the Pannel Bridge site in East Sussex (Waller, 1993). At Holywell Coombe, the later part of the *Juniperus* phase was dated to 9820 ± 90 ^{14}C yr BP. On this basis, an age of *c.* 11 200 cal. yr BP can be assigned to the lowermost pollen record in the MO3 profile at Crabble Mill.

The *Betula–Pinus* phase (CM-2) is dated to 9480 ± 60 ^{14}C yr BP (*c.* 10 700 cal. yr BP) at Crabble Mill. Bennett & Preece (1998) have suggested that at Holywell Coombe the woodland contained almost equal numbers of birch and pine, and the same seems to have been the case at Crabble Mill. As was also apparent at Holywell Coombe, the woodland cover was incomplete and areas of species-rich grassland existed in which a range of taxa (*Artemisia*, *Solidago*, Lactuceae, *Helianthemum*, *Potentilla*, *Galium*, Chenopodicaeae, Apiaceae) were to be found. Isolated stands of juniper scrub were still present. Damper habitats, possibly areas of fen on the valley floors, may be reflected in the presence of tall herbs, such as *Filipendula*, in the occurrence of *Salix*, and also in the abundance of Pteropsida (monolete) spores. High counts for the latter (Filicales) were recorded during the early Holocene *Betula–Pinus* phase at Holywell Coombe, and are also a feature of this vegetational episode at other sites in southeast England, including

Enfield Lock, Middlesex (Chambers *et al.*, 1996), Bramcote Grove, Bermondsey (Thomas & Rackham, 1996; Sidell *et al.*, 2002) and The Grove, Hertfordshire (Druce *et al.*, 2002), suggesting wetter substrates on the floors of many of the valleys at that time (Waller, 1993).

At Crabble Mill, *Corylus avellana* first appears during the birch–pine phase, but expands dramatically sometime between 9480 ± 60 ^{14}C yr BP (*c.* 10 800 cal. yr BP) and 9076 ± 56 ^{14}C yr BP (*c.* 10 300 cal. yr BP), a timing that is in good agreement with dating evidence for the abrupt rise in the *Corylus* pollen curve at Pannel Bridge and Holywell Coombe, and also with the results of isopollen mapping (Birks, 1989). It has been suggested that the rapid expansion of *Corylus* during the early Holocene was in response to a unique set of climatic conditions (greater continentality, enhanced seasonality), which enabled hazel to compete more successfully against birch and pine (Huntley, 1993; Tallantire, 2002). The abrupt decline in Pteropsida, which accompanies the increase in *Corylus* pollen in the Crabble Mill sequence, a coincidence also found in other pollen records from southeast England (Chambers *et al.*, 1996; Druce *et al.*, 2002), may reflect a reduction in shading or a contraction in areas of valley-bottom fen. If the latter, it provides further evidence of a trend towards drier conditions. Although generally considered a shrub, it seems that *Corylus* behaved more as a canopy tree during the Holocene (Chambers *et al.*, 1996) and may initially have outcompeted other trees by casting heavier shade and producing a layer of humus from leaf fall. Such a process would be detrimental to pine seedlings, in particular, which may explain why in many areas *Pinus* declined once *Corylus* became established (Tallantire, 2002). At Crabble Mill, however, although *Pinus* values are significantly reduced in paz CM-3 by comparison with the previous biozone, *Pinus* continues to be represented strongly (values of 10–25% TLP) throughout the phase of *Corylus* dominance, as also is Poaceae. High values for both *Pinus* and *Corylus* have been recorded at Staines, Surrey (Keith-Lucas, 2000), while at the East Sussex site of Pannel Bridge, although *Pinus* declines following the expansion of hazel, it remains a major component of the pollen spectra (Waller, 1993). The evidence therefore suggests that in the downland areas of the southeast, while *Corylus* was widespread at this time, *Pinus* maintained its presence in the early Holocene woodlands, possibly on the fringes of areas of open grassland.

The arrival and establishment of broad-leaved woodland in the vicinity of Crabble Mill begins with the appearance of *Ulmus* at around 8800 ^{14}C yr BP (9900 cal. yr BP), followed by *Quercus* at *c.* 8600 ^{14}C yr BP (9600 cal. yr BP) and *Tilia* at *c.* 8000 ^{14}C yr BP (8800 cal. yr BP) – dates consistent with evidence from other southeast England sites (Birks, 1989). It is possible that these vegetational developments reflect a further shift in climatic parameters, perhaps with milder winters, warmer summers, less pronounced seasonal temperature ranges and, above all, a reduction in summer moisture deficit, all of which had previously given *Corylus avallana* a competitive advantage over the broad-leaved trees (Huntley, 1993). Certainly, a trend towards damper substrates may be reflected in the renewed occurrence of Pteropsida spores in CM-5 and CM-6. The evidence from Crabble Mill suggests that, once established, *Ulmus* expanded to become, along with *Corylus*, the dominant component in the woodland, with *Quercus* playing a secondary role. This contrasts with the Pannel Bridge record in East Sussex, where *Quercus* predominates over *Ulmus* (Waller, 1993) and also with sites further north, such as Bramcote Green and The Grove (Thomas & Rackham, 1996; Druce *et al.*, 2002). *Pinus* survived at Crabble Mill during the initial *Ulmus* and *Quercus* expansions (CM-4 and CM-5), but then declined markedly (later CM-5/CM-6). The complementary reduction in Poaceae indicates an almost complete closing of the woodland canopy and the inevitable demise of the less competitive pine. The rise in values for *Tilia* pollen in CM-6 is accompanied by a slight reduction in *Ulmus* frequencies, confirming the view that by 7500 ^{14}C yr BP (*c.* 8300 cal. yr BP) *Tilia* had become a major woodland component throughout southeast England (Birks, 1989; Waller, 1993) and continued to be so for a further 2000 years (Waller & Hamilton, 2000).

One feature of this part of the pollen record is the occurrence of charcoal. No charcoal was found in MO3, but isolated fragments were found throughout the MO2 monolith, with one marked 'spike' in charcoal at the 24 cm level (paz CM-5). This dates to around 8600 ^{14}C yr BP (*c.* 9600 cal. yr BP), after the establishment of *Ulmus* but around the time of the first consistent record for *Quercus*. Relatively high concentrations of charcoal were found in a number of early Holocene profiles in southeast England during the early Holocene (Lewis *et al.*, 1992; Chambers *et al.*, 1996; Druce *et al.*, 2002). Whether fires were induced by human activity is uncertain, as the regional *Pinus–Corylus* woodland would have been highly combustible and natural fires from lightning strikes would almost certainly have been common. Certainly, in the Crabble Mill sequence, there is no marked ecological effect of burning in the pollen record during paz CM-5, although there is a slight inflection in the *Pinus* curve. To relate the occurrence of this charcoal peak to Mesolithic activity is therefore somewhat speculative.

The final Holocene vegetational development recorded in the Crabble Mill sequence is the expansion of *Alnus* (CM-7). Although the spread of *Alnus* in many areas of the British Isles has often been regarded as climatically driven, it is now apparent that factors other than climate would have contributed to its expansion (Chambers & Elliott, 1989; Bennett & Birks, 1990; Tallantire, 1992). These include local conditions, such as light availability and intensity within the woodland, aspect, the nature of the substrate and local hydrological variations. Human activity in the form of

early woodland clearance may also have played a part (Lowe *et al.*, 1998). Hence, despite the fact that mid-Holocene pollen records are all characterized by a marked expansion in *Alnus*, usually after *c.* 8800 cal. yr BP, there is considerable regional variation in the timing of the event. At Holywell Coombe, for example, alder appeared in abundance after *c.* 8300 cal. yr BP, while at Brede Bridge in the High Weald the alder rise has a calibrated age range of 7180–6445 yr BP (Waller, 1994). At nearby Pannel Bridge, an abrupt increase in *Alnus* is dated to 7942–7616 cal. yr BP (Waller, 1993), although at that site there is evidence (in the form of both pollen and plant macrofossils) for an *Alnus* presence back to before 10 000 cal. yr BP, one of the earliest records for this taxon in the British Isles. In this context, it is interesting to note that isolated counts for *Alnus* occur throughout the MO2 monolith from Crabble Mill, the earliest find for alder pollen dating (by interpolation) to around 9900 cal. yr BP. A record of an early local presence for *Alnus* may therefore be preserved in this site also.

6. MOLLUSCA

Thirteen samples from MC1, Trench 1 (CPM/90) were analysed for Mollusca. All samples derive from the calcareous muds (IId) that stratigraphically overlie the peats (IIa) sampled for pollen (Fig. 6). The samples were dried in an oven and 3 kg of sediment was wet sieved using a 0.5 mm mesh. Minimum totals were calculated for each species present by counting each gastropod apex or bivalve hinge. Occasionally non-apical fragments were also counted when these represented taxa not otherwise encountered. The results are presented in Table 6 and plotted graphically in Figure 9. Taxonomic nomenclature follows Kerney (1999).

Aquatic molluscan record

Thirteen aquatic species were recovered. The most dramatic changes are seen in the aquatic assemblages from the lower part of the sequence. Between 90 cm and 105 cm, the aquatic community is dominated by *Pisidium personatum*, *Lymnaea peregra* and *L. truncatula.* Such species are typical of small, shallow bodies of water, often little more than damp ground. The water body, although shallow, does appear to have been relatively permanent, as suggested by the occurrence of *Valvata cristata* and *Acroloxus lacustris* (lake limpet). At 90 cm abrupt changes are seen in the aquatic species. *Valvata cristata* increases sharply to represent over 45%, *Pisidium personatum* gives way to *P. nitidum* (and *P. milium*) and *Ancylus fluviatilis* (river limpet) appears. These changes suggest an increase in water flow to the sort of conditions found in many springs. This episode of more energetic flow appears to have been rather short-lived because, above 80 cm, several of these faunal trends are reversed. For example, *P. nitidum* declines and is replaced by *P. personatum* and the frequency of *A. fluviatilis* also falls. Conversely, there are sharp increases in the frequency of *L. truncatula* and *Aplexa hypnorum* appears for the first time. These faunal changes suggest that the water flow slackened considerably, turning the water body into a stagnant swamp. Indeed, there are corresponding increases in hygrophilous taxa (Succineidae, *Zonitoides nitidus*, *Carychium minimum*) typical of marsh. Two other marsh species, *Vertigo antivertigo* and *V. moulinsiana,* also occur in low numbers. The latter is known from many other British Holocene tufa deposits, including some from Kent (Kerney *et al.*, 1980; Preece, 1998). However, it is now rare in south-east England (Kerney, 1999) and is classed as Category 3 (Rare) in the *British Red Data Book* (Bratton, 1991), although it still survives at a few sites in Kent (Killeen, 2002).

Further changes in the aquatic assemblages are apparent in the upper levels, where *Valvata piscinalis* occurs above 50 cm. The occurrence of this species coincides with levels containing fragments of *Mytilus* (mussel) shell, indicating a possible association with human activity.

Terrestrial molluscan record

The terrestrial molluscan fauna consists of 42 taxa (plus the subterranean *Cecilioides acicula,* which is intrusive and is not part of the fossil assemblage) and exhibits a less dynamic picture, although changes are apparent nevertheless. The assemblages from the lower part of the sequence are dominated by *Carychium tridentatum* and a range of other shade-demanding taxa. *Vallonia costata*, tolerant of moderate shading, is also common, reaching frequencies of 10%. *Discus rotundatus*, *Acicula fusca* and *Oxychilus cellarius* occur throughout but are particularly common in the lower levels. *Pomatias elegans*, a strong calciphile that often burrows into loose friable soil in woodland margins, was also frequent in the lower levels. *Spermodea lamellata* and *Leiostyla anglica*, two species now rare in southeast England (Kerney, 1999) are represented as single shells in a few samples. A damp shaded environment is indicated, but not closed forest.

The occurrence of *Acicula fusca* and *Oxychilus cellarius*, together with *S. lamellata* and *L. anglica*, indicates that these assemblages belong to zone d of the regional molluscan zonation scheme (Kerney *et al.*, 1980; Preece, 1998), an assumption confirmed by the date of 7198 ± 52 ^{14}C yr BP from a depth of 95–100 cm. At Holywell Coombe (near Folkestone) the type locality of this zonation scheme, the base of zone d was dated to 7650 ± 80 ^{14}C yr BP (Preece, 1998). Its upper boundary is strongly diachronous, since it is determined by the onset of forest clearance, causing a replacement of woodland elements by those of open country.

One peculiar feature of the molluscan assemblages from Crabble Mill was the unusually high incidence of

Table 6. Molluscan analyses from CPM/90, MC1. Totals of bivalves refer to single valves.

Depth (cm)	100–105	95–100	90–95	85–90	80–85	75–80	70–75	65–70	55–60	45–50	35–40	25–30	15–20
Aquatic taxa													
Valvata cristata Müller	—	4	16	142	106	21	89	7	5	10	9	—	1
Valvata piscinalis (Müller)	—	—	—	—	—	—	—	—	—	11	11	3	1
Aplexa hypnorum (L.)	—	—	—	—	—	28	18	1	—	—	—	—	—
Physa fontinalis (L.)	—	—	—	—	3	2	1	—	—	—	—	—	—
Lymnaea truncatula (Müller)	—	16	18	33	27	308	242	33	4	5	1	—	—
Lymnaea peregra (Müller)	13	22	16	42	28	125	135	12	4	10	12	6	9
Ancylus fluviatilis Müller	—	—	—	14	9	4	1	—	—	—	—	—	1
Acroloxus lacustris (L.)	—	3	—	—	—	—	—	—	—	—	—	—	—
Sphaerium sp.	—	—	—	—	—	—	—	—	—	—	—	?1	?1
Pisidium casertanum (Poli)	—	2	2	—	—	—	—	—	—	—	—	—	—
Pisidium personatum Malm	20	94	108	—	2	59	59	7	1	—	—	—	—
Pisidium milium Held	—	—	5	2	9	3	—	?1	—	—	—	—	—
Pisidium nitidum Jenyns	—	—	1	86	109	7	—	2	—	4	—	—	1
Terrestrial taxa													
Pomatias elegans (Müller), shells	2	7	47	9	1	1	1	1	1	1	1	1	2
Pomatias elegans (Müller), opercula	1	3	19	1	1	1	—	—	—	1	1	—	—
Acicula fusca (Montagu)	9	37	276	19	17	189	14	25	3	4	1	1	2
Carychium minimum Müller	—	6	4	3	36	96	63	9	—	3	—	—	—
Carychium tridentatum (Risso)	19	108	568	34	121	189	37	25	3	4	1	1	2
Succinea oblonga Draparnaud	—	—	—	—	?1	—	—	—	—	—	—	—	—
Succinea/Oxyloma	15	24	27	27	28	41	55	16	14	33	36	18	25
Cochlicopa lubrica (Müller)	7	31	139	2	46	54	35	5	24	14	14	3	10
Columella edentula (Draparnaud)	2	7	40	5	5	8	5	2	?1	—	—	—	—
Vertigo pusilla Müller	1	8	30	3	2	2	3	2	1	1	—	—	3
Vertigo antivertigo (Draparnaud)	—	5	2	1	1	1	1	2	—	—	—	—	—
Vertigo substriata (Jeffreys)	1	7	7	1	5	13	2	7	—	—	—	—	—
Vertigo moulinsiana (Dupuy)	2	1	?3	—	—	2	2	1	—	—	—	—	—
Vertigo spp.	—	—	2	4	4	7	3	3	2	2	1	—	1
Pupilla muscroum (L.)	—	—	—	—	—	—	—	—	2	2	1	—	4
Leiostyla anglica (Wood)	—	—	1	—	—	—	—	—	—	—	—	—	—
Lauria cylindracea (da Costa)	2	10	16	1	—	6	1	—	—	—	—	—	—

Table 6. *Continued.*

Depth (cm)	100–105	95–100	90–95	85–90	80–85	75–80	70–75	65–70	55–60	45–50	35–40	25–30	15–20
Vallonia costata (Müller)	19	69	441	12	150	24	12	1	3	5	4	3	8
Vallonia excentrica Sterki	—	—	—	—	—	—	1	—	—	1	—	1	2
Vallonia pulchellalexcentrica	—	—	—	—	—	—	—	—	—	10	—	6	17
Acanthinula aculeata (Müller)	6	8	68	5	6	4	3	1	2	2	1	—	—
Spermodea lamellata (Jeffreys)	—	1	1		—	—	1	—	—	—	—	1	—
Ena obscura (Müller)	—	1	8	1	—	—	1	—	—	—	—	—	—
Punctum pygmaeum (Draparnaud)	3	8	42	6	6	14	8	5	—	5	2	—	1
Discus rotundatus (Müller)	9	34	193	15	111	90	188	53	39	51	33	16	17
Vitrina pellucida (Müller)	1	9	44	2	1	2	—	—	—	1	1	—	2
Vitrea crystallina (Müller)	6	14	105	3	9	22	22	4	2	6	2	2	4
Vitrea contracta (Westerlund)	—	10	24	—	31	—	4	—	—	—	—	—	—
Nesovitrea hammonis (Ström)	—	—	2	—	4	2	—	1	—	1	1	—	3
Aegopinella pura (Alder)	10	45	183	14	62	36	13	9	9	4	2	5	2
Aegopinella nitidula (Draparnaud)	20	29	168	28	38	38	39	50	37	37	29	25	32
Oxychilus spp.	8	38	96	7	31	10	60	15	3	7	2	2	5
Zonitoides nitidus (Müller)	—	5	12	12	6	18	27	2	—	—	—	—	—
Deroceras/Limax	17	30	70	28	46	65	50	47	51	66	63	47	32
Milax sp.	4	5	14	3	9	8	10	13	16	9	12	21	3
Euconulus fulvus agg.	1	2	7	3	14	11	5	2	—	—	—	—	—
Cecilioides acicula (Müller)	8	1	—	3	1	1	1	1	3	15	3	18	37
Cochlodina laminata (Montagu)	—	—	5	—	—	—	1	—	?1	—	—	1	—
Clausilia bidentata (Ström)	3	19	47	5	10	14	12	8	13	6	4	4	2
Balea sp.	—	1	4	2	1	2	—	1	—	—	—	—	—
Monacha sp.	—	—	—	—	—	—	—	—	—	—	—	—	?2
Trichia striolata (C. Pfeiffer)	—	3	13	1	—	—	1	—	—	—	—	—	—
Trichia hispida (L.)	3	35	156	11	11	25	34	4	11	17	17	17	18
Arianta arbustorum (L.)	—	+	+	+	+	+	+	+	+	+	+	+	+
Helicigona lapicida (L.)	—	1	1	1	1	1	1	2	1	1	1	1	2
Cepaea/Arianta	3	15	46	15	15	14	24	10	10	10	12	5	9
Cepaea spp.	—	+	+	+	+	+	+	+	+	+	+	+	+
Marine molluscs													
Mytilis edulis (L.)	—	—	—	—	—	—	—	—	—	+	+	+	+

Totals of bivalves refer to single valves;.+, single shell only.

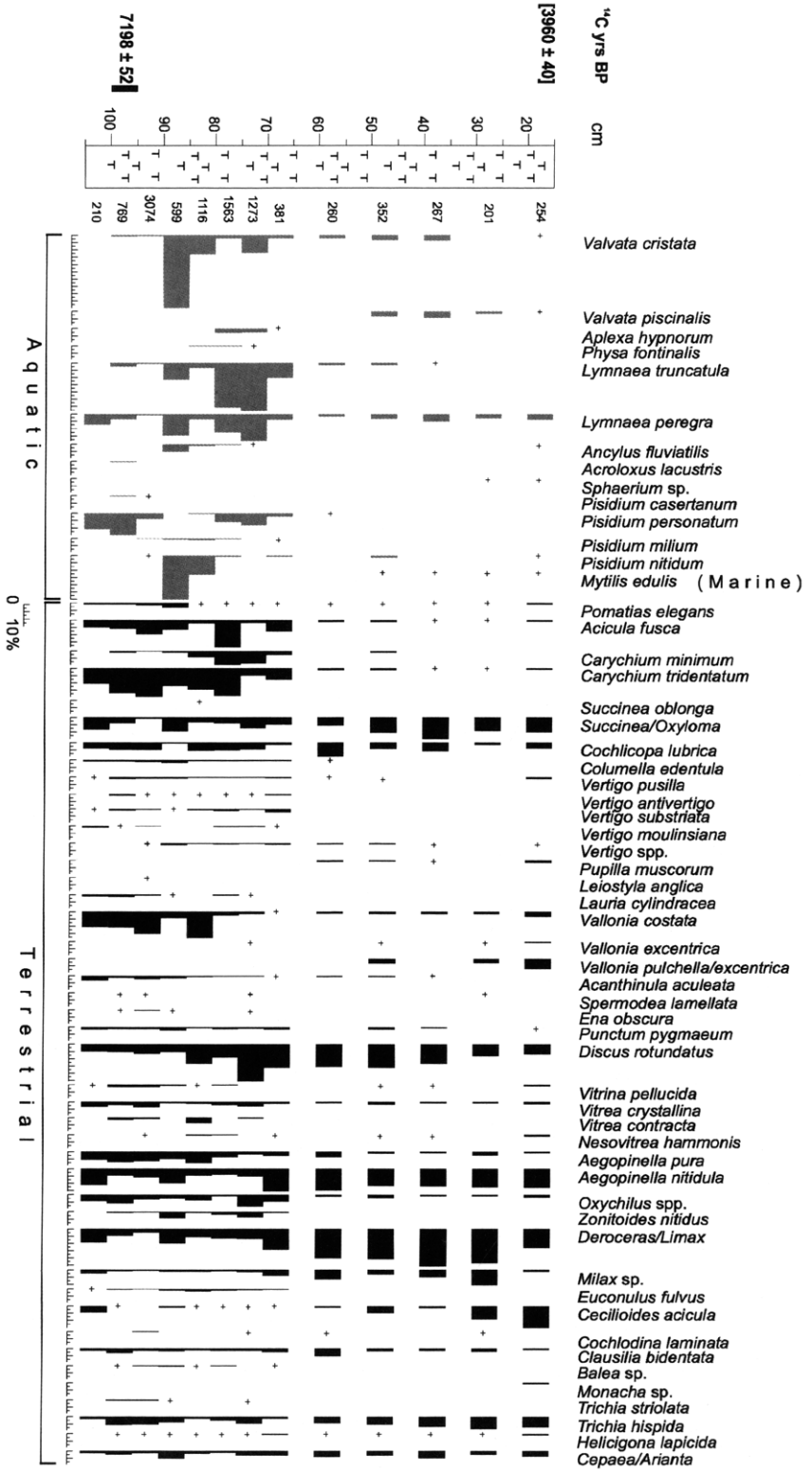

Fig. 9. Molluscan diagram from CPM/90, MC1 data.+single shell only.

Table 7. Ostracod data from Trench 5.

	0–7 cm	7–12 cm	12–17 cm	17–22 cm	22–27 cm	27–32 cm	32–37 cm	37–42 cm	42–47 cm	47–52 cm	52–57 cm	57–62 cm	62–67 cm
Potamocypris zschokkei (Kaufmann)	x	xx	xx	xx	x		x			o	xx	x	x
Ilyocypris bradyi Sars	x	x	x	o								o	
Cryptocandona vavrai Kaufmann	x(j)		x(j)	x(j)	x	x	x(j)	x(j)			x		
Ilyocypris inermis Kaufmann	o	x	x			x							
Pseudocandona marchica (Hartwig)		x(j)	x	x(j)		x	x			x		x(j)	
Candona candida (O.F. Muller)		x(j)					x	x					
Eucypris pigra (Fischer)			x				o						
Nannocandona faba Ekman						o				o			
Cyclocypris sp.												o	

o, one specimen; x, present (several specimens); x(j), present (juveniles only); xx, common.

reversed coiling. Reverse coiling occurs rarely in molluscs as the result of mutation but it may persist in some populations for many years (Preece & White, 2008). The populations of *Cepaea nemoralis* from Bundoran, Donegal, Ireland, which contain a relatively high proportion of specimens where the direction of coiling is left-handed (sinistral), is a well-known example (Taylor, 1914, p. 322). At Crabble Mill, reverse coiling was found in four specimens belonging to two different species. Two sinistral shells of *Acicula fusca* were recovered from 90–95 cm and a further specimen occurred at 65–70 cm, suggesting that the mutation had become stabilized in the population. Interestingly, a sinistral shell of this species was also recovered from a Holocene tufa at Holywell Coombe, Folkestone (Preece, 1998). Other records of sinistrality in this species have been reported from Holocene tufas in Lincolnshire (Kennard & Musham, 1937) and from Graffy, Co Mayo, where two reversed-coiled specimens were found recently (Preece & White, 2008). The relatively high incidence of sinistrality in this prosobranch suggests that either it may be more susceptible to such mutation or its effects are relatively less harmful. Reversed coiling in most European pulmonates is exceptionally rare, but a sinistral shell of *Discus rotundatus* was also recovered at Crabble Mill from 70–75 cm. It is noteworthy that all the sinistral shells from Crabble Mill were juvenile, suggesting that they may have died before reaching maturity.

7. OSTRACODA

Thirty-seven samples were investigated from Unit IId (fine silts and tufa), which overlies the peats. Each sample was weighed and placed in a ceramic bowl for oven drying. Boiling water was poured on the sample subsequently, with a little sodium carbonate added to help remove the clay fraction. The mixture was left to soak overnight prior to washing through a 75 μm sieve with hot water. The residue was decanted back into the bowl for drying back in the oven. When dry, the sample was stored in a labelled plastic bag prior to picking using a binocular microscope. Ostracods were picked out with a fine camel-haired brush from a tray and placed into 3 × 1 inch faunal slides.

Surprisingly, despite the obviously calcareous nature of the sediments, a number of samples proved barren even though there was relatively good preservation of the molluscs. Elsewhere other samples contained ostracods that fell apart when attempting to remove them from the sediment for identification. Fortunately, better preserved samples were present in Trench 5 (Fig. 6) and from the tufa overlying brickearth in Trench 9.

Nine species of freshwater ostracods occurred in Trench 5 (Table 7). Their ecological preferences are described in Table 8. All the main spring- and seepage-dwelling species are present, with the swamp species being less well represented. Similar associations were reported recently from The Grove, near Watford (Whittaker, 2002), although at Crabble the faunas are neither as diverse nor abundant. Consequently, it would seem that the Crabble tufa springs were probably far less well developed and extensive than those at The Grove. Additionally because of the presence of *Pseudocandona marchica*, which often lives in meadow and woodland pools associated with leaf litter, there is some suggestion that the location was surrounded by woodland.

Some ostracods were also obtained from the residues picked for molluscan remains (CPM/90, MC1, 90/95 cm, 95/100 cm and 100/105 cm). These were passed through a 500 μm sieve, through which all but the largest ostracod species would have passed. Nevertheless, they produced very large faunas, composed almost entirely of *Psychrodromus olivaceus* (Brady & Norman) and, especially in samples 90–95 cm and 95–100 cm, they can be counted in hundreds. This species is exclusively a spring-dwelling ostracod, particularly of tufa springs. Griffiths (1995) provided a list of localities in the UK in which it occurs, including other Holocene Kent sites at Holywell Coombe

Table 8. Ostracod species present and their ecological requirements (mostly after Meisch, 2000).

Species	Ecological requirements
Candona candida	Slow-flowing water with a muddy substrate, particularly in ponds, ditches and springs
Pseudocandona marchica	Swarms in meadow and woodland pools and shallow pond margins, often with plant growth and leaf-litter. Also common in all types of lime-rich deposits
Cryptocandona vavrai	Occurs in cold springs and seepages and shallow water bodies associated with springs. Also swampy or mossy pools or floating fen (associated with springs) and can tolerate very acidic conditions. Can burrow in a wide range of substrates
Potamocypris zschokkei	Cannot swim. Lives in spring-fed pools, or streamlets (with a layer of fine mud) flowing from seepages/springs
Eucypris pigra	Cannot swim. Lives in permanent springs and seepages where it crawls or burrows on soft loamy substrates; particularly associated with tufa-depositing springs
Nannocandona faba	Lives in swamps and peat bogs where it has a semi-terrestrial habitat
Ilyocypris inermis	The swimming bristles on the antennae are rudimentary and therefore it is a very poor swimmer. Nevertheless, it is a spring-dweller where it crawls in the bottom mud
Ilyocypris bradyi	Cannot swim in flowing water and lives on muddy substrates in springs or (cooler) water flowing from springs

Mostly after Meisch (2000).

(Robinson, 1998) and Wateringbury (Robinson in Kerney *et al.*, 1980). Curiously, this species was not found in any of the other samples examined at Crabble Mill.

8. VERTEBRATES

Small vertebrates were picked from the same samples as those analysed for Mollusca (Fig. 6; Table 9). Despite excellent preservation of the bones, the samples yielded only a limited vertebrate fauna and most taxa were recorded as only one or two specimens. In view of the small size of the sample, it is not possible to provide a detailed reconstruction of changes in the immediate environment on the basis of this evidence alone.

As Table 9 shows, the small vertebrate assemblage consists of both aquatic and terrestrial species, the former including small fishes, such as three-spined stickleback, consistent with deposition in or near a shallow-water body. Water shrew (*Neomys fodiens*) lives mainly by clear, unpolluted streams and ponds wherever there is cover, but it is also found occasionally at considerable distance from water, often in woodland. The slow-worm (*Anguis fragilis*) is also associated with rather moist habitats with extensive ground cover.

The most interesting small mammal is hazel dormouse (*Muscardinus avallanarius*) represented by two molars from 85–95 cm. This is a rather rare species virtually unknown from British Holocene deposits. Previously the earliest secure Holocene record from Britain is from The Undercliff near Ventnor on the Isle of Wight, with an associated radiocarbon date of 4480 ± 100 ^{14}C yr BP (Preece, 1986). Younger Holocene records, most of which are from poorly dated contexts, are known from only eleven other sites, where they are represented by a very small number of teeth (O'Connor, 1986; Yalden, 1992, 1999). The hazel dormouse is an elusive nocturnal rodent with a specialized ecology. It is associated strongly with well-established, species-rich deciduous woodland (particularly hazel woodland) with a dense mixture of undergrowth (e.g. honeysuckle and bramble) and trees. Woodland margins and glades are probably its favourite habitat (Bright & Morris, 1996; Bright *et al.*, 1996), and a supply of flowers, nuts and fruits through the summer are critical to its survival. Today the range of hazel dormouse is contracting southwards and, even in regions where it is more common, such as southeastern England, its distribution tends to be patchy and sporadic. This range contraction may be a culmination of a longer-term decline caused by woodland destruction that began with Neolithic agricultural clearance and changes in woodland management.

The other elements of the small mammal fauna are not particularly diagnostic of any particular environment, though they mostly have a preference for dense vegetation. Wood mouse (*Apodemus* cf. *sylvaticus*) is relatively common. This species, together with the bank vole (*Clethrionomys glareolus*), inhabits well-vegetated habitats, usually scrub, hedgerows or woodland with ample ground-level cover and could reflect the presence of such habitats. Common shrew (*Sorex araneus*) is found in almost every habitat, provided some cover is present. It is most abundant in bushy scrub, hedgerows and rough grassland, which are also favoured by grassland voles (*Microtus* sp.).

9. HUMAN ACTIVITY

The oldest artefacts recovered from the site include two prehistoric struck flints (an undiagnostic hard hammer flake and a struck fragment) contained within the upper brickearth (unit Ib), where it was sealed below the tufa in Trench 9. Additionally, a single large,

Table 9. Small vertebrate remains from Crabble CPM/90, MC1.

Depth (cm)	15–20	30–35	35–40	40–45	45–50	55–60	65–70	70–75	75–80	80–85	85–90	90–95	95–100	100–105
Fish														
Gasterosteus aculeatus, three-spined stickleback					2									
Indeterminate fish	3						5					1	1	
Reptiles														
Anguis fragilis, slow-worm[a]	1											8	3	1
Mammals														
Sorex araneus, common shrew			1											
Neomys fodiens, water shrew									1	2				
Clethrionomys glareolus, bank vole						1		1						
Microtus sp., vole									1					
Apodemus cf. *sylvaticus*, wood mouse[b]	2	1	1	1									1	1
Muscardinus avellanarius, hazel dormouse											2			
Indeterminate vole	1			1										
Indeterminate small mammal	2		2						1			4	3	5

[a] *Anguis fragilis* identified on the basis of osteoderms. These highly distinctive rectangular ossified 'plates' underlie the scales and provide a form of body armour (Holman, 1998).
[b] Measurements of the *Apodemus* molars from Crabble Mill fall within the size range of wood mouse (*A. sylvaticus*). The presence of the larger yellow-necked mouse (*A. flavicollis*) cannot be discounted, as molar teeth of the two species are morphologically similar and there is some overlap in dental dimensions.

freshly struck (but undiagnostic) flake was recovered from CPM/90, Trench 1 from within the calcareous mud deposits. The deposits producing these flints also contained occasional flecks of charcoal, all of which implies at least casual occupation in the area, prior to the late Neolithic–early Bronze Age.

The majority of the archaeological remains recovered during the recent site investigations (Parfitt, 2006) were located at the eastern corner of the site (Fig. 2, Trenches 7–10), occupying the sloping spur of brickearth, overlooking the river at an elevation of between 23.50 m OD and 21.50 m OD. These remains appear to relate to a larger site that extended beyond the limits of the investigated area. The excavated features consist of seven fairly shallow, circular pits that were cut into the top of the brickearth (Ib) and were sealed by a series of colluvial units (IIIb). Each pit was filled with deposits of dark ashy sediment containing charcoal and large quantities of calcined flint fragments (flints subjected to intense heating). Charcoal samples from two of these pits were radiocarbon dated to 3800 ± 40 ^{14}C yr BP and 3960 ± 40 ^{14}C yr BP, implying a Late Neolithic–Early Bronze Age date (Table 4).

On the downhill side, the pits were surrounded by an 'apron' of dumped ash-rich sediment up 0.40 m thick, enclosing an area about 35 m across (Fig. 10). The composition of the deposit was similar to the fillings of the pits and again contained abundant charcoal fragments with considerable quantities of calcined flint fragments. The deposit also produced some fresh prehistoric struck flints and five small fragments of flint-tempered prehistoric pottery. The flint assemblage includes 54 flakes and blades, 11 flake fragments, two cores and core fragments, together with a discoidal knife and utilized blade. Apart from a single residual, probable Mesolithic bladelet, this material would fit a later Neolithic or Early Bronze Age date. On the west side, a charcoal sample from this spread gave a radiocarbon date of 3870 ± 40 ^{14}C yr BP, similar to those obtained from the pits (Table 4).

Although perhaps unrepresentative of the complete site, the deposits excavated are not equated easily with those of a normal settlement and the large amounts of burnt debris do not appear to represent typical domestic waste. Calcined flints abound but there are only just over 70 struck flints in all, with few tools; there is no bone or shell and pottery is confined to a few small fragments. The excavated contexts thus appear to contain little normal household rubbish and virtually all the material seems to be derived from the heating of flints in fires, apparently on a large scale, and perhaps over a period of many years. The investigated part of the Crabble site therefore seems to be connected with a single, very specific activity or industrial process, involving some sort of hot stone technology. It seems likely that the close proximity of the River Dour was an important factor in the establishment of the site at this particular spot. The presence of a large feature cut into the uppermost tufa pool is, perhaps, not unrelated to this activity as well.

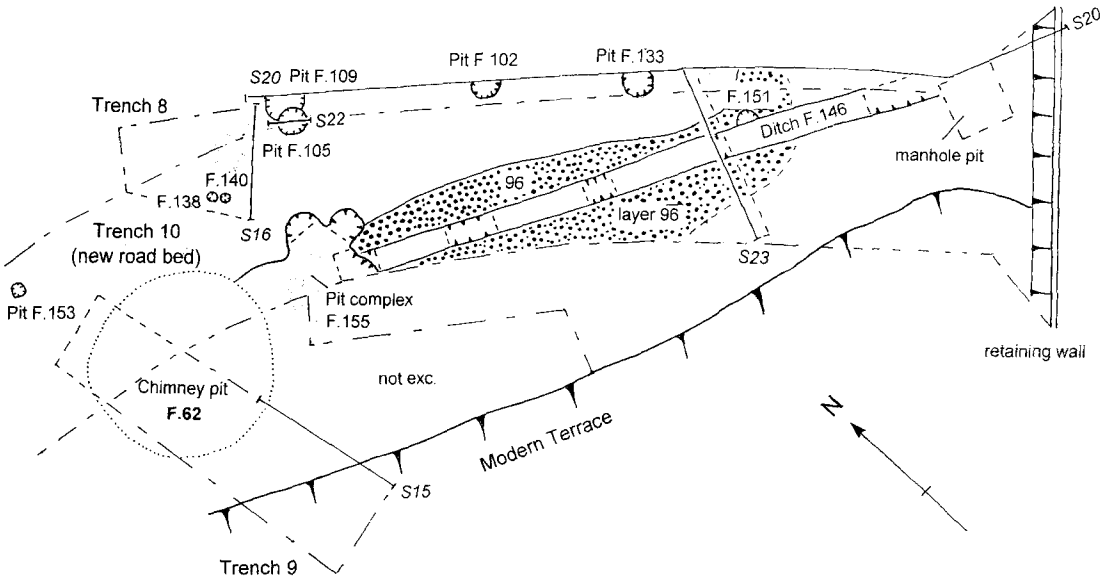

Fig. 10. General plan of the prehistoric site (Trenches 7–10) showing location of the pits and layer of burnt debris (stippled).

The distinctive character of the excavated remains, situated close to the only significant source of fresh running water in this part of southeast Kent, allows Crabble to be readily linked with the somewhat enigmatic class of prehistoric site generally known as 'burnt mounds'. Such sites are characterized by low, oval, crescentic or kidney-shaped heaps, or spreads, of burnt stones and charcoal, and are often associated with pits. They are invariably located adjacent to streams, rivers or other water sources. Such sites are known across Britain (Hodder & Barfield, 1991) and may be dated to the Bronze Age period. Although several sites have recently been discovered in London and the Thames valley (Bowsher, 1991), this is amongst the first to be identified in Kent.

The site was sealed by the thick, complex sequence of colluvial deposits (IIIb) that contained significant quantities of burnt flint, together with a number of struck flints and three shards of prehistoric flint-tempered pottery. At one location a small ditch yielded some animal bone, fifteen prehistoric struck flints and four small pot-shards. The shards consist of two somewhat indeterminate prehistoric pieces, a fragment of late Iron Age–early Roman ware and a small chip of Roman Samian ware. Based on this limited evidence, a late Iron Age or early Roman date for the digging of the ditch seems possible.

10. SITE DEVELOPMENT, PALAEOENVIRONMENTS AND HUMAN ACTIVITY

The evidence from the various strands of information from the site is summarized in Table 10. The sequences preserved at the site document a process of landscape change from the Late Devensian period through the early Holocene culminating in the late Prehistoric period, with the sealing of the site by colluvium resulting from soil erosion after about 3800 ^{14}C yr BP.

The Late Devensian deposits (coarse basal flint gravels (Ia) and silts (Ib)) did not yield any faunal or floral remains, although only minimal investigation of this part of the sequence was undertaken. Faunal remains have, however, been discovered within similar sediments elsewhere in the Dour catchment, for example at Archcliffe Fort, where molluscan remains date the accumulation of the deposits to the Late-glacial Interstadial. Gravels in the town centre also yielded the teeth of a mammoth, probably from the Late Devensian (McDakin, 1900).

The detailed record of local and regional palaeo-environmental development commences in the early Holocene with the deposition of the basal oncoidal tufa gravels (Ib). A sudden switch from siliclastic gravel aggradation to the formation of tufa was noted in a number of locations, the form and distribution of the oncoidal gravels suggesting deposition within a braided floodplain environment on an open valley floor. The switch from oncoidal gravel formation to accumulation of peats and lime muds in the abandoned channels appears to have occurred early in the Holocene, by *c.* 9400 ^{14}C yr BP.

Peats (IIa) continued to accumulate in the abandoned channel network until around 8000 BP, when the change to lime mud deposition occurred. The peats contain a detailed record of early and middle Holocene vegetational development, which shows a succession from open grass and scrubland, through the expansion

Table 10. Summarized site information from Crabble Mill site.

Site stratigraphy	Pollen assemblage zone (paz)	Inferred palaeoenvironments	Age (^{14}C yr BP)	Archaeological evidence
IIIb		Removal of woodlands and development of open agricultural landscape. Bare, eroding valley sides and slope-wash fans at foot of slope		Late Bronze Age to Roman pottery
			3800–3900	Late Neolithic/early Bronze Age pits, burnt mound
IId				Evidence for marine shell fragments
		Stagnant swamp and marsh conditions, damp shaded conditions		
		Spring flows and faster-moving water, damp shaded conditions		Appearance of hazel dormouse
		Small shallow-water bodies with local springs and damp ground, damp shaded conditions	7198	
IIa	CM-7	Mixed broad-leaved woodland, but with alder now a component, and an understorey of holly. A more open forest canopy is indicated by the higher counts for grass pollen		
CM-6		Mixed woodland, dominated by elm and hazel, in which lime is becoming an increasing component; oak is also well represented, but pine is now less abundant. The rise in the Poaceae curve reflects the gradual expansion of grassland	*c.* 8000	

Table 10. *Continued.*

Site stratigraphy	Pollen assemblage zone (paz)	Inferred palaeoenvironments	Age (^{14}C yr BP)	Archaeological evidence
	CM-5	The expansion of elm woodland and the establishment of oak within a landscape of pinewoods and hazel wood/scrub. The progressive reduction in Poaceae suggests closing of the forest canopy	*c.* 8600	
	CM-4	The arrival of elm in the area and its gradual expansion into a landscape of open pine and hazel wood/scrubland	*c.* 8800	
	CM-3	A landscape of pine woodland and hazel wood/scrub, with extensive areas of open grassland		
	CM-2	Birch and pine woodland, with willow, juniper and areas of open grassland into which hazel is beginning to expand. Local damp habitats may be indicated by the fern spores	*c.* 9480	
	CM-1	Open landscape of grassland and juniper scrub, with localized stands of pine, birch and willow	*c.* 9800	
IIb				
Ib		Cold periglacial conditions		
Ia		Cold, periglacial conditions. Braided fluvial channels with high seasonal discharge	Late Pleistocene (10 000–15 000)	

of birch–hazel woodland to the establishment of broadleaved woodland, the latter becoming widespread by 8500 ^{14}C yr BP.

The accumulation of calcareous mud (IId) suggests a switch in local conditions and a more persistent development of springs and calcareous marshes across the site. Changes in molluscan species representations through the lime muds reflect fluctuations in local conditions, with periods of increased water flow alternating with phases of damp marshland, and the presence of local springs and seepages. The upper part of the calcareous mud sequence is also of interest in that it yielded fragments of the edible mussel (*Mytilus edulis*). Given the distance to the sea (minimally 2.5 km) and the absence of brackish water or saline sediments any closer to the site than the town centre, transport by humans is the most likely explanation for their presence. If so, then this is probably the oldest record of human activity at the site, given that the charcoal found in earlier horizons could have been produced by natural fires (i.e. lightening strikes). Additionally, struck flakes were recovered from the calcareous muds during both the first phase of site investigation in 1990 and during the more recent site interventions prior to development.

Elsewhere in the valley, accumulation of oncoidal gravels continued throughout much of the early and middle Holocene. Age estimates from similar sediments in the town centre area (Fig. 3, boreholes DSC-2 and TWS-5) suggest continued accretions of such sediments until at least 4810±95 ^{14}C yr BP. Furthermore, oncoidal gravels were still accumulating around the time of the abandonment of the Dover boat in the town centre area (Keeley *et al.*, 2004).

Major environmental change at Crabble Mill in the late Holocene appears to be associated broadly with a human presence. This is indicated by evidence of pits and burnt mounds that rest stratigraphically on the tufa in places (see Trenches 7–10), as well as by the large feature, noted in the 1990 excavation, which cuts into the tufa and was subsequently sealed by the colluvium (Fig. 4). Because of the limited extent of the archaeological excavations, it was not possible to examine the spatial relationship between human activity and the spring-fed marsh. However, it is interesting to note that at The Grove site near Watford, a complex of tufa pools and barriers appear to have been surrounded by Bronze Age activity where the focus seems to have been the pools and barriers themselves (M. Bates unpublished). A similar pattern may have existed at Crabble and the very large pit excavated into the marsh may be an expression of this relationship.

Major colluviation followed the human activity of the Bronze Age and a thick sequence of colluvium buried the earlier tufa- and peat-dominated landscapes. Although extensive investigation of the colluvium was not undertaken, later Prehistoric and Roman pottery was found throughout the colluvial sequence, suggesting a prolonged period of sediment accumulation. Elsewhere in the valley, colluviation may have continued through into the post-Saxon period. For example, at Buckland Cemetery, Saxon burials appear to have been truncated by Medieval episodes of colluvial activity, reinforcing the idea that human-induced colluviation in the Dour Valley extended over a considerable time range.

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