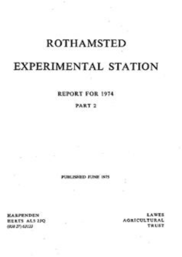
Rothamsted Experimental Station Report for 1974 Part 2



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J. A. Catt, D. W. King and A. H. Weir

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The Soils of Woburn Experimental Farm

I. Great Hill, Road Piece and Butt Close

J. A. CATT, D. W. KING and A. H. WEIR

Introduction

Woburn Experimental Farm was founded in 1876 by the ninth Duke of Bedford and the Royal Agricultural Society with three main objectives: (a) to evaluate the soil improvements made by tenant farmers so that they could be adequately compensated on leaving, (b) to duplicate on a light soil the continuous wheat and barley experiments Lawes had begun earlier at Rothamsted, and (c) to investigate the value of green manuring. Most of the farm is north of Woburn in the parish of Husborne Crawley, and, in terms of solid or bedrock geology, lies across the junction of the Lower Greensand (Cretaceous) and the Upper Jurassic clays (principally the Oxford Clay). The variability of the soils on such texturally diverse deposits soon caused difficulties with the experiments, and Stackyard Field, which is nearer Woburn town and well within the Lower Greensand country, was added to the farm and became the main experimental field. However, even here some features of the continuous wheat and barley experimental results could only be explained in terms of inherent soil heterogeneity producing 'fertility gradients' across the field (Cochran, 1936, pp. 159–161). Crowther (1936) summarised early analytical work on some of the soils, mainly from Stackyard, and described a profile near Stackyard, but subsequently there has been little attention paid to the morphology, composition, origin and variability of the soils on the farm. The adoption since 1926 of the modern experimental designs developed by Fisher and others has perhaps lessened the necessity for studies of this type in helping to interpret experimental results, but much value remains in knowing the detailed composition and variation of the soils on which experiments are laid out, and the natural processes by which they are changed in both the long and short terms.

King (1969) described the soils of the Ordnance Survey 7th edition Sheet 147 (Bedford and Luton), which includes the farm, but this account is too generalised to help with experimental layout and interpretation. In this paper we begin a much more detailed account of the farm soils with descriptions of those occupying the fields immediately north of the road (A418) between the villages of Husborne Crawley and Ridgmont. Table 1 and Fig. 1 give the names and areas of the fields involved.

TABLE 1

Areas of the fields of Woburn Experimental Farm described in this paper

	ha
Honey Pot	1·36
Great Hill Bottom I	1·40
Great Hill Bottom II	1·52
Great Hill I	2·98
Great Hill II, Great Hill III, Road Piece	7·87
Butt Close	5·04
Butt Furlong	—

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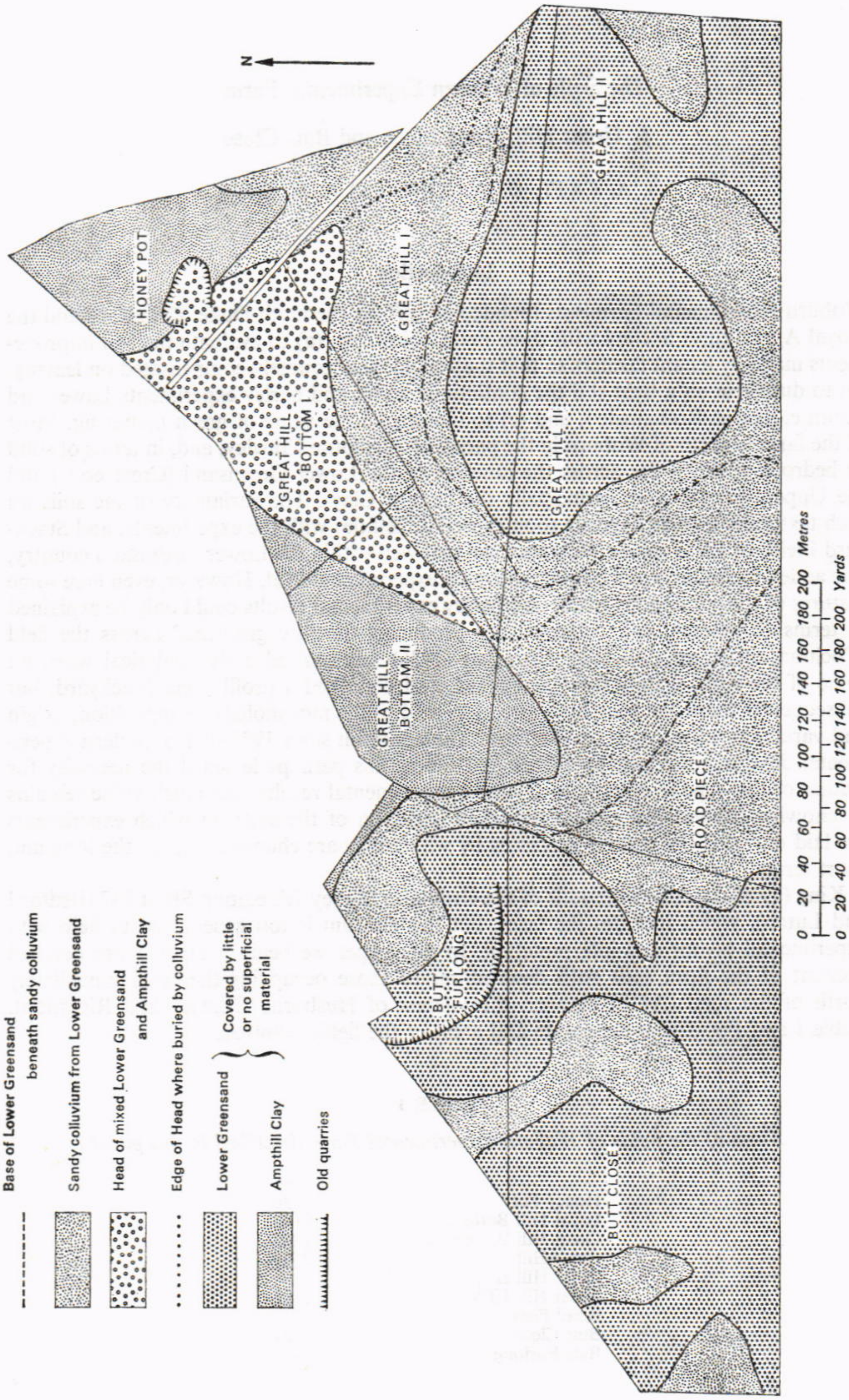

FIG. 1. Geological map of part of Woburn Experimental Farm.

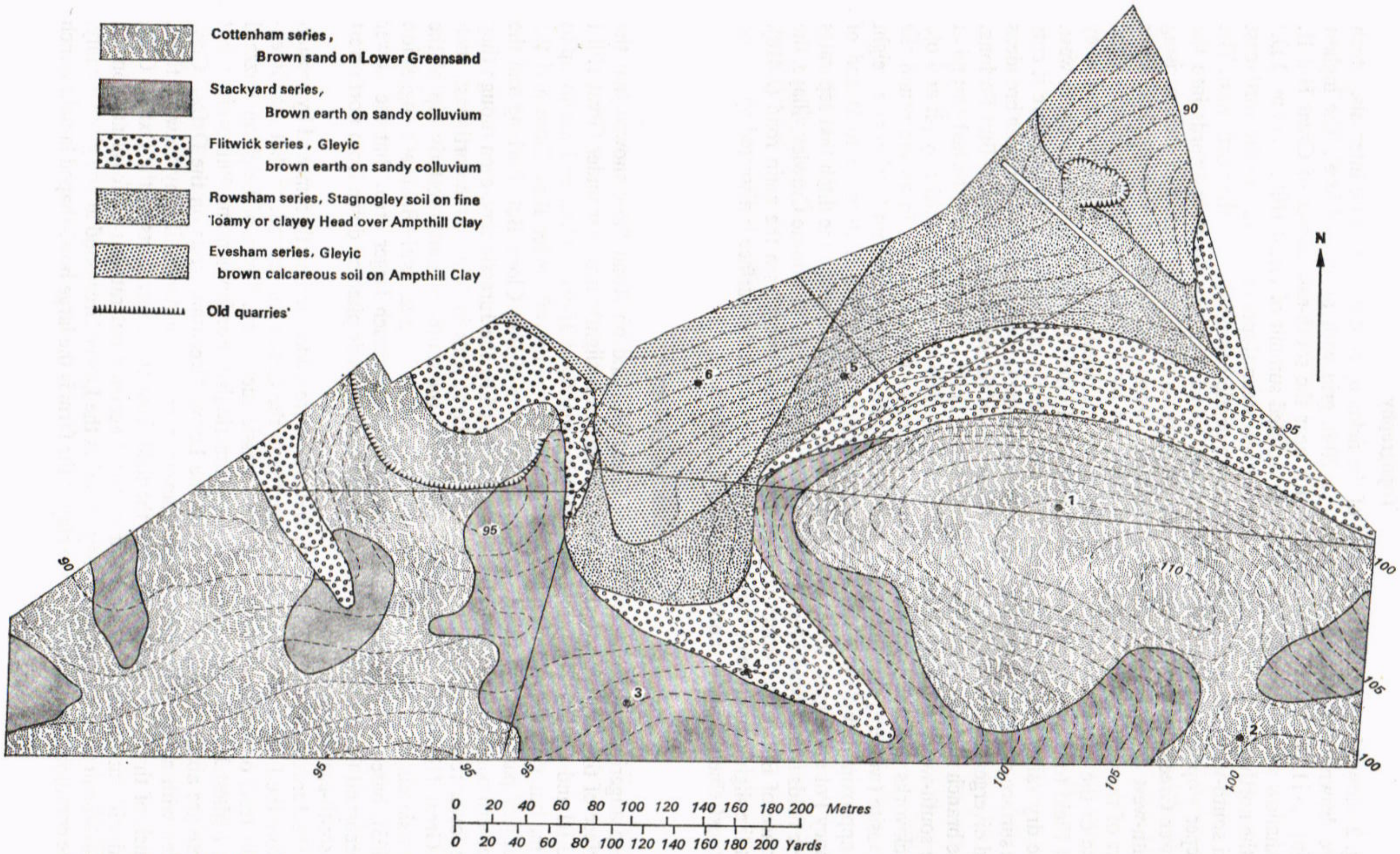

FIG. 2. Distribution of soil types on part of Woburn Experimental Farm, the location of analysed profiles (1–5), and surface topography shown by contours at metre intervals above ordnance datum.

Topography

Fig. 2 shows the surface topography of the fields by contours at metre intervals, which were drawn from heights surveyed on a 20-m grid with an optical level. The highest point (>111 m above ordnance datum) is near the south-east corner of Great Hill II. A shallow saddle separates this from the isolated summit of Great Hill (>110 m O.D.) to the north-west, which is flanked by relatively steep slopes (up to 12°) to the north-east and south-west, but is elongated into a more gentle convex slope to the north-west. The steeper slopes form the sides of dry valleys, which cut back south-eastwards into the Lower Greensand escarpment and are tributary to the Crawley Brook, a stream rising south-west of Woburn and joining the River Ouzel near Newport Pagnell. The lower part of the valley north-east of Great Hill is fed by intermittent springs rising from the base of the Lower Greensand, and the water is carried in a ditch dug between Honey Pot Field to the north-east and Great Hill I and Great Hill Bottom I to the south-west. The dry valley south-west of Great Hill runs steeply down to 93 m O.D. where it cuts the surface of the Upper Jurassic clays underlying the Lower Greensand, but then broadens and diverges into two valleys running either side of the small isolated hill in Butt Furlong. The branch running north-east of this hill (Plate 1) is soon lost in the disturbed ground at the south-western end of Great Hill Bottom II adjacent to the flooded clay pit and old brickworks opposite the farm buildings. The other branch swings in an arc round the opposite (western) side of the hill, and crosses the lane to Ridgmont Station at a height of approximately 87 m O.D. The lowest parts of Great Hill Bottom I and II and of Honey Pot are slightly lower at approximately 86 m O.D. beside the ditch that separates these fields from Broad Mead Field. Further west towards Husborne Crawley village, the surface of Butt Close slopes very gently northwards away from the main road (A418), but the slight curvature of the contour lines shows that this surface is dissected by at least two extremely shallow, northward-trending valleys.

Bedrock geology

Deep augering on the lower flanks of Great Hill and on Road Piece showed that the surface of the clay beneath the Lower Greensand is slightly irregular under Great Hill I and III and Great Hill Bottom II, where it is mainly at 91–94 m O.D. and locally up to 96 m, but slopes down steeply to the south or south-west under Butt Close and the southern part of Road Piece. As a result the soils of Butt Close, Butt Furlong and the southern parts of Road Piece are scarcely affected by the Jurassic clay, even though they are lower relative to O.D. than some of the clayey soils in fields to the north-east, such as Great Hill Bottom. Our local evidence for the south or south-westerly dip of the Jurassic clay surface beneath the Lower Greensand agrees with Bristow's suggestion (1963), based on well and borehole records over a much larger area, that the Lower Greensand fills a steep-sided trough in the Jurassic beds pitching down from north-west to south-east beneath Woburn.

The Jurassic strata of the English midlands were folded and partly removed by erosion before the Lower Greensand was deposited in the Cretaceous period, so that the Greensand rests on various members of the Jurassic succession. South of Leighton Buzzard the highest Jurassic beds are present (Kimmeridgian, Portlandian and Purbeckian), but these are absent around Woburn, and the Lower Greensand rests on the Oxford Clay, often with a relatively thin (0–20 m) development of the Ampthill Clay between them. Much of this is indistinguishable in the field from the upper parts of the Oxford Clay, and without the evidence provided by the diagnostic but rather rare fossil ammonites, it is difficult to be certain which clay underlies the Lower Greensand at any given locality. The commonest macrofossil in the clay at the farm is the large bowl-shaped lamellibranch

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Gryphaea dilatata, which occurs throughout most of the Upper Jurassic sequence. However, a sample of clay from 1·88–2·26 m depth in a core taken from Road Piece (Appendix A, profile 4) was found to contain microfossils (foraminifera, ostracoda and holothurian spicules) characteristic of the *cautisnigrae* and upper *plicatilis* zones of the Ampthill Clay facies of the Upper Oxfordian stage. These were extracted and identified by Dr. R. C. Whatley of the Geology Department, University College of Wales, Aberystwyth, whose micropalaeontological report is given in Appendix B. Evidence from the same core and from augering in Honey Pot and other fields showed that the clay is extremely calcareous, at least in the upper parts just below the Lower Greensand, and contains soft light-grey muddy limestones. The shallow pits on Honey Pot and some other parts of the farm were probably dug for the extraction of agricultural lime from these beds.

Although the clay immediately beneath the Lower Greensand is Ampthill Clay, the thickness of this and the depth to Oxford Clay are unknown. However, the subsoil clay obtained from a core taken on Great Hill Bottom II (Appendix A, profile 5) is mineralogically different from the Ampthill Clay of Road Piece (see p. 21), but does resemble samples of Oxford Clay from near Thame and elsewhere studied previously. If the clay in profile 5 is Oxford Clay, then the Ampthill Clay between it and the Lower Greensand under Great Hill cannot be more than approximately 4 m thick.

The Lower Greensand is composed of yellow and brown sands, which are irregularly iron-stained and locally cemented into ironstone (or 'carstone') bands. At Great Brickhill, Potton and other isolated localities, the lowest layers contain brown phosphatic nodules (Keeping, 1883), but there is little evidence for these on the farm. Well borings at Woburn and Potsgrove (Woodward & Thompson, 1909) showed that locally the base is also green, presumably through the abundance of glauconite in the sand, but again this is not especially true on the farm, although glauconite does occur in small amounts throughout the sands. Thin bands of clay, usually <3 cm thick and light grey, are fairly common, especially in lower parts of the Greensand, and locally expand to form lenticular beds of Fullers' Earth up to 3 m thick (Cameron, 1894; Newton, 1937). Thick Fullers' Earth layers occur nearby at Woburn Sands and Aspley Guise, but do not seem to extend into the area under discussion. Small pebbles, ranging in size from 2 mm to several centimetres across are fairly common in the sands; they are mainly of quartz and quartzite, but a few are of a hard black rock often with thin cross-cutting veins. A thin section (Plate 2) cut from one such pebble showed it to be a quartz-schorlite-hornfels, a metamorphic rock produced by boron metasomatism within the aureole of one of the granite masses of south-west England (Reid, Barrow & Dewey, 1910, p. 74; Reid *et al.*, 1912, p. 48; Edmonds *et al.*, 1968, p. 128); this suggests that the Lower Greensand of the Woburn area was derived at least partly from the west.

Superficial deposits

The main superficial deposit of the Woburn area is the Chalky Boulder Clay, which was deposited over the whole area at least as far south as Leighton Buzzard, probably during the Anglian Glaciation (Bristow & Cox, 1973; Perrin, Davies & Fysh, 1973). Remnants of a once continuous cover of this deposit occur on parts of the farm, but not in a recognisable form on any of the fields listed in Table 1. However, the possibility that material derived from weathered Chalky Boulder Clay has been incorporated in some of the soils cannot be ignored.

The junction between the Ampthill Clay and Lower Greensand on the northern and western flanks of Great Hill is obscured by a rather heterogeneous, slightly stony deposit of mottled sandy clay loam, sandy clay or clay loam. The stones are small carstone

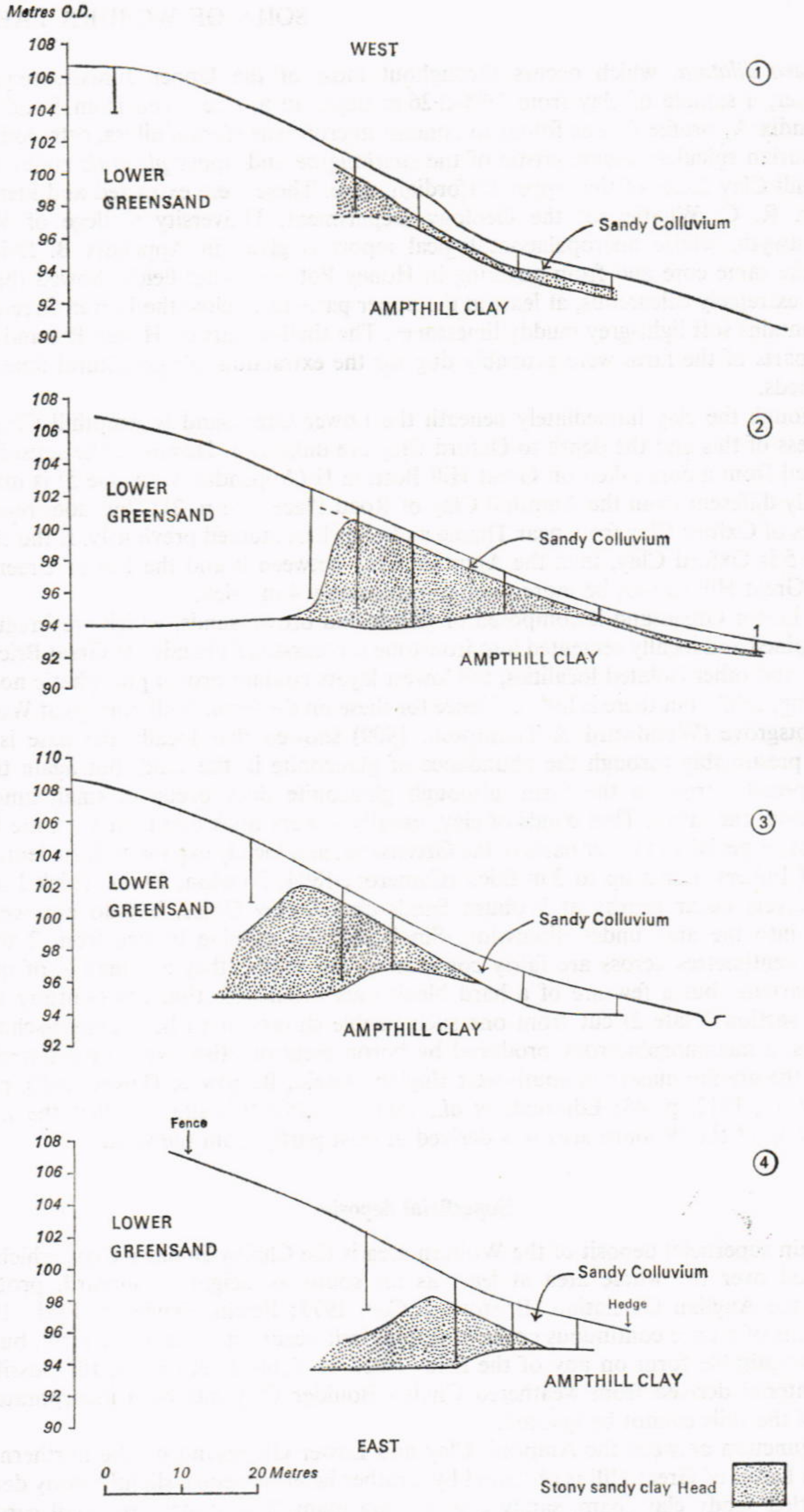

FIG. 3. Relationship of Head and colluvial deposits to bedrock geology on the northern side of Great Hill, based on deep augering along four traverses; positions and depths of boreholes shown by vertical lines.

fragments and pebbles derived from the Lower Greensand, and the clay component is presumably derived from the Ampthill Clay. Deep augering along transects down the northern side of the hill showed that this deposit thickens rapidly uphill beneath a colluvial accumulation of sand washed down from the higher slopes, but ends suddenly when it reaches a thickness of approximately 6 m. The surface of the underlying clay locally slopes southwards, in the reverse direction to the ground surface, suggesting that the clay has been squeezed outwards and upwards at the edge of the Lower Greensand. The bulging of clay substrata into valley sides and the lower slopes of escarpments beneath thick cappings of porous sediment is most likely to occur in fairly cold conditions, when the weight of overburden is increased by accumulation of frozen groundwater; the heterogeneous mixture (Head) of Lower Greensand and Ampthill Clay was probably ejected at the same time by water flowing out under pressure between the impervious clay and permafrost layers. It seems that the Head deposit may have formed in a cold period of the late Quaternary, some time after the deposition of the Chalky Boulder Clay, as the land surface with which it is associated is closely related to the present one and must have already lost its boulder clay cover when the Head was deposited.

The sandy colluvium covering the Head on the northern side of Great Hill is about 1·2 m thick at maximum, and thins downslope, merging into gleyed sandy loams directly overlying Ampthill Clay near the floor of the dry valley to the north-east, and also in a strip running across the lower parts of Great Hill I and thence either side of the fence between that field and Great Hill Bottom. On lower parts of Great Hill Bottom I a thin representative of the Head lies between the clay at about 1 m depth and a surface deposit, about 40 cm thick, of gleyed sandy clay loam or sandy loam. The Head wedges out at the western end of Great Hill, and the valley crossing Road Piece to the south-west contains only gleyed colluvial deposits, which are up to 2·5 m thick, over Ampthill Clay. Fig. 1 shows the distribution of these superficial deposits, and Fig. 3 their relationship to solid geology as traced by augering in transects down the northern slope of Great Hill.

Soils: distribution and profile morphology

The distribution of different soil types was determined by augering to a depth of 1 m at closely spaced intervals, and the detailed morphological features of profiles representing the main soil series were examined in cores extracted at selected sites with the Proline Corer. The cores also provided samples for analytical work. Fig. 2 shows the distribution of soil types, and descriptions of the representative profiles are given in Appendix A.

Well-drained soils on the Lower Greensand. These comprise two main types: the Cottenham series (Hodge & Seale, 1966, pp. 80–82), a Brown Sand on Lower Greensand *in situ* or on colluvium derived largely from Lower Greensand; and the Stackyard series, a Brown Earth in superficial deposits of somewhat finer texture but variable thickness. The distinction between these two series is often difficult in the field, as the Cottenham profiles are rarely completely free of the loamy material that characterises the Stackyard series, and there is an almost continuous gradation from one series to the other. The separation shown in Fig. 2 is based on a topsoil textural distinction between loamy sand (Cottenham series) and sandy loam (Stackyard series) as determined by laboratory estimation of silt (2–63 μm) and clay (<2 μm) in surface soil samples taken on a 20-m grid on Butt Close and a 40-m grid elsewhere. On this basis, the Cottenham series ($2 \times$ clay % + silt % $\leqslant 30$) occurs on either almost flat sites (Butt Close and the summit of Great Hill) or eroded sites on the steep slopes flanking Great Hill; the Stackyard

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TABLE 2

Particle-size distribution at whole ϕ intervals ($\phi = -\log_2 d$, where d is the particle size in mm) of soil samples from profiles at Woburn Experimental Farm, and of Chalky Boulder Clay and Lower Greensand samples from nearby localities (weight percentages of oven dry, decalcified and peroxidised soil <2 mm)

Size fractions (μm)	ϕ Equivalent	Profile: 1. Cottenham (SP 969359) Horizon Depth (cm): Ap 6–15	Bw 25–38	BC1 41–51	BC2 55–65	BC2 70–79	3. Stackyard (SP 966357) Ap 0–7	AB 10–22	Bw 30–40	2C 60–70
1000–2000	0 to −1	0·9	0·8	0·5	0·6	0·6	0·4	1·1	0·2	0·0
500–1000	1 to 0	2·4	2·2	2·5	3·0	3·4	1·8	2·0	1·1	0·7
250–500	2 to 1	22·5	22·8	24·3	25·3	29·0	17·4	17·5	18·8	19·8
125–250	3 to 2	48·3	52·0	52·2	49·7	43·1	49·5	47·6	53·0	62·8
63–125	4 to 3	9·1	8·8	6·7	6·1	3·7	3·3	3·3	3·3	4·2
31–63	5 to 4	0·9	1·2	0·5	0·7	1·2	3·3	2·4	2·5	1·5
16–31	6 to 5	1·4	1·2	1·8	0·1	0·9	2·5	3·0	2·3	1·0
8–16	7 to 6	1·4	0·4	0·5	0·7	0·2	2·5	2·7	2·0	0·5
4–8	8 to 7	0·9	1·2	1·1	0·5	0·7	1·3	2·0	1·0	0·5
2–4	9 to 8	1·4	0·8	1·8	1·5	4·3	4·4	2·4	2·7	2·0
<2	>9	10·8	8·6	8·1	11·8	12·9	13·6	16·0	13·1	7·0

Size fractions (μm)	ϕ Equivalent	4. Flitwick (SP 966357) Ap 0–13	AB 13–24	Bw(g) 26–50	BC(g) 60–72	Cg 100–130	2Cg1 168–184	2Cg2 190–220	2Cg3 235–255
1000–2000	0 to −1	0·5	0·5	0·4	0·7	0·1	0·0	0·0	0·0
500–1000	1 to 0	2·3	1·9	1·7	1·5	0·9	0·0	0·0	0·0
250–500	2 to 1	18·7	19·2	17·9	15·7	15·5	0·3	0·0	0·0
125–250	3 to 2	47·9	48·1	50·5	40·7	38·8	0·6	0·2	0·2
63–125	4 to 3	3·5	3·6	3·6	2·9	4·8	1·7	2·1	2·3
31–63	5 to 4	2·8	3·2	3·7	6·9	7·6	3·3	3·9	3·3
16–31	6 to 5	3·6	3·6	4·7	8·3	5·3	4·1	2·6	4·4
8–16	7 to 6	2·5	2·7	3·3	4·9	3·5	4·3	5·2	6·4
4–8	8 to 7	2·1	2·0	2·1	2·8	1·5	5·2	5·8	5·5
2–4	9 to 8	3·6	3·1	1·9	2·9	3·9	7·2	8·5	7·0
<2	>9	12·5	12·1	10·2	12·7	18·1	73·3	71·7	70·9

Size fractions (μm)	ϕ Equivalent	5. Rowsham (SP 967359) Ap(g) 6–16	AB (g) 24–40	Bwg 42–52	BCg 63–80	Cg 83–100	2Cg 104–120	2Cgk 136–162
1000–2000	0 to −1	0·9	0·9	1·5	0·9	0·3	1·1	0·4
500–1000	1 to 0	2·8	2·6	2·4	1·7	1·2	1·4	0·2
250–500	2 to 1	19·9	17·9	15·9	11·1	8·9	5·7	0·1
125–250	3 to 2	36·2	30·3	27·8	21·1	17·2	10·9	0·4
63–125	4 to 3	2·8	2·4	2·5	6·2	2·2	2·7	0·7
31–63	5 to 4	4·9	5·4	6·2	6·9	10·1	3·6	2·4
16–31	6 to 5	4·0	4·3	6·4	12·9	16·0	4·5	7·1
8–16	7 to 6	3·4	4·0	5·6	7·0	10·2	5·8	4·2
4–8	8 to 7	3·0	3·3	3·3	2·6	4·5	4·5	9·2
2–4	9 to 8	2·1	2·9	3·1	3·6	4·8	6·7	10·5
<2	>9	20·0	26·0	25·3	26·0	24·6	53·1	64·8

ϕ	Grid Reference	Chalky Boulder Clay Samples: 1 SP 930287	2 SP 930287	3 SP 930287	4 SP 930287	5 SP 933302	Lower Greensand Samples: 1 SP 936344	2 SP 936344	3 SP 936344	4 SP 924289	5 SP 923288	6 SP 929287	7 SP7992386
0 to −1		0·9	0·8	1·1	1·1	1·6	0·1	0·1	2·6	0·1	8·1	0·5	1·9
1 to 0		2·2	1·3	3·4	3·0	4·4	2·6	0·6	9·1	1·0	40·8	11·6	4·4
2 to 1		6·8	3·5	10·0	8·6	10·5	24·1	15·1	46·4	58·3	35·8	83·2	44·3
3 to 2		13·5	7·6	18·5	16·0	20·5	56·0	67·9	26·2	32·8	9·3	3·7	32·7
4 to 3		5·8	4·7	5·8	6·4	8·5	5·0	3·2	2·1	0·9	0·4	0·4	1·6
5 to 4		4·1	6·8	4·2	3·3	2·1	0·4	0·5	0·4	0·2	0·1	0·1	0·5
6 to 5		4·7	7·8	3·7	6·9	4·3	0·2	0·3	0·3	0·1	0·1	0·0	0·2
7 to 6		7·5	7·1	7·3	6·0	4·5	0·2	0·3	0·3	0·4	0·1	0·0	0·2
8 to 7		6·6	8·5	6·2	5·6	4·2	0·2	0·3	0·3	0·4	0·2	0·0	0·4
9 to 8		6·4	10·6	6·3	7·5	3·8	0·4	0·4	0·3	0·3	0·2	0·1	0·6
>9		41·5	41·3	33·5	35·6	35·6	11·3	12·0	5·4	4·9	4·9	0·3	12·9

series ($2 \times$ clay $\% +$ silt $\% \geqslant 30$) occurs mainly in valley head sites, even where these are so shallow as to be scarcely recognisable without the help of detailed levelling.

The loamy deposit veneering the Lower Greensand seems to be variable in origin. The small angular flint fragments, which are fairly common in the Stackyard profiles and rarer in the Cottenham, suggest that some of the deposit is derived from weathered Chalky Boulder Clay, which contains flint, but as the silt/clay ratio is more variable than in typical Chalky Boulder Clay (see Table 2 and also Perrin *et al.*, 1973), other sources may also be involved. In particular the small silt/clay ratios of surface soil samples from the eastern side of the small knoll in Butt Furlong could be related to a clay layer or layers within the Lower Greensand, approximately 5 m above its base. A short strip of Stackyard series, only 2–3 m wide and too small to show in Fig. 2, was also found on the south-western side of the same knoll when differential growth of barley was noticed in late June and early July 1972. A narrow band, in which the crop was approximately 40 cm high (almost twice that on either side) and darker green, extended round the hillside parallel to the contour, and was associated with soil that was much more clayey to 90–120 cm depth than on either side, and considerably wetter and stickier below about 65 cm depth. The height and horizontal disposition of this strip would agree with the outcrop of a clay stratum near the base of the Lower Greensand beneath this knoll.

Both the Cottenham and the Stackyard series are non-calcareous throughout and well-drained, though the heavier textured horizons especially in some Stackyard profiles are a little greyer and probably slightly less well drained, as noticed in the subsoil of the strip south-west of the knoll. The fine to medium subangular blocky structure is slightly better developed in the Stackyard than in the Cottenham soils, but the transition at depth to undisturbed Lower Greensand is usually marked in both by a complete loss of structure. In Cottenham profile 1 (Appendix A) the soil is slightly acid (pH 6·0) at the surface and neutral at depth, but the pH values (4·3–5·9) under old grassland in White Horse Field, measured shortly after it was taken over in 1963, suggest that more acid conditions would prevail in natural situations.

Imperfectly drained soils in colluvium. These soils, grouped with the Flitwick series, occur in two types of site: on the floors of dry valleys, mainly where these have cut through the Lower Greensand into the Ampthill Clay (Plate 3), and on the northern flank of Great Hill, where 90–120 cm of sandy colluvium covers the Head formed at the Lower Greensand/Ampthill Clay junction (Fig. 3). The slight gleying in these soils is caused by the impervious nature of the underlying clay or Head, which may be as close to the surface as 80–90 cm, but is usually somewhat deeper. The colluvium in which the higher horizons are developed is similar in texture and stone content to the superficial deposit in many of the Stackyard soils on the adjacent lower valley sides and valley heads, but the subsoil horizons immediately over the Ampthill Clay are often heavier and more stony. There is otherwise a lack of stratification and sorting throughout the deposit, which suggests that it is not alluvial and probably post-dates by a considerable time the period of stream-flow responsible for cutting the valleys.

The loamy surface and sub-surface horizons are non-calcareous and have a weakly developed fine or medium subangular blocky structure, but the clay subsoil is calcareous, often with many secondary carbonate concretions, and has a well-developed medium or coarse prismatic structure. Mottling usually occurs to within 20–25 cm of the surface, and becomes more prominent downwards at least into the higher parts of the clay subsoil.

Poorly drained soils in Head and colluvial deposits over clay. These soils, grouped with the Rowsham series (Jarvis, 1973, pp. 81–84), differ from the Flitwick profiles mainly in being mottled to the surface, at least under grassland. They occur only on the clay,

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which may be within 90 cm of the surface, and are often slightly finer textured at any given depth than the Flitwick soils. The horizon immediately above the clay in profiles on Great Hill Bottom is commonly a stony sandy clay, which is probably a thin, downslope continuation of the Head issuing from the Lower Greensand/Ampthill Clay junction. Horizons above this may be derived from a thin and somewhat finer textured downslope equivalent of the colluvium mantling the higher slopes.

The surface horizon of profile 5 (Appendix A) is slightly more acid (pH 5·0) than that of the Flitwick profile 4 on Road Piece (pH 5·7); both become less acid with depth, and eventually alkaline once the calcareous clay is reached. The fine subangular blocky structure of the Rowsham surface soil is more strongly developed than that of the Flitwick; it becomes coarser in sub-surface horizons and, as in the Flitwick profiles, coarse prismatic within the subsoil clay.

Poorly and imperfectly drained calcareous soils on clay. Soils with slightly stony clay loam or sandy clay loam surface horizons occur on the lower parts of Honey Pot and Great Hill Bottom II where the clay has little or no cover of superficial deposits. The surface horizon is usually non-calcareous, but lower horizons are mottled calcareous clay, or locally extremely calcareous pale grey to white silt loam, derived from disintegrating limestone bands within the clay. The profiles are consequently grouped with the Evesham series (Jarvis, 1973, pp. 72–75).

Fine rusty mottling is common in the finely structured surface horizon, and the subsurface clay horizons are grey or olive with fine to medium yellowish brown mottling appearing at depth. Internal drainage is slow, but the position of the soils on the gentle lower slopes and the moderate structure of the lower horizons ensure that winter waterlogging to within about 30 cm of the surface occurs during not more than approximately three months each year.

Soils: particle-size distribution

Table 2 shows the particle-size distribution of soil samples from profiles 1 (Cottenham), 3 (Stackyard), 4 (Flitwick) and 5 (Rowsham) described in Appendix A, and of unweathered Lower Greensand and Chalky Boulder Clay samples from various deep excavations near Woburn. The samples were decalcified where necessary with acetic acid buffered at pH 3·8, and treated with 12% hydrogen peroxide to remove organic matter. The clay (<2 μm) and five silt fractions (2–63 μm) were determined on 10–15 g sub-samples by the pipette sampling technique after dispersion in dilute (0·1% w/v) sodium hexametaphosphate solution; and five sand fractions (63–2000 μm) were determined on 150–200 g sub-samples by dry sieving after ultrasonic dispersion.

The particle-size distributions of the Lower Greensand samples are slightly variable; some samples contain coarser sand than others, and the clay content ranges from almost nil to 13%. The seven samples analysed were selected in the field as typical of the sands, and at some levels in the Lower Greensand the clay content would certainly exceed 13%. However, the extremely small amounts of silt in any part of the 2–63 μm range seem to be a characteristic feature of the deposit as a whole. In contrast, the Chalky Boulder Clay contains moderate amounts of silt as well as of clay and sand, and this is distributed throughout the 2–63 μm range.

In the Cottenham profile (1), the particle-size distribution throughout is similar to that of the Lower Greensand, with up to approximately 13% clay, only very small amounts of silt, and most of the sand in the 125–500 μm range. The C horizon of the Stackyard profile (3) is similar, but the A and B horizons are in the sandy loam textural class because they contain a little more clay than seems usual in the Lower Greensand and also

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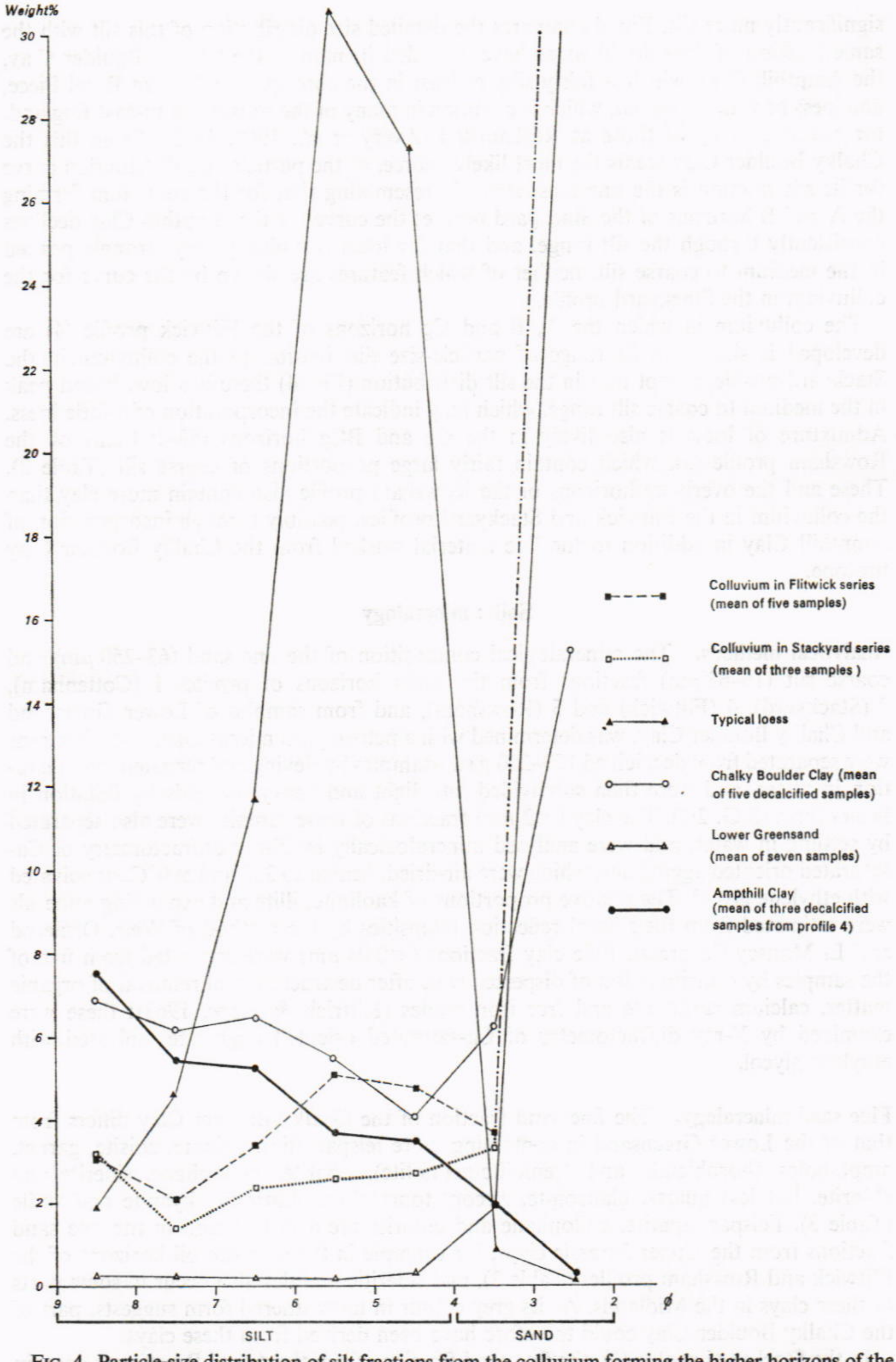

FIG. 4. Particle-size distribution of silt fractions from the colluvium forming the higher horizons of the Stackyard and Flitwick soil profiles at Woburn Experimental Farm, compared with silt fractions from possible source materials.

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significantly more silt. Fig. 4 compares the detailed size distribution of this silt with the same fraction of deposits likely to have provided it, namely the Chalky Boulder Clay, the Ampthill Clay, which is fairly silty at least in the core (profile 4) from Road Piece, and loess or windblown silt, which is common in many of the soils of south-east England, for example many of those at Rothamsted (Avery *et al.*, 1969, 1972). From this the Chalky Boulder Clay seems the most likely source, as the particle-size distribution curve for its silt fraction is the one most strongly resembling that for the colluvium forming the A and B horizons of the Stackyard profile; the curve for the Ampthill Clay declines consistently through the silt range, and that for loess is typically very strongly peaked in the medium to coarse silt, neither of which features are shown by the curve for the colluvium in the Stackyard profile.

The colluvium in which the A, B and Cg horizons of the Flitwick profile (4) are developed is similar in its range of particle-size distribution to the colluvium in the Stackyard profile, except that in the silt distribution (Fig. 4) there is a low, broad peak in the medium to coarse silt range, which may indicate the incorporation of a little loess. Admixture of loess is also likely in the Cg and BCg horizons (53–104 cm) of the Rowsham profile (5), which contain fairly large proportions of coarse silt (Table 2). These and the overlying horizons of the Rowsham profile also contain more clay than the colluvium in the Flitwick and Stackyard profiles, possibly through incorporation of Ampthill Clay in addition to the fine material washed from the Chalky Boulder Clay upslope.

Soils: mineralogy

Analytical methods. The mineralogical composition of the fine sand (63–250 μm) and coarse silt (16–63 μm) fractions from the main horizons of profiles 1 (Cottenham), 3 (Stackyard), 4 (Flitwick) and 5 (Rowsham), and from samples of Lower Greensand and Chalky Boulder Clay, was determined with a petrological microscope. Both fractions were separated from decalcified 150–200 g sub-samples by sieving and repeated sedimentation in water, and were then subdivided into light and heavy minerals by flotation in bromoform (S.G. 2·9). The clay (<2 μm) fractions of these samples were also separated by settling in water, and were analysed mineralogically by X-ray diffractometry of Ca-saturated oriented aggregates, which were air-dried, heated to 335 and 500°C, or solvated with ethylene glycol. The relative proportions of kaolinite, illite and expanding minerals were estimated from their basal reflection intensities by the method of Weir, Ormerod and El Mansey (in press). Fine clay fractions ($<0·04$ μm) were separated from five of the samples by centrifugation of dispersed sols, after destruction and removal of organic matter, calcium carbonate and free iron oxides (Kittrick & Hope, 1963); these were examined by X-ray diffractometry of Ca-saturated oriented aggregates solvated with ethylene glycol.

Fine sand mineralogy. The fine sand fraction of the Chalky Boulder Clay differs from that of the Lower Greensand in containing more felspar, flint, epidote, zoisite, garnet, amphiboles (hornblende and tremolite/actinolite), apatite, collophane, siderite and chlorite, but less quartz, glauconite, zircon, tourmaline, staurolite, kyanite and rutile (Table 3). Felspar, apatite, collophane and chlorite are also common in the fine sand fractions from the Upper Jurassic clays, for example in the clay subsoil horizons of the Flitwick and Rowsham profiles (Table 3), and sideritic nodules also occur in some parts of these clays in the Midlands. As its grey colour in unweathered form suggests, part of the Chalky Boulder Clay could therefore have been derived from these clays.

In the Stackyard profile (3), the fine sand fractions from the A and B horizons contain more felspar, flint, garnet and amphibole than that of the 2C horizon; this supports the

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PLATE 1. View of Great Hill from the west showing distribution of soil types in the valley floored by Ampthill Clay on the northern side of Road Piece (1: Cottenham, 3: Stackyard, 4: Flitwick, 5: Rowsham, 6: Evesham series).

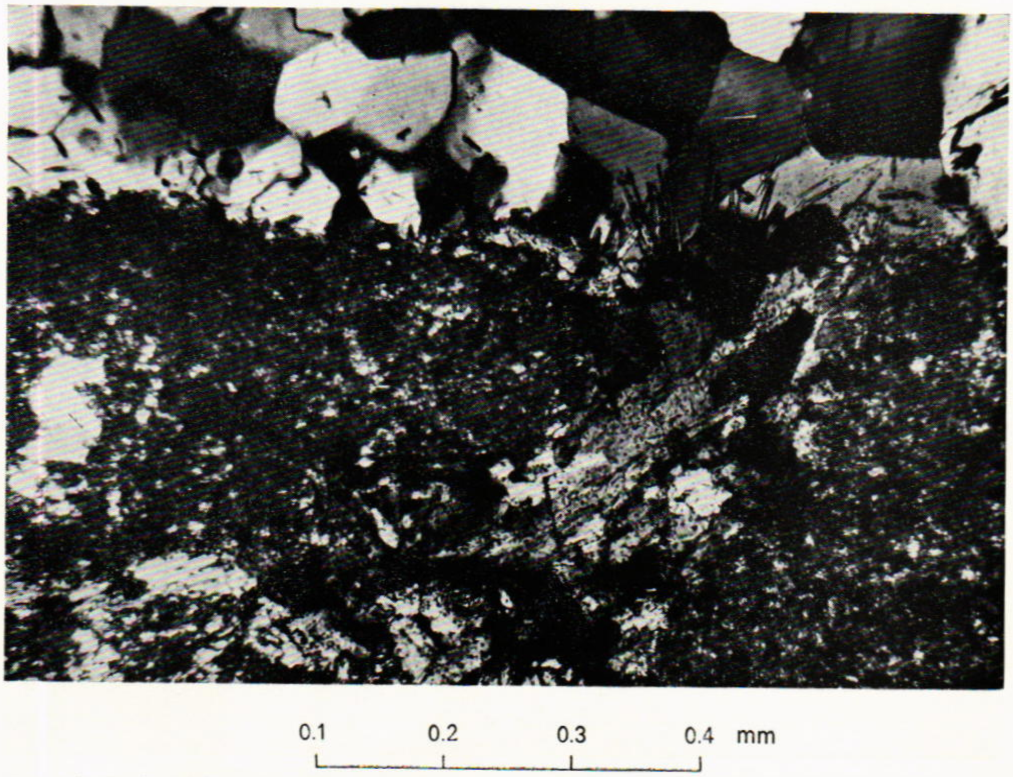

PLATE 2. Optical micrograph of thin section from pebble of quartz-schorlite-hornfels from the Lower Greensand, Woburn Experimental Farm, showing quartz and tourmaline veins cutting fine hornfelsic groundmass.

[*facing page* 16

PLATE 3. View of Road Piece and western flank of Great Hill from the south, showing distribution of soil types (1: Cottenham, 3: Stackyard, 4: Flitwick, 5: Rowsham, 6: Evesham series) and extraction of profile 4 (Flitwick series).

PLATE 4. Soil erosion affecting potato crop, Butt Close, May 1973.

TABLE 3

Mineral composition of fine sand fractions (63–250 μm) from Woburn soil profiles, and from samples of Lower Greensand and Chalky Boulder Clay (light minerals as percentage of total fine sand, non-opaque heavy minerals as parts per thousand (‰) of heavy fraction; opaque minerals omitted)

Profile		1. Cottenham (SP 969359)					3. Stackyard (SP 966357)				4. Flitwick (SP 966357)								5. Rowsham (SP 967359)							Lower Greensand Mean of seven samples	Chalky Boulder Clay Mean of three samples
Horizon Depth (cm)		Ap 6–15	Bw 25–38	BC1 41–51	BC2 55–65	BC2 70–79	Ap 0–7	AB 10–22	Bw 30–40	2C 60–70	Ap 0–13	AB 13–24	Bw(g) 26–50	BC(g) 60–72	Cg 100–130	2Cg1 168–184	2Cg2 190–220	2Cg3 235–255	Ap(g) 6–16	AB(g) 24–40	Bwg 42–52	BCg 63–80	Cg 83–100	2Cg 104–120	2Cgk 136–162		
Light fraction (S.G. < 2·9)																											
Quartz	%	96	95	92	94	95	93	92	92	96	97	96	94	95	95	90	89	87	98	97	96	94	93	91	93	94	88
Alkali felspar	%	1	1	2	1	1	3	3	3	2	1	2	3	3	3	8	10	12	<1	1	2	4	5	4	4	2	7
Flint	%	<1	<1	—	—	—	1	1	1	—	1	1	<1	<1	<1	—	—	—	<1	—	—	<1	<1	<1	—	—	1
Chert	%	1	1	2	3	2	1	2	2	1	—	—	1	1	1	1	—	—	<1	<1	<1	<1	<1	1	—	1	2
Muscovite	%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	<1	<1	<1	<1	—
Glauconite	%	—	<1	1	—	<1	<1	<1	<1	1	—	—	<1	—	<1	<1	—	—	<1	—	—	<1	<1	<1	—	2	<1
Heavy fraction (S.G. > 2·9), total %		1·5	2·1	2·8	1·6	1·4	1·7	1·2	1·6	0·5	1·1	1·0	0·8	0·5	0·8	1·8	1·0	0·7	1·5	1·7	1·7	1·5	1·5	3·0	2·1	0·5	1·7
Zircon	‰	542	516	634	502	572	624	484	709	536	534	427	506	484	524	192	210	95	317	516	481	440	516	513	232	54	72
Tourmaline	‰	116	98	75	110	96	65	87	36	114	96	126	91	129	97	186	260	156	187	102	114	130	89	60	91	96	57
Epidote	‰	47	54	82	68	59	55	23	36	57	73	103	83	89	78	36	—	24	18	30	52	44	30	35	25	26	98
Zoisite	‰	6	10	9	5	7	5	5	4	5	2	15	12	9	13	6	—	4	1	1	8	3	5	2	—	—	15
Colourless garnet	‰	16	10	3	11	1	34	29	16	7	30	21	22	28	27	24	—	50	30	20	37	53	57	54	12	2	95
Pink garnet	‰	3	6	1	2	—	4	22	7	3	4	3	4	5	5	—	—	—	11	—	9	6	16	13	—	2	19
Green hornblende	‰	6	3	1	—	—	15	10	9	—	14	21	9	26	31	6	—	—	30	18	35	30	48	15	—	2	140
Tremolite/ actinolite	‰	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9
Brown hornblende	‰	—	1	—	—	—	3	—	—	—	—	5	2	—	1	—	—	—	4	—	4	4	3	2	—	—	14
Red rutile	‰	13	15	13	15	16	15	7	8	16	10	8	15	13	22	—	—	6	37	31	19	21	14	16	3	17	1
Yellow rutile	‰	18	25	13	16	20	22	19	13	20	19	21	30	24	35	12	60	—	19	15	11	13	8	9	16	13	9
Brown rutile	‰	64	75	42	82	64	52	70	73	70	68	40	46	52	41	23	—	45	67	66	56	58	31	37	28	59	12
Anatase	‰	6	4	6	4	7	3	5	3	5	—	11	7	2	1	1	—	11	4	2	4	6	8	8	3	4	2
Brookite	‰	—	—	1	1	1	—	2	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Staurolite	‰	90	84	67	105	88	62	125	41	73	75	82	70	78	59	42	—	22	148	95	88	83	71	44	25	100	33
Kyanite	‰	73	95	52	79	74	39	106	38	86	68	82	89	59	66	12	—	17	127	104	80	83	64	46	19	127	11
Andalusite	‰	—	3	1	—	—	—	2	3	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	2	—
Apatite	‰	—	—	—	—	—	—	—	—	—	4	8	—	—	—	16	—	—	—	—	—	7	14	27	44	—	28
Collophane	‰	—	—	—	—	—	—	—	—	—	—	4	—	—	—	419	350	352	—	—	—	—	—	110	490	—	44
Sphene	‰	—	—	—	—	—	—	2	1	7	—	—	—	—	—	—	—	—	—	—	—	—	3	3	3	—	—
Augite	‰	—	1	—	—	—	1	—	3	—	1	6	3	—	—	1	—	—	—	—	—	—	—	—	—	—	5
Hypersthene	‰	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Enstatite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Siderite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	317
Chlorite	‰	—	—	—	—	1	—	2	—	—	2	11	5	—	—	24	120	162	—	—	—	17	23	6	9	1	15
Biotite	‰	—	—	—	—	—	—	—	—	—	—	6	2	2	—	—	—	56	—	—	—	—	—	—	—	—	2

TABLE 4

Mineral composition of coarse silt fractions (16–63 μm) from Woburn soil profiles, and from samples of Lower Greensand and Chalky Boulder Clay (light minerals as percentage of total fine sand, non-opaque heavy minerals as parts per thousand (‰) of heavy fraction; opaque minerals omitted)

Profile		1. Cottenham (SP 969359)					3. Stackyard (SP 966357)				4. Flitwick (SP 966357)								5. Rowsham (SP 967359)							LOWER GREEN SAND	CHALKY BOULDER CLAY
Horizon Depth (cm)		Ap 6–15	Bw 25–38	BC1 41–51	BC2 55–65	BC2 70–79	Ap 0–7	AB 10–22	Bw 30–40	2C 60–70	Ap 0–13	AB 13–24	Bw(g) 26–50	BC(g) 60–72	Cg 100–130	2Cg1 168–184	2Cg2 190–220	2Cg3 235–255	Ap(g) 6–16	AB(g) 24–40	Bwg 42–52	BCg 63–80	Cg 83–100	2Cg 104–120	2Cgk 136–162	Mean of seven samples	Mean of three samples
Light fraction (S.G. < 2·9)																											
Quartz	%	67	80	82	87	84	83	84	87	91	85	84	83	82	84	86	89	88	83	85	84	82	82	85	90	91	76
Alkali felspar	%	8	9	10	8	5	14	14	11	5	12	14	14	15	13	12	10	11	14	9	11	14	15	12	8	5	14
Flint	%	<1	<1	<1	—	—	1	<1	<1	—	<1	<1	1	1	<1	—	—	—	<1	<1	<1	<1	—	—	—	—	1
Muscovite	%	3	1	1	1	1	1	<1	<1	1	1	<1	<1	1	1	1	1	1	2	1	<1	2	2	1	1	<1	4
Glauconite	%	20	8	6	3	9	<1	1	1	2	1	1	1	<1	<1	<1	—	—	—	4	4	1	<1	1	1	3	<1
Opal	%	1	1	—	—	—	<1	—	—	—	<1	<1	<1	<1	—	—	—	—	<1	<1	<1	—	—	—	—	—	—
Heavy fraction (S.G. > 2·9) total %		0·6	0·5	0·5	0·5	0·8	0·4	0·4	0·3	0·6	0·5	0·3	0·7	0·7	0·6	<0·1	<0·1	<0·1	0·4	0·5	0·3	0·5	0·5	0·3	<0·1	0·5	4·5
Zircon	‰	213	212	281	405	403	240	246	237	433	225	197	208	186	149	429	465	668	161	163	174	336	195	283	433	421	10
Tourmaline	‰	49	27	64	94	139	25	42	104	141	23	34	17	15	8	75	47	51	23	42	30	24	26	39	65	158	3
Epidote	‰	383	377	331	223	178	379	374	293	167	322	319	314	359	288	109	103	31	374	370	405	264	260	228	84	152	18
Zoisite	‰	16	25	16	18	17	21	23	16	12	23	28	19	16	10	27	19	13	23	17	22	17	10	20	17	12	3
Garnet	‰	55	33	38	24	7	59	20	18	5	22	29	24	18	35	95	37	42	50	56	41	38	52	22	58	11	4
Green hornblende	‰	63	96	55	8	—	158	139	77	3	93	84	121	126	118	—	14	—	149	125	100	56	120	59	14	10	16
Tremolite/ actinolite	‰	10	25	34	13	14	37	40	22	1	33	41	22	34	28	—	—	—	39	40	49	17	18	26	7	—	2
Brown hornblende	‰	3	5	—	—	—	—	7	4	—	9	4	4	13	7	—	—	—	8	3	5	3	4	—	—	—	1
Red rutile	‰	—	—	—	—	—	—	—	2	1	—	1	—	—	1	—	—	1	2	2	—	—	—	—	—	1	1
Yellow rutile	‰	57	58	39	70	59	43	61	60	70	67	74	86	69	63	82	117	84	60	35	60	70	43	88	133	84	3
Brown rutile	‰	5	5	5	13	—	9	10	9	2	8	4	6	9	8	48	38	17	17	8	7	4	6	18	24	3	1
Anatase	‰	48	51	43	32	52	25	27	34	65	48	47	85	56	36	49	72	55	18	34	41	50	33	69	66	70	2
Brookite	‰	3	8	5	11	10	1	2	6	11	8	8	7	5	2	7	—	5	—	3	7	1	1	6	8	17	1
Staurolite	‰	8	2	2	8	3	2	2	4	12	3	2	6	1	2	18	18	16	4	—	3	6	—	2	7	13	—
Kyanite	‰	23	5	7	10	21	1	—	2	14	13	10	10	4	4	20	5	6	12	—	5	10	1	6	3	10	—
Andalusite	‰	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Apatite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15	3	—	—	3	—	2
Collophane	‰	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	23	—	—	—	—	—	—	6	17	—	—
Sphene	‰	—	—	—	—	—	—	—	1	2	—	—	—	—	—	—	—	8	—	—	—	—	—	—	—	—	—
Augite	‰	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—	—	2	—	—	—	1	—	—	—	1
Siderite	‰	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	2	1	—	2	—	—	899
Chlorite	‰	60	56	73	52	83	—	7	84	44	99	112	70	86	228	41	42	3	54	100	32	96	223	124	53	32	32
Biotite	‰	5	15	7	19	14	—	—	20	16	4	5	1	2	13	—	—	—	4	2	2	4	7	2	8	3	1

suggestion, based on particle-size distribution and stone content, that these horizons contain material derived from Chalky Boulder Clay. Most of the other sand minerals that might have been incorporated as part of the boulder clay material (apatite, collophane, siderite and chlorite), yet do not occur in the Stackyard profile, could have been removed by weathering. In the Cottenham profile (1), the amounts of flint, amphibole and garnet are slightly greater in the highest 38 cm than below, which suggests that a trace of boulder clay material occurs to this depth. In the Flitwick and Rowsham profiles, the fine sand fractions of the loamy horizons derived from colluvium are mineralogically similar to those of the upper horizons in the Stackyard profile.

Coarse silt mineralogy. The small amounts of coarse silt in the Lower Greensand are composed mainly of quartz, with subsidiary alkali felspar, glauconite and muscovite in the light fraction, and mainly zircon, tourmaline, epidote, rutile, anatase and chlorite in the heavy fraction (Table 4). The coarse silt of the Chalky Boulder Clay contains more felspar and muscovite, but less quartz and glauconite than that of the Lower Greensand. Siderite dominates the non-opaque minerals of its heavy fraction, but if this is removed (as it would be by weathering in the soils), the remaining non-opaque heavy silt mineral assemblage of the Chalky Boulder Clay contains less zircon, tourmaline, rutile, staurolite and kyanite than that of the Lower Greensand, but more epidote, zoisite, garnet, amphiboles, apatite, chlorite and biotite.

In the soil profiles the influence of different parent materials is more clearly portrayed in the coarse silt fractions than in the fine sands. In particular, in the Cottenham and Stackyard profiles the upward increase in the proportions of felspar, flint, epidote, garnet and amphiboles and concomitant decrease in quartz, zircon, tourmaline and rutile, which result from the superficial admixture of material derived from weathered Chalky Boulder Clay, are more evident in the coarse silts (Table 4) than in the fine sands (Table 3). This is because the proportion of the coarse silt derived from boulder clay is considerably greater than the proportion of the fine sand from the same source. In the Cottenham profile, 30–50% of the coarse silt in the highest 53 cm is from the boulder clay, and in the A and B horizons of the Stackyard profile almost all of it is, but of the fine sands in the same horizons probably $<5\%$ is derived from boulder clay in the Cottenham profile, and $<10\%$ in the Stackyard.

The higher horizons (Ap–Cg) of the Flitwick and Rowsham profiles, developed in the colluvial and Head deposits, have silt fractions that are mineralogically similar to those of the higher horizons of the Stackyard profile, except that they contain more chlorite and biotite; these two minerals may have been removed from the Stackyard A horizon by weathering. It is not possible to confirm the occurrence of loess even in the Cg horizon of the Rowsham profile from the silt mineralogy, because of the overall mineralogical similarity between loess and the silt from boulder clays. The 2Cg horizons of the Flitwick profile and the 2Cgk horizon of the Rowsham, all developed in the upper layers of the Upper Jurassic clays, contain a little more zircon and rutile and less epidote, amphibole and biotite, but otherwise have somewhat similar silt mineral assemblages to the overlying horizons. In these clay horizons, the total percentage of non-opaque heavy minerals in the coarse silt of the subsoil clay horizons is $<0{\cdot}1$, much less than that of the overlying horizons (Table 4). Taken with the overall similarity of the silt mineral assemblages, this suggests that the clay itself has few non-opaque heavy silt minerals, and that a small part of the coarse silt in the subsoil clay horizons was derived from the overlying Quaternary deposits, possibly by deep frost or other disturbance of the clay beneath a thin cover of Quaternary sediment. Analysis of deeper clay samples is needed to clarify this point.

The opaque heavy minerals in both the coarse silt and fine sand fractions of most of

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TABLE 5

Mineral composition of clay fractions (<2 μm) from Woburn soil profiles, and from Lower Greensand and Chalky Boulder Clay. Kaolinite, illite and interstratified smectite : illite are expressed as percentages of the total layer silicate minerals

Profile	1. Cottenham (SP 969359)					3. Stackyard (SP 966357)				4. Flitwick (SP 966357)								5. Rowsham (SP 967359)							Lower Greensand	Chalky Boulder Clay
Horizon Depth (cm)	Ap 6–15	Bw 25–38	BC1 41–51	BC2 55–65	BC2 70–79	Ap 0–7	AB 10–22	Bw 30–40	2C 60–70	Ap 0–13	AB 13–24	Bw(g) 26–50	BC(g) 60–72	Cg 100–130	2Cg1 168–184	2Cg2 190–220	2Cg3 235–255	Ap(g) 6–16	AB(g) 24–40	Bwg 42–52	BCg 63–80	Cg 83–100	2Cg 104–120	2Cgk 136–162	Mean of six samples	Mean of three samples
Kaolinite	6	6	2	3	0	10	10	10	4	10	15	15	15	10	0	3	2	10	10	15	10	10	10	15	2	15
Illite	30	35	35	30	40	30	25	30	35	20	25	30	20	25	15	20	10	10	15	10	15	25	25	30	33	30
Interstratified smectite : illite	65	60	65	65	60	60	65	60	60	70	60	55	65	65	85	75	90	80	75	75	75	65	65	55	65	55
Type of smectite : illite	S	S	S	S	S	SI	SI	SI	S	SI	SI	SI	SI	SI	S	S	S	S	S	S	S	S	S	IS	S	IS
Chlorite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	tr
Goethite	p	p	p	p	p	p	p	p	p	p	p	p	p	p	—	—	—	p	p	tr	—	—	—	—	p	—
Lepidocrocite	—	—	—	—	—	—	—	—	—	—	—	—	—	p	—	—	—	—	—	—	—	—	—	—	tr	—

p = present, tr = trace

the soil horizons and of the Lower Greensand comprise mainly haematite and limonite, with subsidiary magnetite and leucoxene (an opaque microcrystalline aggregate of TiO_2). Much of the limonite has been formed in the soils by oxidative weathering of glauconite from the Lower Greensand, and this mineral is consequently more abundant in the better drained profiles (Cottenham and Stackyard); otherwise there are no significant variations in the percentages of these minerals. Pyrites occurs in the subsoil clay horizons of the Flitwick and Rowsham profiles, but only in small amounts, and the acidity likely to be generated by weathering of this mineral in any of the Woburn soils would be slight, especially as the clays are very calcareous.

Clay mineralogy. The fine clay fractions ($<0{\cdot}04$ μm) separated from samples of Chalky Boulder Clay, Ampthill Clay (the 2Cg3 horizon of the Flitwick profile 4), the Lower Greensand and two surface soil horizons (the Ap horizon of the Flitwick profile 4, and the Ap(g) of the Rowsham profile 5) are all composed of randomly interstratified smectite-illite, but each has different proportions of smectite and illite interlayers. The proportions, determined from the positions of their basal reflections (Weir & Rayner, 1974), are: Chalky Boulder Clay smectite : illite 45 : 55, Ampthill Clay 76 : 24, Lower Greensand 70 : 30, Rowsham series Ap(g) horizon 72 : 28, Flitwick series Ap horizon 63 : 37.

In the whole clay fractions (<2 μm), the expanding minerals could be compared with those described above by the resolution of the first reflection of the glycol-solvated clays (Weir *et al.*, in the press), and could be grouped into those resembling the expanding mineral in the Chalky Boulder Clay, those similar to that in the Ap horizon of the Flitwick profile, and those like the more completely expanded mineral in the Ampthill Clay and Lower Greensand. The first is referred to as IS type (illite layers predominating over smectite) and the second as SI (smectite layers more abundant). The third is called S type, although it is not pure smectite; the Ampthill clay mineral contains 31 me/100 g non-exchangeable potassium, whereas, ideally, a smectite contains none.

In addition to the dominant S type expanding mineral, the small amount of clay (<2 μm) in the Lower Greensand contains much illite, little or no kaolinite, and some free iron oxide, part of which is crystalline goethite, and in some samples part is lepidocrocite. The Ampthill Clay also has S type expanding mineral and little or no kaolinite, but has less illite than the clay fraction of the Lower Greensand and no crystalline iron oxides. The Chalky Boulder Clay contains much illite and no crystalline iron oxides, but differs from the clay in the Lower Greensand and the Ampthill Clay in containing IS type expanding mineral, moderate amounts of kaolinite and a trace of chlorite (Table 5); this is identical to clay fractions (<2 μm) previously analysed from the Oxford Clay near Thame and elsewhere.

In the soil clays from profiles 1, 3, 4 and 5 the influence of different soil parent materials on the mineralogy is seen in the presence or absence of kaolinite and goethite and in the type of expanding mineral. The clay fraction of all horizons of the Cottenham profile (1) resembles that of the Lower Greensand, except that there are small amounts of kaolinite in the Ap and Bw horizons; this may be part of the small amount of material from Chalky Boulder Clay in these higher horizons, but such material has not detectably modified the expanding mineral. The clay fractions of the A and B horizons of the Stackyard profile (3) contain 10% kaolinite, SI type expanding mineral, and goethite, indicating admixture of clay from Chalky Boulder Clay with that from the Lower Greensand, but the 2C horizon has the same clay mineral suite as the Lower Greensand.

The A, B and Cg horizons of the Flitwick profile (4) contain clays that are mineralogically similar to those of the A and B horizons of the Stackyard profile, with evidence of minerals from both the Lower Greensand and Chalky Boulder Clay. The lepidocrocite

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in the Cg horizon probably formed, as a result of imperfect drainage, from amorphous iron oxides derived originally from Lower Greensand.

The clay subsoil horizon (2Cgk) of the Rowsham profile (5) contains kaolinite and IS type expanding mineral, and is thus different from the Ampthill Clay in the subsoil horizons of the Flitwick profile. In these respects it resembles Oxford Clay we have examined from sites in Buckinghamshire, and Chalky Boulder Clay, which is in turn derived largely from Oxford Clay. However, the subsoil clay of profile 5 is not boulder clay, as it contains no erratic stones and little or no fine sand and coarse silt mineralogically akin to that in the boulder clay, so it is probably Oxford Clay. In the overlying horizons the composition of the clay fractions suggests complex parentage of the soil material, as does the sand and silt mineralogy. The occurrence of kaolinite in all horizons suggests that Chalky Boulder Clay or Oxford Clay material is present throughout the profile. However, the expanding minerals in all horizons above the clay subsoil (2Cgk) are of the S type, and therefore derived from the Ampthill Clay and/or Lower Greensand, and the goethite in the three uppermost horizons is probably derived from the Lower Greensand. Taken with the evidence from the particle-size distribution and the fine sand and coarse silt mineralogy, this suggests that the clay in the 2Cg horizon and above is a mixture of those from Chalky Boulder Clay and Ampthill Clay, and that clay from Lower Greensand occurs in at least the three uppermost horizons.

Weathering seems to have had little effect on the clays in the soil profiles. In temperate conditions, weathering does not seem to affect kaolinite, although it often removes interlayer potassium from illite to increase the proportion of expanding (smectite) layers, and in moderately or strongly acid conditions may remove goethite and precipitate interlayer hydrated aluminium compounds to form chlorite-like minerals. However, in the four profiles examined (Table 5), there is no decline in goethite towards the surface, and the smectite : illite ratio of the interstratified expanding layer silicates is unchanged from the surface to the sub-surface horizons. For these minerals, weathering changes have failed to mask the influence of parent materials on the clay fraction of the soils.

Discussion and conclusions

In the fields considered here, almost all the soils that are on or near the Lower Greensand outcrop are affected to a greater or lesser extent by admixture of Quaternary sediment with the sand. The areas mapped as Cottenham series have insufficient Quaternary material to change the surface texture of the soil from the sand or loamy sand typical of the Lower Greensand into sandy loam, but even here the occurrence of small flint fragments in higher parts of the profile and the detailed mineralogical study of the fine sand and coarse silt fractions reported here both indicate that a little of the soil material is derived from weathered Chalky Boulder Clay. In the areas mapped as Stackyard series, the boulder clay admixture is enough to change the soil texture to sandy loam, usually to a depth of at least 40 cm. Although both series are well drained, the slightly greater water retaining capacity of the Stackyard series, which results in a slight greying of the soil in some horizons, is likely to affect the growth of some crops, especially in periods of prolonged summer drought.

The Chalky Boulder Clay, from which the additional silt and clay in the Stackyard and Cottenham soils was derived, does not occur *in situ* on any of the fields described here, but is present on slightly higher ground in Woburn Park south of the Woburn–Ridgmont road (A418). From this area the weathered, decalcified surface soil seems to have been washed downhill during periods of heavy rain, and mixed with sand eroded from the Lower Greensand on the slopes below. This colluvial mixture was deposited mainly on the floors of valleys, which had previously been cut through the Lower Greensand (and

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possibly also its boulder clay cover) into the underlying Ampthill Clay, but was also left partly as a thin veneer on the intervening slopes. Present day erosion on such a large scale is prevented by natural vegetation in the park and other factors, but does occur during and immediately after heavy rain on many of the fields, especially where the soil is not stabilised by grass or well-established crops. For example, during a storm in May 1973, when over 50 mm rain fell in an hour, there was severe sheet erosion on parts of Butt Close (Plate 4), and several centimetres of surface soil and many young potato plants were washed into the shallow valley south-west of the knoll in Butt Furlong, where water stood for many hours in large ponds. On the same occasion much surface soil from Great Hill was swept into the ditch west of Honey Pot field. The areas mapped as Stackyard and Flitwick series are essentially those receiving soil material during such periods of downslope movement.

On Butt Close, the field most frequently subject to erosion among those considered in this paper, the slopes affected are quite gentle (1–3°), and factors such as sudden flushes and the inherent erodibility of the soils on the Lower Greensand are mainly responsible for the movement. Erosion here is certainly aggravated during heavy rain by water running off the main road (A418) to the south, which is 1–2 m higher than the surface of the field. Nevertheless, it is surprising that during heavy rain little of the water penetrates such a light sandy soil that shows every evidence in its profile morphology of good drainage. The dusty surface of the Greensand soils after prolonged drought is noticeably difficult to wet, and for a short while there is little or no penetration, but this phenomenon does not explain the erosion of soil already quite moist. Penetration of water could also be limited by a 'plough pan' formed by smearing of the sub-surface soil when very wet during winter ploughing, or by compaction of the surface soil by heavy machinery. One cause of erosion is the weak structure of the soils. In the spring, light soils which have been autumn ploughed and left with unbroken ridges may be seen to have partially dispersed. The remnants of the ridges are noticeably sandy on their surfaces, whereas the former furrows are filled, and then coated with silt-rich material. Clay has moved further downslope and has been deposited in shallow depressions where it forms the beds of slow-draining ponds. Subsequent farming operations remix these thin surface coatings with the main bulk of topsoil, but the long-term effect of this dispersion and separation of sand, silt and clay affects the distribution of soil type; the heavier Stackyard and Flitwick series soils occur in the valley bottoms in Butt Close and Road Piece, and those of the lighter Cottenham series on higher ground.

The sequence of events that gave rise to the deposits on the north side of Great Hill (Figs. 1 and 3) may be summarised as follows. The topography of the area just before the advance of the ice during the Anglian Stage of the Quaternary was probably not very different from that observed today, because Chalky Boulder Clay occurs *in situ* at heights approximately equivalent to the highest point of Great Hill in Ridgmont village to the south-east, and also on the low ground on Pightle field to the west. The whole area was covered with ice at the maximum of the Anglian glacial advance, and blanketed with boulder clay after its retreat. The boulder clay was weathered and eroded during the subsequent warm periods of the Hoxnian or Ipswichian Stages to the extent that the surface of the Jurassic clays in Great Hill Bottom was completely cleared of it. By the time of the Wolstonian and Devensian cold Stages, the boulder clay on the highest land had been thinned sufficiently for its decalcified remnant to be incorporated into the underlying Lower Greensand by cryoturbation. Also during one of these cold periods, a Head of mixed sand and clay formed on the north side of Great Hill as a mud-flow forced upwards from the base of the Lower Greensand over a frozen outer lip of Ampthill Clay. This spread downslope over a frozen clay surface, and may have extended a long way, but subsequently has been truncated by stream erosion or buried by alluvium in

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the fields to the north (Broad Mead and Warren Field). It is thought to have formed in cold rather than temperate conditions, because a permanently frozen layer in the Lower Greensand is necessary to explain the initial upward movement of the Head over the lip of clay revealed by deep augering (Fig. 3). The sandy colluvium covering the Head was probably formed by soil erosion during a subsequent warmer period, and much of it, like the colluvium on Butt Close, was probably deposited in recent centuries after clearance of the natural vegetation.

Weathering changes have not affected the mineralogical composition of the soils very much, despite the long period of time that has elapsed since deposition of the Chalky Boulder Clay and the climatic fluctuations of the subsequent glacial and interglacial periods. Among the sand-sized minerals that occur in unweathered Chalky Boulder Clay, calcite, apatite, collophane, siderite, chlorite and pyrites have been removed by weathering from the boulder clay-derived material in the A and B horizons of the Stackyard profile. Changes in silt mineralogy indicate variations in the severity of weathering in different soil series. Thus, chlorite and biotite, which occur in unweathered boulder clay, persist in the boulder clay-derived material of the Flitwick and Rowsham profiles, but have been removed by weathering from the equivalent horizon of the Stackyard profile, which is better drained. The only weathering change in the clay minerals that can be recognised with certainty is the removal from the soils of the small amounts of chlorite that were derived from the boulder clay. Other changes looked for, such as the loss of potassium from illite and the resultant modification of expanding minerals, could not be confirmed. The probable reason for this is that all the soil parent materials contain illite and expanding minerals, and the changes in them produced by weathering are small compared with the original differences between them.

REFERENCES

AVERY, B. W., BULLOCK, P., CATT, J. A., NEWMAN, A. C. D., RAYNER, J. H. & WEIR, A. H. (1972) The Soil of Barnfield. *Rothamsted Experimental Station. Report for 1971*, Part 2, 5–37.

AVERY, B. W., BULLOCK, P., WEIR, A. H., CATT, J. A. ORMEROD, E. C. & JOHNSTON, A. E. (1969) The Soils of Broadbalk. *Rothamsted Experimental Station. Report for 1968*, Part 2, 63–115.

BARNARD, T. (1952) Foraminifera from the Upper Oxford Clay (Jurassic) of Warboys, Huntingdonshire. *Proceedings of the Geologists' Association* **63**, 336–350.

BRISTOW, C. R. (1963) *Upper Jurassic and Lower Cretaceous Rocks in the area between Aylesbury (Bucks.) and Leighton Buzzard (Beds.)*. Ph.D. Thesis, London University, 510 pp.

BRISTOW, C. R. & COX, F. C. (1973) The Gipping Till: a reappraisal of East Anglian glacial stratigraphy. *Journal of the Geological Society* **129**, 1–37.

CAMERON, A. C. G. (1894) Geology, mining and economic uses of Fullers' Earth. *Transactions of the Institute of Mining Engineers* **6**, 204–209.

COCHRAN, W. G. (1936) Part II. Statistical examination of the results. In: *Fifty years of field experiments at the Woburn Experimental Station.* Eds. E. J. Russell and J. A. Voelcker. London: Longmans, Green and Co., xvii + 392 pp.

CROWTHER, E. M. (1936) Part IV. The soils of the Woburn plots. In: *Fifty years of field experiments at the Woburn Experimental Station.* Eds. E. J. Russell and J. A. Voelcker. London: Longmans, Green and Co., xvii + 392 pp.

EDMONDS, E. A., WRIGHT, J. E., BEER, K. E., HAWKES, J. R., WILLIAMS, M., FRESHNEY, E. C. & FENNING, P. J. (1968) Geology of the country around Okehampton. *Memoir of the Geological Survey of Great Britain*, xii + 256 pp.

FLETCHER, B. N. (1962) Some Holothurian Spicules from the Ampthill Clay of Melton, near Hull, Yorkshire. *Geological Magazine* **99**, 322–326.

GORDON, W. A. (1962) Some Foraminifera from the Ampthill Clay, Upper Jurassic, of Cambridgeshire. *Palaeontology* **4**, 520–537.

GORDON, W. A. (1965) Foraminifera from the Corallian Beds, Upper Jurassic, of Dorset, England. *Journal of Palaeontology* **39**, 828–863.

HODGE, C. A. H. & SEALE, R. S. (1966) The soils of the district around Cambridge. *Memoir of the Soil Survey of Great Britain*, vii + 183 pp.

JARVIS, M. G. (1973) Soils of the Wantage and Abingdon district. *Memoir of the Soil Survey of Great Britain*, viii + 200 pp.

KEEPING, W. (1883) On the occurrence of Neocomian sands with phosphatic nodules at Brickhill, Bedfordshire. *Geological Magazine*, **]**372–375.

https://doi.org/10.23637/ERADOC-1-9

KING, D. W. (1969) Soils of the Luton and Bedford District. A reconnaissance survey. *Soil Survey Special Survey* No. 1, iv + 39 pp.
KITTRICK, J. A. & HOPE, E. W. (1963) A procedure for the particle-size separation of soils for X-ray diffraction analysis. *Soil Science* **96**, 319–325.
NEWTON, E. F. (1937) The petrography of some English Fullers' Earths and the rocks associated with them. *Proceedings of the Geologists' Association* **48**, 175–197.
PERRIN, R. M. S., DAVIES, H. & FYSH, M. D. (1973) Lithology of the Chalky Boulder Clay. *Nature, London (Physical Science)* **245**, 101–104.
REID, C., BARROW, G. & DEWEY, H. (1910) The geology of the country around Padstow and Camelford. *Memoir of the Geological Survey of Great Britain.*
REID, C., BARROW, G., SHERLOCK, R. L., MACALISTER, D. A., DEWEY, H. & BROMEHEAD, C. E. N. (1912) The geology of Dartmoor. *Memoir of the Geological Survey of Great Britain.*
WEIR, A. H. & RAYNER, J. H. (1974) An interstratified illite-smectite from Denchworth series soil in weathered Oxford Clay. *Clay Minerals* **10**, 173–187.
WEIR, A. H., ORMEROD, E. C. & EL MANSEY, I. M. I. (In the press) Clay mineralogy of sediments of the Western Nile Delta. *Clay Minerals* **11**.
WHATLEY, R. C. (1964) *Callovian and Oxfordian Ostracoda from England and Scotland.* Ph.D. Thesis, Hull University, 591 pp.
WOODWARD, H. B. & THOMPSON, B. (1909) Water supply in Bedfordshire and Northamptonshire from underground sources. *Memoir of the Geological Survey of Great Britain*, 230 pp.

APPENDIX A

Profile descriptions

1 *Cottenham series*

Location: Great Hill I, level site near summit of hill (SP 969359).
Land use: Grassland.

Ap	0–15 cm	Very dark greyish brown (10 YR 3/2) friable loamy sand to sandy loam; very few small subangular carstone fragments; moderately developed fine subangular blocky structure; abundant fine fibrous and common small rhizomatous roots; narrow even boundary.
AB	15–22 cm	Brown (10 YR 4/3) friable loamy sand with very few small carstone fragments; weakly developed medium subangular blocky structure; common fine fibrous roots; earthworm channels filled with topsoil; narrow irregular boundary.
Bw	22–40 cm	Brown (7·5 YR 4/4) very friable loamy sand with a few carstone fragments; structure, roots and earthworm channels as above; merging boundary.
BC1	40–53 cm	Strong brown (7·5 YR 5/6) very friable loamy sand with very few carstone fragments; very weakly developed medium subangular blocky structure; roots and earthworm channels as above; merging boundary.
BC2	53–90 cm	Yellowish brown to brownish yellow (10 YR 5–6/6) loose loamy sand, with a few brown (7·5 YR 4/2) lamellae up to 2 cm thick; very few carstone fragments; very weakly developed medium subangular blocky structure, or structureless; common fine fibrous roots concentrated in earthworm channels.

2 *Cottenham series*

Location: Great Hill II, level site near summit of hill, close to convex slope to west (SP 968357).
Land use: Arable.

Ap	0–15 cm	Dark brown (10 YR 4/3) loamy sand with very few small flints and carstone fragments; very weakly developed fine subangular blocky to medium crumb structure; loose to friable; abundant fine and small fibrous roots; narrow even boundary.
AB	15–30 cm	Brown (10 YR 4/3) friable loamy sand with very few small flints and carstone fragments; very weakly developed fine subangular blocky structure; frequent fine fibrous roots; narrow irregular boundary.
Bw	30–46 cm	Dark yellowish brown (10 YR 4/4) slightly compacted loamy sand, with very few small carstone fragments; sharp irregular boundary.
2C	46 cm+	Loose, pale yellowish brown sand.

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3 *Stackyard series*

Location: Road Piece, 3° slope to north (SP 966357).
Land use: Arable.

Ap	0–7 cm	Very dark greyish brown (10 YR 3/2) sandy loam with few gravel-size carstone fragments and rounded and subangular flints; friable to hard; moderately developed platy to medium subangular blocky structure; merging boundary.
AB	7–25 cm	Very dark greyish brown (10 YR 3/2) friable sandy loam with stones as above; very weakly developed fine to medium subangular blocky structure; narrow boundary.
Bw	25–48 cm	Dark brown (10 YR 3/3) friable sandy loam with stones as above; weakly developed fine to medium subangular blocky structure; sharp boundary.
2C	48–88 cm	Dark yellowish brown (10 YR 4/4) very friable stoneless loamy sand; very weakly developed fine to medium subangular blocky structure.

4 *Flitwick series*

Location: Road Piece, 1° slope to north, near foot of concave slope (SP 966357).
Land use: Arable.

Ap	0–13 cm	Dark brown (10 YR 3/3) friable sandy loam, with a few small carstone fragments; weakly developed medium subangular blocky structure; common fine fibrous roots; merging boundary.
AB	13–24 cm	Dark brown (10 YR 3/3) friable sandy loam, with stones and structure above; few fine fibrous roots; sharp even boundary.
Bw(g)	24–53 cm	Brown (7·5 YR 4/4) very friable sandy loam, with common faint fine to medium brown (10 YR 5/3) and yellowish brown (10 YR 5/4) mottles; stoneless; weak medium subangular blocky structure; very rare fibrous roots; sharp even boundary.
BC(g)	53–83 cm	Brown (7·5 YR 4/4) sandy clay loam, with common faint fine to medium yellowish brown (10 YR 5/4) mottles; slightly sticky, slightly plastic; stoneless; coarse subangular blocky structure; no roots; sharp irregular boundary.
Cg	83–160 cm	Light olive-brown (2·5 Y 5/4) sandy clay loam, with many fine to medium prominent strong brown (7·5 YR 5/8) mottles; slightly sticky, slightly plastic, firm; coarse subangular blocky structure; towards the base becomes more friable with pockets of dark yellowish brown (10 YR 4/4) sandy loam; sharp irregular boundary.
2Cg1	160–188 cm	Dark grey (5 Y 4/1) clay, with common prominent medium yellowish brown (10 YR 5/6) mottles; plastic, sticky; calcareous with small pale grey secondary carbonate concretions; merging boundary.
2Cg2	188–226 cm	Grey (5 Y 6/1) very calcareous silt loam, with many prominent medium and large brownish yellow (10 YR 6/6) mottles; stony in part; merging boundary.
2Cg3	226 cm+	Dark grey (5 Y 4/1) calcareous clay, with many distinct medium and large yellowish brown (10 YR 5/6) mottles.

5 *Rowsham series*

Location: Great Hill Bottom, near foot of 6° north-west facing concave slope (SP 967359).
Land use: Grassland.

Ap(g)	0–18 cm	Very dark greyish brown (10 YR 3/2) friable sandy clay loam, with common fine and very fine reddish brown (5 YR 4/3) mottles; a few small and gravel-size flint and carstone fragments; moderate fine subangular blocky structure; abundant fine fibrous roots; sharp even boundary.
AB(g)	18–42 cm	Dark greyish brown (10 YR 4/2) friable sandy clay loam with common fine to medium reddish brown (5 YR 4/3–4/4) mottles; stones as above; fine to medium subangular blocky structure; common fine fibrous roots; merging boundary.
Bwg	42–53 cm	Dark greyish brown (10 Y 4/2) slightly plastic clay loam, with common fine yellowish red (5 YR 4/8) mottles; stones as above; weak fine subangular blocky structure; a few fine ferruginous concretions; common fine fibrous roots; merging boundary.
BCg	53–82 cm	Dark greyish brown (2·5 Y 4/2) to olive-brown (2·5 Y 4/4) slightly plastic clay loam, with common fine strong brown (7·5 YR 5/8) mottles; rare

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		carstone fragments; weak fine prismatic, breaking to fine subangular blocky structure; common fine manganiferous concretions; rare fine fibrous roots; sharp even boundary.
Cg	82–104 cm	Yellowish brown (10 YR 5/6) slightly plastic clay loam, with common greyish brown (2·5 Y 5/2) mottles; stoneless; structureless; rare manganiferous concretions; very rare fine fibrous roots; narrow boundary.
2Cg	104–120 cm	Grey (5 BG 5/1) plastic clay, with abundant streaks and patches of yellowish brown (10 YR 5/6) clay loam, which become less common with depth; a few black nodules; merging boundary.
2Cgk	120–180 cm	Grey (10 B 4/1) calcareous plastic clay, with many medium light olive-brown (2·5 Y 5/6) mottles; shell fragments occur throughout, and small secondary carbonate concretions to *c.* 150 cm; yellowish red (5 YR 4/6) ferruginous concretions common near 180 cm.

6 *Evesham series*

Location: Great Hill Bottom, near foot of 6° north-west facing concave slope (SP 967359).
Land use: Grassland.

Ap(g)	0–16 cm	Very dark greyish brown (2·5 Y 3/2) slightly plastic clay loam, with rare very fine rusty mottles along root channels; very few small flint and carstone fragments; weakly developed fine blocky to crumb structure; abundant fine fibrous roots; narrow even boundary.
ABw	16–28 cm	Dark greyish brown (2·5 Y 4/2) slightly plastic calcareous clay loam; very few gravel-size flints; moderate fine subangular blocky structure; common fine fibrous roots; narrow even boundary.
B(g)k	28–70 cm	Grey (5 Y 5/1) plastic calcareous clay, with common fine and medium yellowish brown (10 YR 5/6) mottles; very few gravel-size flints; medium prismatic and coarse subangular blocky peds with gleyed faces; common fine fibrous roots concentrated on ped faces; common small secondary carbonate concretions; merging boundary.
Cg	70 cm+	Grey (5 Y 5/1) and yellowish brown (10 YR 5/4) massive plastic calcareous clay, with a few gleyed structural faces; common small secondary carbonate concretions; few fine fibrous roots.

APPENDIX B

Micropalaeontological Report on the Ampthill Clay from the Flitwick Profile (1·88–2·26 m depth), Road Piece

By R. C. Whatley

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Foraminiferida

1. *Rheophax* sp. cf. *R. hounstoutensis* Lloyd 1959. The species present is larger and consists of coarser agglutinated fragments than *R. hounstoutensis,* which was described from the Kimmeridgian of the Dorset coast.
2. *Ammobaculites coprolithiformis* (Schwager) 1867. Range at least Bajocian to Kimmeridgian; recorded from the Corallian of Dorset and the Ampthill Clay of Cambridgeshire (Gordon, 1962).
3. *Textularia pugiunculus* (Schwager) 1865. Range Oxfordian to Kimmeridgian.
4. *Lenticulina muensteri* (Roemer) 1839. Range Jurassic to Cretaceous; reported from Ampthill Clay (Gordon, 1962).
5. *Lenticulina suprajurassica* Gordon 1962. Recorded from the Ampthill Clay (Gordon, 1962).
6. *Lenticulina tricarinella* (Reuss). Range Bajocian to Lower Cretaceous.
7. *Falsopalmula anceps* (Terquem) 1870. Range Bajocian to Upper Oxfordian; present in Ampthill Clay (Gordon, 1962).
8. *Vaginulina barnardi* Gordon 1965. Reported only from the Corallian of the Dorset coast (Gordon, 1965).
9. *Citharina serratocostata* (Gümbel) 1862. Range Bajocian to Lower Cretaceous; common in the Ampthill Clay (Gordon, 1962).
10. *Planularia fraasi* (Schwager) 1865. Range Liassic to Upper Jurassic; common in Ampthill Clay (Gordon, 1962).

11. *Frondicularia irregularis* Terquem 1870. Range Jurassic; reported from the Upper Oxford Clay of Huntingdonshire (Barnard, 1952), but not from the Ampthill Clay.
12. *Dentalina gumbeli* Schwager 1865. Range Jurassic; common in the Corallian of Dorset (Gordon, 1965).
13. *Tristix oolithica* (Terquem) 1886. Range Bathonian to Portlandian; recorded from Ampthill Clay (Gordon, 1962) and Corallian of Dorset (Gordon, 1965).
14. *Eoguttulina liassica* (Strickland) 1846. Range Liassic to Kimmeridgian.
15. *Lenticulina* sp.
16. *Frondicularia* sp.
17. *Patellina* sp.
18. ?*Ammodiscus* sp.

Ostracoda

1. *Cytherella depressa* Donze 1962. Described from the Upper Oxfordian (*cautisnigrae* zone) of south-east France; occurs in the Ampthill Clay near Ridgmont (Whatley, 1964).
2. *Galliaecytheridea wolburgi* (Steghaus) 1951. Range Upper Oxfordian to Lower Kimmeridgian; reported from the *cautisnigrae* zone in Dorset, Cambridgeshire and East Yorkshire (Whatley, 1964).
3. *Galliaecytheridea postrotunda postrotunda* Oertli 1957. Common in the Upper Oxfordian and Corallian, but not hitherto reported from the Ampthill Clay.
4. *Galliaecytheridea nitida* Whatley MS. Reported from the *plicatilis* zone (Corallian) of Dorset, Berkshire and Oxfordshire (Whatley, 1964).
5. *Vernoniella caletorum* Oertli 1958. Range Lower and Upper Oxfordian; common in the *plicatilis* and *cautisnigrae* zones in Britain (Whatley, 1964).
6. *Mandelstamia angulata* Kilengi 1961. Range Lower Oxfordian to Lower Kimmeridgian in Britain.
7. *Procytherura tenuicostata* Whatley 1970. Range Oxfordian; common in the Ampthill Clay.
8. *Eucytherura* (*Vesticytherura*) *costaeirregularis* Whatley 1970. Range Callovian to Upper Oxfordian (*cautisnigrae* zone).
9. *Eucytherura* (*Vesticytherura*) *gruendeli* Whatley MS. Range Lower to Upper Oxfordian (*mariae* to *cautisnigrae* zones); occurs in the Ampthill clay near Ridgmont (Whatley, 1964).
10. *Procytheropteron parvaesulcata* Whatley MS. Range Oxfordian (*mariae* to *pseudocordata* zones).
11. *Lophocythere* (*Neurocythere*) *corrugatocostata* Whatley MS. Previously reported only from the *plicatilis* zone in Dorset (Whatley, 1964).
12. *Lophocythere* (*Neurocythere*) *multicostata* Oertli 1957. Abundant in Upper Oxfordian (*plicatilis* and *cautisnigrae* zones).
13. *Bairdia* sp. A. Whatley MS. Reported from the *plicatilis* zone of Upper Oxfordian in Dorset, Berkshire and Oxfordshire (Whatley, 1964).
14. *Procytheropteron* sp.

Holothuroidea

1. *Achistrum* (*Cancellrum*) *bichordata* Fletcher 1962. Described from the Ampthill Clay, East Yorkshire (*cautisnigrae* zone) (Fletcher, 1962).
2. *Achistrum* (*Cancellrum*) *monocordata* Hodson, Harris and Lawson 1956. Range Oxfordian (*cordatum* to *cautisnigrae* zones).
3. *Achistrum* (*Achistrum*) cf. *issleri* (Croneis) 1932. *A.* (*A.*) *issleri* has been reported from the Lower Oxfordian (*cordatum* zone) in Dorset and the Ampthill Clay (*cautisnigrae* zone) in East Yorkshire (Fletcher, 1962).
4. *Theelia* sp.
5. *Rhabdodites* sp.

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