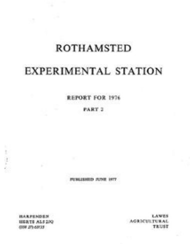
ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1976, Part 2


ROTHAMSTED
EXPERIMENTAL STATION
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The Soils of Woburn Experimental Farm II. Lansome, White Horse and School Fields

J. A. Catt, A. H. Weir, D. W. King, H. H. Le Riche, G. Pruden and R. E. Norrish

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The Soils of Woburn Experimental Farm

II. Lansome, White Horse and School Fields

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Introduction

We continue our detailed description of the soils of Woburn Experimental Station with those of the fields extending south-westwards from the farm buildings as far as School Lane (Table 1); Mill Dam Close II and III are included with Lansome, but Mill Dam Close I is omitted, as it is not used for arable crops or experiments.

The boundary between the Lower Greensand and Upper Jurassic clays lies immediately south and west of the laboratory and farm office (Fig. 1), and gives rise to strong springs in the lowest part of Lansome (previously Mill Dam Close II) and at the western side of Mill Dam Close I. However, the clays are covered by several metres of made ground beneath and west of the laboratory, and do not appear at the surface here. All the fields south-west of the boundary are underlain by Lower Greensand, which is in turn covered by Chalky Boulder Clay on the south-western side of School Field.

From the lowest part of Lansome adjacent to the laboratory (at 84 m O.D.), the ground rises south-westwards to just over 92 m O.D. on either side of the hedge between Lansome and White Horse Fields, then declines to a dry valley running SSE–NNW obliquely to the boundary between White Horse and School Fields, before rising again to just over 91 m O.D. at Husborne Crawley School. Another shallow dry valley heads in the south-eastern corner of White Horse Field and runs SSW–NNE along the south-eastern side of Lansome, where it joins the slightly deeper valley that crosses Butt Furlong and Butt Close and heads on the south-western flank of Great Hill (Catt *et al.*, 1975, Fig. 2). Both this and the dry valley along the boundary between White Horse and School Fields probably originated as tributaries of the Crawley Brook, which earlier flowed some distance to the north and west of the farm but now occupies a closer and largely artificial course. However, in past periods both valleys ended temporarily in small lakes or marshy areas, which at their maximum extent encroached on to the lowest parts of the fields we are considering. A mill pond on Mill Dam Close is shown on maps up to 1850, which were made available to us by Mr. J. Collett-White of the Bedfordshire County Records Office, Bedford, but does not appear on the 1884 edition of the Ordnance Survey, and was therefore drained some time between these two dates. Although it may have been partly supplied by the springs issuing from the base of the Lower Greensand, the early maps show it was also fed by a stream diverted from the Crawley Brook and originally entering the pond at its north-western end. Following enclosure about 1800, the feeder stream was diverted to run along the present north-western boundary of Lansome and along the hedgeline (now removed) between Lansome and Mill Dam Close, thus entering the somewhat enlarged pond from the south. By 1850 a second smaller pond north-west of the main one was being supplied by a new feeder stream from the north-west, but by 1884 both ponds had disappeared, and water from the springs was being diverted to the north-west of the laboratory area. The main field boundaries shown in Figs. 1 and 2 were established around 1800, before which time the area considered was largely in strip cultivation.

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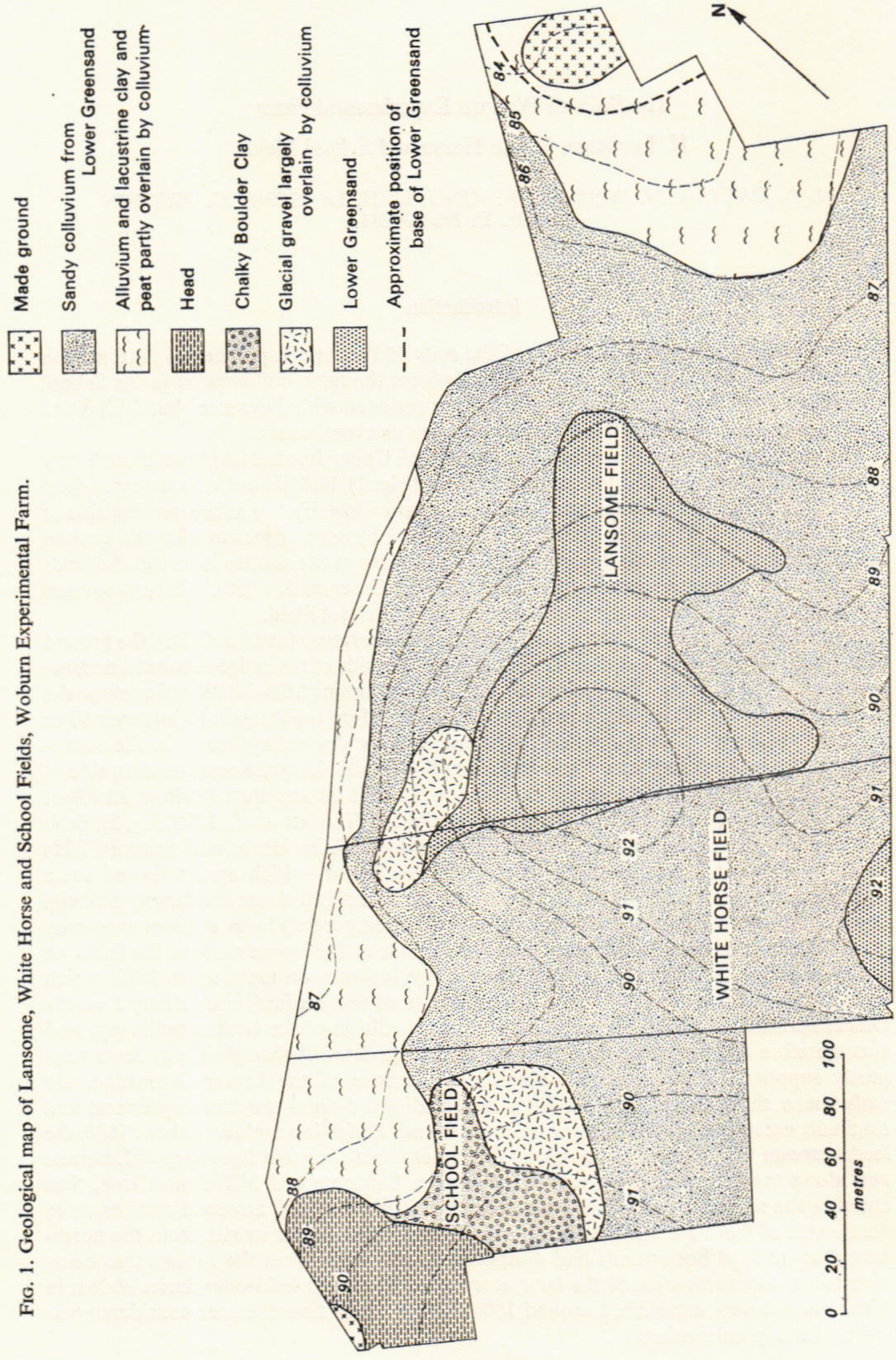

FIG. 1. Geological map of Lansome, White Horse and School Fields, Woburn Experimental Farm.

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FIG. 2. Distribution of soil types on Lansome, White Horse and School Fields, Woburn Experimental Farm, with the location of analysed profiles (1–7) and the surface topography shown by contours at metre intervals above ordnance datum.

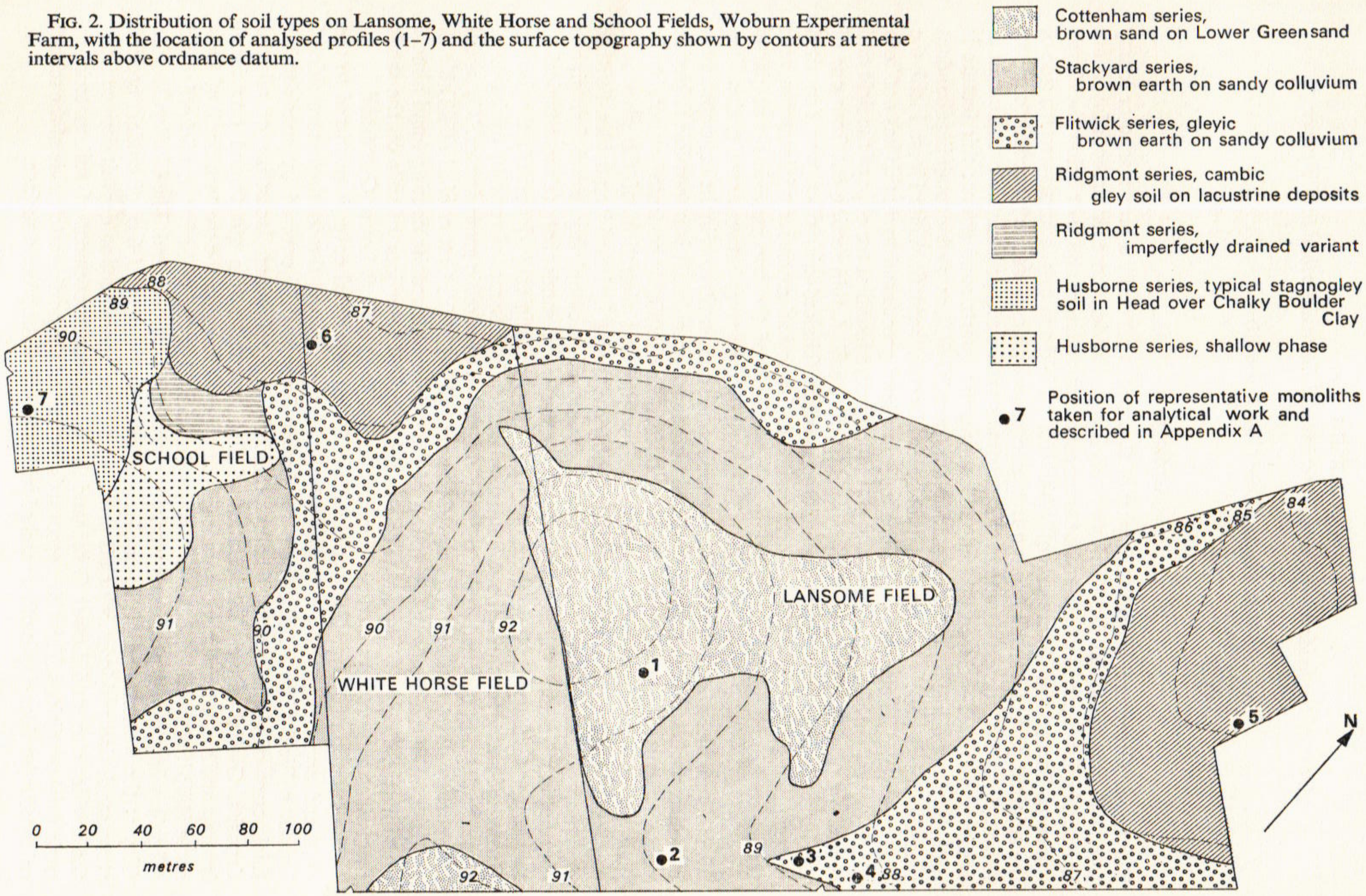

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TABLE 1

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

	ha
Lansome (including Mill Dam Close II and III)	4·95
White Horse	2·04
School	1·66

Geology

The Lower Greensand beneath this part of the farm is generally a brown sand or loamy sand with occasional thin (< 1 cm) grey clay layers. Redder, more ferruginous layers are irregularly distributed through it, but are most common either above or below the clayey horizons. Beneath the lower parts of White Horse Field and on the north-western side of the adjacent part of Lansome, it is a true greensand with a moderate glauconite content. Although part of the glauconite in this occurs as sand-sized pellets, microscopic examination shows that most occurs only as coatings on quartz sand grains; this feature is probably responsible for the pale green colour (near 5G 6/2), as sands containing abundant true glauconite pellets are much darker green. Locally beneath White Horse Field the pale green sand is cemented with silica to form a hard green sandstone; this has not been found *in situ*, but two large blocks 40–50 cm long were found at the edge of the field and several small pieces were also found in the surface soil. A thin section cut from one of the large blocks showed that the microcrystalline (chalcedonic) silica was deposited between the glauconite-coated quartz grains, and also had extensively intergrown with the green fibrous glauconite, as though deposition of the two materials was partly contemporaneous. Parts of the rock with almost all the spaces between sand grains filled with this mixture of chalcedony and glauconite were almost vitreous in the hand specimen, but other parts with many spaces unfilled were more granular. It is impossible to decide whether the porous parts of the rock were once more completely cemented or not, but in their present condition they commonly show incipient alteration of the glauconite coatings to a brownish clayey mixture probably containing hydrated iron oxides. Further oxidation of the coatings would give sand grains with a completely brown ferruginous clay coating, similar to those which constitute the brown sands that are more typical of the Lower Greensand. It is therefore likely that, as originally deposited, the Lower Greensand was green throughout, but has subsequently been made brown by oxidation of these coatings on the sand grains through the action of aerobic groundwater. The small amounts of clay found in the Lower Greensand (0·3–12·9%, Catt *et al.*, 1975, Table 2) probably arise mainly from disruption of the oxidised glauconite coatings, and almost certainly these play an important role in the chemical behaviour of soils on the sands themselves and on the superficial deposits derived largely from Lower Greensand.

The outcrop of Lower Greensand with < 80 cm superficial cover is restricted to the crest and upper slopes of Lansome Hill, the high ground on the south-western side of Lansome Field (Fig. 1). Elsewhere the Lower Greensand is covered by considerable thicknesses of glacial gravel, Chalky Boulder Clay, colluvium, lacustrine or alluvial deposits. Glacial gravel with erratics of flint, quartzite, vein quartz and occasional igneous and metamorphic rocks underlies sandy colluvium on the western flank of Lansome Hill; it also occurs beneath Chalky Boulder Clay and colluvium on School Field (Fig. 1), where it was previously worked in pits at the western end. The Chalky Boulder Clay at the western end of School Field is overlain by up to 1·6 m of crudely bedded stony sand, clay and loam, which is probably a Head or solifluction deposit derived from the boulder clay and Lower Greensand by downslope movement of soil material in periglacial conditions. This thins eastwards, so that on the north-eastern side of the school calcareous boulder clay is often reached within 60 cm of the ground surface.

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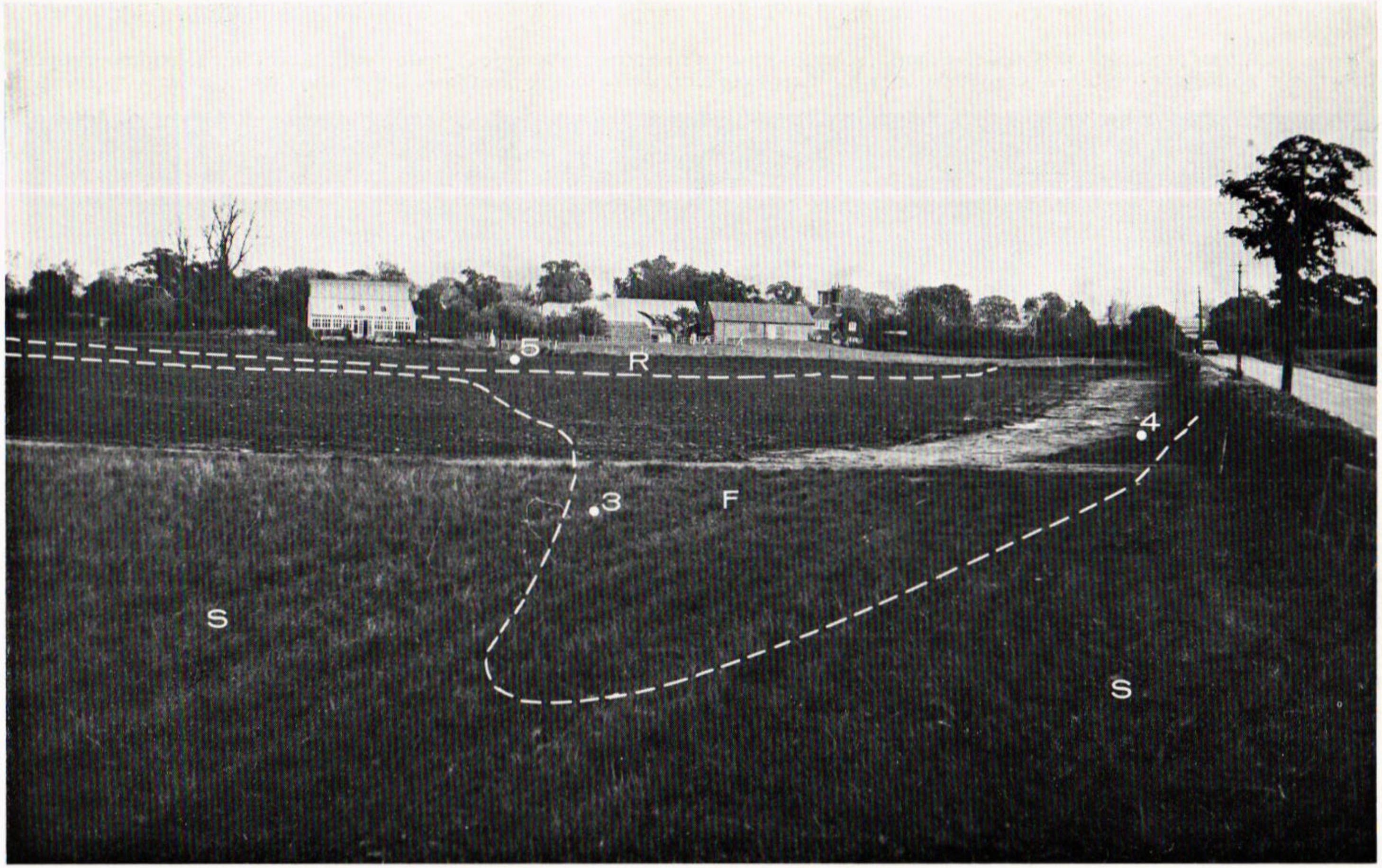

PLATE 1. View of Lansome Field from near its south-east corner, showing the distribution of soil types on part of the Market Garden experiment (foreground) and on the site of the old mill pond, and the location of analysed profiles 3, 4 and 5 (S: Stackyard series, F: Flitwick series, R: Ridgmont series).

(*Facing page 8*)

PLATE 2. View of White Horse (foreground) and School Fields from the summit of Lansome Hill, showing the distribution of soil types, and the location of analysed profiles 6 and 7 (S: Stackyard series, F: Flitwick series, R: Ridgmont series, H: Husborne series).

The lacustrine deposits occupy two small areas, one in the north-western parts of School and White Horse Fields, and the other at the north-eastern end of Lansome Field (previously Mill Dam Close II). In both areas a typical succession is pale grey silty clay, often with fine ochreous mottles, over a thin well-humified peat or humose clay, over gravelly sand, which rests in turn on gleyed Lower Greensand. Radiocarbon dating of a humified peat from a depth of 105–118 cm near the boundary between White Horse and School Fields (National Grid Ref. SP 960359) gave the age 3085 $\pm$ 85 years B.P. (Birm. 761), which suggests the lake there was in existence, possibly surrounded by forest, up to the Middle or Late Bronze Age, but was silted-up soon after. Alluvial deposits occupy a narrow zone along part of the western side of Lansome, but are almost entirely overlain by colluvium. As colluvium has also encroached over most of the lacustrine deposits in White Horse Field, it is difficult to draw a boundary between these and the alluvium, so they have been grouped together in Fig. 1. Elsewhere in the area under consideration colluvium of slightly stony sandy loam or sandy clay loam at least 80 cm thick mantles all the lower slopes and partly fills the dry valleys; in the central parts of the valleys it is 2–4 m thick. A thin layer also overlies marginal parts of the lacustrine deposits at the north-eastern end of Lansome; this must have been deposited after the lake there was drained in the mid-nineteenth century and testifies to the extremely recent origin of much of the colluvium as a result of soil erosion.

Soils: distribution and profile morphology

The distribution of different soil types was determined by augering at closely spaced intervals, and the detailed morphological features of profiles representing the main soil series were examined in monoliths taken with the Proline corer. Fig. 2 shows the distribution of soil types, and descriptions of the representative profiles are given in Appendix A.

Well-drained soils on Lower Greensand. The distinction between Cottenham series (a brown sand on Lower Greensand *in situ* or on sand or loamy sand colluvium derived mainly from the Lower Greensand) and Stackyard series (a brown earth in sandy loam or sandy clay loam colluvium overlying Lower Greensand at depth) recognised elsewhere on the farm (Catt *et al.*, 1975, 11–12) has also been made in the present work. Cottenham series occurs on the crest and upper slopes of Lansome Hill and a subsidiary knoll at the south-eastern end of White Horse Field (Fig. 2). However, it is probably only on the crests that the soils are developed in Lower Greensand *in situ*; the broad tongues spreading down the marginal slopes below the crest of Lansome Hill are largely in colluvium which becomes slightly loamier downslope, and the transition to Stackyard series is drawn where more than half the top 80 cm of the profile is as fine-textured as sandy loam. In some parts of Lansome where Cottenham series in loamy sand colluvium is shown low on the marginal slopes, the colluvium becomes distinctly heavier with depth, probably because the more recent phases of soil movement on the slopes have involved erosion of the Lower Greensand with no loamy cover near the hill crest. The almost complete absence of Cottenham series in White Horse Field south-west of the hedge that crosses Lansome Hill suggests that most of the less loamy colluvium has been deposited since that hedge was established. Stackyard series has also been mapped in areas where loamy colluvium overlies glacial gravel, in particular on parts of School Field and the south-west corner of Lansome. Monoliths representative of the Cottenham and Stackyard series were taken from either end of the area occupied by the Market Garden experiment (1942–76) on Lansome (profiles 1, SP 962359 and 2, SP 962358 respectively).

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Imperfectly drained soils in colluvium. Soils grouped with the Flitwick series occur on the dry valley floors where the colluvium is thick and soil drainage imperfect despite the presence of Lower Greensand at depth. The field distinction between Flitwick and Stackyard series is based upon the presence or absence respectively of distinct mottling within 90 cm of the surface. In some of the Flitwick profiles (e.g. profile 3, SP 963358 on the Market Garden experiment) the mottling is weak at 40–50 cm depth and becomes stronger with pale grey colours at 80–90 cm, whereas in others (e.g. profile 4, SP 963359) the mottling is more obvious with reddish brown and grey colours appearing just below 40 cm. The more strongly gleyed profiles occur in strips in the lowest, central parts of the valleys, where the colluvium is thickest and often slightly less sandy below the surface.

On part of the north-western side of Lansome, on some of the lower parts of White Horse and School Fields and near the north-eastern corner of Lansome, Flitwick series is mapped in relatively thin colluvium over alluvial or lacustrine deposits. In these areas the subsoil horizons at 60 cm or below are distinctly finer in texture and are more poorly drained than in Flitwick profiles elsewhere, but separation of these soils as a distinct series is not justified, because the areas involved are small, and they may be regarded as an intergrade between the Flitwick and Ridgmont series.

Poorly drained soils in lacustrine deposits. These soils, which occupy the lowest areas where small lakes once existed, have dark brown clay loam to sandy clay loam surface horizons, and usually dark reddish brown or grey clay loam subsurface horizons. However, there is locally a fairly abrupt change to very wet, mottled loamy sand or gravelly sand at 30–50 cm (e.g. profile 5, SP 964360). The deeper profiles (e.g. profile 6, SP 960359) have black, humose or peaty clay subsoil horizons, often with a thin, brown, wet gravelly sand below, resting on Lower Greensand usually at depths greater than 1·3 m. In some deep profiles on the north-eastern part of Lansome (formerly Mill Dam Close), a thin, pale grey silty clay with ochreous mottles occurs between the peaty horizon and the reddish brown clay loam above.

Pending correlation with similar soils elsewhere in Britain, we propose to call this cambic gley soil (Avery, 1973) the Ridgmont series. Its clay loam surface and subsurface horizons have a moderately well-developed and fairly stable fine subangular blocky structure, and are slightly sticky and plastic when wet. In these respects it differs from the less clayey soils already described, and it is important that the differences in soil workability are emphasised by recognition of a different series.

A small area of an imperfectly (i.e. better) drained variant of the Ridgmont series has been separated on School Field (Fig. 2), where thin, marginal parts of the clayey lacustrine deposits overlie glacial gravel and/or Lower Greensand, generally with no intervening organic layer. These soils have uniform brown (10YR 5/3) subsurface horizons, and show no evidence of gleying within at least 75 cm of the surface.

Poorly drained soils in Head over Chalky Boulder Clay. These soils, which we name the Husborne series, occur only towards the south-western corner of School Field, and can be divided into deep and shallow phases depending on the depth at which calcareous boulder clay is reached. The deep phase, exemplified by profile 7 (SP 960358), has brown, slightly stony surface and subsurface horizons of sandy loam or sandy clay loam texture, and mottled subsoil horizons which are generally finer in texture and more stony; these rest on grey and often olive-mottled calcareous stony clay (Chalky Boulder Clay) at depths of 1·0–1·6 m, sometimes with intervening horizons of crudely bedded alternating sandy and clayey layers. The shallow phase has somewhat finer textured surface and subsurface horizons than the deep phase, and Chalky Boulder Clay occurs at 40–100 cm depth.

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TABLE 2

Particle-size distribution at whole ϕ intervals ($\phi = -\log_2$ [particle size in mm]) of soil samples from profiles in Lansome, White Horse and School Fields at Woburn Experimental Farm (weight percentages of oven dry, decalcified and peroxidised soil < 2 mm)

Size fractions (μm)	φ Equivalent	Profile	1. Cottenham (SP 962359)					2. Stackyard (SP 962358)								3. Flitwick (SP 963358)							
		Horizon Depth (cm)	Ap1 0–6	Ap2 6–22	B1 22–44	B2 44–57	C 57–80	Ap1 0–7	Ap2 7–25	B1 25–51	B2 51–76	B3 76–95	C1 95–124	2C2 124–178	2C3 178+	Ap1 0–7	Ap2 7–25	B 25–47	C(g) 47–84	2Cg1 84–112	2Cg2 112–134	2Cg3 134–159	2Cg4 159–170
1000 to 2000	0 to −1		0·9	0·7	0·7	0·3	0·2	0·7	0·4	0·6	0·2	0·2	0·1	0·0	0·0	0·5	0·8	0·5	0·6	0·1	0·1	0·0	0·0
500 to 1000	+1 to 0		1·8	1·7	1·1	0·6	0·3	1·6	1·8	1·6	1·0	0·7	0·2	0·2	0·2	1·6	2·1	1·6	1·3	0·2	0·1	0·1	0·2
250 to 500	+2 to +1		12·0	12·6	10·5	8·4	5·0	13·9	14·4	15·0	13·2	12·5	11·5	24·2	27·6	15·3	14·8	15·6	13·2	14·1	16·7	26·3	46·0
125 to 250	+3 to +2		61·9	61·8	67·3	75·3	80·1	57·4	56·0	60·6	58·6	56·8	71·2	60·6	61·2	54·6	54·1	49·7	53·3	68·8	66·8	61·1	40·3
63 to 125	+4 to +3		4·0	4·1	4·8	5·0	4·8	4·1	3·7	3·3	3·7	3·0	3·1	1·7	2·0	3·8	4·1	3·6	3·9	2·0	3·7	1·3	1·9
32 to 63	+5 to +4		1·5	2·6	2·5	1·7	1·1	2·9	2·9	3·8	4·6	5·7	2·5	0·7	0·5	4·0	4·0	5·2	4·3	1·2	0·6	0·4	0·7
16 to 32	+6 to +5		0·9	1·9	1·6	1·6	0·6	2·6	3·8	3·8	2·6	5·3	1·7	0·4	0·1	3·2	3·5	3·3	4·1	1·2	0·4	0·3	0·3
8 to 16	+7 to +6		2·7	1·4	1·5	0·9	0·4	2·4	3·0	2·3	2·8	3·1	1·1	0·2	0·1	2·6	2·2	2·8	3·0	0·2	0·4	0·1	0·2
4 to 8	+8 to +7		1·5	1·3	1·0	0·7	0·8	1·3	0·8	1·3	2·2	1·7	0·7	0·2	0·0	1·9	2·2	2·7	2·7	0·2	0·1	0·1	0·2
2 to 4	+9 to +8		2·6	1·6	1·4	1·0	1·2	1·6	3·9	2·2	3·6	3·7	2·4	3·0	2·4	2·8	1·7	1·9	1·6	2·6	2·4	1·8	1·1
<2	>+9		10·2	10·3	7·6	4·5	5·5	11·5	9·3	5·5	7·5	7·3	5·5	8·8	5·9	9·7	10·5	13·1	12·0	9·4	8·7	8·5	9·1

Size fractions (μm)	φ Equivalent	Profile	4. Flitwick (SP 963359)											5. Ridgmont (SP 964360)			
		Horizon Depth (cm)	Ap1 0–7	Ap2 7–21	B 21–40	B(g) 40–67	Cg1 67–88	Cg2 88–104	Cg3 104–119	Cg4 119–126	Cg5 126–147	Cg6 147–172	2Cg 172+	Ap1 0–6	Ap2 6–31	BCg 31–48	2Cg 48–67
1000 to 2000	0 to −1		0·9	0·7	0·8	0·4	0·7	0·2	0·2	0·1	0·0	0·1	0·2	0·5	0·5	0·6	0·3
500 to 1000	+1 to 0		2·4	2·3	1·9	2·1	1·7	1·1	1·4	0·9	0·7	1·1	0·8	3·5	2·5	4·6	4·2
250 to 500	+2 to +1		19·4	19·8	17·2	15·3	15·4	13·1	15·5	11·4	10·6	17·8	11·5	26·5	18·4	40·2	39·5
125 to 250	+3 to +2		45·1	46·9	42·2	37·5	47·8	41·4	44·0	30·9	32·0	53·6	70·7	27·7	19·5	37·9	42·9
63 to 125	+4 to +3		3·5	3·8	3·7	3·8	3·7	3·1	3·4	2·6	3·2	4·7	2·4	2·0	1·8	1·9	3·5
32 to 63	+5 to +4		4·2	3·4	4·2	4·6	5·7	8·2	7·4	7·7	15·0	5·3	1·1	2·3	4·7	1·9	1·5
16 to 32	+6 to +5		3·7	3·8	4·8	5·8	5·4	8·5	6·9	9·5	13·6	3·2	0·5	4·1	3·8	1·8	1·2
8 to 16	+7 to +6		2·9	2·8	3·4	3·3	3·2	4·5	4·1	6·2	5·1	1·8	1·0	3·8	4·7	1·1	1·1
4 to 8	+8 to +7		2·1	2·4	3·3	3·3	2·6	2·7	2·2	3·3	2·2	0·9	0·3	3·0	5·0	0·3	0·3
2 to 4	+9 to +8		4·4	2·1	4·2	4·3	2·4	3·8	4·5	6·4	5·2	2·5	0·6	3·8	4·4	1·1	0·4
<2	>+9		11·4	12·0	14·3	19·6	11·4	13·4	10·4	21·0	12·4	9·0	10·9	22·8	34·7	8·6	5·1

Size fractions (μm)	φ Equivalent	Profile	6. Ridgmont (SP 960359)							7. Husborne (SP 960358)							
		Horizon Depth (cm)	A 0–23	Bg1 23–40	Bg2 40–56	Cg 56–105	2Cg1 105–118	2Cg2 118–146	3Cg 146+	Ap 0–12	AB 12–23	Bw 23–38	2Bg1 38–80	2Bg2 80–98	3Cg 98–139	4Cg 139–153	5C(g) 153+
1000 to 2000	0 to −1		0·5	0·4	0·5	0·1	0·7	0·2	5·1	0·9	1·7	1·8	0·8	0·4	1·1	0·2	0·8
500 to 1000	+1 to 0		4·0	6·0	2·5	1·7	1·4	2·6	6·7	4·0	4·3	4·4	3·1	1·7	5·5	4·5	1·9
250 to 500	+2 to +1		15·0	13·6	12·3	6·8	4·6	5·9	22·3	18·4	16·4	17·3	10·2	6·3	25·2	33·6	4·2
125 to 250	+3 to +2		22·5	19·2	28·2	18·2	7·6	9·4	46·4	33·0	34·5	32·2	15·2	11·1	34·0	47·3	8·1
63 to 125	+4 to +3		2·8	2·5	3·8	4·3	5·0	4·6	3·7	4·9	4·9	5·0	4·7	4·1	3·8	3·2	4·4
32 to 63	+5 to +4		5·0	4·9	3·9	8·6	2·9	5·3	1·7	5·5	4·9	5·1	3·7	2·9	1·4	0·6	3·9
16 to 32	+6 to +5		4·7	5·1	6·4	9·4	3·6	7·8	0·4	4·8	5·3	5·9	4·7	4·9	1·8	0·2	5·2
8 to 16	+7 to +6		5·3	5·8	5·1	8·0	6·4	5·9	1·1	3·9	4·0	4·7	5·9	5·2	1·6	0·6	7·5
4 to 8	+8 to +7		4·4	5·1	4·8	5·7	7·3	8·3	0·9	3·8	3·5	3·0	5·0	6·2	2·2	0·7	8·9
2 to 4	+9 to +8		5·1	8·7	5·2	5·6	9·0	11·5	2·3	3·1	4·2	2·6	5·4	5·7	2·1	1·1	8·7
<2	>+9		30·7	28·7	27·3	31·6	51·5	38·5	9·4	17·7	16·3	18·0	41·3	51·5	21·3	8·0	46·4

In central parts of School Field the area mapped as Husborne series includes at its margin a narrow zone of imperfectly drained stony soils with sandy clay loam to sandy clay subsurface horizons but no calcareous boulder clay at depth. These probably occur where the Head overlaps the eroded feather-edge of the boulder clay to rest on glacial gravel. Eastwards they give way rapidly to the somewhat coarser textured, well-drained soils in colluvium over glacial gravel that have been included with the Stackyard series.

Soils: particle size distribution

Table 2 gives the particle size distribution of soil samples from profiles 1 (Cottenham series), 2 (Stackyard), 3 and 4 (Flitwick), 5 and 6 (Ridgmont) and 7 (Husborne). 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 subsamples by the pipette sampling technique after dispersion in dilute (0·1% w/v) sodium hexametaphosphate solution; five sand fractions (63–2000 μm) were determined on 150–200 g subsamples by dry-sieving after ultrasonic dispersion.

The main component of all horizons in the Cottenham, Stackyard and Flitwick profiles is fine sand, which is largely in the 125–250 μm range, but tails into the medium sand range (250–500 μm). The Lower Greensand often has the same particle size distribution, and this is undoubtedly the source of the sand in these profiles. The amounts of clay in most samples from profiles 1–4 are also within the range found in the Lower Greensand (Catt *et al.*, 1975, Table 2), but amounts of silt are generally greater. The exceptions are certain horizons of the Flitwick profile (4), which contain more clay than the Lower Greensand, and some of the deeper horizons in all four profiles, which do have almost as little silt as the Lower Greensand. This suggests that Lower Greensand with little or no admixture of other material is reached in all four profiles, probably at 44 cm in the Cottenham, 124 cm in the Stackyard, 84 cm in the Flitwick profile 3, and 172 cm in the Flitwick profile 4, and that some parts of the colluvium in Flitwick profile 4 either contain some clay derived from a clay-rich deposit (e.g. the Chalky Boulder Clay) or have been slightly clay-enriched by water-sorting during transport and deposition.

In the two Ridgmont profiles the lowest horizons, below 31 cm in the first (5) and below 146 cm in the second (6), have particle size distributions similar to the Lower Greensand, but overlying horizons contain much more clay and silt, although their diminished sand fraction is usually concentrated in the range (125–500 μm) typical of the Lower Greensand. In the Husborne profile (7), one deep horizon (4Cg, 139–153 cm) has a particle size distribution similar to that of the Lower Greensand, but all other horizons again contain more clay and silt. Nevertheless, their sand fractions tend to be concentrated in the 125–500 μm range in all the horizons except the Chalky Boulder Clay below 153 cm, suggesting that at least a little of the sand they contain is from the Lower Greensand.

Soils: mineralogy

Analytical methods. The fine sand (63–250 μm) and coarse silt (16–63 μm) fractions of samples from most horizons in all the soil profiles except the Cottenham were analysed mineralogically by the techniques outlined by Catt *et al.* (1975, 16). Their methods were also used for the analysis of clay fractions (< 2 μm), except that oriented aggregates were made from Mg-saturated instead of Ca-saturated clays, and iron oxides and hydrated oxides were removed by treatment with sodium dithionite in a citrate buffer; however, untreated clays were also examined by X-ray diffractometry to identify the iron minerals.

TABLE 3 OPPOSITE:

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

Profile		2. Stackyard (SP 962358)						3. Flitwick (SP 963358)						4. Flitwick (SP 963359)						
Horizon		Ap2	B1	B2	B3	C1	2C3	Ap2	B	C(g)	2Cg1	2Cg3	2Cg4	Ap2	B	B(g)	Cg3	Cg4	Cg5	2Cg
Depth (cm)		7–25	25–51	51–76	76–95	95–124	178+	7–25	25–47	47–84	84–112	134–159	159–170	7–21	21–40	40–67	104–119	119–126	126–147	172+
Light fraction (*S.G.* <*2·9*)																				
Quartz	%	94	93	94	95	94	97	95	93	92	92	96	82	93	92	91	94	93	94	96
Alkali felspar	%	2	3	3	3	4	1	3	4	4	3	1	1	3	3	4	4	6	4	2
Flint	%	1	1	1	1	<1	—	1	1	1	1	<1	<1	2	1	1	1	<1	<1	—
Glauconite	%	2	2	1	1	2	2	<1	1	2	3	3	16	1	2	2	—	<1	2	1
Opal	%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gypsum	%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heavy fraction (*S.G.* >*2·9*), *total*	%	0·8	0·7	0·7	0·4	0·4	0·3	1·0	1·0	0·6	0·5	0·3	0·8	1·3	1·9	2·3	0·6	0·8	0·2	0·7
Zircon	‰	444	499	499	449	579	518	469	429	572	552	454	456	464	419	472	552	409	305	329
Tourmaline	‰	126	111	115	124	81	109	68	100	81	92	164	110	72	76	149	79	95	67	106
Epidote	‰	65	56	63	74	49	80	82	52	56	54	68	94	81	64	64	64	53	71	80
Zoisite	‰	8	2	6	7	3	3	1	6	7	8	5	8	6	4	4	5	3	4	2
Colourless garnet	‰	21	19	16	13	4	1	22	22	16	7	3	4	23	24	28	39	36	39	19
Pink garnet	‰	10	2	4	2	1	—	4	3	2	2	1	1	5	6	6	6	9	7	—
Green garnet	‰	—	1	1	1	2	—	—	1	—	2	1	1	—	—	—	1	1	—	—
Green hornblende	‰	19	14	6	7	2	19	16	9	19	4	1	3	19	15	11	36	28	26	5
Tremolite/actinolite	‰	7	4	3	1	—	—	2	1	1	—	—	—	1	5	5	6	4	2	2
Brown hornblende	‰	2	1	1	—	—	—	2	—	—	—	—	—	1	1	2	3	1	2	—
Red rutile	‰	5	10	9	12	11	8	7	3	12	12	15	19	6	7	11	5	3	2	6
Yellow rutile	‰	12	14	10	21	12	10	14	15	6	17	6	11	16	8	14	14	12	7	19
Brown rutile	‰	66	84	78	66	63	56	44	52	50	62	57	55	49	39	57	40	33	39	44
Anatase	‰	7	6	8	6	3	5	6	5	4	10	5	17	6	6	7	10	10	5	9
Brookite	‰	—	1	—	—	—	1	1	2	—	1	1	—	1	1	1	1	2	3	2
Staurolite	‰	87	88	95	116	107	107	47	141	66	92	124	115	79	80	93	62	69	48	77
Kyanite	‰	65	59	75	76	75	73	66	51	64	60	75	95	47	79	60	51	53	46	107
Andalusite	‰	2	4	—	1	1	1	4	3	2	3	1	—	3	2	1	2	—	2	2
Topaz	‰	3	2	1	—	1	1	4	3	2	6	1	4	1	—	—	—	1	1	—
Apatite	‰	2	2	—	1	—	—	4	—	1	1	—	—	3	—	2	—	—	—	—
Collophane	‰	34	7	3	2	—	4	108	5	1	2	6	—	98	2	—	1	2	—	—
Vivianite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	57	68	—
Monazite	‰	1	1	1	—	—	3	—	—	—	2	1	3	—	—	1	2	—	—	—
Sphene	‰	3	7	4	8	5	1	4	13	8	6	10	4	6	4	2	6	3	4	2
Augite	‰	4	2	1	—	—	—	5	2	5	2	—	—	1	5	1	—	4	—	—
Hypersthene	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pigeonite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Weathered volcanic ash fragments	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Siderite	‰	—	—	—	—	—	—	11	2	2	—	—	—	—	1	—	—	—	—	—
Dolomite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chlorite	‰	7	14	1	13	1	—	9	63	22	3	1	—	11	133	8	14	111	240	2
Biotite	‰	—	—	—	—	—	—	—	17	1	—	—	—	1	19	1	1	1	12	—

Profile		5. Ridgmont (SP 964360)				6. Ridgmont (SP 960359)							7. Husborne (SP 960358)							
Horizon		Ap1	Ap2	BCg	2Cg	A	Bg1	Bg2	Cg	2Cg1	2Cg2	3Cg	Ap	AB	Bw	2Bg1	2Bg2	3Cg	4Cg	5C(g)
Depth (cm)		0–6	6–31	31–48	48–67	0–23	23–40	40–56	56–105	105–118	118–146	146+	0–12	12–23	23–38	38–80	80–98	98–139	139–153	153+
Light fraction (*S.G.* <*2·9*)																				
Quartz	%	87	86	90	90	92	93	94	88	84	89	95	90	85	87	86	85	89	92	85
Alkali felspar	%	3	5	3	3	4	4	2	5	4	8	2	6	9	9	9	11	6	4	11
Flint	%	2	1	1	1	1	1	1	<1	1	2	<1	2	3	2	2	2	2	1	2
Glauconite	%	5	5	1	2	2	1	2	6	<1	1	<1	1	1	1	1	1	<1	<1	<1
Opal	%	—	—	—	—	—	—	—	—	<1	—	—	—	—	—	—	—	—	—	—
Gypsum	%	—	—	—	—	—	—	—	—	10	<1	—	—	—	—	—	—	—	—	—
Heavy fraction (*S.G.* >*2·9*), *total*	%	3·3	3·2	4·8	3·6	0·9	1·0	1·0	1·0	0·8	0·4	2·9	1·4	1·5	1·3	1·5	1·1	3·1	2·5	2·2
Zircon	‰	301	383	361	342	399	354	336	263	465	423	334	404	452	446	295	169	279	271	74
Tourmaline	‰	71	83	125	137	128	133	143	89	83	62	52	87	105	93	134	150	97	113	125
Epidote	‰	72	75	90	100	107	86	102	96	68	85	66	140	103	83	71	110	89	66	118
Zoisite	‰	4	7	—	3	9	10	16	9	4	6	14	8	8	16	7	15	16	9	12
Colourless garnet	‰	13	48	41	43	51	46	41	57	59	45	87	62	63	71	111	90	105	73	67
Pink garnet	‰	7	11	11	10	14	6	14	16	30	17	31	15	20	24	18	23	30	22	18
Green garnet	‰	—	—	—	—	1	—	1	1	—	—	—	1	—	—	—	—	—	—	—
Green hornblende	‰	13	30	25	30	31	66	47	61	40	102	44	51	43	53	82	85	81	63	65
Tremolite/actinolite	‰	1	1	3	3	6	5	3	3	4	1	4	5	2	5	6	8	4	5	5
Brown hornblende	‰	—	1	—	4	3	6	11	6	4	4	4	15	5	11	2	10	4	4	4
Red rutile	‰	3	3	3	6	12	9	5	1	—	5	—	2	8	4	1	3	6	7	—
Yellow rutile	‰	7	14	8	13	17	13	10	13	15	8	1	8	13	11	9	8	9	4	6
Brown rutile	‰	36	40	54	48	42	33	23	41	51	33	33	32	34	38	46	25	42	33	7
Anatase	‰	5	9	—	4	7	8	5	10	6	8	7	5	5	8	19	5	3	3	5
Brookite	‰	—	—	2	4	1	—	3	1	—	—	—	—	—	1	—	—	—	—	—
Staurolite	‰	67	73	93	106	78	90	82	84	53	69	74	53	66	77	81	60	52	63	28
Kyanite	‰	55	53	111	90	63	64	65	62	47	34	44	33	31	42	17	23	38	51	—
Andalusite	‰	1	—	2	3	1	5	1	1	2	2	1	1	2	1	1	1	1	1	—
Topaz	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Apatite	‰	1	6	5	3	6	2	7	1	—	—	1	—	1	—	—	15	23	20	94
Collophane	‰	12	51	16	17	7	1	5	3	2	2	4	6	—	—	4	5	6	87	219
Vivianite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Monazite	‰	—	—	—	—	—	—	—	1	—	—	—	1	1	1	1	1	—	—	—
Sphene	‰	—	—	—	—	2	2	3	6	4	3	—	—	2	3	—	—	3	—	—
Augite	‰	1	1	2	4	3	4	1	4	4	—	3	2	5	3	1	1	7	3	2
Hypersthene	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Pigeonite	‰	—	—	—	—	—	—	—	—	—	—	112	—	—	—	—	—	—	—	—
Weathered volcanic ash fragments	‰	—	—	—	—	—	—	—	—	—	—	61	—	—	—	—	—	—	—	—
Siderite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dolomite	‰	266	7	—	—	—	—	—	—	—	—	—	29	—	—	—	1	—	—	—
Chlorite	‰	63	90	48	29	12	56	69	161	57	89	22	38	26	9	75	176	98	87	130
Biotite	‰	1	14	—	1	—	1	7	10	2	2	1	2	5	—	19	16	7	14	21

Fine sand mineralogy. Comparison of the composition of light and heavy fractions of the fine sand from the soil samples (Table 3) with those of the Lower Greensand and Chalky Boulder Clay (Catt *et al.*, 1975, Table 3) shows that almost all can be interpreted as mixtures of sand in varying proportions from these two deposits. In the upper horizons of the Stackyard and two Flitwick profiles up to about 25% of the sand is from the boulder clay, but in the lowest horizons, below 95 cm in the Stackyard, 84 cm in one Flitwick profile (3) and 119 cm in the other (profile 4), the proportion is much smaller. Two of the subsoil horizons of the more poorly drained Flitwick profile (4) contain vivianite, an iron phosphate mineral that has formed within the soil as a result of anaerobic conditions; the most likely source of the phosphate in this mineral is the component of the colluvium derived from Chalky Boulder Clay, as this often contains easily weatherable phosphate minerals, such as collophane and apatite.

The composition of the sand fractions in the two Ridgmont profiles also indicates mixing of material from the Lower Greensand with about 25% sand from the boulder clay. The proportion of boulder clay material is possibly slightly less in the lowest horizon of each profile, but not as small as in the lowest horizons of the Stackyard and Flitwick profiles. The gypsum in subsoil horizons of profile 6 seems to have formed *in situ*, as it occurs mainly in unabraded concretionary rosettes; the peaty lacustrine deposits may originally have been slightly calcareous, and gypsum could have formed by reaction with sulphuric acid generated by oxidation of pyrites derived from the boulder clay. The lowest horizon of the same profile contains small amounts of sand-sized weathered volcanic ash or lava fragments, and also a volcanic clinopyroxene resembling pigeonite. Some of the other heavy minerals in this and other samples could also be derived from volcanic sources; for example, some of the sphenes are perfect monoclinic euhedra, and many of the amphiboles are large, freshly broken and extremely angular fragments. Some of these volcanic minerals could have been derived from ice-transported erratics in the boulder clay, but their abundance in the lowest horizon of profile 6, which from its relatively small felspar, flint, epidote, chlorite and biotite contents seems to contain less sand derived from the boulder clay than many other samples, makes this explanation unlikely. The only alternative is that the volcanic minerals are derived from the Lower Greensand, and some support for this is provided by the conclusions of Hallam and Sellwood (1968) that Fuller's Earth deposits like those in the Lower Greensand near Aspley Guise are formed from accumulations of volcanic ash.

In the Husborne profile (7), a larger proportion of the fine sand is from boulder clay than in any of the other soils. Approximately half that in the Ap, 3Cg and 4Cg horizons is so derived, and an even greater proportion in the intervening horizons. As the proportion of sand derived from boulder clay is greater in the more clay-rich horizons and the proportion of sand from the Lower Greensand greater in the more sandy horizons of this profile, it is likely that these two components, which form in varying proportions all the horizons above the undisturbed Chalky Boulder Clay below 153 cm, have been mixed by processes of deposition involving little or no dispersion and resorting of their constituent size fractions. This implies mass movement of Lower Greensand and weathered boulder clay material, and as the surrounding slopes are not very steep, solifluction in periglacial conditions is the most likely means of transport. The Ap horizons of this profile and of the Ridgmont profile (5) both contain small amounts of sand-sized dolomite, which has been added recently to the soils to counteract magnesium deficiency.

Coarse silt mineralogy. Comparison of the mineralogical composition of the coarse silt (16–63 μm) fractions of the soil samples (Table 4) with those of the Lower Greensand and Chalky Boulder Clay (Catt *et al.*, 1975, Table 4) shows that most are derived largely from the boulder clay. In many horizons a small proportion of the silt is derived from the

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TABLE 4

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

Profile		2. Stackyard (SP 962358)						3. Flitwick (SP 963358)						4. Flitwick (SP 963359)						
Horizon Depth (cm)		Ap2 7–25	B1 25–51	B2 51–76	B3 76–95	C1 95–124	2C3 178+	Ap2 7–25	B 25–47	C(g) 47–84	2Cg1 84–112	2Cg3 134–159	2Cg4 159–170	Ap2 7–21	B 21–40	B(g) 40–67	Cg3 104–119	Cg4 119–126	Cg5 126–147	2Cg 172+
Light fraction (S.G. <2·9)																				
Quartz	%	81	78	83	78	85	88	79	77	78	80	76	80	83	78	84	76	83	75	58
Alkali felspar	%	12	14	13	16	11	5	14	13	14	12	7	5	11	13	11	19	13	20	12
Flint	%	1	1	1	1	1	—	1	1	1	1	—	—	1	1	<1	1	1	2	2
Muscovite	%	1	2	1	2	1	<1	1	1	1	1	<1	1	1	1	<1	2	1	2	2
Glauconite	%	1	2	1	1	1	5	2	5	4	3	14	9	2	4	3	—	<1	<1	10
Opal	%	1	1	1	1	<1	—	1	1	1	<1	—	—	1	1	1	1	1	<1	<1
Chalcedony spheres	%	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heavy fraction (S.G. >2·9), total	%	2·6	2·0	1·0	0·6	1·2	2·2	2·3	2·0	0·6	2·6	2·7	4·8	1·2	2·4	1·4	0·7	1·0	1·1	16·3
Zircon	‰	214	252	259	206	199	430	171	166	157	268	303	289	193	239	282	125	173	183	136
Tourmaline	‰	52	40	28	32	31	173	55	37	43	63	157	144	51	115	89	25	45	38	9
Epidote	‰	323	309	326	323	341	77	360	342	342	261	93	68	277	193	203	333	269	310	277
Zoisite	‰	32	32	36	36	40	12	41	34	39	37	15	2	39	28	23	30	26	33	21
Garnet	‰	33	24	18	28	26	15	32	33	32	19	17	13	41	60	51	45	45	65	63
Green hornblende	‰	88	97	95	117	142	13	101	110	103	97	12	6	111	69	78	87	152	28	117
Tremolite/actinolite	‰	43	35	41	26	25	4	45	30	40	41	4	3	41	18	40	42	45	29	25
Brown hornblende	‰	5	6	4	2	5	2	5	4	6	3	—	—	8	2	4	6	3	7	5
Red rutile	‰	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—	—	—
Yellow rutile	‰	48	54	66	59	57	56	43	43	41	41	76	79	67	64	69	103	49	48	75
Brown rutile	‰	15	14	18	16	21	38	14	24	15	13	59	61	29	23	14	24	14	20	33
Anatase	‰	50	62	43	67	40	60	36	41	35	27	57	62	57	67	50	91	41	18	47
Brookite	‰	3	1	5	4	5	10	5	5	4	6	7	13	2	4	6	3	5	2	2
Staurolite	‰	5	9	11	6	4	52	14	8	11	28	109	99	8	19	23	7	9	11	7
Kyanite	‰	8	10	7	4	5	21	11	8	8	13	56	65	7	11	13	5	7	3	5
Andalusite	‰	—	—	—	—	—	2	—	—	—	—	6	3	—	—	—	—	—	—	—
Apatite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Collophane	‰	—	—	3	1	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—
Augite	‰	1	—	3	—	—	—	—	—	2	—	—	—	—	—	—	2	2	—	2
Pigeonite	‰	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
Dolomite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chlorite	‰	77	54	37	73	59	31	67	110	115	81	17	30	68	88	53	67	109	201	171
Biotite	‰	—	—	—	—	—	2	—	4	7	2	8	61	—	—	—	—	6	3	5
Brown spinel	‰	3	1	—	—	—	—	—	1	—	—	2	—	1	—	2	3	—	1	—

Profile		5. Ridgmont (SP 964360)				6. Ridgmont (SP 960359)							7. Husborne (SP 960358)							
Horizon Depth (cm)		Ap1 0–6	Ap2 6–31	BCg 31–48	2Cg 48–67	A 0–23	Bg1 23–40	Bg2 40–56	Cg 56–105	2Cg1 105–118	2Cg2 118–146	3Cg 146+	Ap 0–12	AB 12–23	Bw 23–38	2Bg1 38–80	2Bg2 80–98	3Cg 98–139	4Cg 139–153	5C(g) 153+
Light fraction (S.G. <2·9)																				
Quartz	%	83	82	78	77	71	72	69	66	81	82	67	74	81	80	80	77	78	79	76
Alkali felspar	%	9	10	12	13	11	11	13	10	8	14	6	13	12	11	9	11	11	11	9
Flint	%	1	1	1	1	1	1	1	1	1	1	<1	1	1	1	1	1	1	1	2
Muscovite	%	1	1	2	2	1	1	1	2	2	1	<1	2	1	1	2	4	2	3	7
Glauconite	%	3	2	4	2	13	13	14	20	1	<1	11	4	2	3	6	6	2	1	4
Opal	%	1	1	1	<1	1	1	1	1	5	1	<1	2	1	1	—	—	—	—	—
Chalcedony spheres	%	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
Heavy fraction (S.G. >2·9), total	%	1·8	2·5	2·0	5·1	1·5	1·2	1·1	0·2	0·4	0·8	15·9	4·3	2·1	2·7	2·0	1·0	6·0	5·0	2·0
Zircon	‰	108	142	115	200	164	118	166	157	128	125	121	123	179	180	188	247	209	125	149
Tourmaline	‰	78	51	44	45	57	79	69	56	103	86	32	70	70	51	93	65	72	72	45
Epidote	‰	337	288	361	308	333	367	346	357	341	395	319	331	319	335	234	271	271	232	172
Zoisite	‰	31	31	28	28	35	35	33	31	27	34	18	38	28	23	33	27	22	27	23
Garnet	‰	41	35	35	38	28	28	29	27	33	33	107	24	33	23	31	52	56	63	24
Green hornblende	‰	133	164	180	144	141	143	117	136	187	146	123	108	114	128	68	47	53	132	52
Tremolite/actinolite	‰	51	49	51	37	22	31	25	27	30	30	61	51	45	52	31	23	21	17	12
Brown hornblende	‰	8	7	5	10	12	3	5	7	11	10	—	12	5	5	3	4	1	6	1
Red rutile	‰	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Yellow rutile	‰	25	36	25	33	48	46	54	39	19	26	32	14	33	31	55	65	67	43	41
Brown rutile	‰	14	14	11	12	22	19	28	21	11	12	3	15	19	16	24	23	18	14	17
Anatase	‰	23	35	18	42	42	30	33	31	20	34	20	30	32	29	31	38	32	13	33
Brookite	‰	4	4	4	7	7	4	5	4	7	2	17	3	1	5	1	3	6	3	1
Staurolite	‰	9	10	10	5	8	6	11	8	8	7	30	12	14	10	9	16	4	5	5
Kyanite	‰	8	11	7	16	5	6	12	8	7	9	3	8	12	9	9	8	4	4	4
Andalusite	‰	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Apatite	‰	2	1	2	—	—	—	—	—	—	—	—	—	—	—	—	1	—	27	17
Collophane	‰	6	—	2	3	—	—	—	—	—	—	—	—	—	—	—	1	—	—	29
Augite	‰	2	1	1	2	4	2	1	1	2	4	6	—	2	1	1	1	—	—	—
Pigeonite	‰	—	—	1	—	—	—	—	—	—	—	20	—	—	—	—	—	—	—	—
Dolomite	‰	4	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	50
Chlorite	‰	109	118	100	68	67	80	61	87	65	44	85	161	93	99	182	100	156	207	309
Biotite	‰	7	3	—	2	—	1	3	1	1	1	3	—	1	3	7	8	6	10	16
Brown spinel	‰	—	—	—	—	1	2	1	2	—	2	—	—	—	—	—	—	2	—	—

Lower Greensand, but it is only in the lowest horizon (178 cm+) of the Stackyard profile (2) and the lowest two horizons (134–170 cm) of the Flitwick profile (3) that the silt is entirely from this source. The fine sand fractions of these subsoil horizons are also derived entirely from the Lower Greensand, but the slightly higher subsoil horizons of the same profiles and also the subsoil horizons (below 119 cm) of the Flitwick profile (4) that contain sand derived entirely from the Lower Greensand, have silt fractions derived mainly from the boulder clay.

The amounts of partly weathered glauconite in some horizons of the Ridgmont profile (6) on White Horse Field are greater than would be expected in silt derived largely from the boulder clay, and probably come from the glauconite-rich beds in the Lower Greensand, which are buried beneath the colluvium on parts of this field adjacent to the old lake. This suggests that the lacustrine clays overlying the peaty horizons in this profile are derived partly from colluvium, which was carried down the surrounding slopes into the lake and was then washed and sorted to some extent.

Small amounts of biogenic opal (mainly grass phytoliths) occur in the silt fractions of most samples, and are especially abundant in the buried peaty horizon of the Ridgmont profile (6). However, they are absent from the deep subsoil horizons of the Stackyard (2) and Flitwick (3) profiles that contain only silt derived from the Lower Greensand, and also from all the subsoil horizons (below 38 cm) of the Husborne profile (7). Therefore, although they are associated with many horizons in which the silt is derived largely from Chalky Boulder Clay, they did not originate in the boulder clay but were incorporated in surface soil horizons containing boulder clay material; their occurrence in some subsoil horizons of the Stackyard, Flitwick and Ridgmont profiles implies that these soils are composed at least partly of transported surface soil material.

Clay mineralogy. As the clay fraction ($<2\mu$m) of the Chalky Boulder Clay contains moderate amounts of kaolinite and that of the Lower Greensand little or none (Catt *et al.*, 1975, Table 5), the occurrence of this mineral in the clay fractions of the soils (Table 5) may be used to help identify the source of the clay in each horizon. Most of the soil clays contain 5–20% kaolinite, and therefore seem to be derived largely from the boulder clay. However, the amounts in the lowest subsoil horizons of the Stackyard, Flitwick and Ridgmont profiles are less; below 178 cm in the Stackyard (2), 84 cm in one Flitwick (3) and 172 cm in the other (4), the clay is probably derived entirely from the Lower Greensand; below 146 cm in the deeper Ridgmont (6) it is probably a mixture of clay from both sources. In some subsoil horizons composed of colluvium (e.g. the Cl of the Stackyard profile), the total amount of clay is $< 10\%$, the amount usually found in the Lower Greensand, yet the proportion of kaolinite indicates derivation mainly from the boulder clay; this suggests that some sorting of particles occurred during deposition of the colluvium, the clay from the Lower Greensand being largely removed and replaced partly with clay from the boulder clay. Removal of the clay derived from the Lower Greensand probably involves disruption of the ferruginous coatings on sand grains, and during the incorporation of clay derived from the Chalky Boulder Clay it is possible that kaolinite is concentrated to some extent, probably as relatively coarse clay particles. Kaolinite may therefore be an over-sensitive indicator in the colluvium of clay derived from the boulder clay.

In most horizons of the Husborne profile (7) the amounts of kaolinite are the same as in the boulder clay, which confirms that much of the Head in which the upper horizons are developed is derived from that deposit. However, somewhat smaller amounts (7–10%) occur in the more sandy A, Bw (0–38) and Cg (98–153 cm) horizons, which contain somewhat less material derived from boulder clay than other horizons.

The other layer silicate minerals in the soil clays are illite (identified by its 10 Å basal

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spacing) and interstratified illite-smectite, with traces of chlorite. The changes in illite content are difficult to interpret because the clay fractions of the Chalky Boulder Clay and Lower Greensand contain approximately the same amounts, but the upward decrease in amounts evident in profiles 2, 3, 4, 6 and 7 may result from weathering processes, which remove potassium and allow the alumino-silicate sheets to expand and disperse. The interstratified minerals, which comprise 60–90% of the layer silicates, are most simply described as random illite-smectite interstratifications. In upper soil horizons they are of IS type (illite layers exceed smectite), but in the middle horizons of each profile they are SI type. This change may be caused by the translocation of potassium-depleted, weathered clay from upper horizons to lower, as the translocated fine clay would contain more smectite-like particles than the coarser, less altered clay remaining in the upper horizons; however, it may result from the addition of potassium at the surface, some of which is fixed in smectite-like layers and collapses them to form illite-like layers. Both these processes could have occurred in the profiles, because naturally acid conditions in periods before the use of agricultural lime would have resulted in relatively rapid clay weathering, and more recently there have been large additions of potassium to at least the surface soil horizons by fertiliser application.

Table 5 also gives semi-quantitative estimates of goethite and lepidocrocite contents in the soil clays. Goethite is common in the Lower Greensand, and rare or absent from the Chalky Boulder Clay; traces of it occur in almost all the soil clays, but it is slightly more abundant in horizons formed mainly or entirely from Lower Greensand. Lepidocrocite also occurs in the Lower Greensand and not in the Chalky Boulder Clay, but its distribution in the soils is less even than that of goethite; it occurs mainly in the Cg horizons of the Flitwick profiles and somewhat higher horizons of the Husborne, probably because it forms pedologically in drainage conditions giving a certain balance of reducing and oxidising environments.

Soils: chemistry

Analytical methods. Amounts of total K, Na, Mg and Ca in samples from most horizons of the seven soil profiles, and also in four samples of Chalky Boulder Clay and six of Lower Greensand, were determined by atomic absorption spectrophotometry of solutions prepared by the dissolution techniques of Pruden and King (1969). Exchangeable K, Na, Mg and Ca were also determined by atomic absorption spectrophotometry after extraction with M ammonium acetate solution (pH 7). Total Fe and P were determined by the colorimetric methods of Pruden and King, and organic C by the Tinsley III method of Kalembasa and Jenkinson (1973). Dithionite-extractable Fe was estimated by the method outlined by Avery and Bascomb (1974, 37–38). Total S in most samples was determined by X-ray fluorescence spectrometry (Brown & Kanaris-Sotiriou, 1969), but in those with very large amounts the titrimetric method after digestion with nitric acid and magnesium nitrate solution, as described by Bolton *et al* (1973, 559), was used. pH was measured in 1:2·5 mixtures of soil:water and soil:0·01M-$CaCl_2$ solution by glass electrode, and calcium carbonate was determined with a calcimeter of the type developed by Bascomb (1961).

Total amounts of some trace elements (Ba, Co, Cr, Cu, Ga, Mn, Mo, Ni, Pb, Sn, Sr, Ti and V) in the Chalky Boulder Clay and Lower Greensand samples were determined by optical spectroscopy and extractable amounts of those elements plus Zn and Zr were determined by the same method after evaporating to dryness the solutions obtained by treatment with 0·5M-acetic acid, acidified hydrogen peroxide and ammonium oxalate solution (pH 3·3) in ultraviolet light.

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TABLE 5

Mineral composition of clay fractions (< 2 μm) from soil profiles. Kaolinite, illite, interstratified smectite–illite and chlorite are expressed as percentages of total layer silicate minerals

Profile	2. Stackyard (SP 962358)							3. Flitwick (SP 963358)							4. Flitwick (SP 963359)							
Horizon	Ap1	Ap2	B1	B2	B3	C1	2C3	Ap1	Ap2	B	C(g)	2Cg1	2Cg3	2Cg4	Ap1	Ap2	B	B(g)	Cg3	Cg4	Cg5	2Cg
Depth (cm)	0–7	7–25	25–51	51–76	76–95	95–124	178+	0–7	7–25	25–47	47–84	84–112	134–159	159–170	0–7	7–21	21–40	40–67	104–119	119–126	126–147	172+
< 2 μm clay in soil %	11·5	9·3	5·5	7·5	7·3	5·5	5·9	9·7	10·5	13·1	12·0	9·4	8·5	9·1	11·4	12·0	14·3	19·6	10·4	21·0	12·4	10·9
Minerals in the < 2 μm clay fraction																						
Kaolinite	10	10	10	10	10	10	1	10	15	10	15	2	1	1	10	7	7	10	25	15	10	3
Illite	10	10	15	15	15	20	20	10	15	10	15	15	15	15	10	10	10	15	15	7	10	10
Interstratified smectite–illite	80	80	75	75	75	70	80	80	70	80	70	85	85	85	80	85	85	75	55	75	80	85
Type of smectite–illite	IS	IS	SI	SI	SI	IS	IS	IS	IS	IS	SI	SI	SI	SI	IS	IS	IS	SI	SI	SI	IS	IS
Chlorite	0	0	<1	<1	1	1	0	0	0	0	2	0	0	0	<1	0	0	1	3	3	<1	0
Goethite	tr	tr	tr	tr	tr	tr	s	tr	tr	tr	tr	s	s	s	tr	tr	s	s	tr	—	tr	m
Lepidocrocite	tr	—	tr	tr	tr	tr	s	—	tr	—	—	s	tr	m	tr	—	tr	tr	tr	m	s	s

Profile	5. Ridgmont (SP 964360)				6. Ridgmont (SP 960359)							7. Husborne (SP 960358)							
Horizon	Ap1	Ap2	BCg	2Cg	A	Bg1	Bg2	Cg	2Cg1	2Cg2	3Cg	Ap	AB	Bw	2Bg1	2Bg2	3Cg	4Cg	5C(g)
Depth (cm)	0–6	6–31	31–48	48–67	0–23	23–40	40–56	56–105	105–118	118–146	146+	0–12	12–23	23–38	38–80	80–98	98–139	139–153	53+
< 2 μm clay in soil %	22·8	34·7	8·6	5·1	30·7	28·7	27·3	31·6	51·5	38·5	9·4	17·7	16·3	18·0	41·3	51·5	21·3	8·0	46·4
Minerals in the < 2 μm clay fraction																			
Kaolinite	10	10	6	4	7	9	7	10	20	20	4	10	10	10	20	15	7	10	15
Illite	7	3	5	4	4	7	3	6	15	20	10	4	10	5	15	10	10	9	15
Interstratified smectite–illite	85	85	90	90	90	85	90	85	65	60	85	85	80	85	65	75	85	80	70
Type of smectite–illite	IS	SI	SI	SI	IS	IS	IS	IS	SI	SI	IS	IS	IS	IS	SI	SI	IS	IS	IS
Chlorite	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Goethite	tr	tr	s	m	tr	tr	tr	tr	—	—	tr	tr	tr	tr	tr	tr	s	s	tr
Lepidocrocite	—	—	—	—	tr	tr	tr	tr	—	—	—	tr	s	s	m	m	—	tr	tr

m = much, s = some, tr = trace

pH and calcium carbonate. Amounts of calcium carbonate in the four Chalky Boulder Clay samples range from 6·3 to 18·5%, but the Lower Greensand samples and almost all the soil samples, except the 5C(g) horizon of the Husborne profile (7) and some of the A horizons of other profiles, contain none. The 5C(g) horizon of profile 7 is weakly weathered but still calcareous boulder clay, and the surface horizons of soils in many areas have received ground chalk and/or dolomitic limestone. Most of the soils are consequently near neutral in reaction, but weakly acid conditions occur in some subsoil horizons of the more poorly drained profiles, and more strongly acid conditions (pH approximately 4) exist even quite close to the surface in the Ridgmont profile (6). The pH values in calcium chloride solution are 0·1–1·1 units less than those in water, and probably reflect the semi-permanent variations in soil reaction better than the values in water, which are subject to some local and seasonal variations. The differences between pH in water and in calcium chloride solution are least in some of the Chalky Boulder Clay samples and in the more acid, humose, 2Cg horizons of the Ridgmont profile (6), a feature which probably results from the occurrence of gypsum, as this is weakly soluble and slightly increases the natural salinity of horizons containing it.

Organic carbon. The A horizons of the profiles studied contain 1·11–3·94% organic C; the subsurface and subsoil samples contain rather less, except in the Ridgmont profile (6), some of the deeper horizons of which are developed in humose or peaty lacustrine deposits. Lower Greensand samples taken from well below the surface contain almost no detectable organic C, but the Chalky Boulder Clay has 0·29–1·05%, probably in fairly inert 'kerogen' compounds derived from the Mesozoic marine clays that form much of the finer glacially transported material. This organic matter may persist in many of the subsoil horizons of the Stackyard, Flitwick and Husborne series, which contain some material derived from the boulder clay, but the amounts of organic C in the B and Cl horizons of the Stackyard profile (2), the B, C(g) and 2Cgl horizons of the Flitwick profile (3), and the B and Cg horizons of the Flitwick profile (4) are probably too large to have come entirely from the boulder clay. In these horizons the large amounts of organic C (compared with horizons at comparable depths in many other English soils) probably reflect derivation of the soil material from eroded surface horizons.

Total and extractable iron. The iron in the soils that is extractable with dithionite occurs as goethite, lepidocrocite (Table 5) and X-ray amorphous hydrated oxides. Mineral iron, the difference between total and extractable Fe, occurs in illite and interstratified illite-smectite in the clay fractions and in unweathered glauconite and some of the heavy minerals in coarser fractions (Tables 3 and 4). Values of mineral iron for the Chalky Boulder Clay range from 1·15 to 1·93%, and for the Lower Greensand from 0·17 to 1·42%; in the soils the amounts range from 0·14 to 2·01%, and are therefore similar to those in the parent materials from which they are derived.

Amounts of extractable iron in the Chalky Boulder Clay range from 1·61 to 2·75%, and in the Lower Greensand from 0·93 to 2·89%, but the soils contain a wider range (0·40–6·72%), showing that there has been much movement of iron within or between the soils. The accumulation of extractable iron in some of the more poorly drained profiles (3–7) results from fluctuations of the water table, the iron having been reduced, mobilised and brought into the profiles during periods of high water table level, and then re-oxidised and precipitated on ped faces and in voids when the water table was lower. However, in profile (6) the large amount of extractable iron (6·58%) in the 3Cg horizon may have been derived partly from the organic 2Cg horizons above, which contain little (1·97 and 1·06%), as organic decomposition products may have reduced and complexed

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TABLE 6

Selected chemical data for Woburn soil profiles and for samples of Lower Greensand and Chalky Boulder Clay

Profile		1. Cottenham (SP 962359)					2. Stackyard (SP 962358)						
Horizon Depth (cm)		Ap1 0–6	Ap2 6–22	B1 22–44	B2 44–57	C 57–80	Ap1 0–7	Ap2 7–25	B1 25–51	B2 51–76	B3 76–95	C1 95–124	2C3 178+
pH in water		7·2	7·2	7·3	7·1	7·2	7·1	7·2	7·2	7·0	6·9	6·9	6·9
pH in 0·01M $CaCl_2$		6·4	6·5	6·4	6·2	6·1	6·4	6·7	6·4	6·2	6·2	6·1	6·0
Calcium carbonate	%	0·2	0·1	0·1	0·0	0·0	0·1	0·3	0·0	0·0	0·0	0·0	0·0
Organic carbon	%	2·05	1·11	0·58	0·20	0·12	1·85	1·18	0·47	0·33	0·29	0·21	0·06
Total iron	%	2·11	2·05	1·74	1·76	1·75	2·45	2·27	2·39	1·83	1·63	1·73	1·42
Extractable iron	%	1·38	1·58	1·28	1·13	0·97	1·73	1·80	1·76	1·30	1·24	0·83	0·49
Total sulphur	mg kg^{-1}	692	418	200	49	46	567	537	127	72	92	59	24
Total phosphorus	mg kg^{-1}	684	1010	807	415	322	983	881	917	674	545	259	100
Total potassium	mg kg^{-1}	5000	4900	4800	4200	5100	5200	5400	5000	5200	5200	3600	4400
Total sodium	mg kg^{-1}	400	400	400	200	<100	600	600	700	800	900	400	<100
Total magnesium	mg kg^{-1}	900	1000	700	500	900	1100	1000	600	900	900	500	1000
Total calcium	mg kg^{-1}	2100	2700	1900	900	1100	3100	3200	1700	1800	1400	1200	800
Exchangeable potassium	mg kg^{-1}	436	171	182	106	95	162	153	130	122	112	63	66
Exchangeable sodium	mg kg^{-1}	10·0	5·2	4·4	1·4	5·0	5·4	9·0	5·4	4·6	8·6	6·0	3·2
Exchangeable magnesium	mg kg^{-1}	68	70	66	44	55	104	111	71	62	57	35	32
Exchangeable calcium	mg kg^{-1}	1720	2040	1400	740	700	2000	2660	1280	990	920	590	630

Profile		3. Flitwick (SP 963358)						
Horizon Depth (cm)		Ap1 0–7	Ap2 7–25	B 25–47	C(g) 47–84	2Cg1 84–112	2Cg3 134–159	2Cg4 159–170
pH in water		7·1	7·2	6·6	5·9	6·0	6·9	6·0
pH in 0·01M $CaCl_2$		6·4	6·4	5·7	4·8	5·0	6·2	5·2
Calcium carbonate	%	0·2	0·2	0·0	0·0	0·0	0·0	0·0
Organic carbon	%	3·22	1·57	0·74	0·49	0·24	0·12	0·10
Total iron	%	2·09	2·40	3·71	2·73	2·36	1·56	2·43
Extractable iron	%	1·50	1·92	2·98	1·86	1·27	0·49	0·96
Total sulphur	mg kg^{-1}	947	560	150	143	74	50	41
Total phosphorus	mg kg^{-1}	1560	1720	1280	806	373	138	217
Total potassium	mg kg^{-1}	4800	6300	6500	6000	4800	5000	5200
Total sodium	mg kg^{-1}	800	1000	1200	1000	200	100	100
Total magnesium	mg kg^{-1}	1400	1200	1200	1100	1000	1100	1000
Total calcium	mg kg^{-1}	4500	3900	1500	1200	1000	900	3700
Exchangeable potassium	mg kg^{-1}	196	295	172	135	115	108	81
Exchangeable sodium	mg kg^{-1}	15·0	7·6	7·8	4·6	5·8	6·2	3·0
Exchangeable magnesium	mg kg^{-1}	111	125	112	88	74	78	56
Exchangeable calcium	mg kg^{-1}	2220	2260	1170	680	670	970	700

Profile		4. Flitwick (SP 963359)								5. Ridgmont (SP 964360)			
Horizon Depth (cm)		Ap1 0–7	Ap2 7–21	B 21–40	B(g) 40–67	Cg3 104–119	Cg4 119–126	Cg5 126–147	2Cg 172+	Ap1 0–6	Ap2 6–31	BCg 31–48	2Cg 48–67
pH in water		6·8	7·1	7·4	7·0	7·0	6·9	6·8	6·8	6·7	6·2	6·1	6·4
pH in 0·01M $CaCl_2$		6·3	6·3	6·5	6·3	6·2	6·2	6·1	6·0	6·0	5·7	5·5	5·8
Calcium carbonate	%	0·1	0·1	0·1	0·0	0·0	0·0	0·0	0·0	2·5	0·0	0·0	0·0
Organic carbon	%	2·07	1·65	0·79	0·71	0·57	0·62	0·51	0·07	2·84	2·09	0·40	0·11
Total iron	%	3·23	2·98	4·22	5·65	1·79	2·05	1·73	4·93	4·88	4·40	5·12	4·78
Extractable iron	%	2·43	2·28	3·08	4·56	0·87	0·76	0·40	3·60	3·41	3·32	4·26	4·06
Total sulphur	mg kg^{-1}	508	625	195	209	151	180	224	51	768	838	187	93
Total phosphorus	mg kg^{-1}	1140	1130	782	618	289	240	174	396	944	758	627	407
Total potassium	mg kg^{-1}	6600	6500	6400	8000	6900	8700	10100	4800	7600	7700	3500	3500
Total sodium	mg kg^{-1}	2100	900	1700	1000	1700	2100	2400	100	900	900	200	300
Total magnesium	mg kg^{-1}	1700	1800	1700	2000	1000	2300	1900	1000	4100	3500	900	1000
Total calcium	mg kg^{-1}	3800	4500	2400	2900	2000	1900	1600	700	8300	4800	1300	800
Exchangeable potassium	mg kg^{-1}	381	424	294	310	288	440	316	140	524	314	56	45
Exchangeable sodium	mg kg^{-1}	6·8	6·2	6·2	8·6	5·2	6·4	7·2	3·6	9·2	9·4	7·0	6·6
Exchangeable magnesium	mg kg^{-1}	72	79	51	78	83	114	86	45	266	170	38	29
Exchangeable calcium	mg kg^{-1}	2400	2840	2120	2600	1260	1780	1400	640	3600	3900	1280	790

Profile		6. Ridgmont (SP 960359)							7. Husborne (SP 960358)							
Horizon Depth (cm)		A 0–23	Bg1 23–40	Bg2 40–56	Cg 56–105	2Cg1 105–118	2Cg2 118–146	3Cg 146+	Ap 0–12	AB 12–23	Bw 23–38	2Bg1 38–40	2Bg2 80–98	3Cg 98–139	4Cg 139–153	5C(g) 153+
pH in water		6·1	4·5	4·4	4·7	4·0	3·9	5·4	6·2	5·2	5·4	5·4	6·1	6·6	6·8	8·0
pH in 0·01M $CaCl_2$		5·5	4·0	4·0	4·3	3·8	3·8	5·0	5·7	4·7	4·8	5·1	5·7	5·9	6·1	7·6
Calcium carbonate	%	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	10·9
Organic carbon	%	3·94	5·71	2·49	1·06	11·6	14·5	0·47	1·89	0·75	0·46	0·28	0·44	0·16	0·06	0·58
Total iron	%	4·10	4·15	4·39	5·47	3·31	2·12	6·72	3·67	3·54	3·61	4·48	4·46	4·49	3·05	4·19
Extractable iron	%	2·80	3·07	2·95	3·46	1·97	1·06	6·58	2·15	2·69	2·87	3·33	2·96	3·40	1·96	2·44
Total sulphur	mg kg^{-1}	904	953	657	359	3220	3750	299	620	280	212	202	176	99	62	340
Total phosphorus	mg kg^{-1}	1640	1760	1490	1740	725	448	917	693	551	615	274	230	320	306	559
Total potassium	mg kg^{-1}	9700	9900	10800	15700	8400	9100	3900	7700	8200	8600	15000	17900	8200	5300	19200
Total sodium	mg kg^{-1}	1200	1100	1200	1800	1400	1600	200	1300	1400	1400	1200	1500	700	600	1500
Total magnesium	mg kg^{-1}	2900	2400	2600	4100	2400	2200	800	2000	1700	1700	4000	5700	2400	1000	6800
Total calcium	mg kg^{-1}	3600	1700	1700	2100	2200	1900	1300	2500	1500	1100	2600	3800	1500	800	41000
Exchangeable potassium	mg kg^{-1}	758	516	514	584	346	184	52	239	176	177	180	151	72	30	144
Exchangeable sodium	mg kg^{-1}	24	16	13	16	179	97	20	11	5·8	6·6	7·0	44	17	12	30
Exchangeable magnesium	mg kg^{-1}	374	152	100	190	155	181	52	206	96	95	252	334	14	55	296
Exchangeable calcium	mg kg^{-1}	2700	1740	1100	1820	1540	2000	560	2160	1060	1040	2520	3660	1600	730	8360

		Chalky Boulder Clay Samples				Lower Greensand Samples					
		1	2	3	5	1	2	3	4	5	7
Grid reference		SP 930287	SP 930287	SP 930287	SP 933302	SP 936344	SP 936344	SP 936344	SP 924289	SP 923288	SP 992386
pH in water		7·7	7·8	8·4	7·6	7·5	6·0	5·0	5·2	6·0	6·8
pH in 0·01M $CaCl_2$		7·4	7·5	7·8	7·5	6·8	5·2	4·4	4·9	5·6	6·0
Calcium carbonate	%	14·4	15·0	6·3	18·5	0·0	0·0	0·0	0·0	0·0	0·0
Organic carbon	%	0·71	1·05	0·29	0·65	0·02	0·02	0·02	<0·01	<0·01	0·02
Total iron	%	3·91	3·61	3·90	2·95	2·21	1·90	3·86	1·71	1·46	2·96
Extractable iron	%	1·98	1·80	2·75	1·61	1·02	0·93	2·89	1·54	1·10	1·54
Total sulphur	mg kg^{-1}	7220	7360	211	31000	33	24	52	42	21	38
Total phosphorus	mg kg^{-1}	469	338	492	359	141	205	461	108	179	540
Total potassium	mg kg^{-1}	14500	15200	13600	16300	6000	5000	4900	2700	2000	5300
Total sodium	mg kg^{-1}	1500	1800	1000	1100	200	100	100	<100	<100	200
Total magnesium	mg kg^{-1}	6700	7100	4000	6400	1400	1200	800	400	300	1400
Total calcium	mg kg^{-1}	60300	64200	32100	96100	2000	600	100	300	300	1000
Exchangeable potassium	mg kg^{-1}	158	190	103	53	38	40	26	17	30	48
Exchangeable sodium	mg kg^{-1}	25	45	38	28	19	24	14	3·4	5·6	20
Exchangeable magnesium	mg kg^{-1}	342	318	188	121	105	90	20	51	31	68
Exchangeable calcium	mg kg^{-1}	8200	7520	7340	5800	520	520	100	200	240	940

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iron, allowing it then to be mobilised to lower horizons, where aerated groundwater from the Lower Greensand could have caused re-oxidation and precipitation.

Total sulphur. Amounts of S in the soils range from 24 to 3750 mg kg^{-1} (ppm), and increase with increasing amounts of organic C, which suggests that most of it is associated with the organic fraction of the soil. Three of the four Chalky Boulder Clay samples have very large S contents and much larger S:organic C ratios than the soil profile samples; these probably result from the occurrence of pyrites (FeS_2) in the boulder clay, which is derived from Mesozoic marine sediments, such as the Oxford Clay.

Total phosphorus. Amounts of P in the soils range from 100 to 1730 mg kg^{-1}. They generally decrease downwards in the profiles, but are rather variable in the deeper subsoil horizons. This seems to reflect partly the addition of P at the surface, either in fertilisers or farmyard manure, and partly the fact that amounts inherited from the Chalky Boulder Clay are likely to be somewhat greater than those from the Lower Greensand. Most of the P in the boulder clay occurs as calcium phosphate (apatite and collophane) in the sand and silt fractions, and although these minerals are easily removed by weathering, they do occur in many of the soil horizons containing material derived ultimately from weathered boulder clay. The Lower Greensand contains almost no phosphate minerals, and most of the P in it (108–540 mg kg^{-1}) is probably fixed in association with the microcrystalline and amorphous iron oxides and hydrated oxides that coat the sand grains.

The addition of fertiliser P to the surface soils has increased their total P content by about 50–100%. The largest reserves tend to occur in the surface horizons of the more poorly drained profiles, such as the Flitwick and Ridgmont series, but the upward increase is least in profiles 5 and 7, possibly because they are from headlands near field boundaries, and may have received less fertiliser P than more central parts of the fields.

Total and exchangeable potassium. In the soils potassium occurs mainly in illite and the interstratified layer silicate clays and in felspar and glauconite in coarser fractions. In the sandier horizons derived mainly from the Lower Greensand, felspar and glauconite may contain an appreciable proportion of the total K, but in horizons of the Flitwick, Ridgmont and Husborne series containing much material derived from the boulder clay total K varies according to the amount of clay. Total K in the boulder clay ranges from 1·4 to 1·9%, and 2–5% of this is exchangeable; the Lower Greensand contains much less (0·2–0·6% total K), so that although a larger proportion is exchangeable (2·5–13%) the actual amounts of exchangeable K (20–50 mg kg^{-1}) are less than in the Chalky Boulder Clay (50–200 mg kg^{-1}). In the soils total K ranges from 0·35 to 1·45%, and the proportion exchangeable from 3 to 9%. The amounts of total K in the soils are therefore within the ranges of the constituent parent materials, and to a large extent the different amounts reflect varying proportions of the parent materials.

Amounts of exchangeable K in many of the lower soil horizons are a small proportion of the total K and generally reflect changes in clay content, but in the surface and many subsurface horizons the additions of K from fertilisers and manure have increased exchangeable K considerably. The values given in Table 6 should be compared with values of 54–74 mg kg^{-1} for unmanured topsoil from Stackyard Field (Johnston & Chater, 1975). Treatments have added the following approximate amounts of K either as fertiliser or in farmyard manure: 16 700 kg ha^{-1} for profile 1, 12 000 kg ha^{-1} for profile 2 and 15 700 kg ha^{-1} for profile 3 in the period 1942–72; approximately 510 kg ha^{-1} for profiles 4 and 5, and $<$ 185 kg ha^{-1} for profiles 6 and 7 in the three years (1972–75) immediately prior to sampling. In the Cottenham profile (1) at least 50% of the exchange-

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able K in the Ap1 horizon must be residual from the large applications made up to 1972, and a rather smaller percentage in the Ap2 and B1 horizons is probably from the same source, having been carried to a maximum depth of 44 cm down the profile. In the Stackyard (2) and one Flitwick profile (3) approximately 25% of the exchangeable K to depths of 25 and 47 cm respectively seems to be attributable to the fertilisers added between 1942 and 1972. However, in the other Flitwick profile (4) the amounts of exchangeable K are extremely large even as deep as the Cg5 horizon (126–147 cm), and cannot be explained in terms of the soil parent materials; at least 60% of the exchangeable K throughout almost 1·5 m of soil must have been derived from the fertilisers applied during the three years prior to our sampling or perhaps partly at earlier times. In the Ridgmont profile on Lansome (5), the sharp decrease in exchangeable K below the Ap2 horizon results partly from the decrease in clay content, but to some extent may also reflect the failure of fertiliser potassium to penetrate any deeper; relatively large amounts were applied to the soil in the three years before we sampled it, but either very little penetrated deeper than about 31 cm, or the small amounts that did were not retained by the sandy subsurface horizons. The other Ridgmont profile (6) has large amounts of exchangeable K to approximately 118 cm, and at least 60% of it must have been added as fertiliser K, even though the application in recent years has been quite small; adjacent parts of School and White Horse Fields had 185 kg ha^{-1} during 1972–75, but the application at the precise site of profile 6 was probably less, as it was in the hedgeline until the winter of 1975. Finally, the Husborne profile (7) has smaller amounts of exchangeable K than the Ridgmont profiles, and those in all horizons except the Ap (0–12 cm) can be explained in terms of the natural exchangeable K content of the boulder clay component in the soil; even in the Ap horizon 20% or less is attributable to fertilisers added.

The main conclusion to be drawn from this data is that the poorly drained soils in low-lying areas (e.g. profile 6 on White Horse Field and profile 4 on a fairly low-lying part of Lansome) act as sinks for much of the unused potassium applied as dressings not only at the profile site but also in other parts of the fields. During heavy rain the flow of water across the soil surface, which Catt *et al.* (1975, 23) discussed as the cause of soil erosion on Butt Close but also occurs on many other fields, carries away in solution part of the fertiliser K applied to higher parts of the fields. The water accumulates as temporary ponds in low lying areas and eventually penetrates the slowly permeable soils there. This slow penetration allows the soil to absorb much of the K in solution, and as the exchange sites in the surface horizons become filled the K is absorbed by successively lower horizons until a considerable depth of soil contains large amounts of exchangeable K.

Total and exchangeable sodium. Amounts of total Na are much less in the Lower Greensand ($<$ 100–200 mg kg^{-1}) than in the Chalky Boulder Clay (1100–1800 mg kg^{-1}), probably because the latter contains more felspar. In the soils the amounts range from $<$ 100 to 2400 mg kg^{-1}, and are small in horizons derived mainly from the Lower Greensand and somewhat larger in those containing more material from the boulder clay. The amounts of exchangeable Na are very small (generally $<$ 10 mg kg^{-1}) in most of the soil samples, less than in either the Chalky Boulder Clay (25–45 mg kg^{-1}) or many samples of the Lower Greensand (3·4–24 mg kg^{-1}); this is probably because of acid leaching of the soils under natural conditions before the use of agricultural lime. However, the amounts of exchangeable Na in the organic 2Cg subsoil horizons of the Ridgmont profile (6) are much larger than in any of the other samples analysed; because of their humus content these horizons would have a much higher exchange capacity than others studied, but the large increase in exchangeable Na is not matched by similar increases in other exchangeable cations, so its cause is obscure.

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Total and exchangeable magnesium. Total Mg is more abundant in the Chalky Boulder Clay (0·40–0·71%) than in the Lower Greensand (0·03–0·14%), probably because most of it occurs in the silicate clay materials. In the soils it ranges from 0·05 to 0·68%, and thus reflects the spread of values in the two parent materials. Exchangeable Mg ranges from 121 to 342 mg kg^{-1} in the Chalky Boulder Clay (2–5% of the total Mg), and from 20 to 105 mg kg^{-1} in the Lower Greensand (2·5–13% of total). In almost all the subsurface and subsoil horizons the amounts of exchangeable Mg are probably explicable in terms of the different proportions of the soil derived from Chalky Boulder Clay and Lower Greensand. The Ap horizons of profiles 1 and 4 show only a slight increase in exchangeable Mg over the subsurface or subsoil horizons, but the Ap horizons of profile 2 and the Ap and B horizons of profile 3 have rather more exchangeable Mg than subjacent horizons of the same parentage; approximately 25% of their exchangeable Mg seems to be derived from previous magnesium dressings. On the same principle, the A horizons of the Ridgmont and Husborne profiles (5–7) contain yet larger amounts of Mg from fertilisers (probably 50% or more of their exchangeable Mg).

However, the figures given in Table 6 should be compared with the values of 17–24 mg kg^{-1} exchangeable Mg for unmanured surface soil on Stackyard (Bolton & Penny, 1968), and 11 mg kg^{-1} for acid topsoil (pH 5·1) on Stackyard, which had been fallow for two years (Bolton, 1970). This suggests that some of the exchangeable Mg in the Cottenham profile (1), even in deeper horizons, may have been derived from the applications of fertiliser and farmyard manure made between 1942 and 1967, but that it has been more or less evenly distributed down the profile, at least to 80 cm depth. The same could apply to part of the exchangeable Mg in the other profiles, in which case the additional amounts (over subsoil levels) present in the Ap horizons of profiles 2, 3, 5 and 7, the A horizon of profile 6 and the B1 horizon of profile 3, may result only from the most recent Mg-containing dressings.

Total and exchangeable calcium. The Chalky Boulder Clay contains much more total Ca (32 000–96 000 mg kg^{-1}) than the Lower Greensand (100–2000 mg kg^{-1}) mainly because of the chalk fragments it contains. In the soil samples total Ca ranges from 700 to 41 000 mg kg^{-1}, but the amounts do not accurately reflect the mixtures of soil parent materials, as the boulder clay component in most of the samples has been decalcified either naturally or because of the applications of acidifying fertilisers, such as ammonium sulphate. Amounts of exchangeable Ca in the Lower Greensand range from 100–940 mg kg^{-1}, 26–100% of the total Ca contents. The amounts of exchangeable Ca quoted for the Chalky Boulder Clay and calcareous soil samples were determined without prior removal of calcium carbonate, and therefore contain an unknown amount extracted from the carbonate. This makes the pedological interpretation of the exchangeable Ca figures difficult. Nevertheless, it is clear that the smallest amounts of total and exchangeable Ca occur in sandy subsoil horizons derived mainly or entirely from the Lower Greensand, and that the largest amounts are generally in the surface or subsurface horizons, which have been influenced by recent chalk or dolomitic limestone dressings, even though (as in profiles 6 and 7) insufficient of these dressings remains to be detected with the calcimeter or to give the soil a pH greater than approximately 6.

Other trace elements. These were studied only in six samples of Lower Greensand and four of Chalky Boulder Clay, the deposits which constitute the ultimate parent materials of the soils described in this paper. Table 7 gives the means and ranges of the total and extractable amounts of each element studied. From this it is clear that the Chalky Boulder Clay in unweathered form contains more total Ba, Cr, Cu, Ga, Mn, Mo, Ni, Sr, Ti and V than the Lower Greensand, and also more extractable Cu, Mn, Mo, Ni, Pb,

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TABLE 7

Amounts (ppm) of total and extractable trace elements in main parent materials of Woburn soils

			Ba	Co	Cr	Cu	Ga	Mn	Mo	Ni	Pb	Sn	Sr	Ti	V	Zn	Zr
Chalky Boulder Clay (4 samples)	Totals	Mean	472	17	81	19	16	382	4·2	45	20	<30	390	2900	170		
		Range	370–510	15–24	74–85	17–23	13–22	360–410	3–6	44–47	20	<30	130–620	2500–3700	160–200		
	Extractables	Mean	32	8·1	15·8	6·5	0·5	105	0·6	22	5·9	0·3	66	75	41	36	2·8
		Range	26–46	6·5–9·4	7–22	3·7–9·1	0·4–0·6	80–147	0·5–0·8	19–26	3·2–7·7	0·1–0·4	35–92	45–100	21–58	26–47	1·7–3·9
Lower Greensand (6 samples)	Totals	Mean	47	<15	45	<10	<5	142	2·5	22	<20	<30	<20	460	103		
		Range	35–53	<15	20–85	<10	<5	17–330	2–3	10–28	<20	<30	<20	220–740	100–120		
	Extractables	Mean		6·7	27	3·3	0·4	41	0·2	14	3·7	0·2	10	109	64	19	13
		Range		2·5–9·7	15–43	1·0–4·6	0·2–0·7	10–100	0·1–0·3	8–20	2·2–5·3	0·1–0·3	7–14	51–175	36–83	16–25	4–45

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Sr and Zn; however, it contains less extractable Cr, Ti, V and Zr, and approximately the same amounts of total and extractable Co and of extractable Ga. The larger amounts of many elements in the Chalky Boulder Clay result mainly from its greater clay content, and the fact that most of its clay is probably derived from Mesozoic formations (e.g. Oxford Clay) deposited originally in an anaerobic environment on the sea floor; in addition, two of the trace elements in which the boulder clay is conspicuously rich (Ba, Sr) may be associated with its carbonate fraction.

Although we have not analysed the trace element content of the soils, it is nevertheless possible to predict from this data the likely qualitative trace element status of the different series. The Cottenham series, with little or no Chalky Boulder Clay component, is likely to have only small available reserves of many important micronutrients (Cu, Mn, Mo, Ni and Zn); the Stackyard and Flitwick series probably have only slightly larger reserves than the Cottenham, but the Ridgmont and Husborne series probably have greater reserves and are less likely to suffer from deficiencies.

Discussion and conclusions

As on some adjacent parts of Woburn Experimental Farm (Catt *et al.*, 1975), all the soils on the Lower Greensand in Lansome, White Horse and School Fields are affected to some extent by admixture of silt and clay derived from weathered Chalky Boulder Clay. In the Cottenham series the amounts of this additional material are small and usually affect only the uppermost parts of the profile, so that at least half the top 80 cm is loamy sand, the same particle size class as the bulk of the Lower Greensand itself. In the Stackyard series, which is more widespread on the fields considered, the proportion of fine soil material from the boulder clay is slightly greater and affects a greater depth of soil, so that sandy loam textures persist from the surface to depths of 60–200 cm.

Although both the Stackyard and Cottenham series are well drained soils, the slight textural difference between them is likely to result in significantly different available water capacities; estimates based on data given by Hodgson (1976, Table 19) suggest that the difference is about 30%. Previously we predicted this might affect crop growth in periods of prolonged summer drought (Catt *et al.*, 1975, 22), and this was confirmed by crop yields during 1976, when spring and summer rainfall was extremely small. The most extreme example of yield differences was provided by potatoes; Maris Piper grown on Cottenham series at the south-western end of Lansome (near the summit of Lansome Hill) yielded as little as 5 t ha^{-1}, whereas Pentland Crown on Stackyard series in White Horse Field yielded 25–35 t ha^{-1}. Some of the Stackyard soils may also have slightly larger reserves of some plant nutrients (Mg and some trace elements), but the differences are small and unlikely to affect yields much. It seems to be mainly during dry periods that the Stackyard soils perform appreciably better than the Cottenham.

The sandy loam drift in which most horizons of the Stackyard series are developed seems to have been deposited mainly by downslope soil movement during the last few thousand years, probably since deforestation and the start of agriculture in the Middle or Late Bronze Age. This implies that much of the higher ground, such as Lansome Hill, previously had a thin cover of weathered boulder clay. The erosion of this on Lansome Hill has exposed the Lower Greensand around the summit, so that the Cottenham soils there are developed on Greensand *in situ*. However, further recent erosion on this part of Lansome has resulted in the formation of sandy rather than loamy colluvial tongues on the surrounding slopes, and these have also been mapped as Cottenham series. The absence of similar tongues on White Horse Field, and the persistence of loamy colluvium almost to the highest point of the field, suggest that much of the erosion into the Greensand on the summit has occurred since the hedge between Lansome and White Horse

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Fields was established during the enclosures about A.D. 1800. The hedge and the long period during which White Horse Field was maintained in pasture prior to 1961 have together prevented the most recent soil erosion from affecting the field; now it is arable, removal of the hedge would almost certainly result in increased erosion there, and could ultimately change the mapped distribution of the two soil series.

The shallow dry valleys that cross the south-eastern side of Lansome and run along the boundary between White Horse and School Fields may have contained small temporary streams within historic times, and there is some evidence for slight water-sorting of the deposits on their floors, in which imperfectly drained soils of the Flitwick series occur. However, most of the material in the two Flitwick profiles studied is texturally and mineralogically similar to the colluvium in the Stackyard series, and the areas mapped as Flitwick are the main sites of deposition of soil eroded from surrounding slopes. The surface run-off has also transferred potassium from fertilisers applied to the Cottenham and Stackyard soils to the valley floors, and this has considerably increased the potassium reserves in many of the Flitwick soils. The available water of the Flitwick soils is at least as large as that of the Stackyard series, and for much of the year is probably much greater.

Much more clayey and organic deposits, in which soils of the Ridgmont series have been mapped, occupy the lowest areas where lakes occurred, probably until the Late Bronze or Iron Age on School and White Horse Fields, and until the mid-nineteenth century on Lansome (Mill Dam Close). In both areas the clay was probably derived ultimately from weathered Chalky Boulder Clay via a colluvial phase on intervening slopes, and was concentrated by water-sorting; since the sites were drained there has been further encroachment of colluvium, which has not been sorted and clay-enriched to the same extent. Because they occupy the lowest areas, some of the Ridgmont soils have been enriched to a considerable depth with potassium from fertilisers in the same way as some of the Flitwick profiles.

The only high ground which retains a cover of Chalky Boulder Clay *in situ* is on the south-western side of School Field, but here it is buried beneath a variable thickness of a slope deposit formed probably during a cold period or periods before approximately 10 000 years ago. This slope deposit is again a mixture of material derived from the boulder clay and the Lower Greensand, but there is generally a greater proportion of the boulder clay component than in the colluvium, and the mass movement of material in the partly frozen condition has resulted in less dispersion and sorting of the constituent particles. The resulting soils (the Husborne series) are approximately as clay-rich and as poorly drained as the Ridgmont series, but are more stony throughout and are less organic and less acid at depth. All the relatively clay-rich soils probably contain larger reserves of many plant nutrients and micronutrients than the sandier Cottenham and Stackyard soils.

Many of the chemical and hydrological differences between the main soil types are likely to be important in the interpretation of results obtained from agricultural experiments on this part of the farm. For example, the Market Garden experiment, as laid out on Lansome in 1942, included three soil series, the plots of Series A being largely on Cottenham soils with some Stackyard, and those of Series B on Stackyard soils with Flitwick series near the south-eastern margin. The final phase of this experiment involved growing spring tick beans in 1968 and 1969 on all plots (without further additions of manure), to assess the residual value of the previous treatments with bulky organic manures and inorganic fertilisers. Although yields were good in 1968, and were larger on the plots which had received organic manures, they were much smaller in 1969, especially on the Series A plots. Differences between plots previously treated with organic and inorganic manures were still apparent in 1969, but the overall decreases on Series A compared with Series B could not be related to earlier treatments. Johnston and Wedder-

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burn (1975) tentatively attributed these to larger amounts of water on Series B, although they assumed uniform soil type across the experimental area. The soil differences, involving larger amounts of available water in the Stackyard and Flitwick soils of Series B compared with the Cottenham and subsidiary Stackyard soils of Series A, certainly support their suggestion, and seem to be the only way of explaining the yield differences. Other plots have also been laid out across soil boundaries, and have thereby introduced unnecessary complicating factors in the ultimate interpretation of experimental results.

Crowther (1936) attempted to explain the frequent lack of response to potassium by crops grown at Woburn by suggesting that the weathering of glauconite supplied enough potassium for crop requirements. Microscopic examination of the glauconite in the profiles we have studied showed that, although most of the pellets in fine sand and coarse silt fractions are green and unweathered in lower horizons, and that some of these become brown in higher horizons through oxidation, generally they do not decrease in abundance towards the surface. Electron probe microanalysis of typical green and brown pellets by Mr M. A. Carpenter (Department of Mineralogy and Petrology, University of Cambridge) using a Si(Li) detector pulse processor (Statham, 1976) showed that weathering decreases their K content from an average of 6·83% to an average of 5·77%. As the amounts of glauconite in most of the profiles range from 1–5% of the total soil, the total K released by this weathering has been of the order of 0·01–0·05% of the soil, i.e. 300–1500 kg ha^{-1}, assuming the top 23 cm of soil weighs 3×10^6 kg ha^{-1}. Spread over even as short a period as the 100 years since experiments began at Woburn, this amount is clearly much less than the crops would have required. Larger amounts of potassium may have been lost from profile 3 (Flitwick series), in which there is a fairly consistent upward decrease in the glauconite content, but this was the only profile showing such a decrease.

Comparison of the exchangeable K contents of Lower Greensand and Chalky Boulder Clay samples (Table 6) with their clay contents (Catt *et al.*, 1975, Table 2), shows that the Lower Greensand supplies approximately 1 mg kg^{-1} more exchangeable K for every 1% clay than the Chalky Boulder Clay. However, the Lower Greensand samples containing more than average amounts of sand- and silt-sized glauconite do not have more exchangeable K than the less glauconitic samples. This suggests it is the clay fraction of the Lower Greensand rather than the glauconite in its sand and silt fractions which is the main supplier of exchangeable K. Nevertheless, the evidence for glauconitic coatings on quartz sand grains preserved by diagenetic silica cementation in the green sandstone found on White Horse Field suggests that much of the clay in the Lower Greensand was derived from the coatings by intrastratal oxidation (deep subsurface weathering). The clay may therefore resemble the glauconite pellets in mineralogical composition, but is probably able to supply more potassium because it is in small particles rather than pellets.

We conclude that the main natural source of potassium in the sandy soils (Cottenham series, and possibly also Stackyard and Flitwick series) is the small amount of clay derived from the Lower Greensand, which may originally have come from glauconitic coatings on sand grains, but that in the more clay-rich soils (Ridgmont and Husborne series) this source is far outweighed by the large amounts of clay derived from the Chalky Boulder Clay, even though this has a somewhat smaller potassium-supplying power per unit weight. The relatively small amounts of glauconite in the soils play little or no part in preventing crops from responding to applied potassium. The lack of response Crowther noted was probably due to the fact that the clay fraction could supply enough potassium for the small crops grown at the time. Since then nitrogen dressings have increased, yields have been larger, and responses to applied potassium have been noted. We would expect these responses to appear first on the Cottenham and Stackyard soils, which have the smallest amounts of clay and therefore the smallest potassium reserves, and only

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later (or not at all) on the clay-rich and low-lying soils which have been enriched in potassium washed from higher areas.

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APPENDIX A

Profile descriptions

1 Cottenham series

Location: Lansome (SP 962359).
Land use: Market Garden experiment, plot 2.

Ap1	0–6 cm	Dark brown (7·5 YR 3/2), very friable, slightly stony, loamy sand; medium subangular flints; weakly developed medium subangular blocky structure falling to crumb; abundant fine fibrous roots; sharp smooth boundary.
Ap2	6–22 cm	Dark reddish brown (5 YR 3/2), very friable, very slightly stony, loamy sand; small subangular flints and carstone fragments; weakly developed medium subangular blocky structure; common fine fibrous roots; abrupt smooth boundary.

B1	22–44 cm	Dark reddish brown (5 YR 3/2), very friable, very slightly stony, loamy sand; small to medium carstone fragments; very weakly developed coarse to medium subangular blocky structure; few fine fibrous roots; abrupt smooth boundary.
B2	44–57 cm	Brown (10 YR 4/3), loose, very slightly stony sand; medium carstone fragments; structureless, single grain; abrupt smooth boundary.
C	57–80 cm	Yellowish red (5 YR 4/6), loose, very slightly stony sand; medium carstone fragments; structureless, single grain; abrupt smooth boundary.
2C	80 cm +	Light olive brown (2·5 Y 5/4), loose sand.

2 Stackyard series

Location: Lansome (SP 962358).
Land use: Market Garden experiment, plot 71.

Ap1	0–7 cm	Very dark greyish brown (10 YR 3/2), very friable, sandy loam; weakly developed medium subangular blocky structure falling to crumb; abundant fine fibrous roots; abrupt smooth boundary.
Ap2	7–25 cm	Very dark greyish brown (10 YR 3/2), very friable, very slightly stony, sandy loam; small subangular flints; weakly developed coarse to medium subangular blocky structure; many fine fibrous roots; sharp smooth boundary.
B1	25–51 cm	Dark brown (7·5 YR 3/2), very friable, very slightly stony, sandy loam; medium to small carstone, flint, quartzite and vein quartz fragments; weakly developed coarse to medium subangular blocky structure; few medium fibrous roots; smooth clear boundary.
B2	51–76 cm	Brown (7·5 YR 4/2), very friable, moderately stony, sandy loam; subangular sandstone, flint and quartzite fragments; weakly developed coarse to medium subangular blocky structure; few medium fibrous roots; smooth clear boundary.
B3	76–95 cm	Brown (7·5 YR 4/6), friable, very slightly stony, sandy loam; subrounded carstone and quartzite fragments; weakly developed coarse to fine subangular blocky structure; abrupt smooth boundary.
C1	95–124 cm	Brown (7·5 YR 4/4), friable, very slightly stony, loamy sand; carstone fragments and a quartzite dreikanter; weakly developed medium subangular blocky structure; abrupt smooth boundary.
2C2	124–178 cm	Brown (10 YR 4/3), very friable, loamy sand; very weakly developed subangular blocky structure; sharp smooth boundary.
2C3	178 cm +	Greyish brown (2·5 Y 5/2), loose sand, with common distinct yellowish brown (10 YR 5/6) bands.

3 Flitwick series

Location: Lansome (SP 963358).
Land use: Market Garden experiment, plot 80.

Ap1	0–7 cm	Very dark brown (10 YR 2/2), friable, sandy loam; moderately developed fine subangular blocky structure falling to crumb; abundant fine fibrous roots; abrupt smooth boundary.
Ap2	7–25 cm	Dark brown (7·5 YR 3/2), friable, very slightly stony, sandy loam; medium to small subangular flints and subrounded carstone fragments; weakly developed coarse to medium subangular blocky structure; common fine fibrous roots; sharp boundary.
B	25–47 cm	Dark yellowish brown (10 YR 3/4), firm, very slightly stony, sandy loam; medium to small subangular flints; weakly developed coarse to medium subangular blocky structure; few fine fibrous roots; gradual boundary.
C(g)	47–84 cm	Dark yellowish brown (10 YR 4/4), friable, very slightly stony, sandy loam, with many very fine dark reddish brown (5 YR 3/3) mottles; medium to small subangular flints, and subrounded carstone and quartzite fragments; moderately developed coarse to medium subangular blocky structure, with slight tendency to platyness; few fine fibrous roots; gradual boundary.
2Cg1	84–112 cm	Greyish brown (2·5 Y 5/2) loamy sand, with very many coarse, distinct reddish brown (5 YR 4/3) mottles; single grain; clear smooth boundary.
2Cg2	112–134 cm	Olive brown (2·5 Y 4/4) loamy sand, with many coarse, distinct banded brown (10 YR 4/3) mottles; single grain; gradual boundary.
2Cg3	134–159 cm	Greyish brown (2·5 Y 5/2), very friable, loamy sand, with few faint yellowish brown (10 YR 5/4) mottles; weakly developed medium subangular blocky structure; clear smooth boundary.

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2Cg4	159–170 cm	Olive brown (2·5 Y 4/4), very friable, loamy sand, with common coarse reddish brown (5 YR 4/4) mottles concentrated in a central band; weakly developed medium subangular blocky structure.

4 Flitwick series

Location: Lansome (SP 963359).
Land use: Arable.

Ap1	0–7 cm	Dark brown (7·5 YR 3/2), firm, very slightly stony, sandy loam; small subangular flints; moderately developed coarse to medium subangular blocky structure; few fine fibrous roots; gradual boundary.
Ap2	7–21 cm	Very dark greyish brown (10 YR 3/2), friable, very slightly stony, sandy loam; small subangular flints; weakly developed coarse to medium subangular blocky structure; few fine fibrous roots; smooth sharp boundary.
B	21–40 cm	Reddish brown (5 YR 4/3), firm, sandy loam; weakly developed coarse to medium subangular blocky structure; few fine fibrous roots; smooth clear boundary.
B(g)	40–67 cm	Dark reddish grey (5 YR 4/2), firm, sandy clay loam, with many fine faint, dark reddish brown (5 YR 3/4) and grey mottles; weakly developed coarse to medium subangular blocky structure; few fine fibrous roots; abrupt smooth boundary.
Cg1	67–88 cm	Dark greyish brown (10 YR 4/3), friable, sandy loam, with many very fine, distinct dark reddish brown (5 YR 3/4) and grey mottles; weakly developed coarse to medium subangular blocky structure; gradual boundary.
Cg2	88–104 cm	Dark greyish brown (10 YR 4/2), friable, sandy loam, with many very fine, distinct mottles in shades of grey and brown; moderately developed coarse to medium subangular blocky structure; clear smooth boundary.
Cg3	104–119 cm	Very dark greyish brown (10 YR 3/2), friable, sandy clay loam, with common, very fine, faint mottles in shades of grey and brown; ochre-stained sandy pockets and ped faces; a few small carstone fragments and large subangular flints at base of horizon; moderately developed coarse to medium subangular blocky structure; abrupt smooth boundary.
Cg4	119–126 cm	Very dark grey (10 YR 3/1), firm, very slightly stony, clay loam, with few fine brown mottles; rounded quartzite fragments; moderately developed medium subangular blocky structure; sharp irregular boundary.
Cg5	126–147 cm	Greyish brown (10 YR 5/2), firm, silty clay loam, with common medium distinct yellowish brown and grey mottles; some sandy ped faces; moderately developed medium subangular blocky structure; few fine woody roots; abrupt smooth boundary.
Cg6	147–172 cm	Greyish brown (2·5 YR 5/2), very friable, very slightly stony, sandy loam, with very many coarse prominent strong brown (7·5 YR 5/8) mottles; small carstone fragments; abrupt smooth boundary.
2Cg	172 cm +	Loose loamy sand, faintly mottled in shades of grey and brown.

5 Ridgmont series

Location: Lansome (SP 964360).
Land use: Arable (headland).

Ap1	0–6 cm	Dark brown (7·5 YR 3/2), firm, sandy clay loam; moderately developed medium to fine subangular blocky structure, falling to crumb; many fine fibrous roots; sharp smooth boundary.
Ap2	6–31 cm	Dark brown (7·5 YR 3/2), firm clay loam; moderately developed medium to coarse subangular blocky structure; common fine fibrous roots; abrupt smooth boundary.
BCg	31–48 cm	Brown (10 YR 4/3), friable loamy sand, with common fine faint yellowish brown (10 YR 5/8) and some grey mottles; weakly developed medium subangular blocky structure; abrupt smooth boundary.
2Cg	48–67 cm	Brown (10 YR 5/3) loose sand.

6 Ridgmont series

Location: White Horse Field (SP 960359).
Land use: Arable (old hedge line).

A	0–23 cm	Dark brown (7·5 YR 3/2), friable, clay loam; fine subangular blocky structure falling to crumb; common fine fibrous and some medium to coarse woody roots; diffuse boundary.

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Bg1	23–40 cm	Dark reddish brown (5 YR 3/3), friable, clay loam; fine subangular blocky structure falling to crumb; common medium fibrous roots; diffuse boundary.
Bg2	40–56 cm	Dark reddish brown (5 YR 3/3), firm, clay loam; medium subangular blocky structure; common fine fibrous roots; gradual boundary.
Cg	56–105 cm	Very dark grey (10 YR 3/1), firm, clay loam, with many distinct extremely fine, yellowish brown (10 YR 5/6) mottles; coarse prismatic falling to medium subangular blocky structure; common fine fibrous roots, mainly on structure faces; sharp boundary.
2Cg1	105–118 cm	Black (2·5 Y 2/0), humose clay; fine subangular blocky structure; common fine fibrous roots, gradual boundary.
2Cg2	118–146 cm	Black (2·5 Y 2/0), peaty clay; fine subangular blocky structure; few fine fibrous roots; sharp boundary.
3Cg	146 cm +	Brown to dark brown (7·5 YR 4/4), fine gravelly, loamy sand; common medium, subrounded and tabular sandstone fragments.

7 Husborne series

Location: School Field (SP 960358).
Land use: Arable (headland).

Ap	0–12 cm	Dark brown (7·5 YR 3/2), slightly stony, firm, sandy loam; very small subangular and tabular flints; fine subangular blocky structure; few fine fibrous roots; gradual boundary.
AB	12–23 cm	Brown to dark brown (10 YR 4/3), slightly stony, firm, sandy loam; medium subangular flints; medium subangular blocky structure; few fine fibrous roots; clear smooth boundary.
Bw	23–38 cm	Brown to dark brown (10 YR 4/3), stony, firm, sandy loam to sandy clay loam; medium subangular flints; coarse subangular blocky structure; few fine fibrous roots; clear smooth boundary.
2Bg1	38–80 cm	Greyish brown (2·5 Y 5/2), stony, firm clay, with common, distinct, very fine, strong brown (7·5 YR 5/6) mottles; medium rounded carstone and flint fragments; coarse subangular blocky structure; common rounded ferrimanganiferous concretions; clear smooth boundary.
2Bg2	80–98 cm	Grey (2·5 Y 5/0), slightly stony, firm clay, with common distinct, very fine strong brown (7·5 YR 5/6) mottles; medium subrounded flints; coarse subangular blocky structure; clear smooth boundary.
3Cg	98–139 cm	Grey (2·5 Y 5/0), very slightly stony, sandy clay loam, with sandy and clayey bands, and many distinct, very fine, yellowish brown (10 YR 5/6) mottles; many medium, angular, subangular and platy flints; weak medium subangular blocky structure; clear wavy boundary.
4Cg	139–153 cm	Grey (5 Y 5/1), loose, loamy sand; clear wavy boundary.
5C(g)	153 cm +	Dark grey (2·5 Y 4/0), slightly stony, calcareous clay, with many faint, extremely fine, olive brown (2·5 Y 4/4) mottles; small subangular and tabular flints, chalk and sandy limestone fragments; a few irregular, soft secondary carbonate concretions.

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