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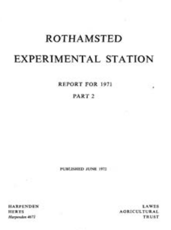

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The Soil of Barnfield

B. W. AVERY, P. BULLOCK, J. A. CATT, A. C. D. NEWMAN,
J. H. RAYNER and A. H. WEIR

Barnfield carried root crops from 1843 to 1968, except for three years of barley (1853–55), and except for some minor changes the arrangement of plots and manurial treatments has remained the same since 1876, when the classical experiment on mangolds was started by Lawes and Gilbert. The latest account of the experiment, which was modified to include sugar beet in 1946, was by Warren and Johnston (1962), who examined results for the 1940–59 period in relation to those for earlier periods, and gave the chemical composition of crop and soil samples taken in 1958 and 1959. We now report recent studies on the profile morphology and composition of the soil, with special reference to particle-size and mineralogical characteristics that reflect its mode of origin and influence its field behaviour.

The field (National Grid Reference TL 133133) extends from north to south along the western side of the Harpenden valley, and slopes more than the other classical fields (Fig. 1). The total area of cultivated land, including pathways and headlands, is approximately 3·44 ha. From the south-west corner, which lies little below the general local level of the Chiltern plateau, the land falls to a shallow re-entrant known as 'the valley', with the lowest point at the eastern end of section 2. The steepest slope (about 4°) is in section 3 south of 'the valley'; on the northern side the gradient is less and the general inclination eastwards. Sections 1, 3, 4, 5 and 6 correspond to series O, N, A, AC and C respectively of the classical experiment, in which a gap approximately 30 m wide (now section 2 plus the headland between 2 and 3) was left between series O and N.

Profile characteristics in relation to land-use history

In common with most of the Rothamsted land, the soil of Barnfield is characterised by a brownish loamy and flinty surface layer of variable depth over Clay-with-flints, which in turn rests on chalk. Fig. 2, based on auger borings at intersections of pathways between plots, shows the variation in depth of the loamy surface soil. Over about 80% of the field, strong brown to yellowish red clay with scattered flints occurs directly beneath the ploughed layer, which is mainly of silty clay loam texture, as defined in the U.S.D.A. system (Soil Survey Staff, 1951, 211). Soil of this type, with red, brown and greyish mottling in lower horizons, was classed as a shallow or eroded phase of the Batcombe series by Avery (1964). It occupies much of Broadbalk (Avery & Bullock, 1969), but the topsoil there is generally a little less clayey than in Barnfield. Chiefly confined to slopes long cultivated, it is usually replaced on level plateau sites by soil of the same series with a thicker and less clayey (silt loam) surface layer, and grades into the Winchester series where the Clay-with-flints thins on valley sides and spurs. The Winchester series has a subsoil layer of reddish plastic clay with large nodular flints and black manganiferous deposits, but little or no red or greyish mottling (the Clay-with-flints *sensu stricto* of Loveday, 1962), which rests irregularly on chalk, usually at depths of 30–120 cm. It occurs in places at Rothamsted where chalk approaches the surface, but consistently mappable areas were not found in Barnfield.

In strips 5–8 of section 3 and in eastern parts of the headland between sections 2 and 3, the flinty silt loam surface layer is 60 cm or more thick, locally with a gravelly layer at

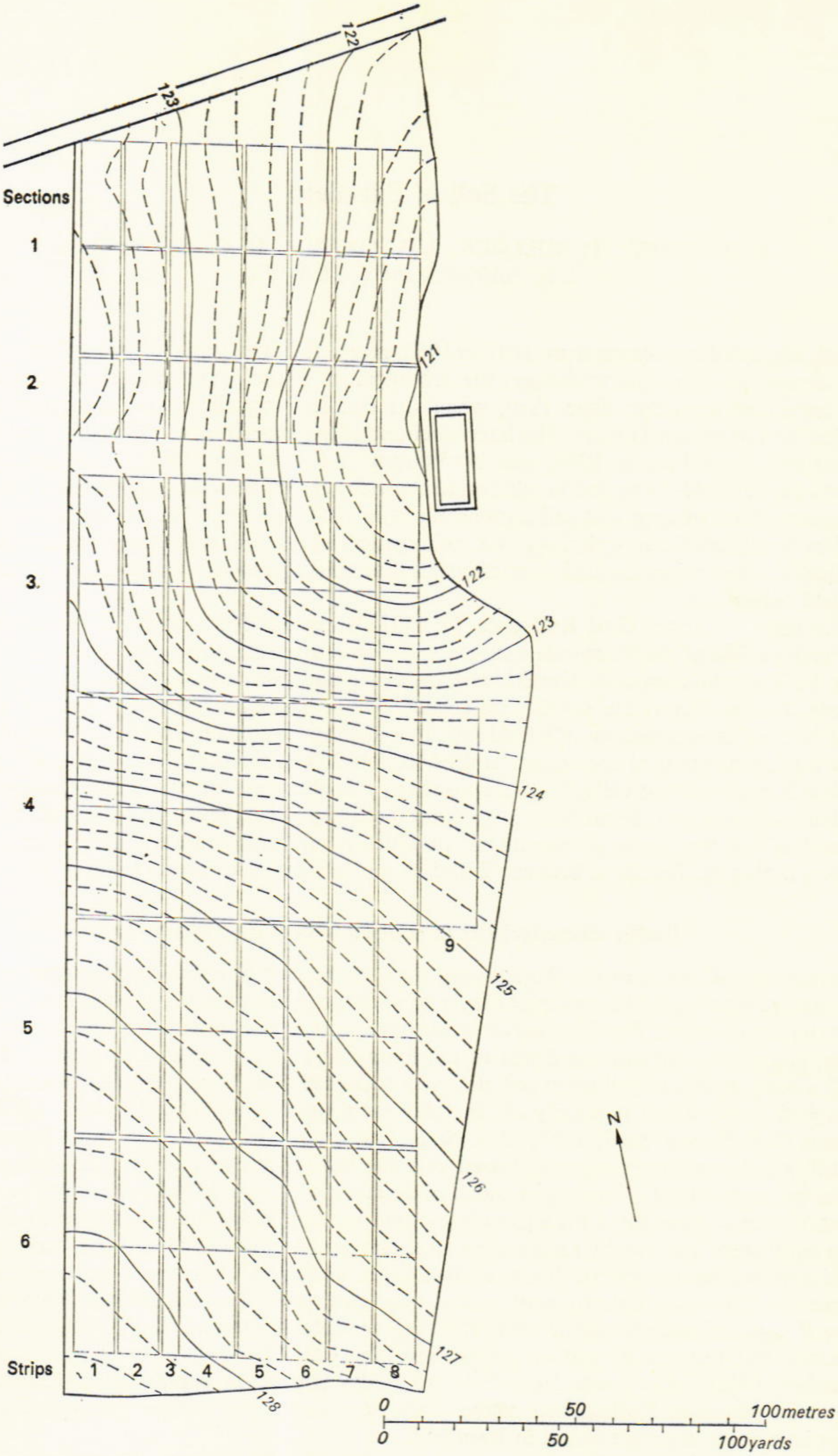

FIG. 1. Map of Barnfield showing position of plots and contours at 0·2 m intervals above ordnance datum.

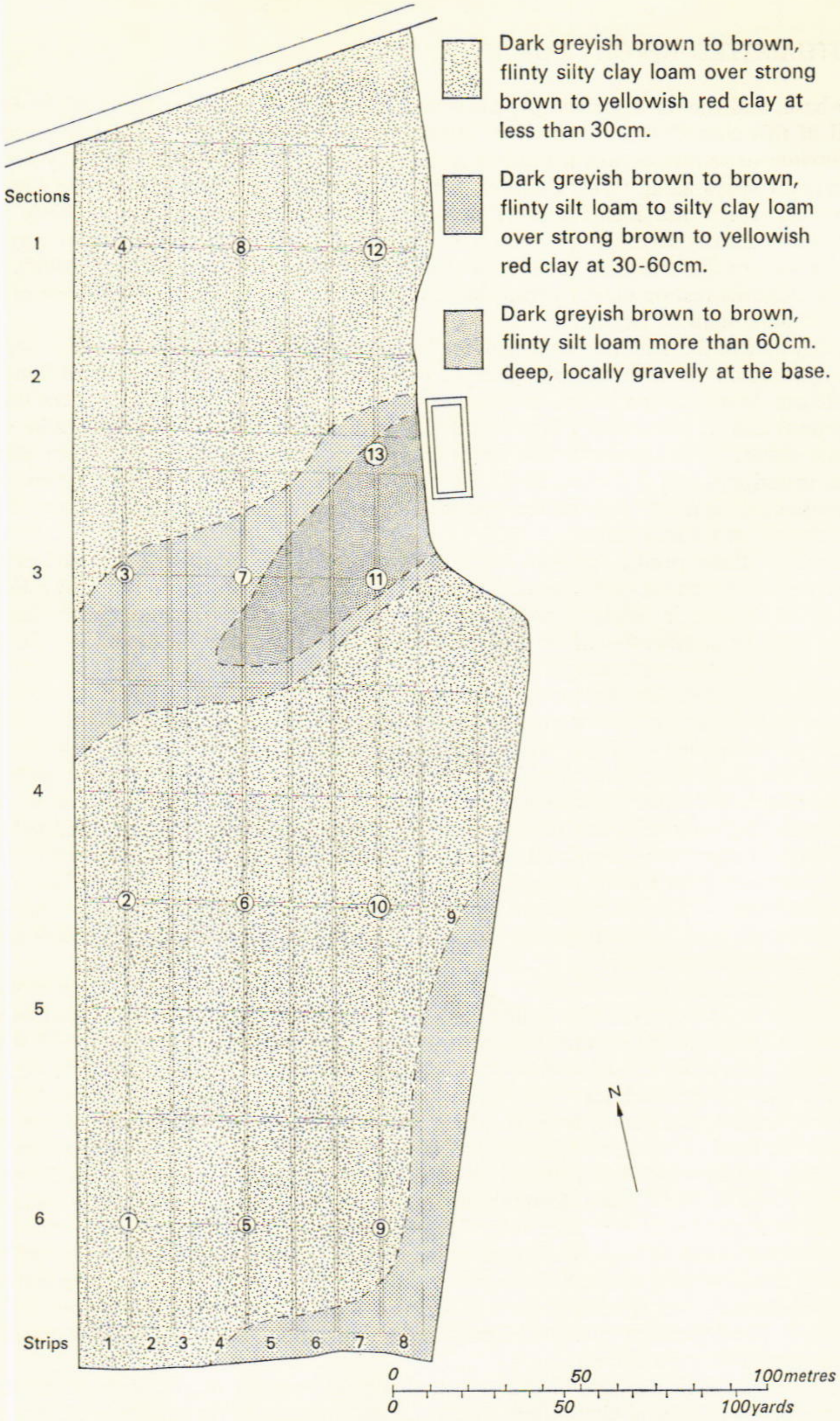

FIG. 2. Soil map of Barnfield, showing sites of profiles sampled.

the base, and the dark surface (A) horizon is thicker than in higher parts of the field. Soil of this character, with an upper layer apparently consisting of recent (Holocene) colluvium or rainwash, was classed as Nettleden series (Avery, 1964). It usually occurs in narrow strips along valley bottoms, and was grouped for mapping with the Charity complex, which also includes other well-drained, naturally non-calcareous flinty and silty soils (Charity series) in head (solifluction) deposits over chalk. In the higher parts of minor valleys that head on the plateau, as in Broadbalk (Avery & Bullock, 1969), the valley deposits rest on slowly permeable Clay-with-flints, and the lower horizons of the profile show signs of gleying.

Elsewhere in the field, the loamy surface layer is mostly of intermediate depth, a brown loamy horizon beneath the ploughed layer resting irregularly on Clay-with-flints at 30–60 cm. In a small peripheral area at the south-east corner, and in places at the upper (western) end of 'the valley', the subsoil clay is distinctly mottled and the profile as a whole conforms to the Batcombe series (normal or uneroded phase). In other places (e.g. in strips 4 and 5 of section 3) the clay is reddish with little mottling, probably because chalk is nearer the surface, and in this respect the profiles resemble those of the Winchester or Charity series.

Each of these profile variants has a brown or reddish weathered sub-surface (B) horizon without native calcium carbonate, and accordingly conforms to the Brown Earth group as defined in England and Wales (Avery, 1965). The Winchester and Charity soils have Bt horizons—argillic horizons in the U.S.D.A. classification (Soil Survey Staff, 1960, 1967)—containing translocated clay, and are accordingly classed at sub-group level as *sols lessivés*. The Batcombe soils also have Bt horizons, but as they show evidence of gleying in lower parts of the profile they are classed as gleyed *sols lessivés*. The Nettleden soils are considered colluvial brown earths with a deep-lying Bt horizon as part of a buried solum. In effect, this classification groups the Batcombe soils, which occupy most of Barnfield, with other relatively well-drained, leached soils that have medium or fine textured, originally acid, surface horizons and slowly permeable, finer textured subsoil horizons. It separates them from otherwise similar soils, classed as surface-water gley soils, that have poor natural drainage resulting in distinct gleying in or directly below the topsoil. Most of the Saxmundham soils, for example, are surface-water gley soils. In the U.S.D.A. classification system, the Batcombe soils conform to the Paleudalf great group in the Alfisol order.

Variations in the depth of loamy soil and in topsoil texture result partly from erosion and deposition since the land was first cultivated. The 'White books' (original manuscript records of Rothamsted experiments) record five occasions between 1889 and 1936 when unusually heavy rain caused surface soil and sometimes also mangold plants to be washed from higher ground and deposited in 'the valley'. In 1894 there was 'an immense flow of water from the park on to the field, which ran in a continuous stream, both down and across the land'. On later occasions excess surface water apparently originated within the field, and flow was concentrated down the paths, especially between strips 2 and 3, 4 and 5, 5 and 6, and 7 and 8, forming streams which bent round and ran across section 3 towards the pond on the eastern side of the field. In a detailed account of the effects of a storm on 21 June 1936, E. W. Russell noted much movement of surface soil on sections 4 and 5 and down the paths. Soil derived mainly from strips 5, 6 and 7 on these sections was redeposited over the lower parts of strips 4–8 of section 3, and the lowest part of section 2. The deposits were up to 3·7 cm thick and on strips 7 and 8 were locally gravelly; many mangolds were buried.

The heaviness of the topsoil over most of the field clearly results from progressive incorporation of subsoil clay. Much sticky clay was brought to the surface in 1930, when the land was cultivated to 30–37 cm depth by steam tackle, and the process evidently still continues, as the ploughed layer in most plots contains nodules of brightly coloured clay in various stages of assimilation. Measurements of drawbar pull by Haines and Keen (1925) showed that the land was lightest in the lower part of 'the valley', and expecially heavy in parts of strip 1, even though this had received 14·2 tons farmyard manure annually. Strip 1 is close to the western boundary of the field, which then as now was marked along most of its length by an abrupt rise in the ground, suggesting that the heaviness results from local removal of the originally loamy topsoil. As the 1843 tithe award map of Harpenden shows no field boundary in this position, formation of the declivity and truncation of the soil profile have probably occurred since the present field boundaries were established and experimentation began. Still earlier, as shown on the 1623 plan of Rothamsted estate, two enclosures called Harwoods and Upper Hagdell were separated by an east–west boundary extending along the southern side of 'the valley' into what is now Great Field.

Because of the relatively heavy soil and the slowness with which it dries out after rain, satisfactory seedbeds for root crops were always difficult to prepare in unfavourable seasons. Before 1876 swedes were grown for 15 successive years, but this regime led to such poor crops that it was discontinued. According to Hall (1917) 'this was mainly due to the incidental circumstance that on growing the same description of crop, with the same comparatively limited and superficial root range . . . , the surface soil became less easily worked, and the tilth, so important for turnips, was frequently unsatisfactory; whilst for want of variety and depth of root range of the crop, a somewhat impervious pan was formed below'. Less difficulty was experienced with mangolds, and Hall attributed this 'partly to the extended root-range of the mangold, partly also to its freedom from insect and fungoid attacks'. However, the 'White books' record several seasons in which uneven germination was associated with a poor seedbed, and some in which a second sowing was needed, apparently because heavy rain around sowing time was followed by a dry period in which the packed surface hardened.

Despite the heaviness of the soil and occasional crop failures attributed to excess surface water, there is no record of systematic under-drainage since experimentation began, although the field was subsoiled to about 10 cm below the usual ploughing depth to break up the pan in 1890 and 1899, and steam cultivated in 1930. However, there is strong evidence that a tile-drainage system was installed earlier. Fragments of drainage tile of an early 'horseshoe' type were unearthed when a trench was dug for an electric cable beside the farm road, and a core sample extracted for our work contained a similar fragment. Also, the concrete-lined pit, which was built on the site of a dell-hole pond within the original eastern boundary of the field, receives a 114 mm outfall pipe aligned parallel to 'the valley' and two 57 mm pipes apparently from north-western parts of the field. After wet weather these together discharge over 200 litres/min. Effluent was sampled from the large pipe on 19 November 1970 after heavy rain; each litre contained 50 mg solid material (mainly fine clay), and 25 mg K, 19 mg Na, 94 mg Ca and 4 mg Mg in solution. This composition suggests it is drainage rather than surface water, but there is no evidence that it all comes from Barnfield.

Sampling and analytical methods

Sampling. To assess 'natural' soil variability within the field on a probability basis, a Proline corer was used to extract undisturbed profiles, 15 cm in diameter and 90 cm deep, from 12 points sited grid-wise in interplot pathways (Fig. 2) to avoid disturbing the plots and to minimise differences related to treatments. To investigate deeper layers in 'the valley', a pit 3·1 m deep (profile 13) was excavated in the headland between sections 2 and 3. The profiles were described in accordance with the U.S.D.A. Soil Survey

Manual (Soil Survey Staff, 1951), and samples from each horizon were analysed for particle-size, chemical and mineralogical composition. For easy reference, samples were numbered consecutively from the surface downwards. The ploughed layer (Ap horizon) was sampled to a standard depth of 15 cm in each core, and where the lower boundary of the dark coloured surface horizon was deeper than 25 cm, the lower part was sampled separately. Other samples from the cores were taken from the whole thickness of morphologically recognisable horizons, which were designated according to the scheme used by the Soil Survey of England and Wales. Thin sections of additional undisturbed samples from selected horizons were prepared after impregnation with Autoplax 110 resin, and studied to estimate the porosity of surface and directly underlying horizons, and to elucidate soil fabric characteristics.

As the cores were taken from regularly cultivated pathways and accordingly contained few roots, the soils were expected to differ to some extent in structure and composition, and especially in organic-matter content, from those under crops. When extracted in October 1970, after several weeks of dry weather, moisture contents of the clay subsoils were near field capacity, and macro-structure (pedality) was barely evident in most horizons. However, differences in the colour, structure and consistence of upper horizons between pathways and adjacent plots were hardly perceptible after ploughing and overwintering, and differences in organic-matter content are small compared with those between dunged and unmanured plots. For example, in profile 3, sited between two dunged strips, the ploughed layer contains nearly 2% organic carbon (Table 5), whereas corresponding layers in profiles 7, 8 and 11 have 0·6–0·8%. Warren and Johnston (1962) recorded total N in the surface soil (0–22·8 cm) ranging from 0·23 to 0·26% in the dunged plots of sections 1–4, and from 0·09–0·10% in other strips; assuming the C : N ratio is approximately 10 : 1, the corresponding organic carbon contents (2·3–2·6% and 0·9–1·0% respectively) are only slightly larger than amounts in the pathways.

Analytical methods. Samples weighing approximately 1 kg were taken from each horizon recognised in the 12 Proline cores, dried and then sieved through a 2 mm mesh to find the percentages of stones (>2 mm) and finer oven-dry soil. The stones (>6 mm) in the surface soil were also sampled near profiles 1, 4, 7, 9 and 12 (to give a quincuncial pattern) by sieving in the field all the soil taken within a circular hoop of 0·62 m^2 area to a depth of approximately 5 cm. Each stone was then weighed, and the size distribution determined by grouping the stones according to limits approximately equivalent to the weights of spheres ranging in size from $-2{\cdot}5$ to $-5{\cdot}5\ \phi$ ($\phi = -\log_2 d$, where d is the diameter in mm) and with a specific gravity similar to that of flint (2·60).

The particle size distribution of <2 mm fractions was determined on 10 g samples of air-dry soil, which were treated with 12% hydrogen peroxide to remove organic matter and then dispersed in a 0·1% w/v solution of sodium hexametaphosphate by shaking for 16 hours. The <2, 2–5 and 5–20 μm fractions were estimated by the pipette-sampling technique, the coarse silt (20–50 μm) was separated by repeated settling in dilute aqueous suspension, and the sand fractions (50–2000 μm) were subdivided with 100, 200 and 500 μm sieves.

Calcium carbonate was measured with a calcimeter (Bascomb, 1961), and organic carbon by Tinsley's (1950) wet-oxidation method. The pH in 1 : 2·5 water and 0·01 *M* calcium chloride suspensions was measured by glass electrode, and 'free iron oxide' by a modification of Deb's method (1950), shaking overnight at room temperature with sodium dithionite buffered at pH 3·8 by acetic acid and sodium acetate. Exchangeable K, Na, Ca and Mg were determined on samples from profiles 5 and 9 by displacement with M ammonium acetate at pH 7.

The 20–50 μm fractions from profiles 1, 2, 3, 4, 5, 8, 11 and 13, and the 50–200 μm fractions from profiles 5, 8 and 11, were separated into light and heavy fractions by flotation in bromoform (specific gravity 2·9), and analysed mineralogically with a petrological microscope. The fine silt (2–20 μm) and clay (<2 μm) fractions from profiles 5, 8 and 11 were separated from 20 g samples of air-dry soil by ultrasonic dispersion and repeated sedimentation in 0·02% w/v sodium hexametaphosphate solution, and analysed mineralogically by X-ray diffractometry of oriented aggregates. Quartz and felspar in the <2, 2–20 and 20–50 μm fractions were estimated by chemical analysis of residues from fusion with sodium bisulphate (Kiely & Jackson, 1965) or extraction with hydrochloric acid (Reynolds & Lessing, 1962).

Additional clay fractions were separated from all samples of profile 5 and samples 1 and 2 of profile 9 to study potassium release. The samples were not treated with hydrogen peroxide, because this may modify the exchange properties of clays. Air-dry samples were dispersed by shaking for 16 hours in 0·01% w/v sodium hexametaphosphate solution, followed by ultrasonic agitation for 2 minutes, and the clays (<2 μm) were separated by repeated sedimentation in a similar solution. Cation exchange capacities were measured by extracting Mg-saturated clays four times with 0·1*M* calcium chloride solution and determining Mg in the extracts by atomic absorption spectrophotometry; the K in these extracts was also measured. Mica-K was extracted by boiling the Ca-saturated clays five times with 0·1*M* barium chloride solution, using 2 litres/g clay (Reichenbach & Rich, 1968). Mg-saturated residues from this extraction were divided by centrifugation into <0·5, 0·5–1·5 and 1·5–2 μm fractions; the untreated Mg-saturated clays were similarly fractionated. Total K in the <0·5 and 1·5–2 μm fractions was measured by atomic absorption spectrophotometry after digestion with hydrofluoric and perchloric acids. X-ray diffractometer traces of oriented aggregates of the original clays and of those treated as described were recorded; to assist recognition of the clay–mineral categories, each of the clays was examined air-dry and after treatment with ethylene glycol.

Morphology of representative profiles

Fig. 3 shows distinctive morphological features of the 13 profiles described and sampled; profiles 5, 8 and 11, which were chosen for mineralogical analysis of <200 μm fractions, are fully described in the Appendix. Profile 12 contained a fragment of drainage tile at about 70 cm depth, but the other profiles showed no evidence of human disturbance below the ploughed layer.

Dark coloured surface horizons are designated Ap. Brown or reddish, weathered sub-surface horizons, differentiated by changes in colour, texture, structure or consistence, extend to >90 cm depth in each profile, and are designated B1, B2, etc. The additional suffix t (German: *Ton* = clay) denotes a B horizon that is more clayey than the A, and contains translocated clay as evidenced by argillans (clay skins) and/or discrete concentrations of strongly oriented clay within peds. The suffix g (gleyed) indicates the common occurrence of grey (chroma <3 and value 5 or more) mottles or streaks attributable to local reduction and translocation of iron. Horizons with common red (2·5 YR 4/6–8) and/or brownish mottles, or with ped faces lighter in colour than the matrix but with few (<2%) or no grey mottles, are denoted by the suffix (g). Roman numeral prefixes show the occurrence of contrasting subsoil layers not attributable to pedological reorganisation; the uppermost layer is not numbered but layers beneath are numbered II, III, etc., downwards.

Terms defined by Brewer (1964) are used to describe micromorphological features. All the horizons studied have a basically *porphyroskelic* fabric, consisting of sand- and silt-size grains embedded in a dense clayey ground-mass or *plasma*, the fabric of which is further distinguished as *argillasepic* or *sepic*. In the former, clay–mineral aggregates are largely unoriented with respect to each other, giving a flecked extinction pattern between crossed nicols. In the latter, the clayey plasma contains recognisable anisotropic patches with preferred orientation, giving a striated extinction pattern. Sepic plasmic fabrics are further differentiated according to the size, arrangement and proportionate extent of anisotropic patches. In a *mo-masepic* fabric, for example, they are arranged partly as a mosaic (*mosepic*) and partly as elongated striated zones (*masepic*).

Within the basic fabric of the horizons are recognisable units (pedological features) distinguishable from the enclosing material by differences in concentration or arrangement of some fraction of the plasma (e.g. clay minerals, iron oxides), or differences in arrangement of the constituents. These include *cutans* (e.g. *argillans*) associated with natural surfaces, *nodules* representing segregations of a particular constituent within the ground-mass, and *papules*, i.e. argillaceous units with continuous and/or lamellar fabric and a morphology incompatible with formation in a single void in the present soil material.

Profiles 1, 2, 4, 5, 6, 8, 9, 10 and 12 each have a thick, strong brown to yellowish red (7·5–5 YR 5/6–8), clayey B horizon directly beneath a moderately flinty ploughed layer of silty clay loam texture, and conform in this respect to the shallow or eroded phase of the Batcombe series. They differ in the intensity of mottling. In 1, 5 and 8 an horizon (B3tg) with prominent red and grey mottles starts at 55–70 cm; 2, 6, 9 and 10 have many red mottles but few grey ones in the deepest horizon reached by the cores, and in 4 and 12, both north of 'the valley', the B horizons are more uniformly coloured, with few grey mottles and fewer and less distinct red and brownish mottles. As already indicated, these differences are probably related to irregularities in the underlying chalk surface, the more uniformly coloured subsoils occurring where the Clay-with-flints is thin and drainage is aided.

Profiles 3 and 7, in 'the valley', have loamy surface and sub-surface horizons with numerous flints and a clear undulating boundary to yellowish red flinty clay at about 65 and 43 cm respectively. The textural change at this boundary was interpreted as a lithological discontinuity, shown by the prefix II in the designations of the lower horizons. The clay subsoils are only faintly mottled, especially in profile 7, which in this respect resembles the Charity rather than the Batcombe series (Avery, 1964).

Profiles 11 and 13, sited close together in the lowest part of 'the valley', resemble those grouped with the Nettleden series. Each has a thick Ap horizon of flinty silt loam, merging into a brown B1 horizon of similar texture, which becomes more flinty with depth. In 11, a well-defined layer (II) of flint gravel in a silty matrix rests on brown stoneless silty clay loam (layer III) with faint to distinct pale brown and reddish yellow mottling. Both these depositional layers evidently have a limited lateral extent within the valley, as neither is clearly represented in profile 13. At that site the loamy B1 horizon rests with a clear undulating boundary on yellowish red flinty clay (IIB2t), which has little mottling and resembles the clayey subsoil in profile 7; this rests in turn on rubbly chalk drift with loamy and clayey inclusions, designated IIIC.

Surface horizons. The Ap horizons are mainly dark brown (10 YR 4/3) when wet and yellowish brown (10 YR 5/4) when air-dry, except in profiles 1–4 (between dunged strips) and in 'the valley' profiles 7, 11 and 13, where the moist colour is nearer 10 YR 4/2 (dark greyish brown). Recorded depths of dark surface soil range from 15–30 cm, but may be slightly under-estimated in some profiles because a little loose material was lost when extracting the cores. In the shallow or eroded Batcombe profiles the lower boundary is sharp and irregular, but in 7, 11 and 13 it is gradational and apparently below current ploughing depth, which suggests that the lower part of the dark surface layer in these profiles represents part or all of a former ploughed layer that has been buried by recent colluvium.

In the cores the silty clay loam topsoils of the shallow or eroded Batcombe profiles showed only weakly developed macro-structure (pedality) and were firm when moist, plastic and slightly sticky when wet, and very hard when dry. However, thin sections of the soil at 13 cm depth in profile 1 and at 7 cm (A1p) and 20 cm (A2p) in profile 2 showed systems of planar voids bounding blocky units of 10–15 mm size with little intra-pedal porosity. The planes may be partly artefacts resulting from drying to 110°C, but the faces of some are bordered by stress cutans, indicating that they are relatively stable natural surfaces. Each section shows heterogeneity in particle-size distribution and plasmic fabric, clearly associated with irregular incorporation of subsoil clay. Within a basic argillasepic porphyroskelic fabric, consisting of predominantly silt-sized grains in a weakly oriented clay matrix, patches of subsoil clay appear as strongly birefringent bodies (pedorelicts), with a mo-masepic plasmic fabric intersected by planar voids.

The silt loam topsoils in 'the valley' profiles (3, 7, 11 and 13) are friable when partly dry, and break down to give fine sub-angular blocky and crumb-like aggregates, but these units seem to have limited stability because few well-defined peds were observed in the cores. In profiles 7, 11 and 13 the lower part of the topsoil (designated A2p) was firmer and denser than horizons above and below, and showed dark (10 YR 4/2) channel fillings (pedotubules) and coatings resembling 'agricutans' as described by Jongerius (1970).

To confirm the existence of a 'pan', the porosity of the A1p, A2p and B1t horizons in profile 7 was measured by point counts of voids in horizontal thin sections taken at 7, 20 and 31 cm depths respectively. Each section was scanned in two directions at right angles; 1500 points were counted in each direction, and the results averaged to give the values in Table 1. The A2p horizon is evidently very dense; whole microscopic fields (diameter 6·6 mm) often contained no voids $>20\ \mu$m across, and $>80\%$ of the voids observed were planar. Sections of the A1p and B1t horizons had much more observable pore-space, and a larger proportion of the voids were irregular vughs rather than inter-pedal planes.

TABLE 1

Relative porosity of horizons in profile 7, given in percentage area of thin sections

Horizon	Depth (cm)	Voids (%)	Vughs* (%)	Channels (%)	Planar voids (%)
A1p	7	9·0	3·1	0·1	5·8
A2p	20	3·8	0·6	—	3·2
B1t	31	7·0	5·0	0·2	1·8

* Relatively large voids, usually irregular and not normally interconnected with other voids of comparable size.

Loamy sub-surface horizons. The loamy sub-surface horizons in profile 3, designated B1t and B2t(g), are finer in texture than the Ap horizon, and contain visible concentrations of brightly coloured clay. The horizon directly beneath the ploughed layer (B1t) has dark coloured coatings and infilled channels, and appears denser and firmer than the horizon below. As seen in thin sections at 30 and 50 cm depth, the fabric of these horizons is heterogeneous and seems to consist of silty material derived from loess, incompletely mixed with Clay-with-flints, because some parts have an argillasepic plasmic fabric with common void argillans, and others have a strongly sepic fabric resembling that of

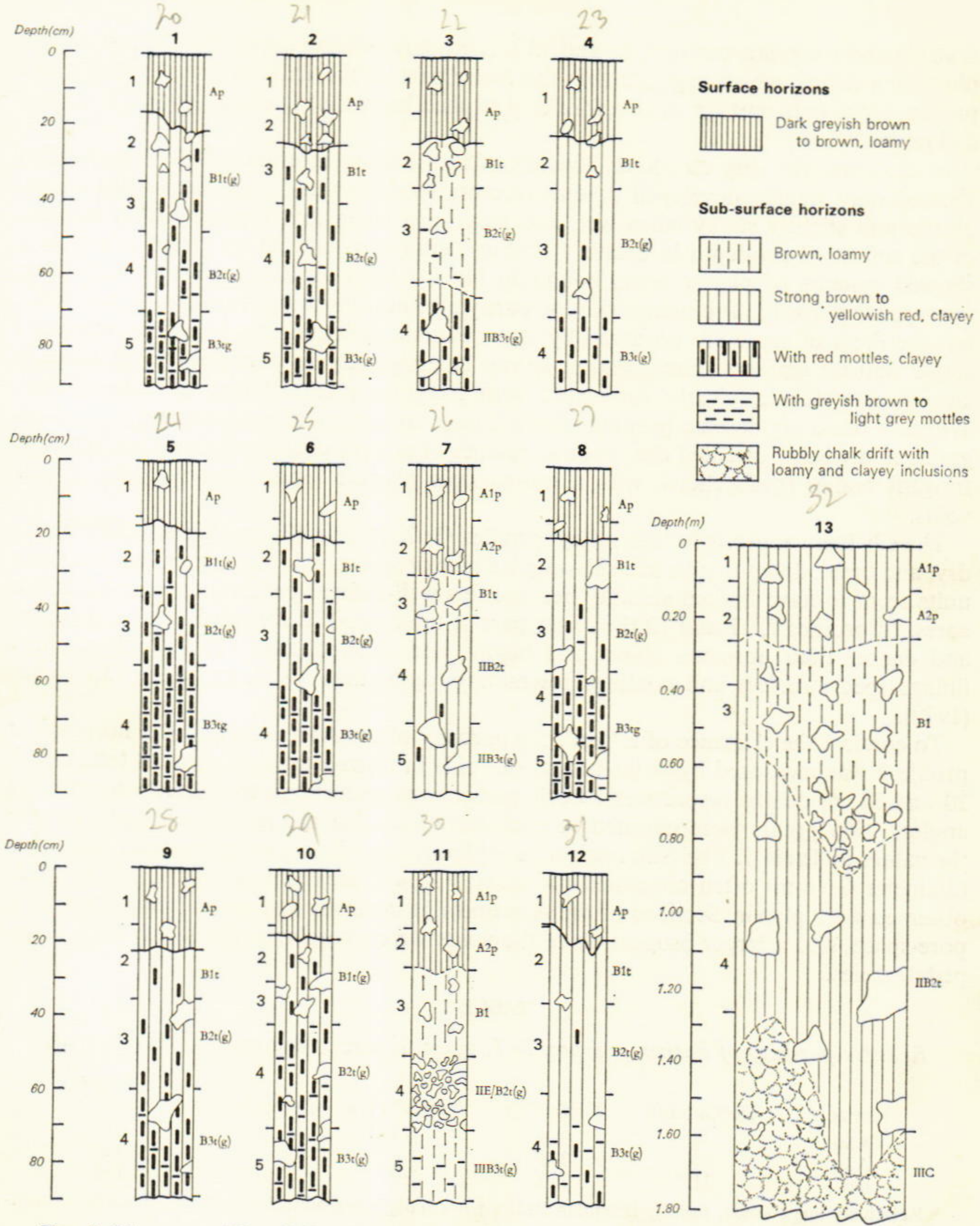

FIG. 3. Diagrams of Barnfield soil profiles, showing sampling depths and designated horizons.

the Clay-with-flints subsoil in profile 5 (q.v.). Dark brown nodules and irregular diffuse segregations, probably of manganese and iron, are common in both thin sections. The thin brown loamy horizon (B1t) below the A2p horizon in profile 7 resembles the B1t horizon in profile 3 in containing relatively large amounts of organic matter (partly in channels and coatings), but is more friable and porous. It has a dominantly argillasepic plasmic fabric and void argillans are common, but these have relatively weak birefringence, probably because of masking by organic matter.

The loamy B1 horizons in profiles 11 and 13 are brown (7·5–10 YR 4/3–4), and more friable when moist than corresponding horizons in any of the other profiles. They contain many channels filled or coated with darker soil, but show no evidence of clay illuviation, suggesting that the material composing these horizons was deposited comparatively recently. As the matrix of the gravel layer in profile 11 has the pale, bleached appearance characteristic of eluvial (E) horizons in the upper part and becomes redder and more clayey near the base, the horizon as a whole is designated IIE/B2t(g). However, it may represent a residual (lag) gravel from which fine material has been partly removed by lateral water flow. The underlying silty clay loam layer, designated IIIB3t(g), contains common vugh and channel argillans, together with embedded argillans or papules, in a mainly argillasepic porphyroskelic matrix. Dark brown ferruginous nodules and irregular diffuse ferri-manganiferous segregations are also common, the latter partly masking the argillans. As in the similar profile (5) in Broadbalk (Avery & Bullock, 1969), this layer is interpreted as the B horizon of a profile that was truncated by erosion and then buried by younger deposits. The sharp upper boundary of the flinty clay layer (IIB2t) in profile 13 is also probably an erosion surface, with undulations that reflect irregular post-depositional dissolution of the underlying rubbly chalk drift.

Clayey sub-surface horizons. The brightly coloured clayey B horizons occurring in all profiles except 11 are plastic or very plastic when wet, and very hard or extremely hard when dry, but partly-dry specimens show a variable tendency to crumble into smaller fragments when pressure is applied. Discrete peds of small or medium size (<2 cm) were seldom clearly apparent in the moist cores, but smooth faces of variable extent occur in all horizons, and a network of cracks developed as the soils dried. Shrinkage was greater in 2, 4, 5, 6, 9 and 12 than in other profiles, and amounted to at least 5% on a vertical linear basis (including surface horizons). Fine or medium blocky peds were most evident after drying in the yellowish red subsoil horizons of profiles 7, 11 and 13, and least evident in B1 horizons directly beneath the ploughed layer and in the red and grey mottled, clay-rich lower horizons (B3tg), as in profiles 1 and 5. The ped faces in slightly mottled horizons are mainly yellower in hue and lower in chroma than the matrix, and grey colours in the more prominently mottled horizons occur mainly around stones and bordering inclined ‘slickensided’ planes, which intersect the clay subsoils at various angles and are often of considerable extent. Most of the profiles contain dark agricutans and infilled channels (pedotubules), but these are less common and extend less deeply in the mottled clay subsoils than in the more loamy materials. Secondary manganiferous deposits, concentrated in small nodules or diffuse segregations, are common in several horizons, notably in profiles 1 (B1), 4 (B1), 8 (B1 and B2) and 12 (B2).

Thin sections of the B2t(g) horizon in profile 1 and the B1t(g) and B3tg horizons in profile 5 showed large differences in the proportion of angular and sub-angular silt grains relative to plasma, presumably reflecting irregular incorporation of loess, as in some of the Broadbalk subsoils (Catt, 1969). The first is rich in silt and has a dominantly argillasepic plasmic fabric intersected by strands of strongly birefringent clay up to 50 μm thick, some of which are associated with voids or ped faces, and therefore result from illuviation. Sections from profile 5, especially from the B3tg horizon, show little silt and have fabric characteristics resembling those in analogous horizons of Broadbalk profile 2 (Avery & Bullock, 1969). Vughs, channels and planar voids are common in the B1t(g) horizon, and divide parts of the fabric into sub-angular aggregates about 0·5–1 mm across, which are not readily apparent in hand specimens. Similar aggregates occur in the B3tg horizon, but here the voids are almost all planar. The clayey plasma in each of these horizons is strongly oriented, giving a mo-masepic porphyroskelic fabric, which is modified or replaced to various degrees by pedological features, including cutans (argillans or ferri-argillans) attributable to illuviation or stress, papules or embedded argillans, and ferruginous or ferri-manganiferous segregations (nodules). As noted in the Broadbalk profile, there are few void argillans directly attributable to illuviation of clay, especially in the B3tg horizon. Identification of these horizons as argillic therefore involves assuming that at least some of the clay bodies that are distinguishable in thin section by strong preferred orientation and absence of skeletal grains, yet are unassociated with existing voids, originated as void argillans and were incorporated in the matrix by pedoturbation resulting mainly from seasonal swelling and shrinking. The clay bodies could also have been incorporated by cryoturbation during Pleistocene cold periods. Alternatively, the bodies may be litho- or pedo-relicts that originated elsewhere and were transported to their present position.

Papules are common in both the B1t(g) and B3tg horizons of profile 5. They are bright yellow, non-pleochroic, and strongly birefringent, and resemble those found in Clay-with-flints layers close to the chalk junction, which are interpreted by Stoops and Mathieu (1970) and Thorez *et al.* (1971) as the result of disruption or deformation of argillans originally formed in solution hollows. Other discrete clay bodies are more granular and less birefringent; these may have originated either by weathering of glauconite grains or by impregnation of strongly birefringent papules with iron oxide.

Red ferruginous areas, which are mainly diffuse and irregular and appear as red mottles to the unaided eye, occur in thin sections of the B2t(g) horizon of profile 1 and the B1t(g) and B3tg horizons of profile 5. They are largest and most abundant in the B3tg horizon of 5, where they occupy about 40% by area. As in Broadbalk profile 2, the densest parts are weakly birefringent and the less dense parts moderately or strongly oriented. As the boundaries of reddened areas occasionally transgress boundaries between papules and matrix, the papules so affected must have originated before iron segregation. Also, as voids traversing the reddened areas are sometimes lined with yellowish strongly oriented clay, both papules and red mottles seem to be relict features. This implies that, although the red mottles possibly originated by reduction and segregation of iron, they may not be related genetically to the grey iron-depleted zones, because the grey zones are commonly associated with existing voids.

Particle size distribution and chemical data

Coarse fragments (stones and gravel). Average weights per acre of stones (>6 mm) and fine dry soil from successive 23 cm layers, quoted for the chief Rothamsted experimental fields by Hall (1917, 26), show that the surface layer of Barnfield is on average nearly twice as stony as the soil at 46–69 cm, and that it is significantly more stony than the surface layers of Broadbalk and Hoosfield, but not quite as stony as Agdell. The concentration of stones at the surfaces probably results partly from frost action, including contemporary frost-heaving and deep-reaching cryoturbation under Pleistocene periglacial conditions, and partly from removal of finer soil by differential erosion.

Assuming a specific gravity of 2·60 for flint, Hall's figures give mean values of 14·5, 10·0 and 7·8% by volume for the stone contents of the three successive 23 cm layers in Barnfield. Corresponding mean values for the weight percentage of stones are 24·9, 16·5 and 13·5%. Table 2 gives the weight percentages of stones (>2 mm) in 1 kg samples taken from all horizons in the 12 cores. The range of stone contents (9–24%) in the Ap horizons (0–15 cm) gives a smaller mean than Hall's average for the first 23 cm layer, even though he excluded fine gravel (2–6 mm); this is probably because the larger stones are not adequately represented in 1 kg samples. However, the values show where the major differences in stoniness occur, and were useful in representing the profiles

TABLE 2

Weight percentage of stones (> 2 mm) in oven-dry samples from Barnfield soil profiles

Profile no.	1	2	3	4	5	6	7	8	9	10	11	12
Sample 1												
Depth (cm)	0–15	0–15	0–15	0–15	0–15	0–15	0–15	0–15	0–15	0–15	0–15	0–15
% Stones	12	22	16	18	9	10	16	9	19	18	24	11
Sample 2												
Depth (cm)	16/23–35	15–23/28	21/24–35	21/25–35	16/20–35	18/21–35	15–30	19/21–35	22/23–35	17/19–30	15–25	15–35
% Stones	26	30	52 ×	5	<1	7	21	<1	1	11	24	<1
Sample 3												
Depth (cm)	35–48	23/28–40	35–65	35–70	35–55	35–60	30–41	35–55	35–60	30–42	25–50	35–60
% Stones	17	14	21	<1	1	2	28	<1	<1	32	18	<1
Sample 4												
Depth (cm)	48–70	40–74	65–90	70–85	55–90	60–90	41–70	55–70	60–90	42–70	50–70	60–90
% Stones	<1	4	21	1	8	3	13	11	15	3	69 ×	7
Sample 5												
Depth (cm)	70–90	74–90	—	—	—	—	70–90	70–90	—	70–90	70–90	—
% Stones	18	4					23	17		5	<1	

TABLE 3

Size distribution of stones (> 6 mm) in the surface soil of Barnfield

Weight limits (g)	Approx. ϕ equivalent	Near profile 1		Near profile 4		Near profile 7		Near profile 9		Near profile 12	
		Wt (g)	Wt (%)	Wt (g)	Wt (%)	Wt (g)	Wt (%)	Wt (g)	Wt (%)	Wt (g)	Wt (%)
<0·25	<−2·5	6·6	0·13	5·0	0·10	10·6	0·15	8·1	0·10	7·5	0·13
0·25 to 0·75	−2·5 to −3·0	140·2	2·86	119·9	2·49	257·2	3·52	226·1	2·76	126·4	2·19
0·75 to 2·0	−3·0 to −3·5 8mm	336·6	6·86	308·1	6·39	662·5	9·08	626·3	7·64	312·1	5·40
2·0 to 5·0	−3·5 to −4·0	643·9	13·13	645·9	13·40	1467·1	20·12	1332·2	16·26	567·0	9·81
5·0 to 15·0	−4·0 to −4·5 16mm	1115·7	22·74	927·9	19·25	1700·9	23·32	2387·7	29·14	903·4	15·63
15·0 to 40·0	−4·5 to −5·0	1338·7	27·29	1203·3	24·96	1536·4	21·07	1945·2	23·74	935·7	16·19
40·0 to 120·0	−5·0 to −5·5 32mm	952·8	19·42	1084·2	22·49	1176·2	16·13	922·3	11·26	1016·3	17·58
>120·0	>−5·5 −6·0	371·0	7·56	526·0	10·91	482·4	6·61	745·2	9·10	1912·8	33·09
	Totals 64mm	4905·5	99·99	4820·3	99·99	7293·3	100·00	8193·1	100·00	5781·2	100·02

2

< 6 cm
dominant

> 6cm
dom.

2-6 mm
6-20 mm
20-60 mm
60-200 mm

diagrammatically (Fig. 3). The topsoil tends to be more stony in 'the valley' and on its steeper southern slope than in other parts of the field, and the loamy sub-surface horizons in profiles 3, 7 and 11 are more stony than the clayey sub-surface horizons of the shallow Batcombe soils, which commonly contain only a few large nodular or broken flints.

Size distribution of stones in the topsoil. Four of the five samples of stones (>6 mm) taken from the surface soil show approximately the same size distribution (Table 3), but at profile 12 near the north-east corner of the field there is a greater proportion of the largest stones (>120 g) than elsewhere. These large stones are irregularly-shaped, unworn flint nodules or large fragments of nodules; examples as large as 30 cm across are fairly common in north-eastern parts of the field. They are derived by natural dissolution of the chalk, and have not been moved very far; flints of this type are accordingly typical of the lowest layer of Clay-with-flints (the Clay-with-flints *sensu stricto* of Loveday, 1962), which rests on the chalk. This confirms the soil morphological evidence that the chalk is closer to the ground surface in northern parts of the field than elsewhere.

Cultivation, especially rotovating, makes the stones smaller; this affects mainly the flints, probably because they are larger than other types of stone, more irregularly-shaped and more brittle. Many freshly broken or abraded surfaces of flints show after rotovating, but quickly become soil-stained or weathered.

Type of stones. Flint nodules and fragments are the most common stones over the whole field, but there is also a wide range of other types (Table 4). Most of the rarer stones occur naturally and were derived from the Reading Beds, but others result from human activity. The pebbles are smooth, well rounded when unbroken, and probably originated in streams that flowed across south-east England when the Reading Beds were deposited during Eocene times. Most of them are composed of flint and have black or grey surfaces, but a few are white and are composed of quartzite or coarsely crystalline quartz from veins in Palaeozoic or older rocks. One pebble, found at 50 cm depth in the core of profile 3, was composed of tourmalinated quartz, which probably came originally from a Devon or Cornish granite. The brown chert (chalcedonic silica) and sandy ironstone are both derived from the Reading Beds; similar materials commonly form cementing media around the Eocene pebbles in the 'Hertfordshire pudding-stone', and some pieces found in Barnfield bear the smooth, ovoid impressions of pebbles. The chalcedony is derived from chalk fossils, especially *Inoceramus*, and resembles that described by Brown *et al.* (1969).

The chalk fragments are small and are the remains of ground chalk applied at various times to correct acidity. Many of the other small stones (coal, shale, sandstone, slate, coke, clinker, brick, tile, pottery, glass, metal objects, etc.) were probably introduced when road sweepings containing horse droppings were used as manure. A few of the flints are reddened by fire, and others have a reticulate pattern of surface cracks, probably a result of quenching. The igneous rocks occur only on the western side of the field, and seem to be spread fairly evenly along the dunged strips 1 and 2 and less regularly on 3 and 4. This distribution eliminates the possibility that they are natural (e.g. glacial) erratics, and suggests that they are associated with the farmyard manure. They also occur on the dunged plots of Broadbalk and other Rothamsted fields. Many of them are typical roadstones (e.g. markfieldite from Leicestershire, diorite and norite from Guernsey), but they are commonly 8–10 cm across and thus too large for road surfacing. The most probable origin is that coarse 'gravel' from roadstone quarries was used to line cattle yards, and some was picked up with the farmyard manure.

Particle size distribution in <2 mm fractions. Clay (<2 μm) contents of the topsoils in the 12 systematically sited profiles range from 22–36% (Table 5), with a mean value

TABLE 4

Relative amounts of different stone types (>6 mm) in the surface soil of Barnfield

Type	Probable source	Near profile 1			Near profile 4			Near profile 7			Near profile 9			Near profile 12		
		No.	Wt (g)	Wt (%)	No.	Wt (g)	Wt (%)	No.	Wt (g)	Wt (%)	No.	Wt (g)	Wt (%)	No.	Wt (g)	Wt (%)
1. Flint nodules and fragments	Chalk	610	3410·3	69·52	581	3712·0	77·01	1162	4708·2	64·56	1104	5141·0	62·75	600	4517·3	78·14
2. Chalcedony from chalk fossils	Chalk	9	3·4	0·07	11	3·3	0·07	5	2·8	0·04	3	1·1	0·01	8	3·3	0·06
3. Pebbles and broken pebbles	Reading Beds	332	1258·0	25·64	245	992·6	20·58	672	2479·9	34·00	644	2867·8	35·00	248	1000·2	17·30
4. Brown chert	Reading Beds	20	66·3	1·35	50	78·9	1·64	43	94·1	1·29	51	148·2	1·81	47	76·8	1·33
5. Sandy ironstone	Reading Beds	2	21·4	0·44	0	0·0	0·00	1	0·7	0·01	3	3·2	0·04	3	173·2	3·00
6. Chalk	Human activity	2	1·2	0·02	2	0·6	0·01	9	3·0	0·04	13	9·0	0·11	3	1·3	0·02
7. Coal, shale, slate, coke, clinker	Human activity	21	14·4	0·29	14	10·4	0·22	2	0·8	0·01	6	3·3	0·04	2	4·1	0·07
8. Grey sandstone	Human activity	3	2·1	0·04	2	1·7	0·04	2	1·7	0·02	1	0·8	0·01	0	0·0	0·00
9. Brick, tile, pottery, glass, metal objects	Human activity	25	47·5	0·97	10	10·3	0·21	3	2·1	0·03	13	18·7	0·23	4	5·0	0·09
10. Igneous rocks	Human activity	4	80·9	1·65	4	10·5	0·22	0	0·0	0·00	0	0·0	0·00	0	0·0	0·00
	Totals	1028	4905·5	99·99	919	4820·3	100·00	1899	7293·3	100·00	1838	8193·1	100·00	915	5781·2	100·01

of 30·6 ± 1·4. The mean value for 12 Broadbalk topsoils sampled on a similar basis is 25·3 ± 1·5 (difference between means significant at $P = 0{\cdot}05$). If 'the valley' profiles (3, 7 and 11) are excluded, the mean for the remaining Barnfield topsoils is 32·9%.

In all the shallow or eroded Batcombe profiles (i.e. 1, 2, 4, 5, 6, 8, 9, 10 and 12), the clay content increases to more than 40% at the base of the ploughed layer, and at least one of the horizons beneath has more than 50% clay. In profile 4 the main increase occurs at about 35 cm depth, between the B1t and B2t(g) horizons. In profiles 3, 7 and 13 there is again a large difference in clay content between the upper loamy horizons (22–35%) and the substrata (58–65%), but the sharp increase occurs at 40 cm or deeper. Profile 11 has a minimum clay content of 16% (of <2 mm soil) in the gravelly layer (50–70 cm), and a maximum of 35% in the horizon beneath.

In all the topsoils and most of the subsoils the dominant non-clay fraction is coarse silt (20–50 μm), and the total amount of sand >100 μm exceeds 15% only in the lowest layers of profiles 1, 3, 8 and 12 and in the gravelly layer of 11, where the coarse sand (500–2000 μm) is mostly flint fragments derived from fine gravel crushed while preparing the <2 mm samples. In soils derived from sediments, differences in the nature and origin of the parent material both within and between profiles are often better shown by the

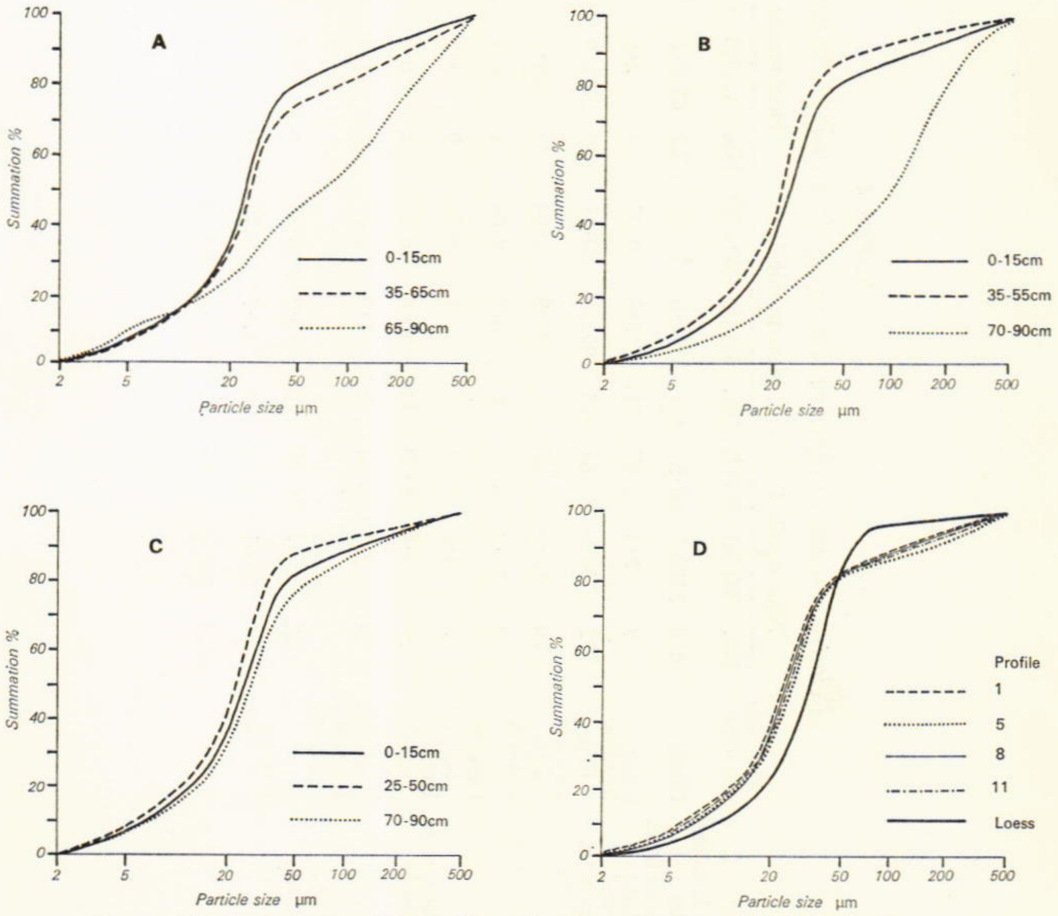

FIG. 4. Distribution of particles 2–500 μm in selected horizons of Barnfield soils.
A Profile 3
B Profile 8
C Profile 11
D Topsoils from profiles 1, 5, 8 and 11, and typical loess (Pegwell Bay, Kent).

distribution of sand and silt fractions than by differences in clay content, which can also result from weathering of coarser particles or from movement of clay. As in the Broadbalk soils, summation curves representing the distribution of 2–500 μm particles in selected horizons show significant differences (Fig. 4, A–C). Samples from the Ap and B2t horizons of profiles 3 and 8 and from all three horizons representing profile 11 evidently have a similar particle size distribution in this range, indicating the dominance of coarse silt. The similarity of the curves for the Ap and B2t horizons in profiles 3 and 8 supports the micromorphological evidence that the increase in clay content between these horizons results at least partly from downward movement of clay particles. Curves for the IIB3t horizon of profile 3 and the B3tg horizon of 8 show that the non-clay fractions are less well sorted and contain more sand relative to silt than the higher horizons, indicating a discontinuity in parent material.

As elsewhere in southern England, the well sorted silt in the surface and many sub-surface horizons is considered to originate from loess. Fig. 4(D) compares the curves for four of the Barnfield topsoils with a similarly constructed curve for slightly weathered loess from Pegwell Bay Kent (Weir *et al.*, 1971, Table 1, horizon 6). The Barnfield samples have a similar distribution in the silt (2–50 μm) fractions but evidently contain more sand, showing that they are not derived entirely from loess. This is also indicated by their clay contents, which are much greater than in surface horizons of soils in deep loess (Maréchal, 1958, 105–129; Weir *et al.*, 1971).

In profile 3, the apparent discontinuity in parent material is associated with a marked increase in clay content, but in profile 8 it is not. This could be because the main horizon of clay enrichment by illuviation lies below the discontinuity in the first profile and above it in the second, but probably results mainly from variability in the particle-size distribution of the Clay-with-flints, of which the sub-surface horizons largely consist.

Calcium carbonate. All the surface horizons have a little calcium carbonate (Table 5) because ground chalk has been spread on the field; amounts decrease downwards in all the profiles except 11, and the subsoil below 15–40 cm depth is carbonate free. Profile 11 has slightly more carbonate at 15–25 cm (A2p horizon) than above, which suggests that part of the colluvium forming the upper horizons of this profile was deposited after chalk was applied to the field.

'Free iron oxide'. As in other soils consisting wholly or partly of Clay-with-flints, the proportions of dithionite-extractable iron (Table 5) are larger than in many British brown earths of similar texture. Expressed as Fe_2O_3, the amounts range from 3·0–7·5% of <2 mm oven-dry soil, and are largest in the lower horizons of profiles 2, 4 and 6. 'Free iron' and clay content are correlated (Fig. 5); the ratio is approximately 1 : 10 in all topsoil and subsoil horizons except the gravelly layer (sample 4) of profile 11, which contains many sand-sized limonite concretions.

Organic carbon. Table 5 gives the amounts of organic C in profiles 3, 5, 7, 8 and 11. Excluding profile 3 (between dunged strips) they range from 0·64–0·86% in the surface horizons, and decrease gradually with depth, so that amounts <0·2% occur only in profiles 8 and 11 below 70 cm. The A2p horizons in profiles 7 and 11 contain only slightly less organic matter than the corresponding A1p horizons, which confirms the supposition that they are buried topsoils.

Soil reaction (pH). The originally acid soil of Barnfield now has a uniformly neutral to alkaline reaction to at least 90 cm depth (Table 5), because of the chalk dressings.

TABLE 5

Particle size distribution and chemical data for Barnfield soil profiles

(Particle size distribution quoted as weight percentages of oven dry peroxidised soil <2 mm; other percentages are on an oven-dry <2 mm soil basis)

	Profile 1				
Sample no.	1	2	3	4	5
Depth (cm)	0–15	16/23–35	35–48	48–70	70–90
<2 μm	34·8	50·6	49·1	46·4	51·7
2–5 μm	4·6	6·4	5·2	5·8	2·8
5–20 μm	18·5	13·9	17·1	20·7	8·6
20–50 μm	26·9	19·5	21·0	22·4	11·5
50–100 μm	3·7	2·3	2·2	1·9	4·8
100–200 μm	4·0	2·2	1·8	1·2	11·5
200–500 μm	3·4	1·9	1·5	0·8	6·2
500–2000 μm	4·2	3·2	2·1	0·8	2·8
$CaCO_3$ %	0·10	0·10	0·00	0·00	0·00
Free Fe_2O_3 %	3·70	5·65	5·05	4·00	5·15
Organic C %	—	—	—	—	—
pH in water	7·6	7·6	7·5	7·3	7·3
pH in 0·01*M* $CaCl_2$	7·1	7·1	7·0	6·9	6·9

	Profile 2					Profile 3				Profile 4				Profile 5			
Sample no.	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4
Depth (cm)	0–15	15–23/28	23/28–40	40–74	74–90	0–15	21/24–35	35–65	65–90	0–15	21/25–35	35–70	70–85	0–15	16/20–35	35–55	55–90
<2 μm	32·3	31·6	66·0	67·3	71·7	26·8	34·4	35·2	63·5	34·1	43·3	66·2	74·6	34·1	57·9	65·0	73·6
2–5 μm	5·1	6·0	4·7	4·3	3·7	5·5	5·5	4·9	3·1	4·3	4·9	3·8	2·6	4·4	5·8	3·5	3·6
5–20 μm	18·5	19·0	10·8	9·4	7·5	20·2	18·0	16·3	4·9	18·4	18·2	11·4	6·9	17·6	12·4	9·9	5·9
20–50 μm	28·7	28·5	12·2	12·4	9·6	30·6	25·6	25·3	6·6	27·8	26·0	14·9	9·7	30·2	19·7	16·3	10·1
50–100 μm	3·3	3·4	1·3	1·7	1·7	3·7	3·4	3·6	3·4	3·0	2·3	1·3	1·6	3·4	1·6	1·8	2·0
100–200 μm	3·9	3·9	1·5	2·4	2·7	4·2	4·5	5·5	6·6	3·4	2·1	1·3	2·4	3·4	1·0	1·8	2·8
200–500 μm	3·8	3·8	1·4	1·8	2·3	4·3	4·4	5·0	7·1	3·8	1·9	0·7	1·7	5·2	1·2	1·4	1·8
500–2000 μm	4·4	3·7	2·0	0·7	0·9	4·8	4·3	4·3	4·8	5·2	1·3	0·4	0·5	1·6	0·4	0·4	0·2
$CaCO_3$ %	0·20	0·25	0·05	0·00	0·00	0·95	0·05	0·00	0·00	0·60	0·05	0·00	0·00	0·80	0·05	0·00	0·00
Free Fe_2O_3 %	4·05	4·00	6·65	6·50	7·45	3·50	3·95	4·30	6·85	3·70	4·35	6·00	7·00	4·20	5·35	5·70	6·70
Organic C %	—	—	—	—	—	1·97	0·56	0·43	0·38	—	—	—	—	0·86	0·55	0·37	0·31
pH in water	7·6	7·6	7·5	7·3	7·3	7·8	7·7	7·5	7·2	7·8	7·6	7·3	7·3	8·1	7·4	7·3	7·2
pH in 0·01*M* $CaCl_2$	7·2	7·2	7·1	7·0	7·0	7·4	7·2	7·1	7·0	7·4	7·2	7·0	7·0	7·5	7·1	7·0	6·9

	Profile 6				Profile 7					Profile 8					Profile 9			
Sample no.	1	2	3	4	1	2	3	4	5	1	2	3	4	5	1	2	3	4
Depth (cm)	0–15	18/21–35	35–60	60–90	0–15	15–30	30–41	41–70	70–90	0–15	19/21–35	35–55	55–70	70–90	0–15	22/23–35	35–60	60–90
<2 µm	33·7	65·4	61·2	69·4	22·1	23·6	28·1	57·6	59·1	34·9	64·9	60·4	59·3	52·5	27·0	51·1	64·1	68·6
2–5 µm	3·8	2·9	2·8	2·9	4·9	5·1	5·6	4·0	3·4	4·2	2·9	3·6	2·4	1·9	4·5	4·8	4·1	3·6
5–20 µm	18·2	10·6	10·2	7·6	21·4	21·4	20·8	12·5	12·3	18·1	12·3	13·0	7·4	5·7	20·4	13·7	10·1	7·1
20–50 µm	29·5	14·5	13·9	9·8	33·9	33·5	30·4	16·3	16·4	28·2	15·9	18·0	10·5	8·6	32·7	21·4	15·6	10·3
50–100 µm	3·3	1·3	1·5	1·9	3·9	3·7	3·2	2·4	1·6	3·1	1·7	1·8	3·5	6·0	3·8	2·4	2·3	3·1
100–200 µm	3·7	1·6	2·5	3·4	4·0	3·7	3·0	2·4	1·4	3·7	1·1	1·5	7·4	13·7	3·8	2·4	2·1	2·8
200–500 µm	3·3	2·3	5·3	3·6	4·1	3·9	3·6	2·3	1·8	3·9	0·8	1·1	7·4	8·7	3·5	1·9	1·1	2·2
500–2000 µm	4·4	1·4	2·6	1·4	5·8	5·0	5·2	2·4	4·0	3·8	0·4	0·7	2·2	2·9	4·3	2·3	0·6	2·2
$CaCO_3$ %	0·10	0·00	0·00	0·00	1·45	0·95	0·05	0·00	0·00	0·90	0·05	0·00	0·00	0·00	2·10	0·05	0·00	0·00
Free Fe_2O_3 %	3·80	5·85	5·20	7·15	3·15	3·30	3·80	5·70	5·90	3·80	5·55	5·55	6·15	5·70	3·15	5·35	6·15	6·80
Organic C %	—	—	—	—	0·74	0·64	0·53	0·53	0·36	0·64	0·44	0·36	0·24	0·14	—	—	—	—
pH in water	7·7	7·3	7·2	7·1	8·2	8·2	7·7	7·3	7·4	8·2	7·5	7·2	7·2	7·2	8·2	7·6	7·4	7·4
pH in 0·01*M* $CaCl_2$	7·0	7·0	7·0	6·9	7·6	7·5	7·2	7·0	6·9	7·5	7·1	6·9	6·9	6·9	7·6	7·2	7·1	7·1

	Profile 10					Profile 11					Profile 12				Profile 13			
Sample no.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	1	2	3	4
Depth (cm)	0–15	17/19–30	30–42	42–70	70–90	0–15	15–25	25–50	50–70	70–90	0–15	15–35	35–60	60–90	0–10	15–28	38–53	102–127
<2 µm	28·9	42·7	47·6	53·1	56·7	21·9	23·1	24·7	16·1	34·6	36·4	62·3	71·2	59·3	25·8	25·1	24·3	65·2
2–5 µm	4·0	4·2	3·3	3·3	3·1	4·7	4·9	5·6	4·4	4·0	4·7	4·1	4·0	3·4	5·0	5·2	4·7	3·8
5–20 µm	19·5	15·7	13·6	12·3	10·8	20·9	20·8	23·8	16·8	16·4	17·4	11·3	8·5	6·4	21·8	22·3	20·2	10·6
20–50 µm	31·9	24·3	21·5	20·4	17·5	33·9	32·9	33·7	28·5	29·0	27·3	16·9	11·7	10·7	31·3	32·5	30·5	14·7
50–100 µm	3·6	3·1	2·9	3·4	3·0	3·8	3·9	3·0	3·5	5·4	2·9	0·6	1·2	3·4	3·6	3·8	2·8	1·7
100–200 µm	4·1	3·8	3·6	4·2	4·2	4·3	4·4	2·3	2·9	5·4	3·8	2·6	1·2	6·9	3·4	3·7	3·0	1·6
200–500 µm	3·8	2·9	2·9	2·4	2·7	4·6	4·5	2·9	7·5	3·9	4·2	1·4	1·4	7·5	3·7	3·7	4·5	1·4
500–2000 µm	4·2	3·3	4·6	1·0	1·9	6·0	5·5	4·0	20·3	1·3	3·3	0·8	0·9	2·3	5·4	3·8	9·9	1·1
$CaCO_3$ %	0·35	0·05	0·00	0·00	0·00	1·80	1·95	0·00	0·00	0·00	1·10	0·05	0·00	0·00	—	—	—	—
Free Fe_2O_3 %	3·55	5·30	5·30	4·85	5·70	3·35	3·00	3·00	5·70	3·55	3·85	5·70	5·85	5·70	—	—	—	—
Organic C %	—	—	—	—	—	0·80	0·69	0·45	0·24	0·19	—	—	—	—	—	—	—	—
pH in water	8·2	7·7	7·5	7·4	7·3	8·2	8·2	8·0	7·8	7·5	8·2	7·7	7·9	7·3	—	—	—	—
pH in 0·01*M* $CaCl_2$	7·5	7·2	7·1	7·0	6·9	7·7	7·6	7·4	7·2	7·1	7·6	7·2	7·3	7·0	—	—	—	—

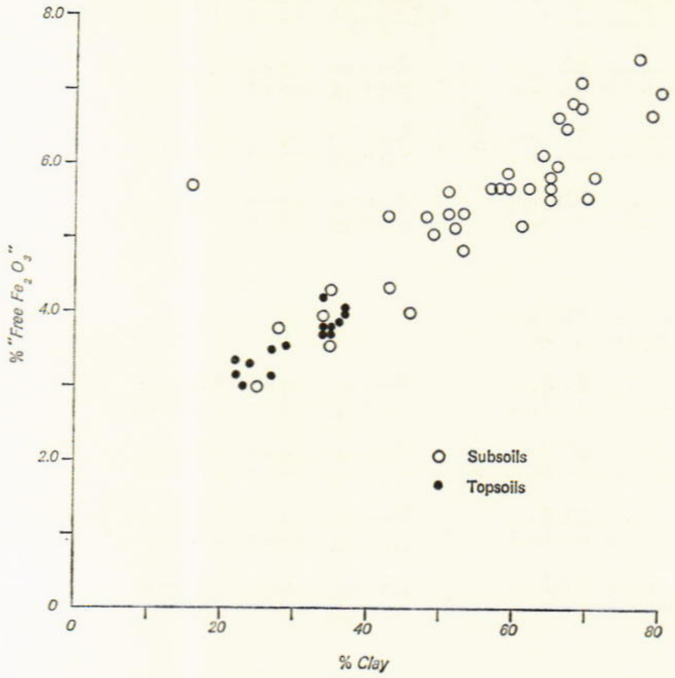

FIG. 5. Relationship between 'free Fe_2O_3' and % clay (<2 μm) in Barnfield soils.

The most alkaline sub-surface layers are the A2p horizons in profiles 7 and 11, which probably reflects the recent colluvial origin of the surface soil in parts of 'the valley'.

Mineralogy

Fine sand mineralogy. The fine sand fractions (50–200 μm) of samples from profiles 5, 8 and 11 resemble mineralogically the fine sands of Broadbalk soils (Weir *et al.*, 1969, 83). They contain 81–95% quartz, 2–5% flint, 1–9% felspar, and small amounts of chalcedony, muscovite, glauconite, calcite, bone fragments and various heavy minerals. The chalcedony is optically similar to that in the Broadbalk soils, and is derived ultimately from the shells of fossil lamellibranchs, brachiopods and echinoids in the Chalk (Brown *et al.*, 1969). The microcrystalline calcite (chalk) and bone fragments are both remains of materials added to the soil. In profiles 5 and 8 they are fairly common in the highest 15 cm, rare between 15 and 35 cm, and absent at greater depths, but in profile 11 they are more abundant at 15–25 cm (A2p horizon) than in the surface horizon (A1p) and are fairly common in the sand from 25–50 cm depth. This confirms that the top 15 cm of soil in profile 11 was derived by lateral movement of topsoil from other parts of the field since chalk and ground bones were applied.

In profile 11 the proportions of quartz and felspar and the heavy mineral assemblages of the fine sands do not change significantly with depth, at least within 90 cm of the surface; in this respect they resemble the fine sand fractions from profiles 4 and 5 of Broadbalk. However, profiles 5 and 8 have smaller amounts of felspar below 55 cm depth than in higher horizons, and the quartz contents are correspondingly greater. At the same depth the heavy mineral assemblages also change; whereas only iron ores, zircon, tourmaline, rutile, staurolite, kyanite, andalusite and anatase occur below 55 cm, the soil above contains these minerals together with epidote, chlorite, garnet, amphiboles, zoisite, biotite and augite. Similar mineralogical changes occur within 1 m of the surface

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TABLE 6

Mineralogical composition of coarse silt (20–50 µm) fractions from Barnfield soils

(Main components given as percentages, minor constituents as parts per thousand of non-opaque heavy minerals)

Profile no.	Sample no.	Depth (cm)	% Quartz	% Felspar	% Flint	% Glauconite	% Calcite	% Gypsum	% Muscovite	% Iron ores	% Non-opaque heavy minerals	‰ Epidote	‰ Zoisite	‰ Zircon	‰ Tourmaline	‰ Green hornblende	‰ Brown hornblende	‰ Tremolite and actinolite	‰ Chlorite	‰ Garnet	‰ Yellow rutile	‰ Brown rutile	‰ Red rutile	‰ Anatase	‰ Brookite	‰ Staurolite	‰ Kyanite	‰ Biotite	‰ Augite	‰ Andalusite	‰ Collophane
1	1	0–15	82	14	2	0	0	0	<1	1	0·5	409	21	178	70	110	17	23	63	28	26	7	4	18	3	10	10	3	0	0	0
	2	16/23–35	82	12	1	2	0	0	<1	2	0·7	378	8	136	166	46	9	25	122	19	36	7	2	19	3	12	9	3	0	0	0
	3	35–48	78	14	2	2	0	0	1	2	0·9	390	13	180	106	50	7	28	114	16	30	9	4	22	6	10	10	3	2	0	0
	4	48–70	79	15	2	1	0	0	<1	2	0·5	416	21	153	83	61	11	21	143	14	21	14	3	22	3	6	6	2	0	0	0
	5	70–90	90	4	1	2	0	0	<1	2	0·7	122	7	476	176	14	2	8	13	8	60	9	19	37	20	14	15	0	0	0	0
2	1	0–15	83	13	1	1	0	0	<1	1	0·4	412	21	166	80	97	12	20	43	22	47	16	6	27	7	11	11	2	0	0	0
	2	15–23/28	84	12	1	1	0	0	<1	1	0·4	410	20	162	65	92	13	23	64	23	47	18	5	25	6	12	11	3	1	0	0
	3	23/28–40	86	7	1	3	0	0	1	1	0·5	350	14	284	112	36	8	15	22	6	50	17	14	39	9	13	10	1	0	0	0
	4	40–74	91	3	1	2	0	<1	<1	2	0·7	178	8	390	192	25	5	10	17	5	60	15	11	39	10	18	16	1	0	0	0
	5	74–90	90	2	1	5	0	<1	<1	1	0·4	90	6	508	160	10	2	2	5	5	83	14	13	52	16	18	16	0	0	0	0
3	1	0–15	82	13	2	1	0	0	<1	1	0·3	388	16	174	100	112	12	26	43	27	37	12	6	24	4	10	9	0	0	0	0
	2	21/24–35	82	13	1	1	0	0	1	1	0·4	442	16	144	70	83	10	20	43	31	63	10	4	34	5	10	10	0	0	0	0
	3	35–65	84	11	1	2	0	0	<1	1	0·4	441	16	158	50	65	7	22	99	31	43	18	8	23	4	6	6	3	0	0	0
	4	65–90	88	4	2	2	0	<1	<1	3	0·7	142	7	472	152	26	4	6	32	8	62	5	15	24	10	23	10	2	0	0	0
4	1	0–15	84	11	2	1	0	0	<1	1	0·4	419	22	185	80	75	7	16	43	27	38	25	5	27	5	13	11	0	2	0	0
	2	21/25–35	83	12	1	2	0	0	<1	1	0·4	455	34	182	66	53	6	13	42	24	45	17	8	23	5	11	12	3	1	0	0
	3	35–70	83	9	1	5	0	<1	<1	1	0·7	288	20	296	140	42	5	15	32	10	46	16	10	38	8	15	18	1	0	0	0
	4	70–85	89	4	1	3	<1	<1	<1	2	0·7	190	12	403	186	20	3	5	16	5	67	12	15	28	9	16	13	0	0	0	0
5	1	0–15	86	11	1	0	<1	0	<1	1	0·6	446	10	178	84	56	11	36	47	33	28	10	8	25	0	15	4	3	0	1	5
	2	16/20–35	84	10	1	2	<1	0	1	1	0·9	267	6	350	118	29	8	16	38	23	53	12	20	26	4	17	11	0	0	1	1
	3	35–55	85	8	1	4	<1	0	<1	1	0·8	338	8	319	121	26	4	13	29	15	40	9	4	35	11	12	16	0	0	0	0
	4	55–90	91	2	1	2	<1	0	<1	3	0·6	108	4	433	238	10	1	3	9	5	64	3	9	59	18	24	11	0	0	1	0
8	1	0–15	84	12	1	1	<1	0	<1	1	0·4	405	34	224	113	58	5	12	24	22	40	15	4	25	7	6	5	1	0	0	0
	2	19/21–35	77	12	1	8	0	0	<1	1	0·7	408	19	205	123	53	8	10	52	20	34	12	4	30	3	7	9	2	1	0	0
	3	35–55	78	11	1	8	0	0	1	1	0·4	419	25	191	128	56	8	9	27	21	36	11	2	23	11	14	13	5	1	0	0
	4	55–70	91	2	1	2	0	0	1	2	1·0	126	11	422	231	11	2	5	4	5	59	10	2	67	15	13	16	1	0	0	0
	5	70–90	93	1	1	2	0	0	<1	2	0·9	58	8	586	124	4	2	2	1	22	69	28	9	56	10	21	13	0	0	2	5
11	1	0–15	85	12	1	<1	<1	0	<1	1	0·7	390	16	205	107	70	15	11	51	21	34	14	5	25	7	13	15	1	0	0	0
	2	15–25	85	12	1	<1	<1	0	<1	1	0·5	370	17	228	81	75	10	11	60	24	56	18	4	23	3	9	6	2	3	0	0
	3	25–50	83	14	1	<1	0	0	<1	1	0·6	379	25	166	76	117	8	21	88	20	39	9	2	24	6	7	8	3	2	0	0
	4	50–70	78	16	2	<1	0	0	1	2	1·0	409	20	152	60	93	10	12	103	37	34	9	3	31	3	7	5	11	1	0	0
	5	70–90	84	12	1	1	0	0	<1	1	0·8	405	27	220	92	37	6	11	84	20	33	15	4	24	8	6	4	3	1	0	0

in Broadbalk profiles 2 and 3. As in the Broadbalk profiles, they suggest in conjunction with the particle-size data that the soil near the surface is a mixture of two mineralogically distinct materials, one of which is rare or absent at depth.

Glauconite occurs in the fine sands of profiles 5, 8 and 11; in 5 and 8 it is most abundant between 15 and 55 cm depth, but in profile 11 it is detectable only below 50 cm. Most of it is brown and partly weathered, but a few green unaltered grains occur in deeper horizons. Many of the fine sand fractions also contain ferruginous clay aggregates, which resist disaggregation even by mild ultrasonic treatment. A few of these are papules of well oriented clay, but most are either strongly weathered glauconite pellets or weakly birefringent, iron-impregnated papules.

Coarse silt mineralogy and the distribution of loess. The mineral assemblages in the coarse silt fractions (20–50 μm) of samples from profiles 1, 2, 3, 4, 5, 8 and 11 (Table 6) resemble those of Broadbalk soils (Weir *et al.*, 1969, 84), and, like the fine sand fractions, are apparently mixtures of two main components. One contains up to 93% quartz, but has little or no felspar, and its heavy fraction is composed mainly of iron ores, zircon, tourmaline, rutile, anatase, kyanite and staurolite. This resembles the coarse silt fractions of the Reading Beds. The other component contains less quartz, and up to 17% felspar, and its heavy fraction contains epidote, zoisite, amphiboles, chlorite and garnet in addition to the heavy minerals typical of the first component. We attribute this to loess.

We calculated the amounts of loess in the analysed samples by three methods, two based on the assemblages of non-opaque heavy minerals in the coarse silts and the third on the proportions of quartz and felspar. First, the non-opaque heavy mineral assemblages of coarse silt fractions from weathered loess at Pegwell Bay, Kent (Weir *et al.*, 1971) and from Reading Beds and Clay-with-flints in Sussex (Hodgson *et al.*, 1967) were used as standards to estimate the relative amounts of these two materials that would best fit the composition of the same fractions in the Barnfield soils. This estimate minimised the sum of the squares of the differences between the observed proportions of each mineral and those calculated for mixtures of the two standards. The estimates of the two components were constrained to total 100%, as the totals of unconstrained estimates ranged from 99 to 117%. The proportion of the heavy coarse silt derived from loess was then converted to the proportion of loess in the whole <2 mm air-dried soil by multiplying by twice the percentage of coarse silt in the soil. This calculation is based on the average amount of coarse silt (approximately 50%) in the loess at Pegwell Bay, and on the assumption that the proportion of material derived from loess is the same in the whole of the coarse silt as in its non-opaque heavy fraction. Second, the non-opaque heavy mineral assemblages were used in a principal components calculation, and the extreme values of the first principal co-ordinate (corresponding to samples 8_5 and 3_2) were taken to represent 0% and 100% respectively of coarse silt derived from loess. The mineralogical compositions of these two samples in fact resemble those of the external standards used in the first calculation. The proportions of loess in the soil samples were then calculated as before. Third, the amounts of quartz and felspar in the coarse silt fractions were estimated chemically after removing layer silicates by fusion with sodium bisulphate; principal component analysis was applied graphically to give percentages of coarse silt derived from loess, and the proportions of loess in the whole soil were obtained by multiplying by twice the percentage coarse silt.

Table 7 gives the amounts of loess in the soils calculated by these three methods. The first two give similar results, which are usually larger than those based on proportions of quartz and felspar (column C), especially for the samples rich in loess. The felspar content of the most felspathic sample (11_4) strongly influences all the loess percentages calculated by the third method, so that the accuracy of the result depends on one felspar determination. For this reason the results given in columns A and B are preferred to those of column C. However, the results obtained by the third method, which are based on almost the whole of the coarse silt, are close enough to the results from the other methods to justify the assumption, made earlier, that the proportion of material derived from loess in the non-opaque heavy fraction resembles that in the whole of the coarse silt. The percentages in Table 7 are of stone-free soil, and therefore over-estimate the loess content of the whole soil, especially in very stony samples, such as 11_4.

TABLE 7

Loess percentages in Barnfield soils (<2 mm, air-dried) calculated from the mineralogical composition of coarse silt (20–50 μm) fractions

A. By microscopic determination of non-opaque heavy minerals, and comparison with loess and Clay-with-flints from other localities.
B. By microscopic determination of non-opaque heavy minerals, and principal component analysis.
C. By chemical determination of quartz and felspar percentages, and principal component analysis.

Profile no.	Sample no.	Depth (cm)	A	B	C
1	1	0–15	48	50	43
	2	16/23–35	32	36	29
	3	35–48	35	38	39
	4	48–70	40	44	42
	5	70–90	4	4	5
2	1	0–15	51	54	42
	2	15–23/28	51	54	38
	3	23/28–40	16	17	16
	4	40–74	8	9	3
	5	74–90	2	2	2
3	1	0–15	52	55	47
	2	21/24–35	48	51	39
	3	35–65	47	51	32
	4	65–90	3	3	3
4	1	0–15	48	51	35
	2	21/25–35	47	50	36
	3	35–70	17	18	18
	4	70–85	6	7	4
5	1	0–15	54	58	34
	2	16/20–35	20	21	24
	3	35–55	20	21	16
	4	55–90	3	4	2
8	1	0–15	44	48	38
	2	19/21–35	26	28	29
	3	35–55	30	32	30
	4	55–70	4	5	2
	5	70–90	0	0	0
11	1	0–15	54	58	43
	2	15–25	51	54	42
	3	25–50	59	62	52
	4	50–70	52	56	57
	5	70–90	46	50	39

Loess is an important constituent of much of the soil of Barnfield, but no sample consisted entirely of it. The percentage of loess in the <2 mm soil of the ploughed layer throughout the field is fairly constant (45–55% approximately), but decreases downwards in all the profiles except 11, so that over most of the field there is little or none below 60–70 cm. A loess-free horizon was not reached in the 90 cm core of profile 11, and loess was most abundant at 25–50 cm. The downward decrease of loess content is slightly more gradual in profiles 2, 4 and 5 than in 1, 3 and 8. The depth in profiles 3 and 8 at which the transition to soil containing little (<10%) or no loess occurs is the same as that indicated by the particle size distribution of 2–500 μm fractions (Fig. 4). In profile 3 this transition occurs at the boundary between the brown loamy surface layer and the reddish clayey subsoil, but in profiles 1, 2, 4, 5 and 8 the upper horizons of the brightly coloured clayey subsoil contain 15–40% loess.

The principal components calculation showed that mixing of the two postulated components accounts for 92% of the variance in observed mineral composition of the heavy coarse silt fractions. Second and third vectors account for 3% and 2% of the variance respectively. This suggests that the heavy coarse silt fractions of Barnfield soils contain little or no material other than that derived from loess and Reading Beds, and that weathering has not strongly altered these fractions.

The coarse silt fractions of samples from profile 11 and the deeper layers exposed in the pit (profile 13) show that materials containing loess occur to greater depths in 'the valley' than elsewhere on Barnfield. The reddish clay layer (sample 13_4), which rested on the rubbly chalk drift and extended to a maximum depth of 170 cm in the pit, contained approximately the same amount of loess (20–30%) as upper layers of the reddish clay subsoil in profiles 2, 4 and 5; also, silty inclusions within the rubbly chalk drift at 280–310 cm depth contained at least 50% loess. This shows that the rubbly chalk drift and the reddish clay overlying it (the IIB2t horizon) were deposited in 'the valley' during or after deposition of loess. However, the profiles north and south of 'the valley' indicate that, although mixing subsequently occurred to a depth of approximately 70 cm, the loess was originally deposited after formation of the Clay-with-flints that forms the lowest horizons in these profiles.

Fine silt mineralogy. The fine silt fractions (2–20 μm) of samples from profiles 5, 8 and 11 are composed mainly of quartz with subsidiary amounts of felspar, mica, kaolinite, chlorite and expanding layer silicate minerals. Differences in the relative amounts of these constituents between the samples reflect mainly the changes in parent material already discussed. The fine silts of loess-rich horizons, such as the Ap horizons of profiles 5 and 8 and all horizons of profile 11, contain approximately 20% felspar, 5–10% mica, moderate amounts of chlorite, but little or no kaolinite, or expanding minerals. In contrast the loess-free horizons (e.g. the B3tg horizons of profiles 5 and 8) contain 2–3% felspar, 3% mica, moderate amounts of kaolinite and expanding minerals but only traces of chlorite. The expanding mineral in the B3tg horizon of profile 8 resembles an interstratified smectite–vermiculite, as it has an interlayer spacing of 16·8 Å when Mg-saturated and treated with ethylene glycol.

Clay mineralogy. The clay fractions (<2 μm) of samples from profiles 5, 8 and 11 contain minerals similar to those in the clay fractions of Broadbalk soils (Weir *et al.*, 1969, 85–87). They are composed mainly of complex mixtures of layer silicate minerals, for which there is at present no satisfactory nomenclature. We describe them by analogy with pure minerals of largely non-pedological origin (mica, chlorite, kaolinite, vermiculite and smectite), which give X-ray diffraction patterns similar in part to those obtained from soil clays, but as in Broadbalk soils (Catt, 1969) this nomenclature inevitably involves some oversimplification.

In the subsurface clay-rich B horizons of the shallow Batcombe soils (profiles 5 and 8) the <2 μm fractions are composed mainly of expanding layer silicates, with subsidiary mica and kaolinite, and small amounts of quartz and goethite. The expanding material resembles that in the Batcombe subsoil of Broadbalk; in Mg-saturated form it expands from 14 Å to 17 Å when treated with ethylene glycol, and collapses on heating to give a 10 Å reflection tailing to slightly larger spacings. It therefore resembles smectite, but further study described below showed that it is a complex interstratified material containing smectite and other layers. In these subsoil horizons the amounts of mica decrease slightly with depth, and the expanding layer silicates increase.

The clay fractions of the loamy B horizons in profile 11 are also composed mainly of expanding minerals, but contain a vermiculite component in addition to smectite. There is more mica, kaolinite and quartz than in the Batcombe subsoil clay, and also small amounts of chlorite and felspar; sample 11_5 has appreciable amounts of lepidocrocite. The loess-rich Ap horizons of all three profiles contain mineralogically similar clay fractions to the B horizons of profile 11, but the X-ray reflections from the expanding minerals are broader and less intense, probably because the diffracting units are smaller and the stacking sequences less regular. This difference probably results from weathering of the expanding clay minerals in the surface soil. However, as in the soils of Broadbalk, the composition of the clay fractions is determined mainly by the parent materials. The clay fractions of loess-rich horizons differ from those consisting mainly or entirely of Clay-with-flints in containing vermiculite, chlorite and felspar; they also contain more mica, kaolinite and quartz, but less smectite.

Potassium release from the clay fractions

Remarking on the wide range of exchangeable potassium in Barnfield soils, Warren and Johnston (1962, 244) noted that the unmanured strip contains more soluble potassium than corresponding plots on Broadbalk, Hoosfield, Agdell and the exhaustion land. Their tests did not measure potassium release, so we applied recently developed techniques that measure potassium release from micas and soil clays. Because lengthy experiments were needed, only samples from profiles 5 and 9 could be examined. Core 5 probably contains some potassium from fertilisers applied to Strip 4, but core 9 was taken between strips 7 (no potassium since 1902) and 8 (no potassium since 1845).

The amount of potassium in equilibrium calcium chloride extracts of Mg-saturated soil clays usually decreases with successive treatments until the concentration of potassium in solution, expressed relative to calcium as the ratio $K/\sqrt{Ca}$, declines to a critical value; thereafter nearly constant amounts of potassium are removed in each successive extract. The critical ratio, $R(K/\sqrt{Ca})$, defined as the smallest observed value of $K/\sqrt{Ca}$, varies from soil to soil and is thought to measure the 'background' release of potassium from the layer silicates. For muscovite, R is about 15×10^{-6} mol$^{1/2}$ litres$^{-1/2}$, and is the solution concentration of potassium, relative to calcium, above which potassium is not released from the mica. The proportion of soil clay potassium removed by calcium chloride solution at room temperature is small, usually $<2\%$ of the total, and no change in the structure of the clay is detectable by X-ray diffraction. In contrast, barium chloride solution at 100°C is very active, but selective for potassium in micas; it causes no detectable change in other minerals, and extracts insignificant amounts of potassium from felspars. It therefore measures the total potassium that may be ultimately released by cation exchange should the potassium concentration ratio in the soil solution remain below R for a long time.

The ammonium acetate exchangeable potassium is greater in samples from profile 5, expecially the Ap horizon, than in profile 9 (Table 8), presumably because potassium sulphate was applied to strip 4. R for all the clay fractions is very small (Table 9) and for the Batcombe subsoil clay is similar to that for muscovite; in even the most potassium-deficient of Barnfield soils the initially exchangeable potassium gives a concentration ratio at least ten times this value. Probably more is released from the Ap horizons of

TABLE 8

Ammonium acetate exchangeable bases (me/100 g soil) in samples from Barnfield profiles 5 and 9

Sample no.	5_1	5_2	5_3	5_4	9_1	9_2
K	1·03	0·52	0·51	0·48	0·28	0·30
Na	0·19	0·28	0·26	0·22	0·16	0·21
Ca	36·1*	31·1	33·2	33·7	48·4*	25·9
Mg	1·28	1·17	1·17	1·04	0·98	0·87

* The exchangeable Ca of Ap horizons includes some derived from calcium carbonate.

profile 5 because fertilisers were applied to strip 4. Therefore the amounts of readily exchangeable potassium and of potassium in the soil solution seem enough to inhibit the release of potassium from the soil mica.

TABLE 9

Cation exchange capacities (CEC) and 'background' K release from clay fractions (< 2 µm) of Barnfield soils

Sample no.	CEC (me/100 g)	K release $10^6(\mathrm{K}/\sqrt{\mathrm{Ca}}\ \mathrm{mol}^{1/2}\ \mathrm{litre}^{-1/2})$
5_1	49·5	40·5
5_2	50·7	18·4
5_3	48·9	17·4
5_4	45·8	15·3
9_1	62·4	26·4
9_2	49·8	22·3

After they had been extracted five times with boiling barium chloride solution, mica could not be detected by X-ray diffraction in the coarse and fine clay fractions of profile 5. In the coarse clays it was replaced by a vermiculite-like mineral giving five or more orders of basal reflections, which were much sharper than those from the untreated clay. Despite the apparent absence of mica, 0·79–1·55% K remained in the extracted coarse and fine clays (Table 10). Felspar probably accounts for a little residual potassium in the coarse clays of the loess-containing horizons (5_1–5_3), but the fine clays have little or none, and the 0·1–2 µm fractions of loess-rich horizons in Broadbalk average only 0·2% of felspar potassium. Therefore most of the residual potassium probably occurs in individual potassium-containing layers interstratified with expanding layers.

TABLE 10

Percentages of potassium in coarse and fine clay fractions of Barnfield profile 5 before and after barium chloride extraction

Sample no.	5_1	5_2	5_3	5_4
Coarse clay (1·5–2 µm) as % of total clay	17·6	10·9	10·0	7·8
K content, K-saturated	3·36	3·13	2·96	2·82
K content, Mg-saturated	2·36	2·08	1·84	1·46
K content after extraction	1·22	1·21	0·90	0·79
Fine clay (< 0·5 µm) as % of total clay	60·4	70·6	72·1	77·4
K content, K-saturated	3·29	3·07	2·94	3·22
K content, Mg-saturated	1·70	1·48	1·48	1·34
K content after extraction	1·55	1·20	1·17	1·06

Weir *et al.* (1969, 87) expressed all the non-exchangeable, non-felspar potassium in the clay fractions of Broadbalk soils as mica potassium, and did not subdivide the potassium between micas and individual potassium-containing layers interstratified with other layers (expanding or non-expanding). This subdivision can be made semiquantitatively for the clay fractions of Barnfield profile 5, because barium chloride seems to extract the potassium from micas but not from distributed potassium-containing layers. The amounts of mica (Table 11) were calculated from the potassium extracted by barium chloride from the Mg-saturated clays, assuming that mica contains 8·3% K (Jackson, 1956, 544). The proportions of distributed potassium-containing layers were similarly calculated from the amounts of residual potassium, after correcting for 0·2% felspar potassium in the coarse clays of samples 5_1–5_3; however, this probably under-estimates the amounts of these layers, because barium chloride may extract some of their potassium; also they may contain <8·3% K.

TABLE 11

Percentage mica, distributed mica layers and smectite layers in the clay fractions of Barnfield profile 5

Sample no.	5_1	5_2	5_3	5_4
1·5–2 μm fraction				
% mica	14	11	11	8
% distributed potassium-containing layers	12	12	9	9
% smectite layers	25	27	29	35
<0·5 μm fraction				
% mica	2	3	4	3
% distributed potassium-containing layers	19	14	14	13
% smectite layers	40	41	38	48

The coarse clay fractions of each sample from profile 5 contain approximately equal proportions of mica and distributed potassium-containing layers, both decreasing with depth (Table 11). The fine clay fractions contain more distributed potassium-containing layers, which also decrease downwards, but lost very little potassium when extracted with barium chloride solution. This suggests that the fine clays release their potassium less readily than the coarse clays. This is contrary to the views of Arnold (1960) and others that more potassium is released by fine clays than coarse, but is supported by the results of Doll *et al.* (1965), Scott (1968) and Smith *et al.* (1968). Also, we find fine clay from many other localities in England to be similarly stable to barium chloride extraction. Assuming that the fine clay is mineralogically similar to the coarse clay but more finely divided, the interlayer potassium should be more accessible to exchange in the smaller particles, because the diffusion path is shorter, and their larger specific surface provides more area per unit weight for replacing cations to enter. However, the fine clay fractions of Barnfield soils are mineralogically different from the coarse clays, and in particular contain less mica.

The percentage of smectite layers in both the coarse and fine clay fractions of sample 5_4 (Table 11), calculated from the differences in potassium content between the Mg-saturated and K-saturated forms (assuming an exchange capacity for smectite interlayers of 100 me/100 g), is approximately four times that of distributed potassium-containing layers. X-ray diffraction indicates that the distributed potassium-containing layers are not simply 10 Å mica layers. Reynolds and Hower (1970) calculated diffraction profiles for random and partly ordered interstratifications of mica and glycol-solvated montmorillonite layers, and showed that the position of the intensity maximum between

$d = 7{\cdot}5$ and 10 Å moves from 8·50 for 100% montmorillonite layers to 10·18 for 100% mica layers. For the composition 80% montmorillonite : 20% mica, the calculated peak position was $d = 8{\cdot}69$ Å. The maximum intensity for the Barnfield clays is at 8·2 Å, which is on the high angle side of the position not only for 80% montmorillonite but also for 100% montmorillonite.

This position of maximum intensity suggests that the interstratification involves 14 Å layers instead of or in addition to 10 Å layers. Other maxima observed at $d = 4{\cdot}88$ and 3·40 Å also suggest a 14/17 Å interstratification. If the 14 Å layers are vermiculitic, they cannot contain potassium, because the layer spacing of potassium vermiculite is mainly 10 Å. The interstratified material may be a three-component mixture of 10, 14 and 17 Å layers, but the diffraction profiles for this have not been calculated and are difficult to predict by qualitative argument. However, if the 14 Å layers contain hydrolysed aluminium ('hydroxyaluminium interlayers'), which inhibits collapse and also fixation of potassium and ammonium (Rich, 1960; Shen & Rich, 1962), they could perhaps retain some potassium, the release of which would be blocked by the hydrolysed aluminium. Some evidence suggests that there is such blocking in the fine clay of sample 5_4. Potassium was removed from this fraction only by the first four barium chloride extractions and not by the fifth, suggesting that the extraction was complete. However, extracting the residue with 0·25*M* sodium citrate solution at 100°C (a reagent that complexes iron and aluminium) released 6% of the total Fe, 14% of the total Al, and a further 5% of the residual K. This additional potassium was probably unblocked when the aluminium and iron were dissolved by the citrate, but further work is needed to decide whether the blocking materials are surface-adsorbed sesquioxides or interlayer hydroxy compounds.

Discussion and conclusions

Nature, origin and development of the soils. Our work confirms that the soil in 'the valley', including most of section 3, differs significantly in topsoil texture and in depth of loamy material from the soil of the rest of the field, and that significant movement of surface soil has occurred since experimentation began. This should be considered in interpreting experimental results.

Vertical and lateral variability result from differences in parent material, transformation and movement of soil constituents by pedogenic processes, the variable incidence of erosion and redeposition, and from cultural treatments. Except for the chalky substratum of profile 13, all the horizons examined show evidence of post-depositional modification, but effects of recent alteration *in situ* cannot always be distinguished from those of earlier phases of pedogenesis, in which the soil materials were transformed either in their present position, or elsewhere prior to local transport.

Shallow Batcombe soils, with a dark brown loamy and flinty surface horizon over Clay-with-flints, occupy 80% of the field and are exemplified by profiles 1, 2, 4, 5, 6, 8, 9, 10 and 12. They morphologically resemble soil variant A of Broadbalk (Avery & Bullock, 1969), but generally have a more clayey surface horizon and locally (e.g. in profiles 4 and 12) are less mottled at depth. The particle size distribution and mineralogical composition of >2 μm fractions also resemble those of Batcombe soils in Broadbalk and elsewhere, showing that they have developed in the same parent materials. The Clay-with-flints subsoil is derived mainly from Reading Beds, which have been extensively disturbed, weathered and mixed with insoluble residue from the underlying chalk (mainly flint and chalcedony from fossil shells). The loamy surface soil contains more coarse silt relative to sand than most of the Clay-with-flints, and the mineralogical composition of this silt shows that approximately half the topsoil is derived from loess and half from Reading Beds.

Most of the loess in south-east England was probably deposited during the later part of the Weichsel Glaciation (approximately 20 000–14 000 years ago), because it resembles mineralogically the glacial detritus of that age in Norfolk (Catt *et al.*, 1971). The loess might have been partly mixed with the Clay-with-flints by cryoturbation during this and later cold periods, and the incorporation of a little loess in the highest 40–50 cm of the subsoil beneath the ploughed layer in profiles 1, 2, 4, 5 and 8 is best explained in this way. However, the Barnfield topsoil contains more material derived from Clay-with-flints than the Broadbalk topsoil, because more of the loess-rich surface layer has been removed by erosion, and subsoil clay is incorporated in the ploughed layer. North of 'the valley' there are more large unworn flint nodules and the subsoil clay is less mottled than in southern parts of the field; both features suggest that chalk is nearer the surface.

The Clay-with-flints subsoil horizons have a strongly sepic plasmic fabric, probably attributable to seasonal swelling and shrinking. They show segregations of clay, iron and manganese, evincing much pedological reorganisation, which probably occurred partly in a pre-Weichselian phase of profile development before the deposition and incorporation of loess. The extent to which the changes in clay content with depth reflect downward movement since the Weichsel is consequently problematical and cannot be determined from this investigation.

The soils in 'the valley', exemplified by profiles 3, 7, 11 and 13, have a thicker loamy surface layer. In profile 3 on the western side of the field, the loamy layer rests on mottled Clay-with-flints with little loess admixture, resembling that in the shallow Batcombe profiles. In the other three profiles, horizons to at least 1 m depth have developed in colluvial or solifluction deposits of differing lithology and age, all of which contain loess. Surface soil has moved into the lower part of 'the valley' on several occasions since the experiment began, and the distribution of organic carbon, chalk and bone fragments in profile 11 shows that the top 15 cm at least has accumulated during the last few centuries. Comparison of future topography with that of the present (Fig. 1) may allow the rate of soil erosion and redeposition to be calculated.

The sub-surface layers in 'the valley' are probably pre-historic, but more deep exposures are needed to clarify their stratigraphic relationships. The oldest deposit that we have seen there is the rubbly chalk drift in profile 13, which probably underlies most of the lower part of section 3. Similar chalky deposits elsewhere in southern England are attributed to solifluction in periglacial conditions, so are at least as old as the 'Younger Dryas' period, which ended about 10 000 years ago. 'The valley' must have been cut through the Clay-with-flints into the underlying chalk before this date. The reddish flinty clay (profile 13, IIB2t horizon) overlying the rubbly chalk drift differs from the main mass of Clay-with-flints forming the Batcombe subsoil in containing a little loess and no red or greyish mottles, and in these respects resembles the Bt horizons of soils classed as Charity series (Avery, 1964). As it contains loess, it must have originated, presumably by solifluction, during or after the period of loess deposition. The clay subsoil in profile 7 (IIB2t and IIB3t(g) horizons) has similar morphology and particle size distribution, and is probably part of the same deposit. Both these flinty clay layers, and the stoneless silty clay loam at the base of profile 11, show evidence of pedological reorganisation and seem to have been truncated by erosion, possibly during temporary stream-flow, before deposition of the layers above. In profile 11, which resembles profile 5 (variant D) in Broadbalk, the gravelly layer may also result from this short period of stream activity. The B1 horizons of profiles 11 and 13 are both part of a comparatively recent deposit of uniform colour and texture, which was encountered in all borings in the lowest part of 'the valley'.

After the original cutting of 'the valley' during Weichselian times or earlier, the most probably sequence of events was: (a) deposition of rubbly chalk drift and flinty clay

(13_4, 7_4, 7_5) by solifluction during a Late Weichselian or earlier cold period; (b) deposition of stoneless silty material (11_5) and soil development during early Post-glacial times (10 000–7000 years ago); (c) stream erosion, possibly arising from increased run-off after deforestation; (d) deposition of loamy colluvium (B1 and A2p horizons of profiles 11 and 13) by rainwash from the adjoining slopes in medieval times or earlier; (e) further deposition of loamy colluvium (A1p horizons of 11 and 13) after chalk and ground bones were first applied to the field. The dating of these events is tentative.

The differences in mineralogical composition of the clay (<2 μm) and fine silt (2–20 μm) fractions between horizons in profiles 5 and 8 and 11 reflect mainly the different proportions of loess and Clay-with-flints. The Ap and other loess-rich horizons contain more mica, chlorite and felspar in both these size fractions than the Clay-with-flints horizons. The expanding mineral, which is an important constituent of clay fractions from all horizons, and also occurs in the fine silts, is probably interstratified smectite–vermiculite. Some of the potassium in the clay fractions probably occurs in the 14 Å layers, but its release is blocked by 'hydroxyaluminium interlayers' or sesquioxidic surface coatings. The amounts of this potassium in the coarse clay fractions (1·5–2 μm) throughout profile 5 (shallow Batcombe soil) approximately equal those in mica, but in the fine clays ($<0{\cdot}5$ μm) it accounts for almost all the potassium in layer silicates. There is enough potassium in the soil solution and in readily exchangeable sites to inhibit natural release of potassium from mica, and mica weathering is not actively advancing in the soils at present. Some potassium may be released locally from mica, for example near active roots, where the concentration of soluble potassium is temporarily diminished, but such regions are transient. The only evidence for recent weathering of clay minerals in the surface soil is the broader and less intense X-ray reflections from the expanding minerals. More extensive alterations probably occurred in pre-Weichselian times, but these cannot be evaluated because the original unaltered clay needed for comparison with the soil clays no longer exists at or near Rothamsted.

Physical qualities affecting cropping behaviour. Our observations in Barnfield confirm Hall's (1917) account of the texture, structure and working qualities of the Rothamsted topsoil. The surface of fallow ground slakes after heavy rain, and the topsoil in the core samples seemed nearly massive below the upper few centimetres. There is field evidence of a plough pan, especially in the deep silt loam soils of 'the valley', and this was confirmed by porosity measurements on the upper horizons of profile 7. Effects of gleying, which were ephemeral in so far as they were barely perceptible later in the season, were noted in April 1971 at the base of the ploughed layer in shallow Batcombe soils, especially in the dunged plots of sections 5 and 6, where gleying was clearly associated with partly decomposed organic matter. Haines and Keen (1925) recorded a similar observation.

Slaking, massive structure and associated gleying effects in the ploughed layer, and a plough pan, are all features that have been described as characteristic of soils where structure has been degraded by continuous cropping (e.g. Agricultural Advisory Council, 1970), yet there is no positive evidence that their occurrence in Barnfield is associated with loss in yields of potatoes or sugar beet under the present cropping regime. Morphological features related to slaking and other 'regrouping phenomena' (Jongerius, 1970) are probably more evident in the silt loams than in the heavier soils that predominate in Barnfield, because the heavier soils recover their structure to a greater extent by cracking in dry periods, and because fine aggregates produced by drying after freezing or wetting, or by cultivation under favourable conditions, are more water-stable (Williams, 1971).

A distinctive quality of Barnfield (and Broadbalk) soils, which they share with other fine textured gleyed brown earths, is moderately good natural drainage. Although many more measurements (e.g. of pore-size distribution and hydraulic conductivity in sub-surface horizons, and of seasonal changes in moisture content and tension) are needed for fuller understanding of the water/air regimes in these and other soils, our morphological observations are consistent with the view that the Clay-with-flints subsoils are rather more permeable than corresponding horizons in many soils of similar texture in Pleistocene and pre-Pleistocene clay formations, including undisturbed Reading Beds Clay. Hall (1917, 25) attributed this apparent permeability to pockets of subsoil sand and gravel, and to thinning of the Clay-with flints over buried chalk pinnacles. Internal drainage is evidently impeded to some extent over most of the field, but sub-surface horizons to a depth of 50 cm show only slight gleying, suggesting that they are seldom waterlogged for significant periods. Micromorphological studies of these horizons showed very fine sub-angular aggregates bounded by fissures, which are not readily apparent to the unaided eye, but may aid circulation of air and water in the wet season. The structural characteristics of the Clay-with-flints subsoils, and their tendency to crumble when partly dry, may be related to their content of free iron oxide in relation to clay (Kemper & Koch, 1966), which is significantly larger than in most British clay subsoils, partly as a result of long continued oxidative weathering.

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REFERENCES

AGRICULTURAL ADVISORY COUNCIL (1970) *Modern farming and the soil.* Ministry of Agriculture, Fisheries and Food. London: H.M.S.O., 119 pp.

ARNOLD, P. W. (1960) Potassium-supplying power of some British soils. *Nature, London* **187**, 436–437.

AVERY, B. W. (1964) The soils and land use of the district around Aylesbury and Hemel Hempstead. *Memoirs of the Soil Survey of Great Britain.* vii + 216 pp.

AVERY, B. W. (1965) Soil classification in Britain. *Pédologie, Gand*, No. Speciale 3, 75–90.

AVERY, B. W. & BULLOCK, P. (1969) The soils of Broadbalk: morphology and classification of Broadbalk soils. *Rothamsted Experimental Station. Report for 1968*, Part 2, 63–81.

BASCOMB, C. L. (1961) A calcimeter for routine use on soil samples. *Chemistry and Industry* 1826–1827.

BREWER, R. (1964) *Fabric and mineral analysis of soils.* New York: J. Wiley, 470 pp.

BROWN, G., CATT, J. A., HOLLYER, S. E. & OLLIER, C. D. (1969) Partial silicification of chalk fossils from the Chilterns. *Geological Magazine* **106**, 583–586.

CATT, J. A. (1969) The soils of Broadbalk: the origin and development of the soils. *Rothamsted Experimental Station. Report for 1968*, Part 2, 89–93.

CATT, J. A., CORBETT, W. M., HODGE, C. A. H., MADGETT, P. A., TATLER, W. & WEIR, A. H. (1971) Loess in the soils of north Norfolk. *Journal of Soil Science* **22**, 444–452.

DEB, B. C. (1950) The estimation of free iron oxides in soils and clays and their removal. *Journal of Soil Science* **1**, 212–220.

DOLL, E. C., MORTLAND, M. M., LAWTON, K. & ELLIS, B. G. (1965) Release of potassium from soil fractions during cropping. *Soil Science Society of America. Proceedings* **29**, 699–702.

HAINES, W. B. & KEEN, B. A. (1925) Studies in soil cultivation III. Measurements on the Rothamsted classical plots by means of dynamometer and plough. *Journal of Agricultural Science, Cambridge* **15**, 395–406.

HALL, A. D. (1917) *The book of the Rothamsted experiments.* 2nd ed. London: John Murray, 332 pp.

HODGSON, J. M., CATT, J. A. & WEIR, A. H. (1967) The origin and development of clay-with-flints and associated soil horizons on the South Downs. *Journal of Soil Science* **18**, 85–102.

JACKSON, M. L. (1956) *Soil chemical analysis—an advanced course.* Madison, Wisconsin: published privately, 991 pp.

JONGERIUS, A. (1970) Some morphological aspects of regrouping phenomena in Dutch soils. *Geoderma* **4**, 311–332.

KEMPER, W. D. & KOCH, E. J. (1966) Aggregate stability of soils from Western USA and Canada. *U.S. Department of Agriculture Technical Bulletin*, No. 1355.

KIELY, P. V. & JACKSON, M. L. (1965) Quartz, felspar and mica determination for soils by sodium pyrosulfate fusion. *Soil Science Society of America. Proceedings* **29**, 159–163.

LOVEDAY, J. (1962) Plateau deposits of the southern Chiltern hills. *Proceedings of the Geologists' Association* **73**, 83–102.

MARÉCHAL, R. (1958) Contribution à l'étude des terrains superficiels de la région condrusienne. *Pédologie, Gand* Memoire No. 1, 320 pp.

REICHENBACH, H. G. von & RICH, C. I. (1968) Preparation of dioctahedral vermiculites from muscovite and subsequent exchange properties. *Transactions of the 9th International Congress of Soil Science, Adelaide* **I**, 709–719.

REYNOLDS, R. C. & HOWER, J. C. (1970) The nature of interlayering in mixed-layer illite–montmorillonites. *Clays and Clay Minerals* **18**, 25–36.

REYNOLDS, R. C. & LESSING, P. (1962) The determination of dioctahedral mica and potassium feldspar in submicroscopic grain sizes. *American Mineralogist* **47**, 979–982.

RICH, C. I. (1960) Aluminium in interlayers of vermiculite. *Soil Science Society of America. Proceedings* **24**, 26–32.

SCOTT, A. D. (1968) Effect of particle size on interlayer potassium exchange in micas. *Transactions of the 9th International Congress of Soil Science, Adelaide* **II**, 649–660.

SHEN, M. J. & RICH, C. I. (1962) Aluminium fixation in montmorillonite. *Soil Science Society of America. Proceedings* **26**, 33–36.

SMITH, S. J., CLARK, L. J. & SCOTT, A. D. (1968) Exchangeability of potassium in soils. *Transactions of the 9th International Congress of Soil Science, Adelaide* **II**, 661–669.

SOIL SURVEY STAFF (1951) *Soil Survey Manual. U.S. Department of Agriculture Handbook* No. 18, vii + 503 pp.

SOIL SURVEY STAFF (1960) *Soil classification: a comprehensive system, 7th approximation.* Washington: U.S. Department of Agriculture, 265 pp.

SOIL SURVEY STAFF (1967) *Supplement to soil classification system (7th approximation).* Washington: U.S. Department of Agriculture, 207 pp.

STOOPS, G. & MATHIEU, C. (1970) Aspects micromorphologiques des argiles à silex de Thiérache. *Science du Sol* **2**, 103–116.

THOREZ, J., BULLOCK, P., CATT, J. A. & WEIR, A. H. (1971) The petrography and origin of deposits filling solution pipes in the chalk near South Mimms, Hertfordshire. *Geological Magazine* **108**, 413–423.

TINSLEY, J. (1950) The determination of organic carbon in soils by dichromate mixtures. *Transactions of the 4th International Congress of Soil Science* **I**, 161–164.

WARREN, R. G. & JOHNSTON, A. E. (1962) Barnfield. *Rothamsted Experimental Station. Report for 1961*, 227–247.

WEIR, A. H., CATT, J. A. & ORMEROD, E. C. (1969) The soils of Broadbalk: the mineralogy of Broadbalk soils. *Rothamsted Experimental Station. Report for 1968*, Part 2, 81–89.

WEIR, A. H., CATT, J. A. & MADGETT, P. A. (1971) Postglacial soil formation in the loess of Pegwell Bay, Kent (England). *Geoderma* **5**, 131–149.

WILLIAMS, R. J. B. (1971) Relationships between the composition of soils and physical measurements made on them. *Rothamsted Experimental Station. Report for 1970*, Part 2, 5–35.

APPENDIX

Profile descriptions

Profile 5

Ap	0–16/20 cm	Dark brown (10 YR 4/3) flinty (5–10%) silty clay loam; firm when moist, very hard when dry; weak medium to coarse blocky structure; abrupt irregular boundary.
B1t(g)	16/20–35 cm	Strong brown (7·5 YR 5/6) clay with few (<5%) flints and faint reddish and brownish mottles; very firm when moist, very plastic when wet and extremely hard when dry; weak coarse blocky structure, with brown (7·5 YR 5/4) ped faces and channels filled with material resembling horizon above; few fine black manganiferous nodules; gradual boundary.
B2t(g)	35–55 cm	Strong brown (7·5 YR 5/6) clay with few (<5%) flints and common, faint to distinct, brown (7·5 YR 5/3–5/4) and red (2·5 YR 4/6) mottles; firm when moist (distinctly more friable than above), very hard when dry; weak blocky structure, with smooth brown cleavage faces; gradual boundary.
B3tg	55–90 cm	Strong brown to reddish yellow and red, flinty (5–10%) clay with few to common, light brownish grey to light grey (5/1) mottles; the proportion of red (2·5 YR 4/6) material increases with depth, becoming dominant at the base, and grey mottles become increasingly prominent, occurring in association with cutans around flints and lining planes or channels; very firm to extremely firm when moist, very plastic when wet and extremely hard when dry; weak coarse blocky structure, with some widely spaced slickensided planes inclined at acute angles to the horizontal.

Profile 8

Ap	0–19/21 cm	Dark brown (10 YR 4/3) flinty (5–10%) silty clay loam; firm when moist, very hard when dry; weak, medium to coarse blocky structure; abrupt irregular boundary.
B1t	19/21–35 cm	Strong brown to yellowish red (7·5–5 YR 4/6–5/6) clay with few large flints, faint brownish mottles, and few infilled channels; very firm when moist, very plastic when wet and very hard when dry; weak coarse blocky structure, massive directly below Ap; common black ferri-manganiferous nodules; gradual boundary.
B2t(g)	35–55 cm	Strong brown to yellowish red clay with few large flints; common, faint to distinct, fine reddish and brownish mottles, and common (up to 20%) black diffuse manganiferous concentrations; brown (7·5 YR 5/4) on ped faces and where stones are embedded; firm when moist (manganiferous material distinctly more friable), plastic when wet and very hard when dry; weak blocky structure; clear boundary.
B3tg	55–90 cm	Brown and yellowish red flinty (10–15%) clay with common to many (with increasing depth) medium to coarse red (2·5 YR 4/6) mottles and few to common light brownish grey to light grey mottles or streaks, mainly around flints and lining planes or channels; very firm when moist, plastic to very plastic when wet and extremely hard when dry; weak coarse blocky structure, with widely spaced slickensided planes.

Profile 11

A1p	0–18 cm	Dark greyish brown (10 YR 4/2–3) flinty (15–20%) silt loam; friable to firm when moist and hard when dry; weak fine to medium subangular blocky structure; clear boundary.
A2p	18–28 cm	Dark brown (10 YR 4/3) flinty (15–20%) silt loam with darker (10 YR 4/2) material associated with subvertical planes and infilled channels; firm when moist and very hard when dry; more compact than above; weak medium to coarse angular blocky structure; clear wavy boundary.
B1	25–50 cm	Brown (7·5–10 YR 4/4 moist, 5/4 dry) flinty (10–15%) silt loam with darker (4/2) material in channels and coating peds; friable to firm when moist, slightly plastic when wet and hard when dry; weak fine subangular blocky structure; common fine manganiferous nodules; clear smooth boundary.
IIE/Bt(g)	50–70 cm	Loamy gravel containing 50–70% angular and subangular flints and flint pebbles, mainly small (< 5 cm), in a porous matrix of brown to pale brown (10 YR 5/4 moist; 10 YR 6/3–6/4 dry) silt loam; redder (7·5 YR 4/4–5/6), denser and finer in texture in places near lower boundary, with clay skins on stones; common fine ferrimanganiferous nodules and coating on stones; clear smooth boundary.
IIIB2t(g)	70–90 cm	Strong brown to reddish yellow (7·5 YR 5–6/6) silty clay loam with common fine distinct pale brown to light yellowish brown (10 YR 6/3–6/4) mottles and common diffuse black ferrimanganiferous concentrations; few flints; few channels with darker coloured infilling; firm when moist, slightly plastic to plastic when wet and very hard when dry; weak blocky structure.