Bosworth Field Investigation

Soil Survey Report

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EXECUTIVE SUMMARY

This Report has four components:

1. the text and Tables are contained within this Word® .doc file;
2. technical terminology is presented in Appendix I as a separate .doc file;
3. maps, diagrams and photographs are presented as Figures in Appendix II as a separate .doc file; and
4. datasets in Excel® spreadsheets and GIS files in ESRI ArcView® shapefile format are provided electronically.

Introduction

Four broad **aims** to the soil investigation were encompassed within three **Work Packages (WP)** – WP A soil desk study, WP B field soil survey and WP C re-assessment:

1. to provide soil information for the Bosworth Field site from a documented survey of 1976 (WP A);
2. to provide newly acquired soil information for areas in and around Ambion Wood (WP B);
3. to provide evidence from the soils to support an alternative location for the 'Marsh' (WP A, WP B & WP C); and
4. to provide an assessment of the corrosion potential (aggressivity) of the soil towards buried ferrous artefacts (WP B).

WP C, a re-assessment of potential sites of interest, was deferred until the results for WPs A and B were known, however some work was done to allow correlation of the old and new surveys.

Methodology

WP A – The data from field maps and hand-written notes for a published soil map for Sheets SP38/39 have been transcribed for the battlefield area and entered into a series of Excel ® worksheets.

WP B – A soil survey was carried out during Nov 2005 and Feb 2006 at selected investigation sites using a GPS receiver, by augering by hand down to a depth of about 1.2 metres where possible, using Dutch and gouge augers. All soil layers (soil horizons) and depths at which changes occur were studied and properties such as soil depth, texture, structure, colour and mottling, the presence of carbonate (free lime), drainage status and stones were described and recorded in accordance with the 'Soil Survey Field Handbook' onto a computer-compatible record card. Soil resistivity was investigated at 35 of the sites using an Electrical Conductivity probe for the topsoil at 20 cm depth, and the upper subsoil at 35 and 45 cm depths. The pH of a field-moist topsoil sample was measured and recorded.

WP C – Field survey was carried out as in WP B at nine sites across the alluvium and White Moors ridge.

Results

WP A 1976 Soil Map – A digitised version of the soil map is made available as an ESRI ArcView® shapefile and is reproduced as Figure 4. The map units (polygons) are of 'soil series', the lowest level in the hierarchical classification system of the Soil Survey of England and Wales.

WP A Aerial Photographs – Panchromatic aerial photography of the area flown by Cartographical Services (Southampton) Ltd 6 May 1975, at scale 1:15,000, print numbers Contract 491 1019–1022, were used during the original survey as an aid to drawing soil boundaries using tonal changes. They were loaned to the Project Leader for scanning and for a digital copy to be retained for use in the Battlefields Project.

WP A Geology – Three versions of existing geological mapping dating from 1932, 1985 and 2005 were available for background information and are presented with explanation as Figures 5 to 7.

WP A Transcription of 1976 soil data – The distribution of the 192 auger bores transcribed is shown in Figure 8, numbered as in the original survey. Details of a total of 623 horizons (layers) have been entered in the Excel ® spreadsheet SP39_bores.xls as a number of worksheets. Three bores within square SP3998 encountered organic-rich material (Table 2).

WP B Field Soil Survey – The distribution of the new 71 auger bores completed during this survey is shown in Figure 9, numbered consecutively.

WP B Soil Mapping – Figure 10 is a new soil series map for the battlefield area including a re-assessment of the 1976 soil survey. The map is also made available as an ArcView® shapefile. The full map legend is in Appendix I.

WP B Single-factor Maps – two general (soil series-based) practical assessments are presented:

- Topsoil Texture, Figure 12 – indicating where topsoils are heavy, light or in-between and thereby influencing trafficability; Figure 11 shows the directly estimated textures made at each investigation site as an alternative map.
- Soil Wetness Class, Figure 13 – indicating the probable severity and duration of waterlogging in the original undrained state, using late 20th century climatic data and the concept of Field Capacity Days.

Four maps show site-specific, classified data:

- Topsoil pH, Figure 14 – indicating whether topsoils are acidic, neutral or alkaline in reaction; all topsoils are potentially acid but soil management practices have raised pH to acceptable levels for modern farming.
- Topsoil Resistivity, Figure 15 – indicating the potential aggressivity of the topsoil to corrode buried ferrous artefacts; highly aggressive soils tend to have clay or heavy clay loam topsoils while lighter textures are less aggressive.
- Thickness of alluvium, Figure 16 – a plot of measured thickness at each bore; the map indicates not only the extent of mapped alluvium but indicates areas where it is thin or absent, as to the west of the White Moors ridge.
- Soil colour, Figure 17 – indicating where reddish topsoils occur; as these are rare in the battlefield area, the name 'Redemore' is unlikely to be derived from the red colour of the soils.

Conclusions

The southern slopes of Ambion Hill can be dismissed as the site of a 'Marsh' on evidence of the soil there, which has strong similarities to many other profiles studied across the Battlefield site, developed in thin till over Wolston Clay. The soils would have been waterlogged for long periods in winter (Soil Wetness Class IV) but would not have presented soft, marshy ground, especially in summer.

Consistently thick alluvium occurs between the White Moors ridge and the Apple Orchard Farm ridge to both the north and south of the Fenn Lanes Roman road, to support the battle location theory of Foss. On soil/geological evidence this broad valley with a restricted outlet just south of Shenton seems to be the most likely contender for the 'Marsh'. The alluvium on the western side of the White Moors ridge is thinner and patchy in occurrence and there may not have been a marsh of sufficient extent to present a problem during the battle.

Thick alluvium over peat (Site 13) occurs in the narrow valley of the Sence Brook south west of Greenhill Farm, near to the crossing of the Roman road, an alternative site of Richard's demise.

The valley or 'meadow' extending from the Sence Brook north-eastwards towards Sutton Cheney contains alluvium shown on the geology map of 1932 but omitted from the later editions of 1982 and 2005, and from some other maps derived from these. No alluvium was found in the narrow valley spur extending northwards along the eastern side of Ambion Wood, the 'tender ground' of Nichols.

The Sence Brook and its tributary in the vicinity of Greenhill Farm both contain alluvium and would have been marshy at some period. It is possible that one or both of these could have formed a sufficient, although narrow, barrier during the battle.

Foss suggested that ‘Sandeford’ lay near the Fenn Lanes road crossing of the stream feeding the valley east of White Moors, ‘a fording-place associated with sand in the geology’. This site has not been studied in any detail for evidence of sandy soil during either soil survey. That Sandeford represents ‘a ford with a sandy, gravelly bed’ is supported by the occurrence of loose sandy-gravelly soil at the base of the alluvium in the soil survey (Figures 17 & 18) that may represent the original bed of the stream.

An alternative site for Sandeford proposed by Wright and Bale is located where the Sence Brook is crossed by Fenn Lanes south west of Greenhill Farm. Coarse gravelly soils occur along the southern side of the Brook and as (recent?) overbank deposits on the north side.

There are at least four critical areas still considered to require (re-)assessment:

1. a dense network of auger bores covering the main contenders for the ‘Marsh’, in Moorey Leys Mead, Fen Meadows east of the White Moors ridge and north and south of Fenn Lanes, and Fomer Meadow to the west;
2. investigation of Sand Pit Close field as a possible link to the location of Sandeford;
3. investigation of the Sence Brook terrace south of Shenton blocking off drainage from the south; and
4. investigation into an alternative Sandeford and marshy area to the east of the Fenn Lanes crossing of the Sence Brook.

It is recommended that all auger borings and trial pits are recorded in a systematic fashion; perhaps a system of recording similar to the soil survey of 2005–06 would be suitable.

It may be possible to correlate the corrosion of buried ferrous artefacts with the topsoil resistivity map produced for part of the battlefield area. A majority of the soils with clayey and medium loamy textures are classed as potentially highly aggressive. All topsoils are potentially acid but have been considerably altered by lime applications in modern times. Although acidity is an important contributory factor to corrosion potential, measured topsoil pH is not considered a useful tool in distinguishing spatial distribution over such a long period of time.

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INTRODUCTION

The National Soil Resources Institute (NSRI) of Cranfield University at Silsoe, Bedfordshire, was commissioned by The Battlefields Trust to provide soil information and advice for the Bosworth Field battlefield site, with particular reference to the possibility of Ambion Wood being the location of the 'Marsh' or 'Morass' (as indicated by Hutton, 1813 and Williams, 1975) and to the location of the 'Marsh' elsewhere in the district (*e.g.* Wright, 2002 and Foss, 1990 & 1998). Documents prepared by Foard (2004a; 2004b; 2005) provide a background to the current knowledge of the Battlefield and the design of larger Battlefield Project investigation.

Aims

There are four broad aims to the soil investigation:

5. to provide soil information for the Bosworth Field site from a documented survey of 1976, published in 1980;
6. to provide newly acquired soil information for areas to the north and east of the land surveyed in 1976, notably in and around Ambion Wood;
7. to provide evidence from the soils of the district to support an alternative location for the 'Marsh' (Foss, 1990 & 1998); and
8. to provide an assessment of the corrosion potential (aggressivity) of the soil towards buried ferrous artefacts, an indicator of artefact survival from 1485.

The soil and stratigraphic information would further support investigations by other researchers. Once a general assessment of the battlefield has been made, smaller areas may be targeted for a more detailed soil and palaeo-environmental appraisal which would be too time consuming to complete for the whole site.

Sources of information

The main sources of published information are three versions of the geology map of the British Geological Survey (BGS 1932, paper; BGS 1982, paper and digital; BGS 2005, digital) and a soil map for the south-western part of the Battlefield, sheet SP29/39 Nuneaton (Whitfield and Beard, 1980). A run of panchromatic aerial photographs commissioned for the Nuneaton soil survey and flown in 1975 was available from the NSRI archive.

Work Programme

Three work packages (WP) were initially proposed by NSRI to achieve the Aims, namely:

Work Package A
A desk study to assess previously recorded information, by transcribing soil profile descriptions from the 1976 soil survey field notebook and reviewing the map of sheet SP39 between Stoke Golding and Shenton, and digitising updated soil boundaries. This covers about 8 km^2.

Work Package B
Commission of new 1:25,000-scale soil mapping to cover areas without detailed mapping.

- square SP 4099 Ambion Wood to assess possible marsh
- square SP 4098 north Dadlington
- ½ square SK 4000S Battlefield Centre
- ½ square SK 3900S Shenton Station
- with boundary lines digitised and observations georeferenced

The field survey would include soil pH and representative electrical conductivity (EC) measurements, for which the soil needs to be at field capacity (*i.e.* re-charged with moisture).

Work Package C
For a field re-assessment of potential sites of interest in the area mapped in 1976 between Stoke Golding and Shenton, recording expert observations on alluvial and colluvial soils, soil wetness scenarios, organic/alluvial sequences, buried soils, *etc*. Liaising with Andy Howard for sites for fuller investigation.

WPs A and B were accepted and are reported on below. WP C was deferred until the results for WPs A and B were known and their usefulness reviewed. However, to be able to correlate between the 1976 mapping and the new mapping, it was considered necessary to re-visit a small number of locations in the area mapped in 1976.

METHODOLOGY

WP A – Soil Desk Study

Published soil information in the form of soil map, land use capability map and accompanying report (Whitfield and Beard, 1980) covers 200 km^2 ; 12 km^2 cover the battlefield site and its environs.

Neat copies of the original 1:10,560 field sheets and details of the auger bore investigations are stored in the NSRI archive at Silsoe. For each 1 x 1 km grid square the investigation sites are numbered from 1 to *n*, *e.g.* SP3898/1–33. Each is marked on the field sheet by a point with the bore number and brief soil profile details beside it. The notebook contains hand-written details of the soil profile in abbreviated format. Since the records were made before computerisation and the use of a standard computer-compatible soil record card, there is no set content and some records lack information that others contain. The authors, who are both retired, have been consulted about certain idiosyncrasies in content.

The data have been transcribed and entered into a series of Excel ® worksheets, with the following fields (columns) for easy integration into a GIS:

Bore_No	bores are numbered 1–*n* for each 1 x 1 km square
Easting	for georeferencing
Northing	for georeferencing
Horizon	numeric, 1 for top and 2, 3, 4 *etc*. sequentially downwards
Upper depth	of horizon/layer in cm
Lower depth	of horizon/layer in cm
Series	the soil series name in the NSRI classification scheme (see Appendix I)
Subgroup	the soil subgroup in the NSRI classification scheme in numerical format (see Appendix I)
Munsell	the soil matrix colour as a Munsell code for hue, value and chroma
Mottles	an indication of the degree of mottling and an indication of waterlogging (may be relict and not current)
Texture	text code for one of the 11 texture classes plus organic matter class, based on hand texturing (see Appendix I)
Slope	an indication of angle and shape
Drainage	an indication of drainage status – well, moderate, imperfect, poor (see Appendix I)
Geology	if noted by the surveyor
Notes	space for free text

Values for Easting and Northing were measured directly from the field map as the information was not included with the profile description in the notebook.

To gain a better understanding of the background to the soils and in preparation for the field survey, the desk study also involved study of the geological information available and stereoscopic pairs of aerial photographs.

WP B – Field Soil Survey

The survey work was carried out by an experienced soil surveyor (Rodney Burton) from the National Soil Resources Institute of Cranfield University based at Silsoe in Bedfordshire.

The whole soil profile was investigated, to include the subsoil and not just the topsoil, at investigation sites selected by the surveyor by 'reading' the landscape when in the field and not pre-determined, except for the specific objectives of the Battlefield Project. Spacing of the bores was determined by soil complexity and local soil variability. Boreholes were made by augering by hand down to a depth of about 1.2 metres where possible, using a 4-cm wide Dutch (Edelman) auger (Figure 1) and a 2.5-cm diameter gouge auger. The location of each auger bore was recorded as Ordnance Survey co-ordinates, Easting and Northing in metres, using a GPS receiver.

All soil layers (soil horizons) and depths at which changes occur were studied (Figure 2). Properties such as soil depth, texture, structure, colour and mottling, the presence of carbonate (free lime), drainage status and stones were described and recorded in accordance with the 'Soil Survey Field Handbook' (Hodgson, 1997) onto a computer-compatible record card.

Soil resistivity was investigated at 35 of the sites using a geohm and Eijkelkamp Electrical Conductivity (EC) probe (Figure 3) which was inserted into a pre-drilled 2-cm diameter borehole made by a gouge auger. Actual soil temperature was also recorded at each site using a thermometer probe. EC readings were recorded for the topsoil centred at 20 cm depth, and the upper subsoil at 35 and 45 cm depths. These were converted to values of resistivity in ohm cm at 25°C using the temperature data.

The pH of a field-moist topsoil sample was measured in a 1:1 soil:deionised water mixture using a digital field pH meter.

WP C – Field Re-assessment

Field survey was carried out as in WP B at nine sites across the alluvium and White Moors ridge.

RESULTS

WP A – Soil Desk Study

1976 Soil Map
The original soil map is presented in Figure 4 for a 3 x 4 km block (SP3796 to SP3999). Map units (polygons) are of 'soil series', the lowest level in the hierarchical classification system of the Soil Survey of England and Wales (SSEW) (*i.e.* Major Soil Group, Soil Group, Soil Subgroup, Soil Series). The key gives the map symbol and series name for each delineation. Definitions of each soil type are given in Appendix I. More information about the soils can be obtained from the book accompanying the soil maps and is not repeated here. It must be borne in mind that the original published map was designed to address mainly agricultural issues and is one interpretation of the data gathered.

Aerial Photographs
For the 1976 survey, SSEW commissioned panchromatic aerial photography of the area to be mapped, flown by Cartographical Services (Southampton) Ltd. Flying date was 6 May 1975, scale approximately 1:15,000 and the relevant print numbers are Contract 491 1019–1022. Copyright now rests with Cranfield University. The photographs were used during the original survey as an aid to drawing soil boundaries using tonal changes. They were loaned to the Project Leader for scanning and for a digital copy to be retained for use in the Battlefields Project.

Geology
Three versions of existing geological mapping were available for background information:

1. a paper Atherstone Geology Map sheet 155 at 1:63,360 scale, published 1932 (Figure 5);
2. a paper Coalville Geology Map sheet 155 at 1:50,000 scale, published 1982, and a digital version of this (Figure 6); and
3. a revised digital version of the Coalville Geology Map sheet 155, made available to the project in 2005 (Figure 7).

Solid formations: Triassic Mercia Mudstone (formerly known as Keuper Marl) underlies the whole of the district and is effectively impermeable. Along the western side of the area of interest there are narrow outcrops of sandstone. At outcrop the soils have a distinctive reddish hue of 7.5YR passing to 5YR with depth.

The glacial sequence: the 1932 BGS map did not differentiate named glacial units, with till indicated by a spread of blue and a large area of 'Brickearth' underlying the Ambion Wood hill. This map was used as a guide to mapping during the 1976 Soil Survey. The 1982 map shows a much less extensive spread of till but across the whole of the battlefield is a substrate of 'glaciolacustrine deposits', capped by 'glaciofluvial deposits'. The former are represented by clays and silty clays with a distinctive 'chocolate brown' matrix colour (7.5YR5/4), and calcareous reaction with nodules of secondary carbonate. These clays, named variously as Bosworth Clay (Douglas, 1975) or later as Wolston Clay (BGS, 2005), formed in the extensive pro-glacial Lake Harrison during the disputed Wolstonian Glaciation. By 2005 BGS separated the till into three separate members, a Middle Pleistocene Till, the reddish Thrussington Till and the yellowish brown, originally chalky, Oadby Member, each distinguished most readily by colour and stone content, reflecting the source of the material, and by position in the landscape. The glaciolacustrine deposits had been split into an undifferentiated area north-east of the Sence Brook, and Wolston Clay south of Shenton and south-west of the Sence. An explanation of the local sequence is presented in Table 1 from a published internet source.

Table 1. The classical Wolston sequence.
(Source: http://www.staffs.ac.uk/schools/sciences/geography/staff/harrist/quatuk/quateastanglia.htm)

Lithological Unit	Environment of Deposition	Interpretation
Dunsmore Gravel	Pro-glacial sandur	Retreat of ice at the end of the cold period
Oadby Till	Sub-glacial	Complete advance of ice over the lake
Upper Wolston Clay	Lacustrine	In southern parts of the lake deltaic sequences are capped by further lacustrine sediments
Wolston Sands and Gravels	Lacustrine	Prograding deltas forming within the lake as ice advanced once more, completely filling parts of "Glacial Lake Harrison"
Lower Wolston Clay	Lacustrine	Retreat of ice, pro-glacial lake forming in front of ice
Thrussington Till	Sub-glacial	Ice advance over midlands area
Baginton-Lillington sand and gravel	Pro-glacial sandur	Advancing ice margin from north east. Onset of glaciation.

The Flandrian (post-glacial) sequence: the most notable feature is that the mapped boundaries of the deposits of alluvium changed between the 1932 and later geological maps. A branch of alluvium from the Sence Brook near Greenhill Farm extending north-eastwards past the corner of Ambion Wood towards Sutton Cheney, shown on the 1932 map, has been omitted in the later maps – this may have importance in battlefield interpretations although Foard (2004a) dismisses this 'tender ground' as '*never extensive enough to represent the marsh recorded by Virgil*'.

Transcription of 1976 soil data
The distribution of the 192 auger bores transcribed is shown in Figure 8, numbered as in the original survey. The extent of alluvium from the geology map of 2005 is also shown as an aid to location; this delineation is used as it was available for the whole area compared with the limited area of soil mapping of the same feature. Details of a total of 623 horizons (layers) have been entered in the Excel ® spreadsheet SP39_bores.xls. The spreadsheet contains a number of worksheets:

- six worksheets for the individual 1 x 1 km squares transcribed, 38 97N, 38 98, 38 99, 39 97N, 39 98 and 39 99;
- SP39, a combined worksheet for the whole area transcribed;
- SP39_Topsoil, for data extracted from the whole dataset for topsoils only, *i.e.* with ‘1’ in the horizon field and ‘0’ in the ud-upper depth field;
- SP39_Topsoil_Red, for topsoils with hue redder than 10YR in the munsell field, signifying reddish soil colour;
- KEY, with explanations of the data fields used and the entries; and
- Soil classification, an explanation of the specialist soil classification for the soil types encountered.

The dataset is best queried within a GIS to reveal the details in a spatial context.

The fieldwork was undertaken in 1976 during a long period of dry weather. This is reflected in the difficulty in augering through stony subsoils and many bores were terminated before the desirable 1.2 m depth. Some soil profiles could not be classified accurately without the lower subsoil information.

Some points of interpretation can be noted:

The 1976 soil survey made use of the 1932 geology map as background information to the soil parent materials, however the linework differs in detail in places. In the case of the alluvium, this may be because of interpretation as the alluvium thins against a gentle slope. Ploughing in modern times has disturbed the upper 25 cm and altered the characteristics of the alluvium by incorporating other subsoil material.

The soil pattern is commonly complex spatially, with notable differences in the soil characteristics over short distances. The Beccles (map symbol bW) and Ragdale (Rq) map units are especially of this nature. However, to create a soil map that can be readily interpreted for agricultural purposes, and to accommodate a reduction of the scale from 1:10,560 to 1:25,000 for publication, some simplification had been made.

Beccles and Ragdale series are typical of soils developed in ‘Chalky Boulder Clay’ from the Anglian glaciation. Beccles has clay loam topsoils and usually upper subsoils too, over clay, whereas Ragdale series is clayey throughout. The subsoils are too thin and too deeply leached to contain any chalk stones in the Bosworth Battlefield area. This interpretation is considered in the allocation of soil types on the combined soil map following the investigations in 2005–06.

The alluvium is usually underlain by drift containing stones, but in three bores within square SP3998 organic-rich material was encountered (Table 2).

Table 2. Investigation sites with organic material overlain by alluvium.

Bore No.	Easting	Northing	depth cm	texture
3998-21	439260	298485	60–80	hCL humose clay loam
3998-28	439600	298060	30–65	(h)C slightly humose clay
3998-34	439230	298615	25–45	hC humose clay

In some areas mapped by BGS as alluvium, *e.g.* the north-south spread immediately west of the White Moors ridge (around SP28499856 to 38189921 and including Fomer Meadow), no alluvium was identified (*e.g.* 1976 sites 3898-21, 3897-26, 3899-23 & -29) and the soil was considered to have developed in till over Wolston Clay or other soil parent materials. This suggests that the alluvial spread in this valley is thin and not extensive, and is not a good candidate for ‘the Marsh’.

Alluvium is mapped by BGS along the eastern edge of the White Moors ridge (Moorey Leys Mead) but is not quite as extensive on the soil map, seeming to terminate at the current stream – no alluvium was found at 1976 sites 3898-27 & -36, and 3899-25 & -28, for example.

WP B – Field Soil Survey

The distribution of the new 71 auger bores completed during this survey is shown in Figure 9, numbered consecutively. The extent of alluvium from the geology map of 2005 is also shown as an aid to location. Although much of the discussion on the geology, such as age and provenance, is academic but needs to be stated, features such as permeability, clay content (texture) and hydrology have more practical implications. From the extent of the 2005–06 survey it is useful to have a project team member who has field knowledge of the geology and soils of the district and is able to differentiate these readily on site and indicate their spatial extent on maps.

It is easier to name and describe the geology than the soils as the former falls into broader, simpler groupings. However, the geology of the district is not easy to follow without a greater density of recorded observations from auger bores. It is also not easy following the field notes from earlier surveys (1976) which were free-form rather than designed for computer input, and these 'pioneers' were sometimes unsure of what they were observing.

Soil Mapping

Although a traditional soil map, (and a geological map showing essentially the distribution of soil parent materials) is a desirable fundamental aid for any thorough investigation project, and the soil type (soil series) as presented in the published soil map for SP29/39 is useful for communication, it is understood mainly by a few soil specialists. It is the interpretation of the soil information for specific needs that is more useful.

In a re-assessment of the 1976 soil survey the linework of the map units has been retained or only slightly adjusted, but new interpretations have been placed upon the map units and combined with the new mapping (Figure 10).

Single-factor Maps

In the Battlefield context a number of single-factor assessments are considered more practical in interpreting scenarios. Hence for this project report two such maps are presented for the area of the published map and the additional new mapping:

- Topsoil Texture – indicating where topsoils are heavy, light or in-between and thereby influencing trafficability
- Soil Wetness Class – indicating the probable severity and duration of waterlogging in the original undrained state

Additionally, four maps show site-specific, classified data, where extrapolation between investigation sites is not possible:

- Topsoil pH – indicating whether topsoils are acidic, neutral or alkaline in reaction
- Topsoil Resistivity – indicating the potential aggressivity of the topsoil to corrode buried ferrous artefacts
- Thickness of alluvium – a plot of measured thickness at each bore
- Soil colour – indicating where reddish topsoils occur

Topsoil texture

To be able to ascertain texture is a fundamental element of soil characterisation. It's a field skill that can be acquired with training and consists of rubbing a sufficiently wetted soil sample between thumb and fingers to estimate the proportions of sand, silt, clay and organic matter. More costly and time-consuming laboratory procedures can produce an accurate measurement of these components. Estimates or measurements can be grouped into standard (for England and Wales) **particle-size classes** (Appendix I).

There are 11 particle-size classes, 13 if the clay loam and silty clay loam classes are split into heavy and medium, and these are further amended where organic matter content is sufficient. The classes may be grouped or simplified into six subgroups – clays, medium loams, light loams, medium silts, light silts and sands.

Hand texturing was undertaken for all horizons studied in both the 1976 and 2005–06 soil surveys. Topsoil texture is important as it is a major determinant of trafficability in a field. In wet periods clays tend to retain moisture and become sticky and impassable while sands are porous and allow the soils to drain more rapidly. Loamy and silty soils are intermediate in their behaviour. Similarly, clayey subsoils (and other textures if compacted) hold up drainage of water from above and can cause 'top-ponding'; such soils are affected by surface water problems. Sandy soils are generally permeable but can be affected by fluctuating ground water; they tend to be easier to drain providing a suitable fall can be achieved.

Topsoil texture is not necessarily reflected by geology, which usually refers to the substrate at around a metre depth. A 'simplified surface geology' map produced by Foard (2004a, Figure 8) showed the distribution of clay, alluvium (clay), mudstone (clay), sandstone and sand and gravel. This implies there is a large area with clay topsoils. The distribution of 'boulder clay' shown on the 1932 geology map (Figure 5) is a good reflection of the area covered by till, however, this cover is in most places very thin – it influences the topsoil conditions but is presumably too thin to be considered the dominant geology in the modern geological classification scheme.

Figure 11 is a graphical expression of topsoil textures estimated during the soil surveys. Each of the 263 investigation sites is allocated a texture; the abbreviations in the legend refer to standard ones given in Appendix I. These have been colour coded by texture subgroup, clays, medium loams, medium silts, light loams and humose/organics. No sands or light silts category occurs. Figure 12 is an alternative map that shows general topsoil textures grouped according to the mapped soil series. This gives a broader, simpler view but does not have the local accuracy of the directly estimated textures made at each investigation site.

The clay (C), silty clay (ZC) and heavy clay loam (HCL) textures represent the most difficult ones to work or traffic in wet weather. The maps show that these are concentrated in the vicinity of the White Moors ridge and the valley bottoms on each side, with a scatter east of Ambion Wood and south west of the Fenn Lanes crossing of the Sence Brook. Humose topsoils are only noted within the wood, as a result of litter accumulation and not of waterlogging, and at one site in Fen Meadow.

In trying to project backwards to 1485, differences from this pattern are only likely to have occurred in the alluvial valleys. Much rests on the date that peat accumulation gave way to sedimentation of clay, presumably contemporaneous with clearing of woodland and widespread cultivation that caused soil erosion. This is mostly likely to have been long prior to the late 15th century so that silty clay (ZC) or silty clay loam (ZCL) textures would have been prevalent in these tracts as now.

Soil Wetness Class

No direct measurements are readily available of the water regime of the soils at the present day let alone from five centuries ago. Schemes for allocating a Drainage Class or a Wetness Class to a soil type have been devised by the national soil survey organisation. These are briefly explained in Appendix I. In the current Wetness Class scheme (Hodgson, 1997), a soil can be allocated to a class for its drained and typical undrained state. A combination of soil factors such as texture, structure, bulk density, porosity and colour can be used to estimate the wetness regime. Colour and the degree of mottling are a quick guide to the depth and duration of waterlogging. Soils, once drained, tend to retain their original colour and mottling from their waterlogged state; this is a useful feature for predicting the situation that occurred in the past before drainage.

Climatic conditions are not uniform across the country and a soil type in different climate zones can have different Wetness Class allocations. The scheme uses the concept of duration of Field Capacity in days (FCD), when the soil is completely recharged with water, usually from late autumn until early spring. Mean agro-climatic data are presented in Table 3 for the Bosworth Battlefield for the period 1941–1970. The field capacity period lasts for 152 days on average and the annual rainfall is 664 mm. Winter wheat crops require moisture reserves equivalent to 101 mm of rainfall to draw upon during summer when evapotranspiration exceeds rainfall. Further, during a typical August there is potential transpiration of 75 mm under a short grass crop, with a maximum potential soil moisture deficit of 115 mm building up during that month.

Table 3. Late 20th Century AgroClimatic Data for Bosworth Battlefield. (Source: NSRI)

Grid Ref	ALT	AAR	LAAR	ASR	LASR	AT0	ATS	MDM WHT	MDM POT	FCD
SP390990	84	664	0.4	337	0.20	1379	2326	101	92	152

ALT	Altitude, m
AAR	Average annual rainfall, mm
LAAR	Lapse rate for average annual rainfall, mm/m
ASR	Average summer rainfall (April to September), mm
LASR	Lapse rate for summer rainfall, mm/m
ATO	Accumulated temperature above 0°C (January to June), day°
ATS	Accumulated temperature above 0°C (April to September), day°
MDM WHT	Moisture deficit for winter wheat, mm
MDM POT	Moisture deficit for potatoes, mm
FCD	Duration of field capacity, days

Figure 13 gives an assessment of the Wetness Class of the soils in their undrained state for the recent west Leicestershire climate; the majority have various degrees of wetness, even today. Clayey soils tend to be in Wetness Class IV – waterlogged for long periods in winter. In late summer, these consolidated clays would have, at worst, a muddy surface layer after heavy rain, unless occurring in a depression. Soils in Wetness Class V, severely waterlogged, would be the soft, unconsolidated alluvial clays and silty clays that received water from upstream and upslope as well as direct rainfall. For soils to fall into Wetness Class VI, permanently waterlogged, one would expect accumulation of organic matter at the soil surface from rank vegetation and the formation of peat. There is little evidence of this from the soils as they remain now, although the field name evidence suggests there might have been locally; a peaty surface may have been lost through turbary activity or oxidation after draining in the 1580s.

An August date for the battle rather than a winter one points to the extreme waterlogging of the alluvial soils as being the candidate for the critical battle event. In a comprehensive internet review of historical weather, Rowley (2006) had gathered no specific information of major weather events for the year 1485. It is stated that the 'Little Ice Age' had one of its peaks during the later 15th century and cold winters were experienced at the beginning and end of the 1480s. Bale (2006) suggested dry conditions prior to the battle ' … there having been a particularly hot, dry summer', although the primary source for this is not stated. Although many of the soils in the Battlefield area have heavy texture and slowly permeable subsoils, it would be expected that these would be passable during late August unless a severe rainfall event had occurred prior to the battle. If such an event had occurred then there may have been some documentary evidence.

Topsoil pH

All topsoils (0–25 cm) and upper subsoils (about 25–60 cm depth) are non-calcareous (contain no free lime) and are thus *potentially* acid. This would also have been the case in 1485 as 9,500 years of soil leaching had passed since the last major periglacial disturbances of the Devensian cold stage. The younger alluvium is non-calcareous as it formed from sedimentation of fine particles derived from older non-calcareous material from near the soil surface of eroding fields. In the absence of liming and chemical reactions upon drainage, and with accumulation of humus material, the soil surface would be the most acid part of the soil profile.

Some of the much older boulder clay or till was once part of the extensive spread of 'Chalky Boulder Clay' and would have been calcareous and have contained chalk stones. However, it forms a leached, thin remnant cover across the district and no chalk stones or calcareous materials were found in the field survey or mentioned in the 1976 field notes.

The Wolston Clay is calcareous beneath a thin upper leached layer, and commonly has soft nodules of secondary calcium carbonate, but these calcareous materials do not crop out at the soil surface.

Figure 14 shows the distribution of pH values recorded for topsoils in the 2005–06 soil survey, colour coded according to reaction class. Woodland soils, such as in Ambion Wood, are typically very acid due to the accumulation of litter. No particular pattern can be seen from the remaining measurements. The picture for arable and pasture is a modern one and does not relate to the situation in the 15th century. The recommended pH value for a general arable rotation is 6.5 and for pasture it is 6.0. It would be expected that farmers would have limed their fields to these values to maintain yield over the last 50 years at least.

Corrosivity Assessment

Principles: Corrosion of metal artefacts in the soil is performed by complex electro-chemical processes. The contributing soil factors include:

- Soil moisture content, wetness degree and duration
- Soil acidity
- Soil texture
- Soil aeration
- Soluble salt concentration
- Electrical resistivity

The resistivity of the soil gives a direct measurement of corrosion potential and incorporates the elements of moisture and aeration, texture, and soluble-salt concentration of soil electrolyte, essential in the corrosion process. Soils with low resistivity will encourage corrosion. Resistivity is the most singly useful assessment of soil aggressivity and corrosion risk.

Resistivity, or its inverse, electrical conductivity (EC), can be measured directly in the field using an EC probe, or by taking a soil sample and preparing a saturated paste in the laboratory for measurement there. *In situ* measurements are useful in that they measure the exact conditions as found in the field. The probe can be inserted into a pre-drilled vertical hole and measurements made at any chosen intervals down to a metre depth. Measurements were made centred upon 20, 35 and 45 cm depths where possible. Based on the principle of the four-electrode Wenner array, the electrodes are equidistantly spaced in a straight line with the two outer electrodes serving as the current, or transmission, electrodes and the two inner electrodes serving as the potential, or receiving, electrodes. The probe measures the electrical conductivity of a volume of soil, about 15 cm in diameter, around the electrodes. It is connected by four cables to an earth resistivity meter (Geohm) capable of reading resistance of 0–5000 ohm. By this means individual layers can be assessed rather than the more rapidly measured whole profile using standard geophysics techniques.

Since any of the above contributing factors can influence the result, especially moisture content, the survey was carried out during winter 2005–06 when it was expected that the soils would have returned to field capacity. Soil texture and pH were also recorded, as was the cropping and topsoil condition that would influence the porosity and bulk density (and connectivity) of the soil. Texture, especially the soil clay content will affect results. Clay, which has a large surface area has relatively more charge capacity than sand and silt and subsequently has greater ability to accommodate electrolytes. Additionally, it is typical for clay soils to retain more moisture and have greater connectivity with smaller micropores. Temperature also influences results and soil temperature was measured in the field for a correction factor to be used to standardise all results to 25°C.

To obtain the electrical conductivity of the soil, the measured resistance in ohm, R, is converted with the following formula:

$$ECb = \frac{1000 \times C \times ft}{R} \quad mS\ cm^{-1}$$

where ECb = the electrical conductivity of the soil at 25°C in mS cm^{-1}; C = an empirically determined constant dependent on the spacing and shape of the electrodes and for the EC-probe is 0.02 cm^{-1}; and ft is a temperature coefficient for conversion to a standard temperature of 25°C. Electrical conductivity can be then further converted to give a value for resistivity with the equation

$$Resistivity = \frac{1000}{ECb} \quad ohm\ cm$$

Soils with resistivities of less than 2,000 ohm cm at field capacity moisture levels should be regarded as aggressive towards buried ferrous artefacts, with fairly severe conditions indicated by values less than 1,000 ohm cm.

The scale used by NSRI for individual soil horizons and layers in corrosion work is given in Table 4.

Table 4. Definition of soil resistivity classes.

Risk Code	Resistivity Class	Soil Resistivity (Ω cm)
0	Non-corrosive (N)	>20,000
1	Mildly corrosive (S)	10,000–20,000
2	Moderately corrosive (M)	5,000–10,000
3	Corrosive (C)	3,000–5,000
4	Highly corrosive (H)	1,000–3,000
5	Very highly corrosive (V)	500–1,000
6	Extremely corrosive (E)	<500

A total of 35 shallow soil profiles were assessed for resistivity; deeper assessments were not made as most archaeological artefacts on a battlefield are said to remain within the topsoil (within about 25 cm depth). No values were obtained within Ambion Wood as the soil was too dry at the time of survey (7 Feb 2006) to obtain meaningful results. Figure 15 shows the distribution of results for the 20 cm depth as a value expressed as the mean of three direct measurements, and as a colour-coded class. The full results are presented in Table 5. As bulk density and connectivity tend to increase with depth, it is usual for resistivity values to become lower and hence soil aggressivity to increase.

Assuming there is no differential moisture influence (which there probably is, though soils were considered to be at field capacity) the resistivity generally reflects the texture of the topsoil – low for clays (*i.e.* aggressive soil) and high for coarse-textured soils such as sandy loams (*i.e.* less aggressive).

Table 5. Resistivity (Res) values in ohm cm for the 20, 35 and 45 cm depths

Easting	Northing	Bore	Topsoil Texture	Land use	Condition; Crop	Res 20 cm	Res 35 cm	Res 45 cm	Res 20/45	Series Name	Series Sym	Sub-group
440383	299835	1	HCL	pgr		5332	2535			Hallsworth	Hk	712
440288	299718	2	MCL	pgr		6850	5890	4090	1.7	Pinder	PN	711
440109	300030	3	SL	ara	established; rape	24862	18128	10497	2.4	Arrow	aO	543
439994	299974	4	MCL	ara	established; rape	2666	2722	1882	1.4	Kearby	Ky	572
440013	300291	5	HCL	ara	established; rape	2476	2476			Salwick	So	572
439980	300424	6	SL	pgr		5356	5726	4450	1.2	Astley Hall	AH	572
439955	300601	7	MCL	pgr		2760	2487	1014	2.7	Dunkeswick	Dk	711
440207	300566	8	MCL	pgr		1800	1243	1571	1.1	Dunkeswick	Dk	711
440430	300483	9	MCL	ara	loose; beans	3174	1309	1211	2.6	Spetchley	Sy	712
440681	299153	10	SL	pgr		2330				Loquiers	LU	711
440568	298961	12	SL	pgr		5432	4123	1538	3.5	Fladbury	Fa'	811
440360	299015	13	ZCL	pgr		1974	1276	1669	1.2	Fladbury	Fa'	813
440105	299071	14	ZCL	ara	stubble	2389	1243	1047	2.3	Fladbury	Fa	813
440060	299200	15	SL	ara	stubble	12455				Dunnington Heath	Db	572
439989	299322	16	MCL	ara	stubble	2823	1983	2923	1.0	Dunkeswick	Dk	711
440280	299426	17	MCL	ara	stubble	2083	1983	941	2.2	Dunkeswick	Dk	711
440431	299315	18	ZCL	pgr		1299	887	813	1.6	Fladbury	Fa	813
440662	299338	19	HCL	ara	maize stubble	2643	1680	907	2.9	Dunkeswick	Dk	711
440395	300724	20	HCL	ara	established; wwh	1492	1202	794	1.9	Whimple	wM	572
440537	300748	21	MCL	ara	established; wwh	3721	2555	2106	1.8	Whimple	wM	572
440701	300421	22	HCL	ara	loose; beans	4800	2072	566	8.5	Dunkeswick	Dk	711
440791	300340	23	HCL	ara	loose; beans	3890	2693	870	4.5	Crewe	Cg'	711
440665	300251	24	HCL	ara	loose; beans	2337	822	477	4.9	Waingate	Wgt	421
440424	300372	25	HCL	ara	loose; beans	2739	735	1278	2.1	Foggathorpe	Fp	712
439075	298912	27	HCL	sa	resown	1134	1043	856	1.3	Fladbury	Fa'	813
439056	298717	28	ZCL	pgr		1140	644	513	2.2	Fladbury	Fa	813
439016	298612	29	ZCL	pgr		1406	994	1530	0.9	Fladbury	Fa'	813
440471	298862	31	HCL	ara	established; wwh	2887	2428	2224	1.3	Dunkeswick	Dk	711
440533	298604	32	HCL	ara	established; wwh	2048	1506	1154	1.8	Kearby	Ky	572
440671	298619	33	SL	ara	established; wwh	4944	1346	1112	4.4	Kearby	Ky	572
440545	300040	62	SL	pgr		7096		3021	2.3	Loquiers	LU	711
440713	299797	64	SCL	pgr		3524	1525	1066	3.3	Dunkeswick	Dk	711
440770	299815	65	HCL	pgr		1975	676	951	2.1	Dunkeswick	Dk	711
440767	299609	66	ZCL	pgr		1349	696	965	1.4	Fladbury	Fa	813
440851	299592	67	HCL	pgr		1580		986	1.6	Hallsworth	Hk	712

Key:

Num Code	Class code	Resistivity in ohm cm	Rating class
1	N	>20,000	Non-corrosive
2	S	10,000–20,000	Slightly corrosive
3	M	5,000–10,000	Moderately corrosive
4	C	3,000–5,000	Corrosive
5	H	1,000–3,000	Highly corrosive
6	V	500–1,000	Very highly corrosive
7	E	<500	Extremely corrosive

Thickness of alluvium

As stated above, the valley bottoms would have originally accumulated peat in perennially flooded sites, fed by base flow (perennial springs) and relatively sediment-free run-off. Peat accumulation gave way to sedimentation of fine silt and clay particles, presumably contemporaneous with clearing of woodland and widespread cultivation that caused soil erosion.

To add to the sites with buried organic material in Table 2, one further site was found in a deep alluvial profile in the narrow Sence Brook valley south west of Greenhill Farm (Table 6).

Table 6. Investigation sites with organic material overlain by alluvium.

Bore No.	Easting	Northing	depth cm	texture
13	440360	299015	122–137	LHP loamy humified peat

The organic layer, textured as a loamy humified peat, indicates that some fine mineral sediment (loamy component) was incorporated into the peat, and that waterlogging was reduced in summer to allow some decomposition of the peat (humified component) during accumulation. More severe waterlogging would theoretically have led to accumulation of a more fibrous peat with preserved identifiable plant remains.

Absolute dating of the peat-alluvium boundary would place the battle within the vertical profile of the valley fill; the boundary is likely to have occurred prior to the battle as the open-field strips were already in existence, usually aligned downhill, and presumably contributed to the source of sediment. Volume of alluvial sediment would relate to catchment area and it should be possible to estimate an accumulation rate for the alluvium.

Figure 16 shows the distribution of bores where alluvium was identified. The graduated size of the symbols indicates the thickness of the alluvium. A cross indicates a bore within an area mapped as alluvium by BGS where no alluvium was identified, although it may have been fully incorporated into the disturbed topsoil through ploughing.

Soil colour

Although the more common interpretation of 'Redemore Plain' is 'the place of the reedy marsh', Hutton's interpretation as being derived '*from the colour of the soil*' can be tested following the soil survey. All soil descriptions carry a colour estimate of each horizon using the Munsell Soil Colour system, with a code for the elements of Hue, Value and Chroma. Increasingly reddish hues are coded 7.5YR, 5YR and 2.5YR whereas brown hues are designated 10YR and increasing yellow as 2.5Y and 5Y.

The recorded colours from the soil surveys show a very limited occurrence of topsoils with hue redder than 10YR (Figure 17), mainly along the western side of the study area and in the north east near Fields Farm (SK406 008). At these places the Triassic Mercia Mudstone and associated drifts crop out, but elsewhere the drift derived from the north east combined with intimate humus impart mainly brownish 10YR hues. Thus there is little to defend the idea that Redemore implies red soil here.

WP C – Field Re-assessment

Soil profiles investigated in November 2005 in Fomer Meadow, across the White Moors ridge and in Moorey Leys Mead have been assembled in a transect diagram (Figure 18) to reflect the relationship between the soil, geology and topography. Alluvium was not found at the site in Fomer Meadow (Site 60), although it does occur elsewhere; it attained 79 cm thickness (Site 28) and 74 cm (Site 30) in Moorey Leys Mead. Surface elevation values for each grid reference were provided by Glenn Foard from a Digital Terrain Model (DTM) dataset.

A typical profile of the soft silty clay alluvium is illustrated in Figure 19. The close-up view in Figure 20 shows 1). the lack of soil structure development, which would require efficient drainage and deep seasonal drying to form, and 2). the grey colouring and mottles indicating formation in anaerobic conditions. Although the soil is relatively firm now and fully ripened after drainage, it would have been of much softer consistency six centuries ago.

The study did not include the site where terraces of the Sence Brook south of Shenton (SP3852 9962) block off the left-bank tributary valleys, implied in BGS mapping of 1982 and 2005, which may have been the cause of the impounding of water upstream.

What is thought to be a thin remnant of till caps the White Moors ridge (Sites 57, 58 & 59) over Wolston Clay; in the last two sites it is a firm, stoneless mottled clay with hues of 10YR, 1.5Y and 2.5Y in the upper subsoil – it has the colour of till but lacks stones. Similar stoneless yellowish brown clays were found in slight hollows south west of where Fenn Lanes crosses the Sence Brook (Site 37 at SP40327 98827) and at Fields Farm (Site 26 SK40380 00617). They are classed as Foggathorpe Series on the soil map (Figure 10). Both coincide with small areas lacking open-field strips ascribed to 'meadow or marsh' on David Hall's (2006) draft map of land use.

The complexity of the geological deposits is shown in Figure 21 for Site 27 at SP39075 98912, in which four contrasting strata/soil parent materials occur within 1 metre depth – alluvium, over till, over reddish drift, over Wolston Clay. Two and three differing layers are common in soil profiles and create a problem in allocating the soils to one of the 725 nationally recognised soil series.

CONCLUSIONS

The southern slopes of Ambion Hill, with prominent ridge and furrow, can also be dismissed as the site of a 'Marsh' on evidence of the soil which has strong similarities to many other profiles studied across the Battlefield site, developed in thin till over Wolston Clay, all being stagnogley soils (Loquiers, Hallsworth and Dunkeswick series at Sites 17, 67, 69, 70 and 71). The soils would have been waterlogged for long periods in winter (Soil Wetness Class IV) but would not have presented soft, marshy ground, especially in summer.

Consistently thick alluvium occurs between the White Moors ridge and the Apple Orchard Farm ridge to the east, to both the north and south of the Fenn Lanes Roman road, to support the location theory of Foss (1990 and 1998). On soil/geological evidence this broad valley with a restricted outlet just south of Shenton seems to be the most likely contender for the 'Marsh'. The alluvium on the western side of the White Moors ridge is thinner and patchy in occurrence and there may not have been a marsh of sufficient extent to present a problem during the battle.

Foard (2004a) claimed that 'there are no extensive areas of alluvium beside the Sence itself and there was little potential for the formation of marshes'. Thick alluvium over peat (Site 13) occurs in the narrow valley of the Sence Brook south west of Greenhill Farm, near to the crossing of the Roman road, an alternative site of Richard's demise (Wright, 2002; Bale, 2006).

The valley (Figure 22) or 'meadow' extending from the Sence Brook north-eastwards towards Sutton Cheney contains alluvium proved to a thickness of 74 and 76 cm (Sites 18 and 66). This was shown on the geology map of 1932 but omitted from the later editions of 1982 and 2005, and from some other maps derived from these, *e.g.* Foard (2004a, Figure 8). The narrow valley spur extending northwards along the eastern side of Ambion Wood (Figure 23), the 'tender ground' of Nichols (?), has mottled stagnogley soil developed in till overlying Wolston Clay but no alluvium was found. Foard (2004a) recognised these as 'a narrow meadow alongside the small stream running along the south east boundary of Ambion Wood, the area where Nichols identified the site of a small area of 'tender ground' where they claimed Richard had been killed. The tiny area of boggy ground that existed there in the 18th century is now wholly drained, but was never extensive enough to represent the marsh recorded by Virgil'.

The Sence Brook and its tributary in the vicinity of Greenhill Farm both contain alluvium and would have been marshy at some period. It is possible that one or both of these could have formed a sufficient, although narrow, barrier during the battle.

Foss (1998, p.38) suggested that 'Sandeford' lay near the road crossing of the stream feeding the valley east of White Moors and was 'a fording-place or crossing associated with sand in the geology'. This site has not been studied in any detail for evidence of sandy soil during either soil survey, although the field name of 'Sand Pit Close' from 1849 would help to support Foss's theory, as he explained. That Sandeford represents 'a ford with a sandy, gravelly bed' (Foss, 1990, quoted by Bale, 2006) is supported by the occurrence of loose sandy-gravelly soil at the base of the alluvium (Site 28 in the soil survey, Figures 17 & 18) that may represent the original bed of the stream. Foss (1998, p.38) stated that Fenn Meadows have 'pockets of running sand below the soil surface'. Foss's (1998, p.38) theory that the crossing was a decayed causeway which had impounded drainage water to cause peat accumulation is supported by his evidence of 'small quantities adjacent to Fenn Meadows'. However, the existence of peat and alluvium in Roman times is uncertain without dating evidence, and the broad valley may have then had a sandy-gravelly bed which may have been easier to cross than marshy terrain.

An alternative site for Sandeford proposed by Wright (2002) and Bale (2006) is located where the Sence Brook is crossed by Fenn Lanes south west of Greenhill Farm. Coarse gravelly soils occur along the southern side of the Brook (Site 36), represented by Waterstock Series soil type (map symbol Wtk, in Figure 10). and as (recent?) overbank deposits on the north side (Site 12).

Bale (2006) proposed that "the marsh stretched along the northern side (*sic*) of the old Roman road, from the Tweed (Sence Brook) crossing point, towards Sutton Cheney, and that its 'extent was deceptive in 1485, there having been a particularly hot, dry summer'. Based on the current geological map, Bale's marsh could perhaps have been on the *southern* side of the road, which may have been diverted to the north east at this point to avoid it. This area was outside of the remit of WP B and has not been investigated.

There are at least four critical areas still considered to require (re-)assessment:

5. a dense network of auger bores covering the main contenders for the 'Marsh', in Moorey Leys Mead, Fen Meadows east of the White Moors ridge and north and south of Fenn Lanes, and Fomer Meadow to the west;
6. investigation of Sand Pit Close field as a possible link to the location of Sandeford;
7. investigation of the Sence Brook terrace south of Shenton blocking off drainage from the south; and
8. investigation into an alternative Sandeford and marshy area to the east of the Fenn Lanes crossing of the Sence Brook.

It is recommended that all auger borings and trial pits are recorded in a systematic fashion; perhaps a system of recording similar to the soil survey of 2005–06 would be suitable. These would then be made available to all project members interested.

Because of the complexity of the geology and soil distribution, with several thin strata occurring within a metre or so depth, in places over a short range, maps of geology and soil maps presented here showing soil types, topsoil texture and soil wetness class are to be considered somewhat general approximations. Three published geology maps are shown to give quite different interpretations of the superficial deposits. More practical reliance can be made from information from individual investigation sites shown on single-factor maps or as spreadsheet datasets within a GIS.

It may be possible to correlate the corrosion of buried ferrous artefacts with the topsoil resistivity map produced for part of the battlefield area. A majority of the soils with clayey and medium loamy textures are classed as potentially highly aggressive. All topsoils are potentially acid but have been considerably altered by lime applications in modern times. Although acidity is an important contributory factor to corrosion potential, measured topsoil pH is not considered a useful tool in distinguishing spatial distribution over such a long period of time.

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APPENDIX I – Technical Details

Soils and their Properties

Soils are grouped into **soil series** which form the basic units on a soil map. A soil series consists of a narrow range of soils with similar profile characteristics formed from the same or similar geological parent material. Because of the limitations of scale and of the variation of the natural soil mantle, some soil map units contain more than one soil series. Soil series were devised by the Soil Survey of England and Wales (SSEW, and now part of NSRI) and are used nationally. They are identified by the properties and arrangement of distinct layers, or **horizons**, down the soil profile. The properties used to identify a soil series are physical characteristics, such as texture or stone content which are permanent or not easily altered by management, and not minor differences in soil chemistry such as nitrogen content, levels of which are more readily altered by farming practice. Soil series have broadly similar characteristics over a wide area and hence can be used for comparison.

Texture refers to the size of the individual particles that make up the soil and the proportions in which they occur. The coarsest particles are **sand**, and they give a gritty feel when aggregates that form the soil structure are wetted and broken down by rubbing between fingers and thumb. Sand can be divided into **fine**, **medium** and **coarse grades**. **Clay** particles are the finest of all and give the soil its body and stickiness. Particles intermediate in size between sand and clay are termed **silt**, which give the moist soil a silky smooth feel. The relative proportions of sand, silt and clay give a soil its textural or **particle-size class** (see diagrams). These classes can be combined into a smaller number of subgroups. A soil series is characterised by the main soil texture subgroup down the soil profile, or in the case of soils with contrasting layers, by a combination of two texture subgroups.

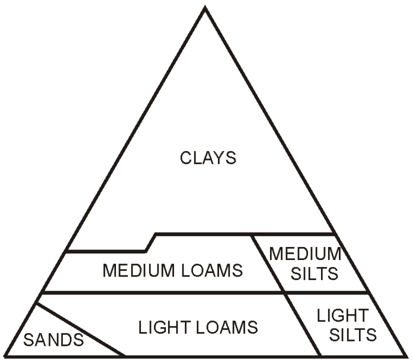
Peat soil material consists of more than 50% organic matter. It may be humified, semi-fibrous or fibrous depending on the degree of decomposition. **Loamy peat** or **sandy peat** has 50 to 35% organic matter content; **peaty loam** between 35 and 20%. Below this the mineral soil material is prefixed by **humose** down to 10% organic matter for clays and 6% organic matter for sands.

Mottles are ochreous or grey spots in a brown or grey soil matrix and can indicate degree and duration of waterlogging in a soil. In situations where effective drainage measures have been taken, mottling bears little relationship to the present soil moisture regime.

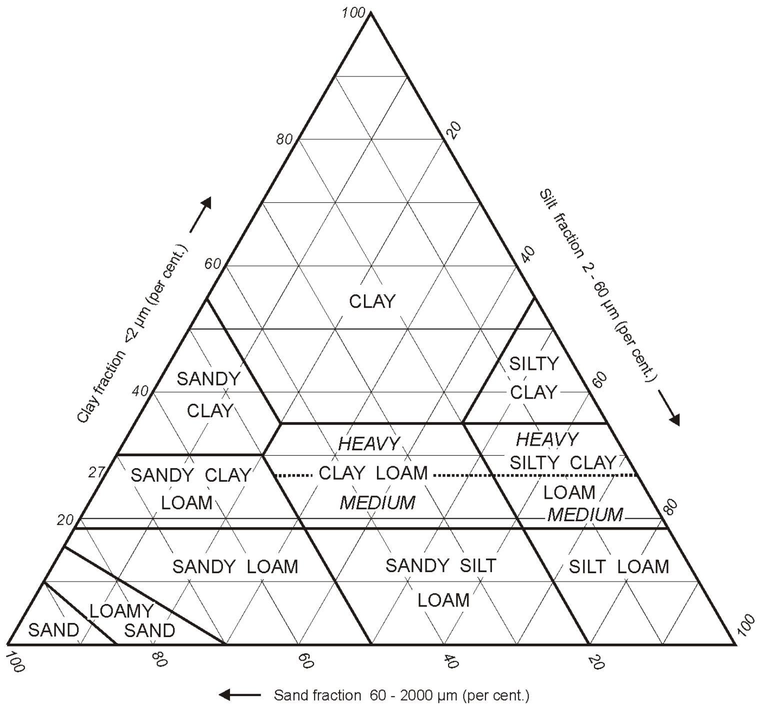
Calcium carbonate (lime) has a beneficial effect on soil structure and in maintaining a high pH. Soil material containing free carbonate is **calcareous**. It is tested in the field by applying dilute hydrochloric acid to a soil sample. Material containing more than 10% carbonate is termed **very calcareous**; that with more than 40% is **extremely calcareous**.

Texture Classification

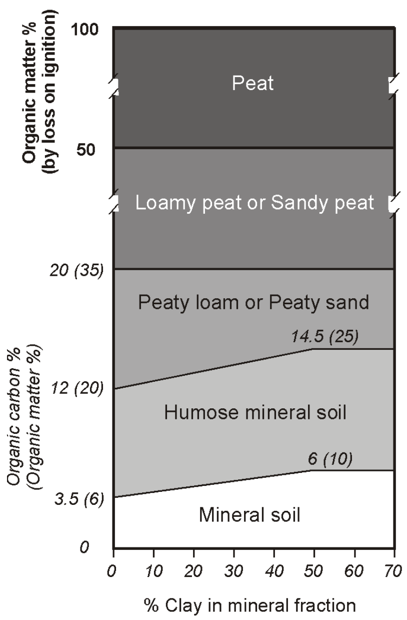
SUBGROUPS



PARTICLE-SIZE CLASSES
mineral soils, with limiting percentages of sand, silt and clay fractions



ORGANIC MATTER STATUS



Texture abbreviations

C	clay	S	sand
HCL	heavy clay loam	LS	loamy sand
MCL	medium clay loam	SL	sandy loam
ZC	silty clay	SCL	sandy clay loam
HZCL	heavy silty clay loam	SC	sandy clay
MZCL	medium silty clay loam	SZL	sandy silt loam
ZL	silt loam		
f	fine grade	m	medium grade
c	coarse grade		
HP	humified peat	MP	mesic (semi-fibrous) peat
FP	fibrous peat		
LP	loamy peat	PL	peaty loam
SP	sandy peat	PS	peaty sand
h	humose (mineral soil)		

Bosworth Soil Map Legend

for Figures 4 and 10; soil types that appeared on the 1976 map but were re-classified for the 2005–06 map are bracketed.

4. PELOSOLS *4*

4.2 Non-alcareous pelosols

4.21 Typical non-calcareous pelosols

WAINGATE	Wgt	reddish-clayey stoneless drift

4.3 Argillic pelosols

4.31 Typical argillic pelosols

WORCESTER	Wf	reddish-clayey material passing to clay or soft mudstone

5. BROWN SOILS *5*

5.4 Brown earths

5.43 Gleyic brown earths

ARROW	aO	light loamy drift with siliceous stones

5.72 Stagnogleyic argillic brown earths

ASTLEY HALL	AH	reddish-light loamy over clayey drift with siliceous stones
FLINT	Fc	reddish-medium loamy over clayey drift with siliceous stones
WHIMPLE	wM	medium loamy or medium silty drift over reddish-clayey material passing to clay or soft mudstone

5.73 Gleyic argillic brown earths

WATERSTOCK	Wtk	medium loamy drift with siliceous stones

7. SURFACE-WATER GLEY SOILS *7*

7.1 Stagnogley soils

7.11 Typical stagnogley soils

(BECCLES	bW	medium loamy over clayey chalky drift) … becomes DUNKESWICK
DUNKESWICK	Dk	medium loamy over clayey drift with siliceous stones
LOQUIERS	LU	light loamy over clayey drift with siliceous stones
RUFFORD	Rg	reddish-light loamy over clayey drift with siliceous stones
SALOP	Sh	reddish-medium loamy over clayey drift with siliceous stones

7.12 Pelo-stagnogley soils

CREWE	Cg	reddish-clayey stoneless drift
FOGGATHORPE	Fp	clayey stoneless drift
HALLSWORTH	Hk	clayey drift with siliceous stones
(RAGDALE	Rq	clayey chalky drift) … becomes HALLSWORTH
SPETCHLEY	Sy	reddish-clayey material passing to clay or soft mudstone

8. GROUND-WATER GLEY SOILS *8*

8.1 Alluvial gley soils

8.13 Pelo-alluvial gley soils

COMPTON	Ce	reddish-clayey river alluvium
FLADBURY	Fa	clayey river alluvium

8.3 Cambic gley soils

8.31 Typical cambic gley soils

QUORNDON	Qn	light loamy drift with siliceous stones

Definitions of Wetness Classes (Hodgson 1997)

Wetness Class	*Descriptive term**	*Duration of waterlogging***
I	*Rarely wet* (Well drained)	The soil profile is not wet within 70 cm depth for more than 30 days in most years.
II	*Seldom wet* (Slight seasonal waterlogging)	The soil profile is wet within 70 cm depth for 31–90 days in most years or, if there is no slowly permeable layer within 80 cm depth, it is wet within 70 cm for more than 90 days, but not wet within 40 cm depth for more than 30 days in most years.
III	*Occasionally wet* (Seasonally waterlogged)	The soil profile is wet within 70 cm depth for 91–180 days in most years or, if there is no slowly permeable layer within 80 cm depth, it is wet within 70 cm for more than 180 days, but only wet within 40 cm depth for between 31 and 90 days in most years.
IV	*Commonly wet* (Waterlogged for long periods in winter)	The soil profile is wet within 70 cm depth for more than 180 days but not within 40 cm depth for more than 210 days in most years or, if there is no slowly permeable layer within 80 cm depth, it is wet within 40 cm depth for 90–210 days in most years.
V	*Usually wet* (Severely waterlogged)	The soil profile is wet within 40 cm depth for 211–335 days in most years.
VI	*Permanently wet* (Permanently waterlogged)	The soil profile is wet within 40 cm depth for more than 335 days in most years.

* Alternative terms in brackets ( ) may be used depending on context.
** The number of days specified is not necessarily a continuous period; 'in most years' is defined as more than 10 out of 20 years.

Drainage classes

Prior to the introduction of the above scheme, Drainage Classes (Soil Survey Staff, 1960) were allocated to soil profiles, as in the 1976 survey, based on soil morphology as a means of estimating the frequency and duration during which profiles are wholly or partly saturated. The following Classes were recognised:

Drainage Class	Equivalent* Wetness Class
Excessively drained	I
Well drained	I
Moderately well drained	II & III
Imperfectly well drained	III & IV
Poorly drained	V
Very poorly drained	VI

* direct comparison between the two systems is not a recommended procedure to determine Wetness Class.

APPENDIX II – Text Figures

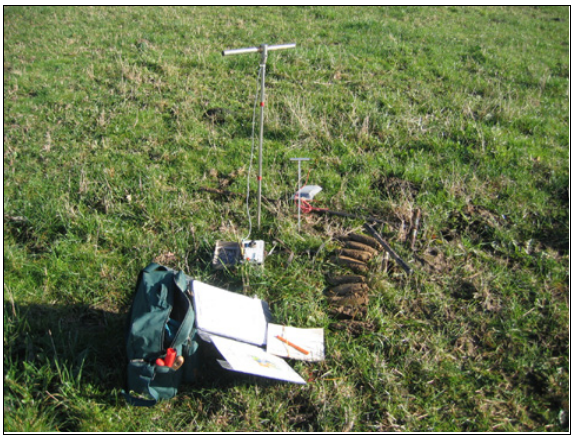


Figure 1. Soil survey equipment and investigation set-up.

Figure 2. Soil samples laid out for study, from the topsoil (left) to the subsoil at 10-cm depth intervals.

Site 64: 0–23 cm sandy clay loam; 23–52 cm mottled, slightly stony clay till; 52–98 cm mottled, stoneless silty clay glacio-lacustrine Wolston Clay, calcareous below 70 cm; 98–120 cm stoneless, reddish brown loamy medium sand, glacio-fluvial deposits, wet.

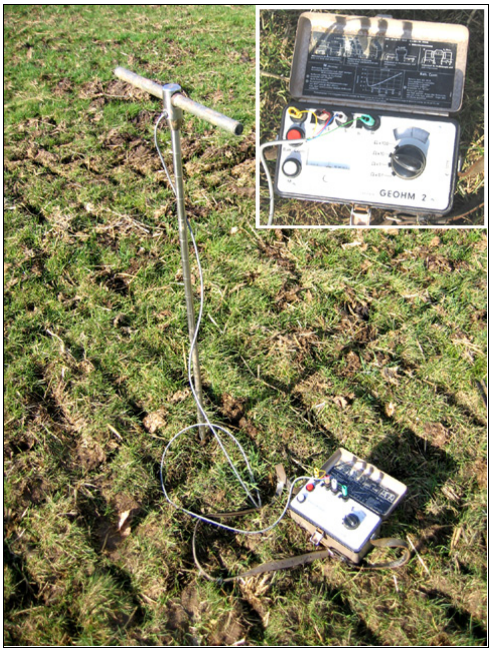


Figure 3. The EC probe inserted into the topsoil and, inset, the geohm box.

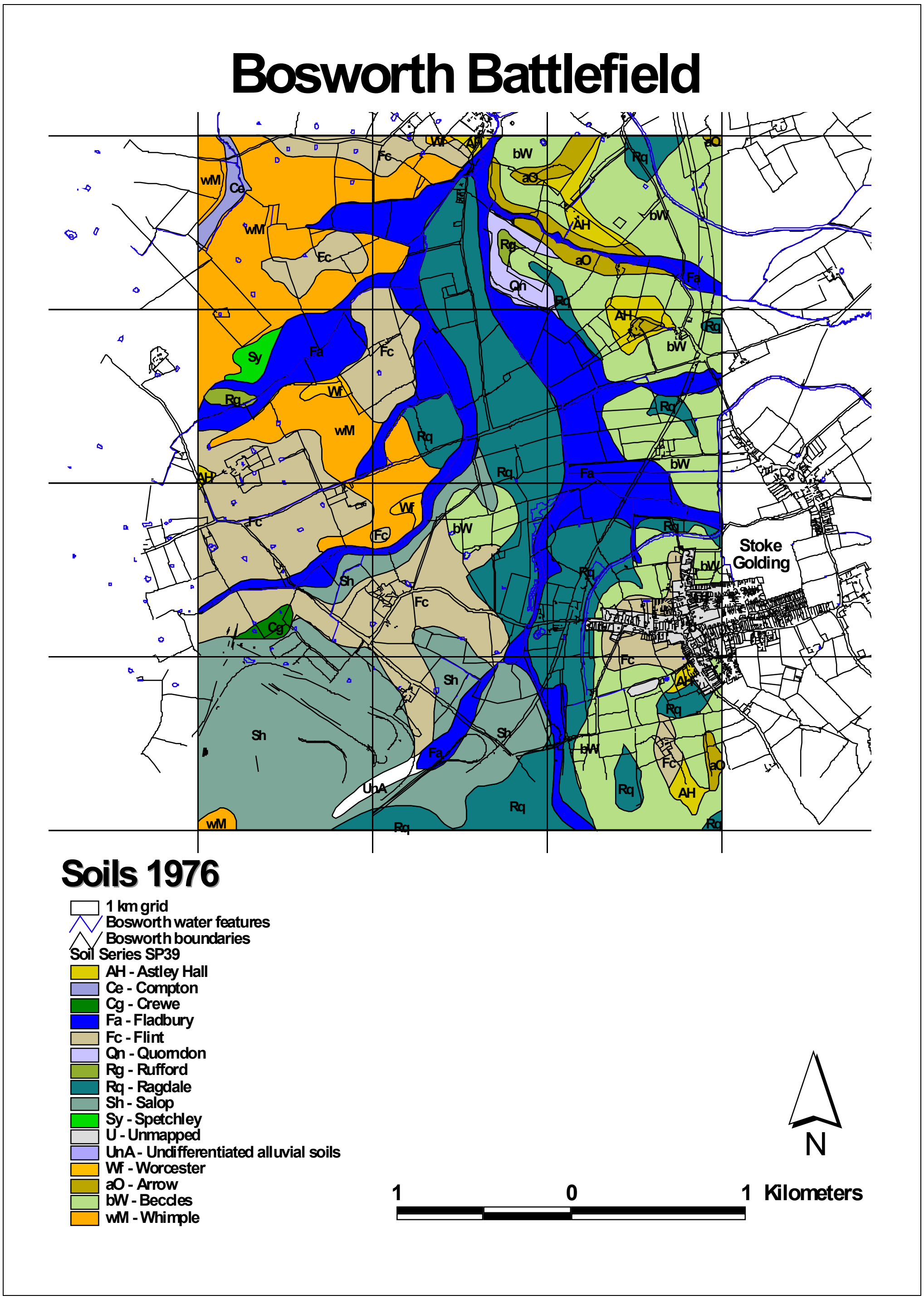


Figure 4. The digitised soil map from the 1976 soil survey. Alluvium is represented by the symbol Fa for Fladbury series, pelo-alluvial gley soils, clayey river alluvium.

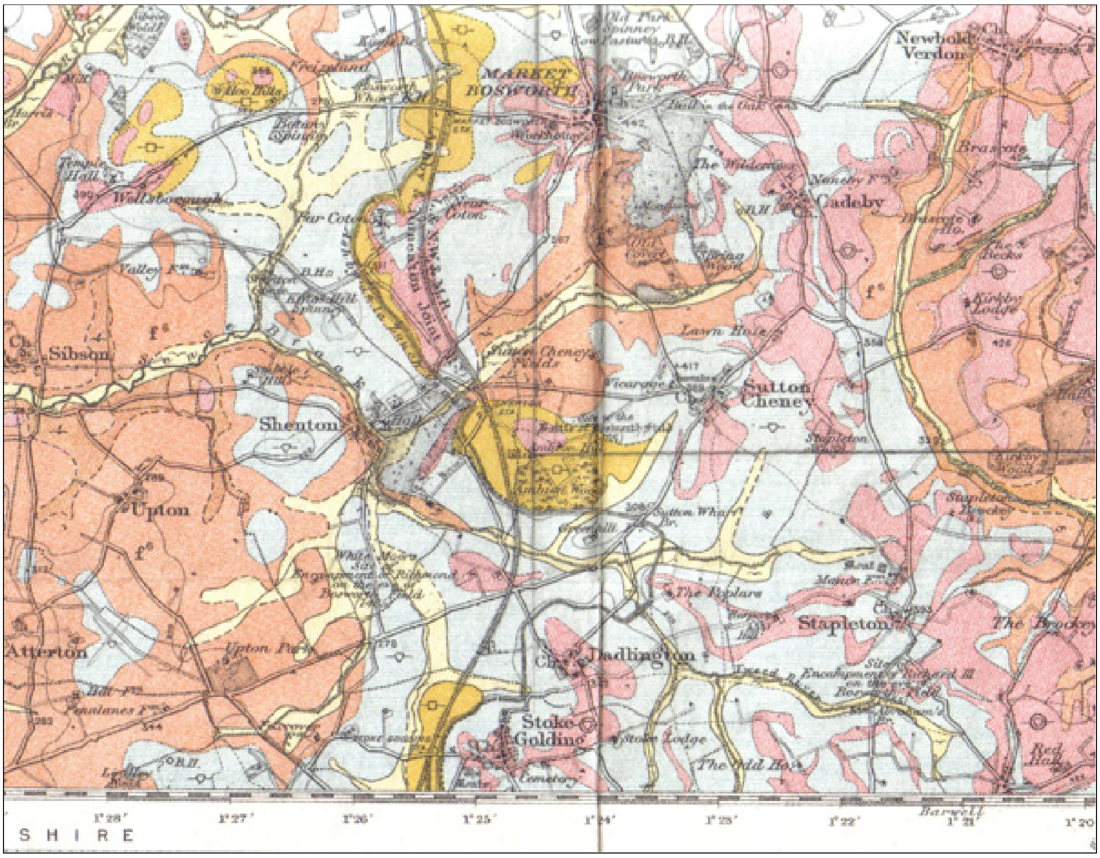


Figure 5. Scanned image of part of the Atherstone Geology Map, Sheet 155, 1932.

Key:

Post glacial
Alluvium
River terraces

Glacial
Boulder clay with
under and overlying Sand & Gravel
Brickearth

Trias, Keuper
f^6 Red Marl with Beds of Sandstone

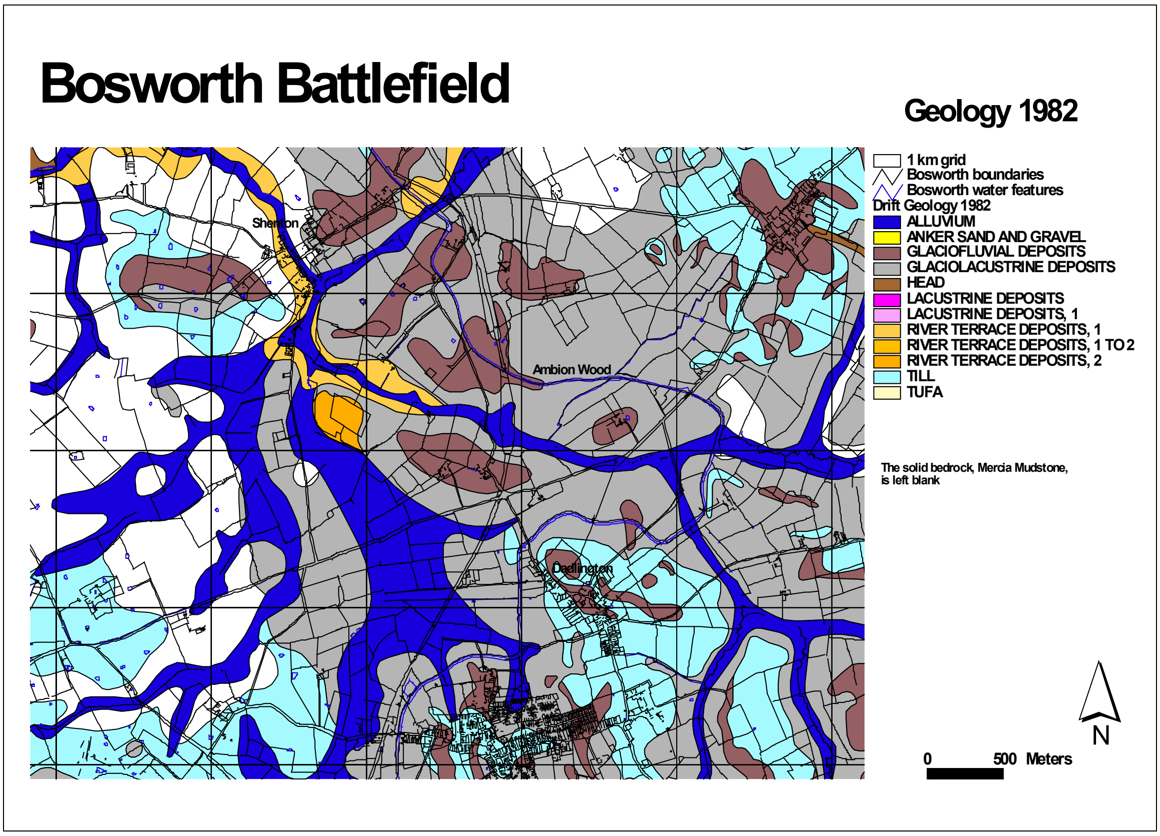


Figure 6. Coalville Geology Map sheet 155, 1982, digital version – superficial deposits.

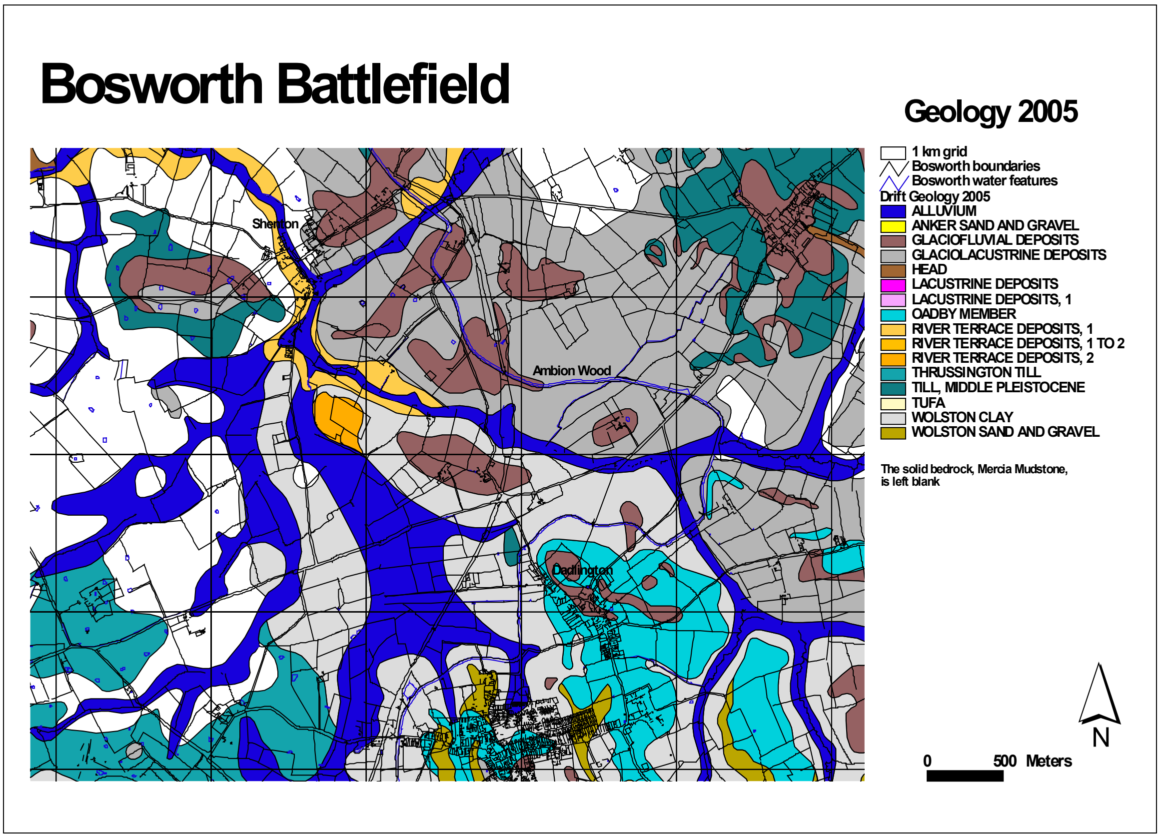


Figure 7. Coalville Geology Map sheet 155, 2005, digital version – superficial deposits.

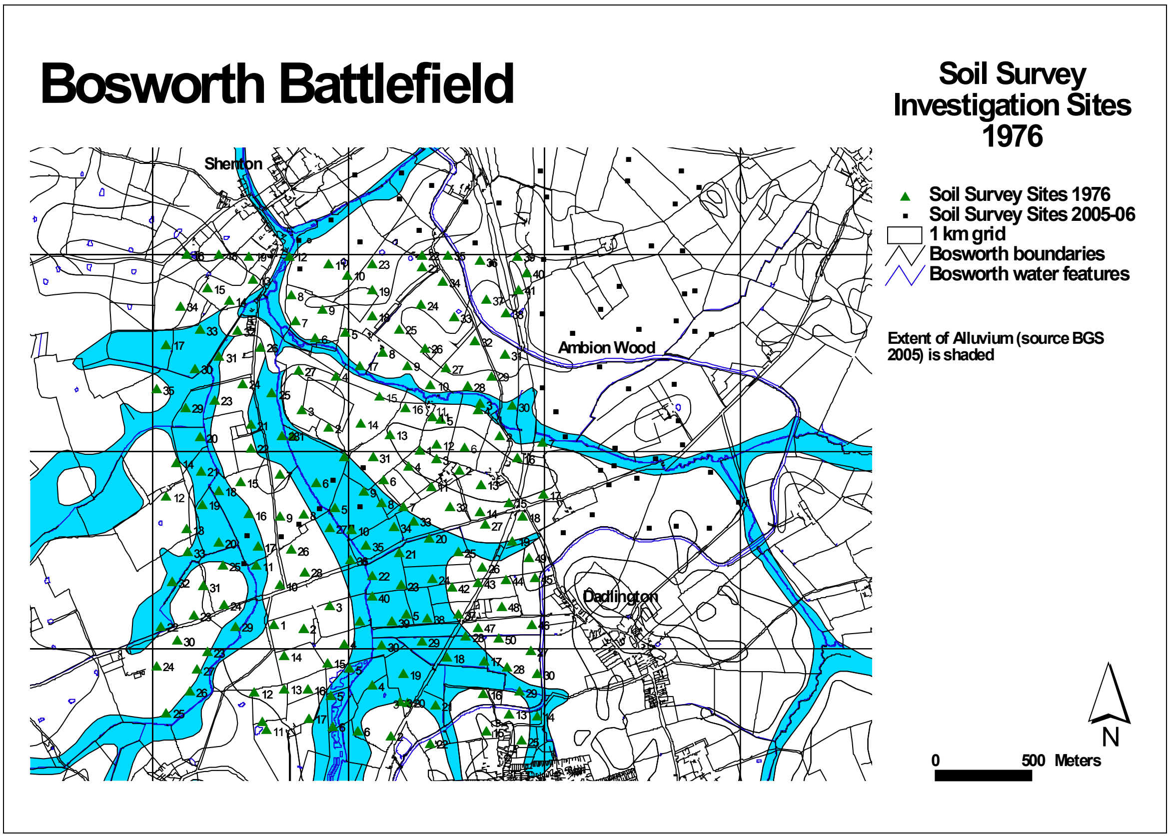


Figure 8. The distribution of the transcribed investigation sites (triangles) from the 1976 soil survey, with those of the 2005–06 survey indicated (squares).

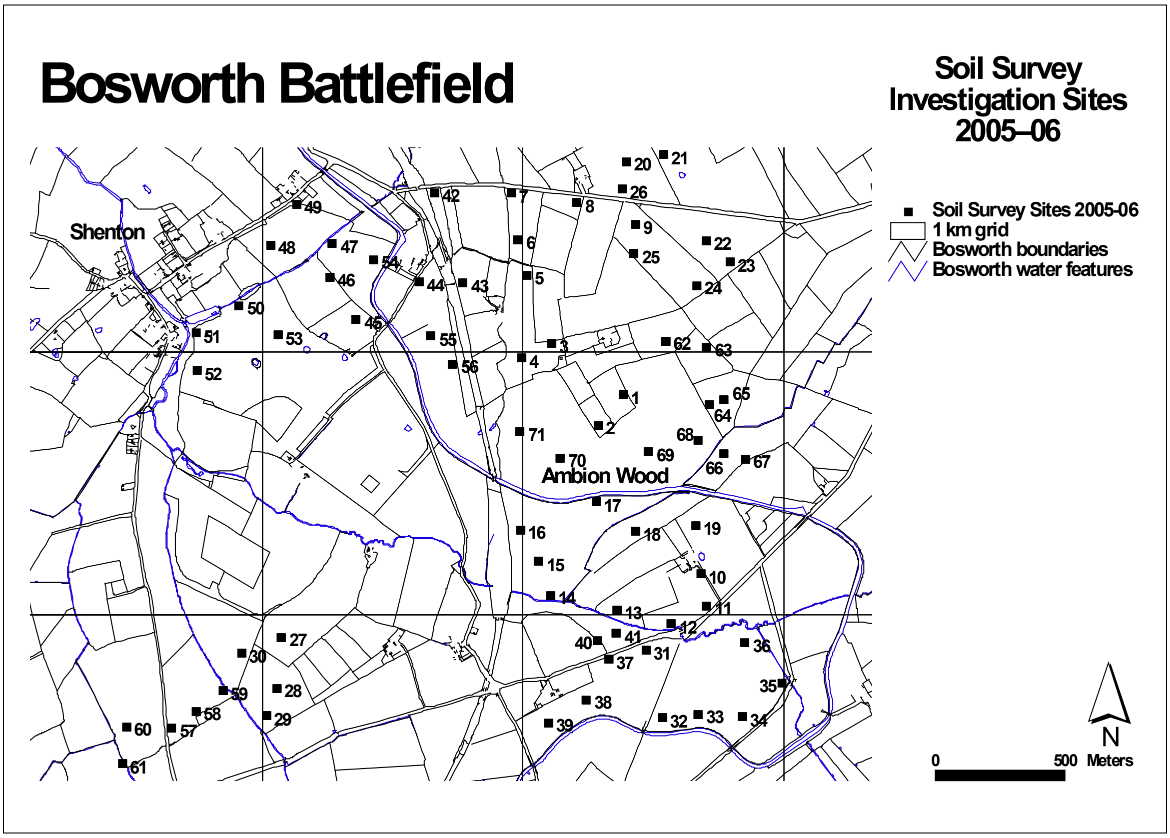


Figure 9. Location of the 71 auger bores for the WP B & C soil profile investigations.

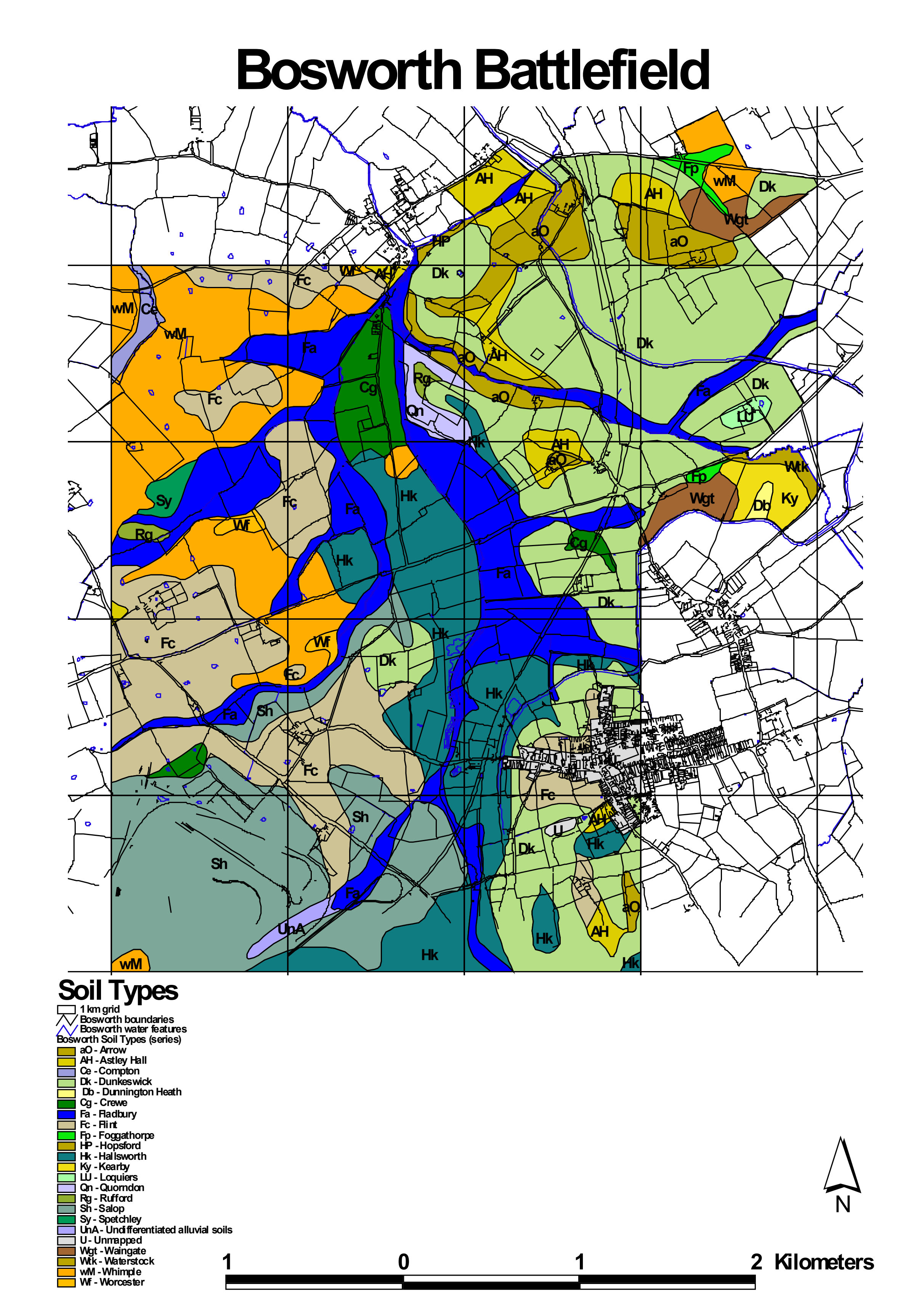


Figure 10. The digitised soil map from the 1976 and 2005–06 soil surveys. Greyish alluvium is represented by the symbol Fa for Fladbury series, pelo-alluvial gley soils, clayey river alluvium.

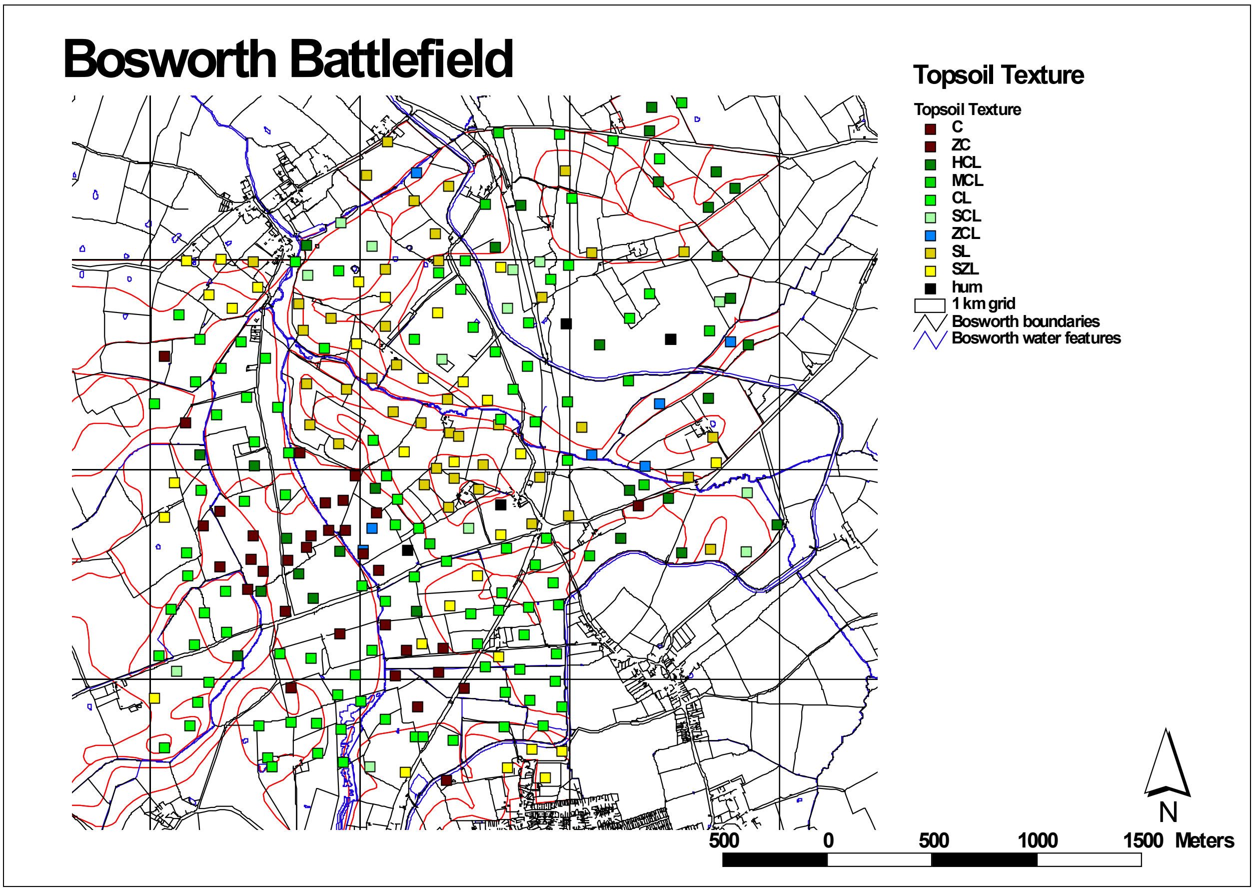


Figure 11. Distribution of site-specific topsoil texture classes for the 1976 & 2005–06 soil surveys.

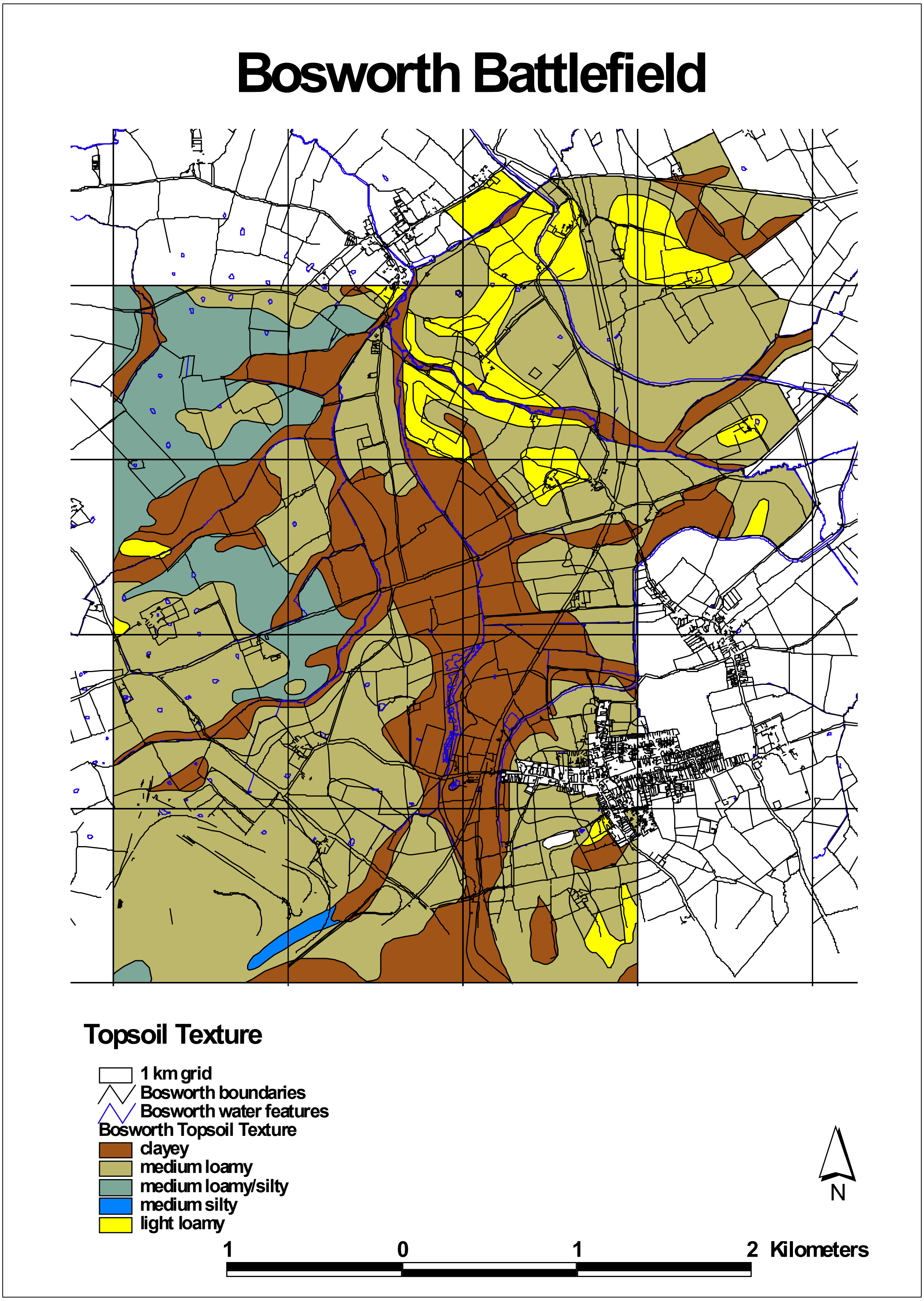


Figure 12. General topsoil texture grouped by soil series rather than individual investigation sites. See Appendix I for an explanation of the Texture Subgroups.

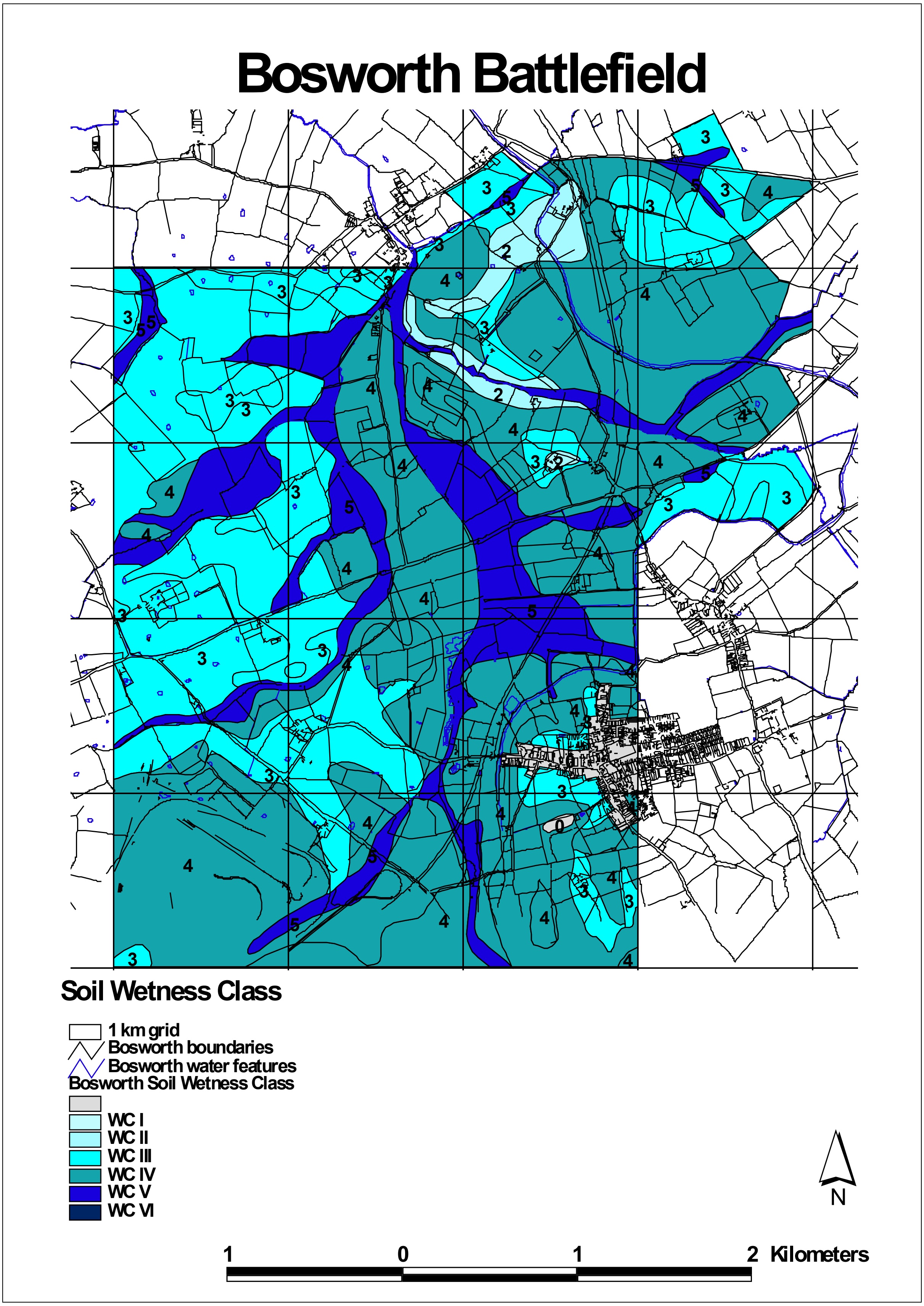


Figure 13. The soils of the soil survey classified by Soil Wetness Class (I–VI). See Appendix I for a description of the Wetness Class system.

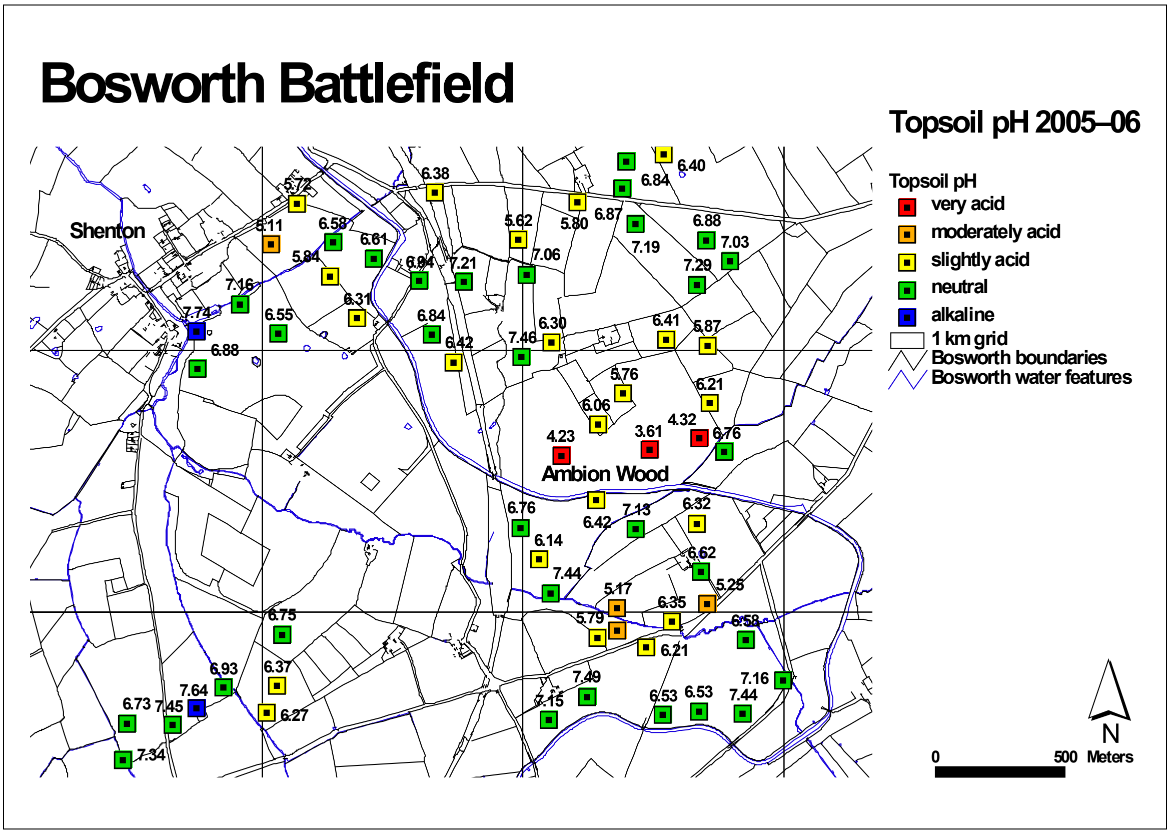


Figure 14. Distribution of measured topsoil pH values and classes for the 2005–06 soil survey.

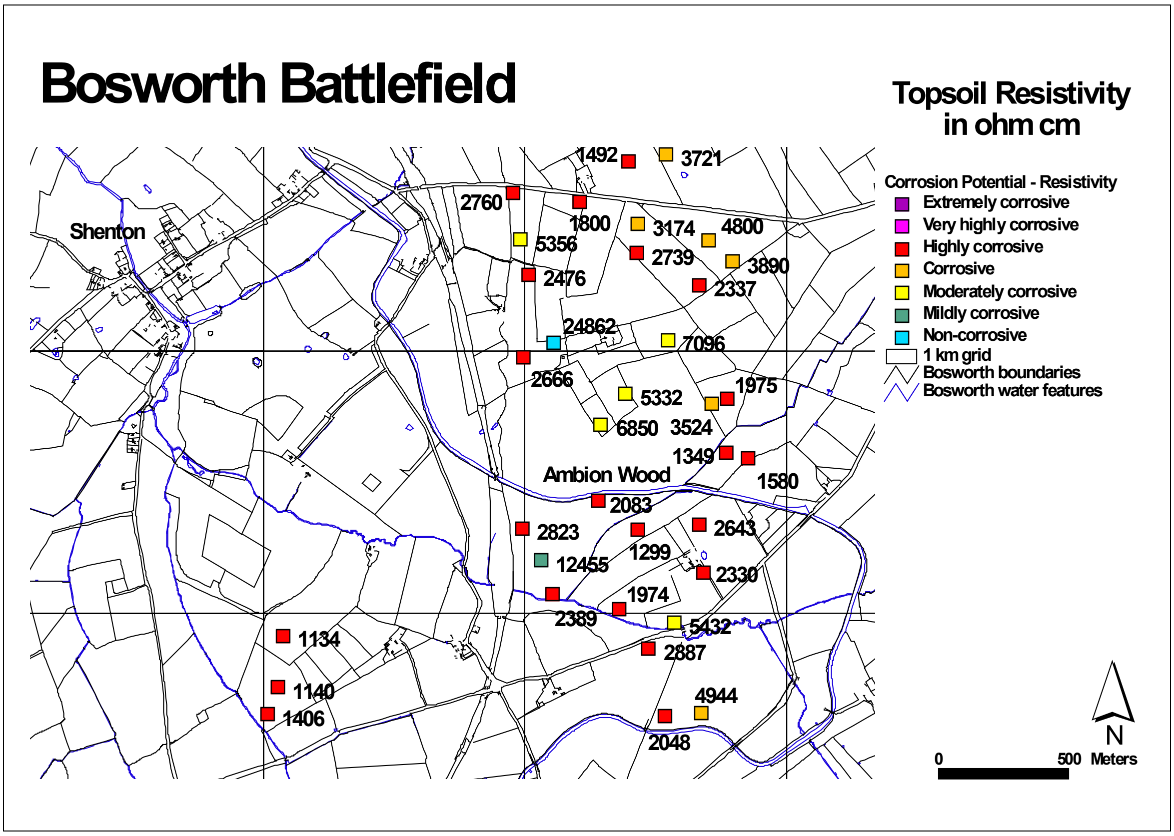


Figure 15. Distribution of Topsoil Resistivity values and classes.

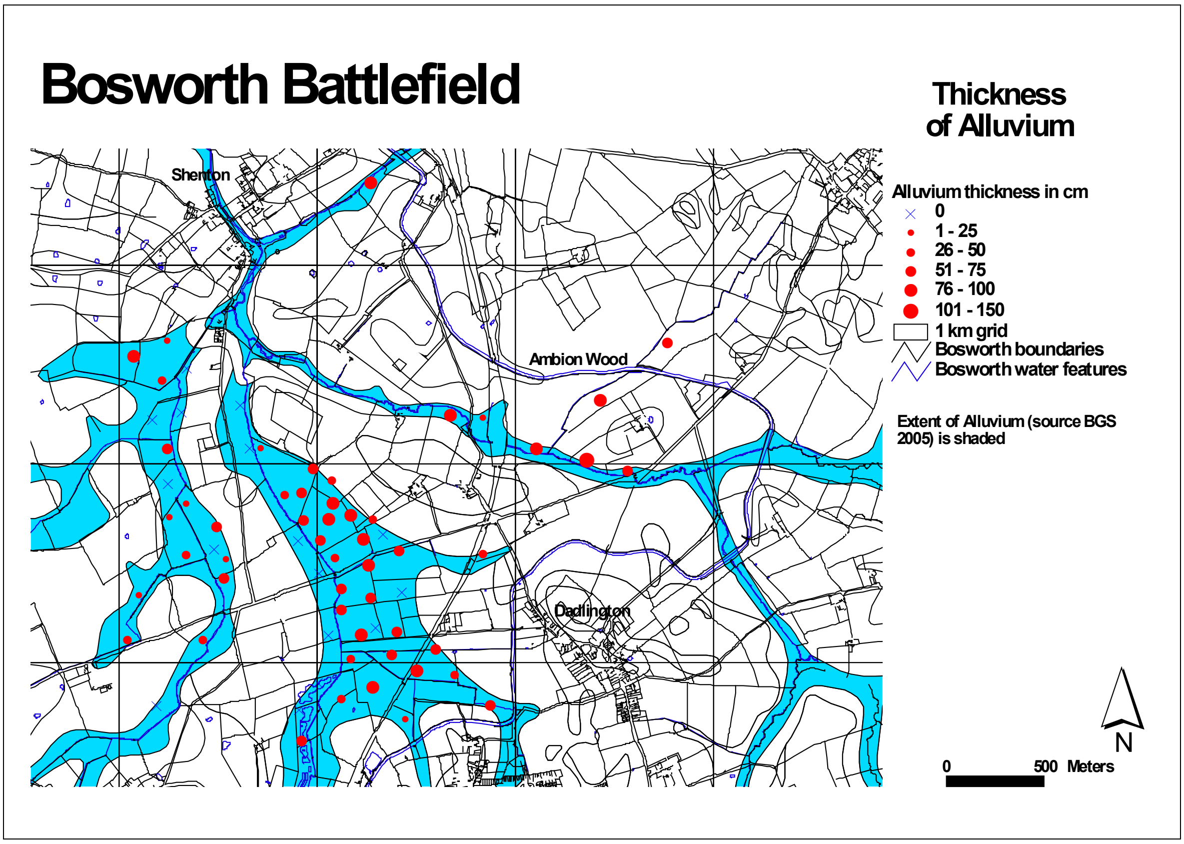


Figure 16. Distribution of measured value for the thickness of alluvium.

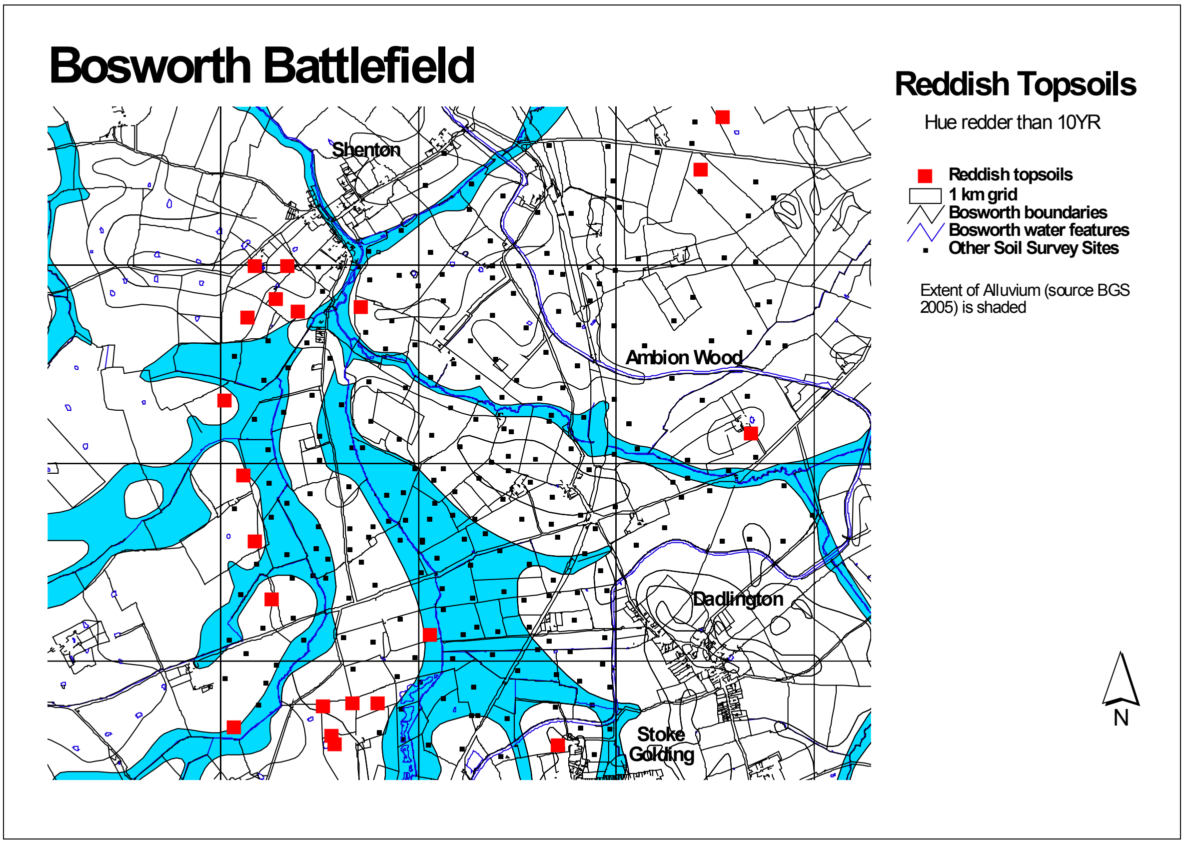


Figure 17. Distribution of auger bores with reddish topsoils, with Munsell hue redder than 10YR.

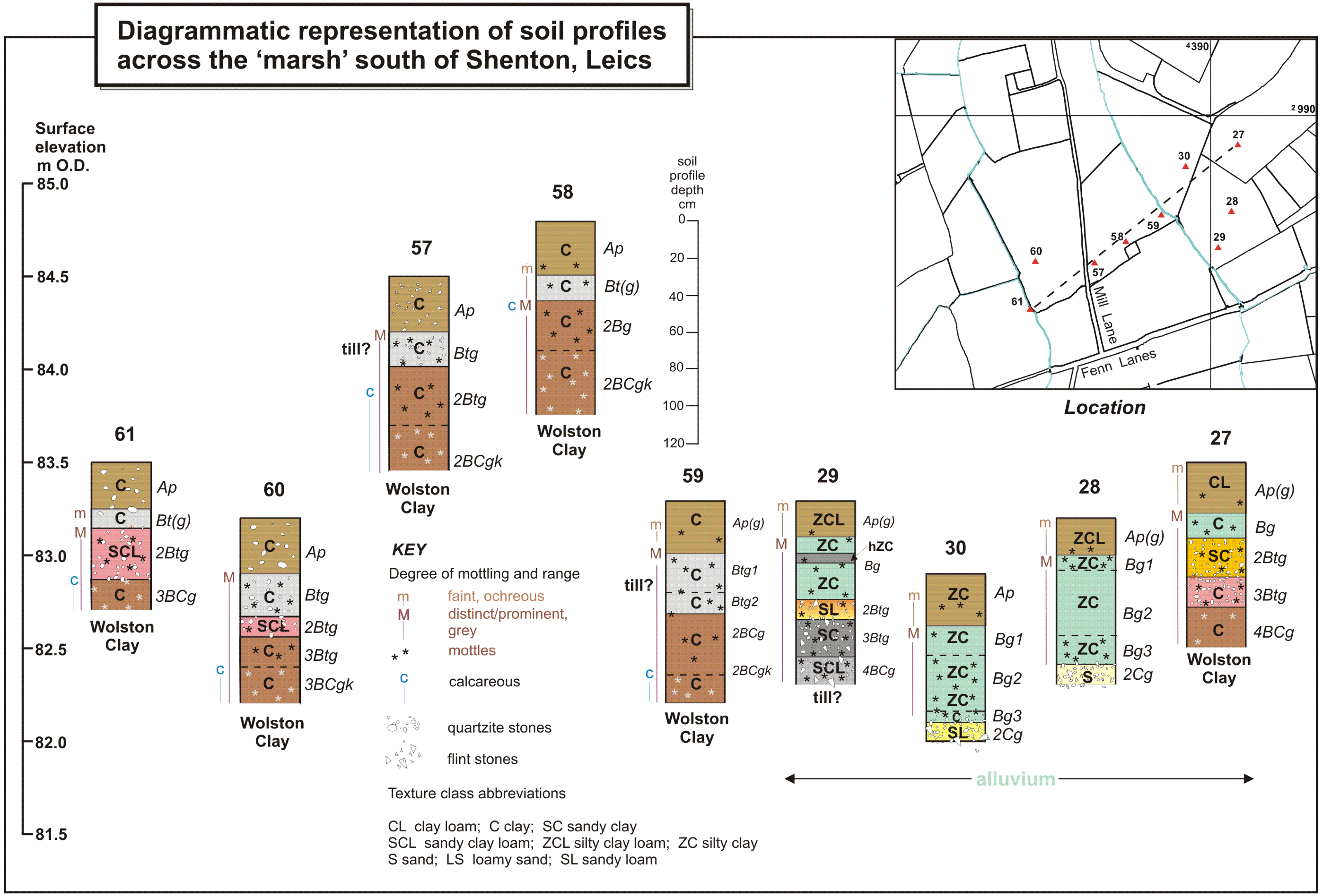


Figure 18. An assembled 'dog's leg' transect from Fomer Meadow (left) through the White Moor ridge and across Moorey Leys Mead; the surface elevations are from the Digital Terrain Model (DTM) with 10 cm vertical resolution, and the depths are from the soil survey with 3–5 cm accuracy.

Figure 19. Soil profile in alluvium.
Site 28**:** the alluvium is 79 cm thick over medium sand with stones.

Figure 20. Detail of subsoil alluvium.
At 40–50 cm depth, with a grey soil matrix and yellowish brown mottles.

Figure 21. Four parent materials within one metre depth.
Site 27: clay alluvium top, over yellowish brown sandy clay till over reddish clay stony drift, over Wolston Clay.

Figure 22. View NW from Site 67 across the narrow valley north of Greenhill Farm towards Ambion Wood and Sutton Cheney.

Figure 23. View NE from the eastern side of Ambion Wood near Site 64 towards Site 65; this valley spur, representing Nichols's 'tender ground', is a receiving site for drainage water but has soils in till, not alluvium.

NOTES