Quaternary Field Mapping: Lowland Britain

Training and Staff Development

Internal Report IR/06/099

BRITISH GEOLOGICAL SURVEY

TRAINING AND STAFF DEVELOPMENT

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Quaternary Field Mapping: Lowland Britain

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Foreword

This guide has evolved as that the Lowland Britain Quaternary Mapping Course has been run since 2000. The training course is run with the aim of providing geologists familiar with basic mapping skills, additional experience in mapping Quaternary successions and landforms in Lowland Britain.

Acknowledgements

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This course could not be run without the willing co-operation of the many landowners and farmers who continue to grant us unfettered access to their land; it is the responsibility of everyone on the course to respect this privilege.

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This report provides an outline for the Lowland Quaternary Mapping Course showing theoretical and practical approaches to Quaternary mapping. The document also outlines the sites to be visited during the course.

1 Introduction

1.1 PREAMBLE - BACKGROUND TO THE QUATERNARY

Some of you may be aware that the status of the Quaternary has been a matter of recent debate (Pillans and Naish, 2004; Gibbard *et al*., 2005; Zalasiewicz *et al*., 2006). The Quaternary is a subdivision of geological time (the Quaternary Period), which covers the last two million years up to the present day. The exact duration is a matter of debate with estimates of the onset placed at between 1.8 and 2.6 million years. The Quaternary and the previous Tertiary (Neogene) Periods together form the Cenozoic Era. The Quaternary may be divided into two epochs – the Pleistocene (around 2 Ma to 10 K years ago) and the Holocene (10 K years ago to the present day).

In the last 30 years evidence from deep sea drilling has shown that at about 25 Ma ago during the Tertiary, the earth's climate began to progressively cool and ice caps became established in high latitude polar areas. The cause of this, slow, inexorable, change is still not known with any degree of certainty but scientists believe that it may be the result of a change in the global configuration of continents and oceans, which would have altered temporal and spatial patterns of the transfer of heat and moisture around the world.

Climatic deterioration continued into the Quaternary Period, with climate between about 2.6-1.2 Ma, characterised by numerous small magnitude climatic oscillations. At about 1.2Ma, a point in the Quaternary commonly referred to as the 'Mid Pleistocene revolution', a notable climatic shift occurred with the transition to a climate change dominated by larger oscillations between temperate climates in warm periods ('interglacials') to glacial climates in cold periods ('glacials'). This has continued to the present day.

The overriding influence on such dramatic shifts in global climate, relates to the shape of the earth's orbit around the sun as this controls the amount of solar radiation received from the sun and its temporal and spatial distribution over the earth's surface. Three such orbital cycles were proposed by Milutin Milankovitch, a Serbian astrophysicist, and the largest of these occurs over 100k year cycles and this equates to the periodicity of cycles between glacial-interglacial-glacial climates.

The effects of these climatic changes in a mid-latitude region such as ours have been marked - at times the geological record reveals that climates have been as warm and arid as the Mediterranean, and only 50k years latter, as cold as the arctic. Quaternary climate change has produced a geological record dominated by sediments deposited under glacial, periglacial and temperate environmental conditions and this by its very nature, a fragmentary one. Neatly disposed deposits of alternating glacial and interglacial sediments are not the norm – partial sedimentary records that are difficult to piece together and interpret are commonplace. The repeated and extensive cold stages have included some intensive glaciations and these (especially north of the Devensian ice limit) have destroyed much of the preceding record leaving a landscape with many features of indeterminate age.

The present-day landscape and the sedimentary record beneath it are our only links with the past Quaternary processes and former environments. Observing and recording the landscape and sedimentary record in a consistent manner underpin what we do as mapping geologists. A systematic consistent approach can only aid our and (importantly), future researchers interpretation of the information portrayed on our geological maps. What should be borne in mind on those inevitable damp cold days when mapping is proving less than an attractive occupation – that the information you are collecting will provide the primary, ground–truth data for numerous geo-related applications enabling the Survey to provide considered advice on such issues as science, engineering implications, flood potential, ground stability, etc.

1.2 BACKGROUND TO THE COURSE

This course has been created directly as a result of the deliberations of the team involved in the former Quaternary Methodologies and Training project (QMT) and earlier conclusions published in Walton and Lee (2001).

Regardless of your level of mapping experience and/or Quaternary knowledge, it is hoped you will gain from this training course. The key to success or failure both for yourself and of the course will depend very much upon your active participation. It is not intended that the information flow should be solely from course leaders to course participants. For you to benefit most – and for improving the content of future courses – the course organisers are seeking open discussion and an exchange of ideas.

1.3 AIMS OF THE COURSE

The aims of this course include:

- to provide a hands-on opportunity to gain confidence in field mapping
- to familiarise individuals with some basic techniques to use when mapping the range of Quaternary and man-made deposits commonly encountered in parts of lowland southern Britain.
- to acquire an understanding of Quaternary depositional processes and landforms – developing a ‘landscape literacy’ skill
- to undertake mapping to British Geological Survey (BGS) Corporate standards
- to emphasise relevant Health and Safety issues, particularly in the use of augers.

The mapping of Quaternary deposits draws upon the disciplines of both geology and geomorphology, and is perhaps best exemplified by the studies of Quaternary terrains in the highland areas of Scotland and Wales, as well as much of northern Britain. This course is intended to complement other Quaternary-focussed training courses offered by BGS.

- Applied Quaternary Geology
- Mapping Glaciated Terrain and Glacial Sedimentology in Highland Britain
- Modern glacial landscapes – Icelandic Analogues for British Quaternary Environments
- Engineering Geology: Description and Classification of Rocks and Soils
- Clastic Sedimentology

The aspects to be covered during this course are:

- Mapping Middle Pleistocene marine and glacial deposits of lowland Britain
- Mapping deposits typical of Devensian glaciation of lowland Britain
- Recognition of periglacially affected ground, landslipped ground, river terraces and alluvial sediments and Artificial Ground

The course on this occasion is set up as three discrete modules:

- **Module 1:** East Midlands

  Periglacial features, river terraces, landslipped and Artificial ground
- **Module 2:** Vale of York

  Devensian and Holocene sequences
- **Module 3:** Norfolk

Middle Pleistocene and Holocene sequences

This course will hopefully lead to improvements in ‘standards’ and consistency of Quaternary mapping at a time when BGS is increasingly being asked to provide ‘better’ Quaternary maps. Many of BGS’s clients consider the acquisition of information about Quaternary and artificial deposits (as opposed to bedrock geology) as ‘very important’ (Walton and Lee 2001), reflecting the current pressures on builders and developers to comply with environmental legislation. The report by Foster *et al*. (1999) makes the point that Quaternary geology is important, simply because much of the UK landmass is covered by Quaternary (‘drift’) deposits. Such material is largely unconsolidated and in engineering terms often classified as ‘weak’; it forms the foundations to many buildings, waste is commonly placed by landfill into it, and the water that we drink has usually passed through it.

The course emphasis is on subdued terrain in lowland Britain, including river terraces and landslipped ground in the **East Midlands (Module 1)**, and glacial deposits in the **Vale of York (Module 2)** and **Norfolk (Module 3)**. Modules 2 and 3 provide a different slant on mapping lowland glacial deposits because the younger glacial deposits of the Vale of York are relatively well defined by glacial landforms, whereas in Norfolk these are largely absent. Landform mapping is also an important technique for delineating land-slipped ground and artificial ground, and for mapping the valleys of the large floodplains that dissect the Middle Pleistocene glacial sequences, and these topics are covered in Module 1.

1.4 RATIONAL AND APPROACH OF THIS MANUAL

Although geological surveying is commonly regarded as a ‘traditional’ function of the BGS, such a term belies the fact that the techniques of field mapping have been evolving and diversifying over the years, and have incorporated new developments in various disciplines. This manual includes much information that refers to generic approaches to field mapping; however, the methodologies presented in this instance, are focussed towards their application to mapping Lowland Quaternary deposits.

Aside from this introductory chapter, the manual contains information pertaining to individual modules that make up the course. The imminent publication of two currently internal BGS documents, the Quaternary Methodologies and Training (QMT) manual and the System for Integrated Geospatial Mapping (SIGMA) procedures will provide additional advice on approaches to field mapping and methods for capturing data.

1.5 HEALTH AND SAFETY

This course seeks to encourage you to get involved not only in the practical aspects of mapping but also discussions relating to processes, methods etc. Your views are as pertinent as those of the course leaders. Only in one respect do the course leaders have the final and definitive word and that relates specifically to the Health and Safety issues during the course.

By the time you read this you will have been provided with the Health and Safety information and asked to confirm by signature you have read and understood the objectives of the Health and Safety documentation. Please remember Health and Safety issues are both an individual and collective responsibility.

Health and Safety guidance information for fieldwork is provided by Aldiss (2003) and is available both as hard copy from BGS libraries but also as a downloadable PDF file. Further information is also available via the BGS intranet and NERC websites.

ALDISS, D T. 2003. BGS Guidance Note: a safe system of fieldwork. *British Geological Survey Report* IR/02/094, 45pp. [\\kwsan\store\Publications\Documents\IR\2002\IR02094.pdf]

BGS Intranet [http://intranet/corporate/health&safety/policies_and_guidance.htm]

NERC Website [http://www.nerc.ac.uk/healthsafety/procedures.asp]

1.6 SUMMARY

This chapter provides the background to this course and its context. You have covered:

- the reasons for providing training in mapping lowland Quaternary geology
- course aims and what you should get out of it
- topics covered and places visited during the course
- introduction to Health and Safety for the course and fieldwork in general

2 Before you start mapping

2.1 THE MAPPING PROJECT

Prior to the commencement of fieldwork, there are several aspects of the project and fieldwork that need to be discussed and undertaken. These include:

- defining the mapping project objectives
- pre-fieldwork data acquisition

2.1.1 Defining the Mapping Project Objectives

Before any mapping project gets underway in the field, there should be at least one project meeting that involves the Programme Manager, Project Manager and the Project Team. The purpose of these meetings is to clearly defining the working parameters of the mapping project, and to establish the anticipated deliverables from the team as individuals and collectively as the project itself. Detailed discussions of the issues that are typically discussed at such meetings are beyond the scope of this guide, and readers are directed towards the QMT and SIGMA manuals (see Section 1.4) for further information. In general however, discussions will focus upon the following themes:

- the purpose and objectives of this mapping project
- Health and Safety field-related issues (a project H&S document will record these)
- the domain characteristics of the mapped area – what are the known complexities of the Quaternary deposits?
- the extent/range/validity of previous work including mapping
- the availability/usefulness of Remote Sensed imagery and Digital Terrain Models
- the mapping scale (1:10,000 or 1:25,000) and the presentation scale (traditionally 1:50,000)
- the field methodologies to be employed in this instance
- the mapping intensity level needed to achieve the desired mapping resolution
- an assessment of a realistic timeframe for fieldwork and the anticipated delivery date (this should include assessing the time on the ground and the timing of this effort. It may be that the field effort is best undertaken with all of the team out at the same time. This will require judicious management and diplomacy to achieve this last objective).

Conducting *preliminary research* into previous work should lead to a better understanding of the Quaternary depositional and/or mass-movement processes that may have been operating in the field area (e.g. ice directions and lithology/provenance of erratics; river terrace sequence and chronology). In addition to assisting with the field interpretation of the deposits, pre-field literature research lends scientific direction to a project and stimulates interest in the mapping task.

Assessing the *availability and potential usefulness of various techniques* (e.g. Remote Sensed data etc). The aim here is to focus on techniques that may increase the efficiency of field mapping. Some techniques will need to be budgeted for and/or acquired well in advance of mapping (e.g. stereo or orthorectified photos). Usefully, a good deal of information is now being bought corporately so that the overhead to individual projects is not such an issue. Table 2.1 provides a general overview of the range of techniques that can be employed within Lowland Quaternary mapping, and their relative usefulness in (1) Devensian glacial terrains; (2) Middle Pleistocene glacial terrains; (3) Modern floodplains.

The conclusions of *these deliberations should be documented* from the outset as part of the evolving and recorded *project strategy*. At this stage the anticipated *project outcomes* should be clearly defined, along with the working instructions to individual team members.

2.1.2 Pre-fieldwork data acquisition

There is a wide range of data sources available to the geologist that can be used to attain a good background understanding of the field area, as well as sources of information that can be used in the field. A substantial proportion of project time should be allocated to gathering this information. Potential sources include:

Geological fieldslips, standards

Any existing fieldslips/standards/published maps of the area should be examined. If you are making a revision survey, there should be 1:10,000 or 1:10,560 scale field slips and Standards available within the BGS archives. If you are making a primary survey there will be at best only one-inch to one-mile (1:63, 360) scale geological maps available. It may be worthwhile enlarging these and printing them off onto a modern 1:10,000 scale topographic base, which may highlight any obvious errors where the geology conflicts with the topography.

Borehole logs and well records

These should always be examined prior to commencing any fieldwork (Figure 2.1). In general, site investigation boreholes will be more accurately logged than wells. Be aware that many wells were recorded relatively crudely, for example ‘100 feet of blue clay on 200 feet of brown sand’, yet when metricated these figures can look very precise ‘30.48m of blue clay on 60.96m of brown sand’. Similarly, heights of many of the older wells were estimated from the 100 ft contours on the maps – again these can look very precise when metricated.

Aerial photographs

BGS has aerial photographs for the whole of England, Scotland and Wales. The images are stored digitally and georeferenced in 1km squares so can be downloaded directly into a GIS layer, or opened simply in a photo software package. The best aerial photographs are those flown during spring or autumn when the greatest numbers of fields are bare. 1:10,000 scale photos are best, but 1:25,000 scales are generally acceptable. In areas of lowland Britain where the relief is subdued, northern East Anglia is a good example; aerial photographs have not proved to be greatly beneficial away from the coastal areas.

Digital Terrain Models (DTM)

The nationwide available Ordnance Survey DTMs (based on 10 or 5 metre contours) are useful to provide an overview of the morphology of the area and will pick up large features such as the Escrick moraine. They are however often not suitable for detailed mapping as the data is often sparse in flat areas and spot heights on roads etc have been used to generate these datasets.

Airborne radar derived DTMs such as NEXTMAP and LIDAR have proved very useful in delineating subdued features such as sand dunes and terraced topography (e.g. river terraces). However, even these very accurate DTM models will not reveal buried geological units with no topographical expression e.g. former glacial channels or help to determine what lithology comprises the feature. Data sets providing higher resolution may not necessarily be better for the task in hand as higher resolution also enhances the background ‘noise’ caused by vegetation and, in urban and industrial areas - buildings.

Terrain type	Devensian glacial	Middle Pleistocene glacial	Floodplain
PRE FIELD			
Borehole data	●●●●	●●●●	●●●●
Soil maps	●●●	●●	●●●
Literature	●●●●	●●●●	●●●●
Historical records			●●
Flood data			●●●●●
DEM	●●●	●●●	●●●
REMOTE SENSING			
Aerial photos	●●●●●	●	●●●●
Satellite images	●●●		●●
Airborne radiometrics	●●	●	●●
LIDAR / SAR	●●●●	●	●●●●
FIELD METHODS			
Landform mapping	●●●●●	●●	●●●●●
Soil and brash type	●●●	●●●●	●●●
Standard augering	●	●●●●●	●
Altimetry (thalwegs)			●●●●
Section logging	●●●	●●●	●●●
Pitting	●	●●●	●
Shell & auger boreholes	●●●●	●●●●	●●●●
Flight auger boreholes	●●●	●●●	●●●
Hollow stem auger boreholes	●●●●●	●●●●●	●●●●●
Delft system drilling	●●●●●	●●●●●	●●●●●
ANCILLIARY TECNIQUES			
Biostratigraphy	●●	●●	●●
Clast lithologies	●●●	●●●●●	●●●●●
Clay Mineralogy	●●	●●	●●
Heavy Mineral analysis	●●	●●●	
Particle size	●●●	●●●	●
Palaeoecology	●	●●	●
Radiometric dating	●●	●●●	●●●
EXPOSURE TECHNIQUES			
Sedimentary logging	●●●●●	●●●●●	●●●●●
Clast fabric	●●●	●●●	
Orientation of structures	●●●	●●●	●
Field sketches and photos	●●●●●	●●●●●	●●●●●
Lithological analysis	●●●	●●●	●
Collection of samples	●●●●	●●●●	●●
GEOPHYSICS			
EM Methods	●	●	●
High resolution seismic	●	●●	●
Ground penetrating radar	●	●	●
Resistivity	●	●●	●

Table 2.1: Suggested prioritising of mapping techniques for different types of drift deposits. The greater the number of dots, the higher the priority of the technique for use in a given type of Quaternary drift domain.

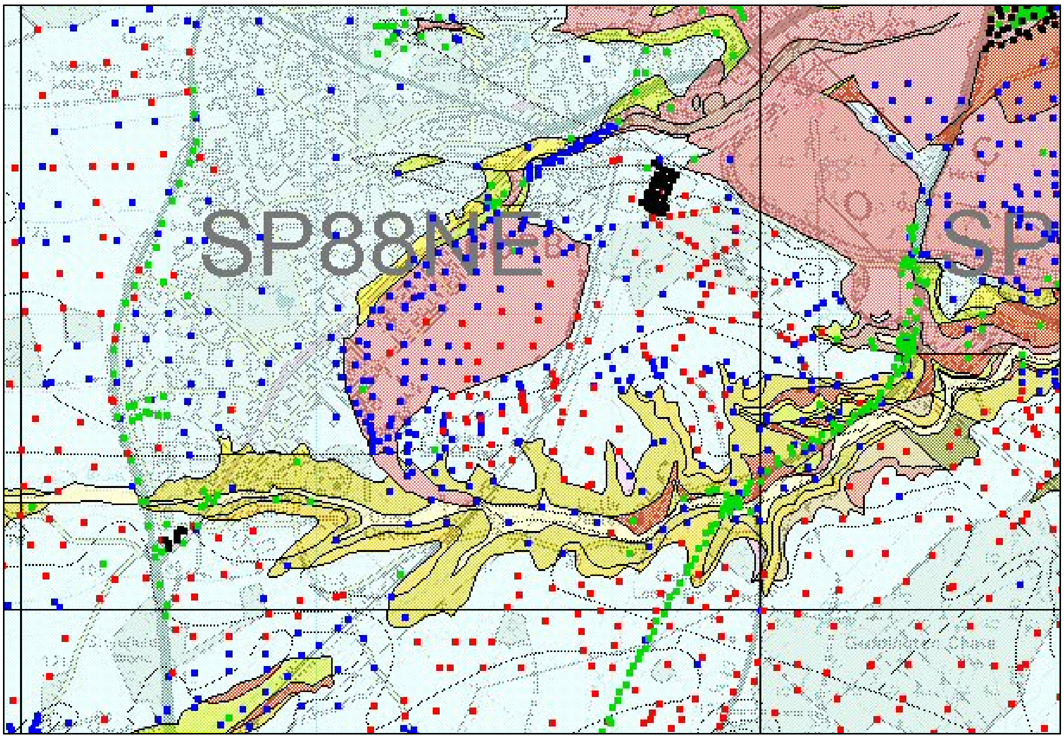


Figure 2.1: A map extract showing the distribution of boreholes around the town of Corby.

Soil Survey data

It is always worth looking to see what Soil Survey data exists for the mapping area. This might only be 1:250,000 scale coverage but in a number of areas 1:25,000 scale maps are available; associated with these maps, grid surveyed soil sampling to one metre depth may be obtainable on request and at a price from the NGRS. Care should be exercised to ensure that Soil Survey linework is not replicated to produce a 'new' geological map. Asides from the important issue of Copyright Infringement, your lines should be based on geological observation and interpretation (but see below).

Preliminary trials with the use of 're-classified' soil data, as base data for geological mapping have proved reasonably successful in parts of the Vale of York. The success was tempered by factors such as complexity of the underlying geology (especially the presence of thin "blanket deposits"), the classification scheme used by the soil surveyor and the subsequent translation of this soil schema into geological terminology.

Old OS Maps

Scans of these are available on the intranet GDI (Geoscience Data Index). These may show evidence of former land use e.g. quarrying, mining, smelting which may pose contaminated ground issues. They are also useful as they can show evidence of former hedges and ditches that have been removed or in-filled (Figure 2.2).

Other information

The BGS National Geoscience Record Centre (NGRC) holds a series of files based on individual 1:50,000 sheets. These contain a miscellany of information – some of which might prove useful but it must be treated with considered caution! The NGRC also holds the collection of BGS field notebooks. These can provide much information, but it is not always easy to locate the geographical position of sections etc., in notebooks that pre-date the National Grid.

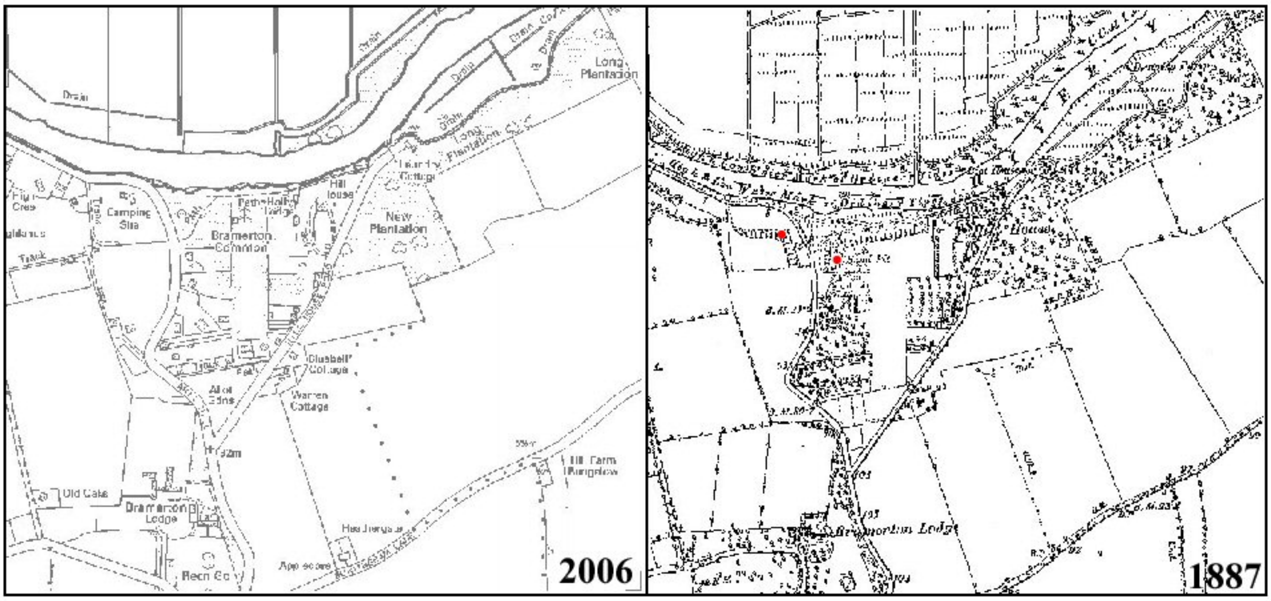


Figure 2.2: OS maps from 2006 and 1887 for the area near Bramerton, southeast of Norwich. The red dots on the 1887 map show sand pits that are no longer working and evident on the 2006 map. The old map also shows several field boundaries that have since been removed – a subtle crest line and area of worked ground may be found adjacent to these previous field boundaries.

Please ensure that any paper record material (photographs, field observations made as notes off the field map) contributing to the interpretations made on the map are deposited with the stamped and signed field map. Traditionally, the working *field map* is referred to as the *field slip*.

2.2 ACCESS TO LAND AND PARKING OF VEHICLES

For this course, land access will have already been negotiated and approved prior to your arrival. However when undertaking mapping as part of project, it is important that you secure land access from the landowners *prior to* commencing mapping. Most farmers are very reasonable, but remember that farmers are having a difficult time at present and may resent any visitors who they perceive as being from the ‘government’.

Experience has shown that it is best to call upon farmers at the time of fieldwork rather than to write to them in advance. Most geologists tend to visit the farms unannounced and simply ask for permission to carry out the survey, but some prefer to phone the farmers first to make an appointment – this might be preferable on some of the larger farms and estates, which have managers. Always have your pass and business card available. The Act of Parliament, quoted on our passes, which allows BGS staff access to any land for the purpose of making a geological survey has never been tested in court. It is advisable not to confront any difficult farmers/landowners by quoting this Act to them, but you could perhaps hand them your official pass with it on. If the farmer continues to be difficult it may be easiest to withdraw gracefully if he does not own much land, but for large landowners it may be necessary to arrange for a formal letter to be sent from the Programme Manager. As a ‘trade off’ or inducement to ‘difficult’ farmers it is common practice to offer relevant extract copies from the field slips or some free borehole data in return for access permission for the survey or for more invasive methods such as drilling or trenching.

Farmers often prove useful sources of information providing an insight on the local geology as they will be able to tell you where there are unusual conditions such as particularly heavy ground, springs, gravel pits, artificial ground etc. Many farmers have had boreholes drilled for irrigation purposes, and some have had surveys for aggregate conducted on their land. A few farmers may have commissioned soil surveys of their ground. If they are prepared to let you have sight of or to copy this information it is worth pursuing.

Whilst accessing the land, the farmer should be asked about dangerous farm animals, spraying of pesticides or any matter that relates to you safely conducting the survey. If such hazards are present, farmers may restrict your access or arrange for you to visit these areas at a more convenient date. Common reasons for this may include:

- land occupied by cows, pigs and poultry which can be particularly prone to disease such a TB, swine fever and avian flu, respectively.
- dangerous animals – cows after calving or bulls
- pheasant breading and shooting
- fungal infections of root crops such as potatoes (*Phytophtora infestans*) and sugar beet (*Fusarim)* – this may result in affected fields being quarantined for several years
- spraying of pesticides or sulphuric acid on potato plants

Guidance on working around livestock and pesticides can be found at the following two websites and within the BGS safe fieldworking procedures.

- DEFRA www.defra.gov.uk/animalh/animindx.htm
- PSD www.pesticides.gov.uk/home.asp.
- ALDISS, D T. 2003. BGS Guidance Note: a safe system of fieldwork. *British Geological Survey Report* IR/02/094, 45pp.

Please note that following DEFRA guidance, it is now necessary for visitors to record which farms (and fields) they have visited and when – just in case there is a further National emergency like Foot and Mouth. If farmers are concerned about hygiene they may insist that boots and vehicle wheels are disinfected before and after the farm visit has been made. The most recent DEFRA guidance (summer 2003) puts the onus on farmers to provide disinfectant if they require visitors to use it.

With regards parking, it is best if BGS vehicles are not parked in farmyards where they may come into close contact with farm animals or farm vehicles. Drivers should always ensure that their vehicles do not obstruct field access. When parking a hired vehicle, leave some form of identification on the dashboard. This will enable farmers, police, etc to realise that the vehicle has not been abandoned.

2.3 SUMMARY

This chapter has covered several key elements that need to be addressed before field mapping can be started. These include:

- defining the mapping project objectives and methodologies, including your own deliverables.
- the availability and appropriateness of different types of data that can be used to enhance geological mapping
- dealing with landowners and farmers, land access and parking of vehicles

3 Field observations and data recording

Within Chapter 2, those procedures that need to be implemented before geological mapping is undertaken were outlined. This chapter provides guidance for mapping lowland Quaternary deposits. By the end of this chapter, you should have a better understanding of:

- the basic principles of mapping Quaternary (superficial) deposits
- representing geological units on a map
- what does a geological line on a map imply?
- accurate positioning
- field techniques for mapping lowland Quaternary deposits
- map data compilation in the field and fair drawn map production in the office

3.1 BASIC PRINCIPLES OF MAPPING QUATERNARY (SUPERFICIAL) DEPOSITS

Geological mapping inevitably involves many uncertainties, some of which will not be determined even after the completion of the map-making process. Starting from a base of information gathered during the project-planning phase, the proven methodology (not exclusive to Quaternary mapping) is to place reliance on what can be observed and recorded about **landform** and **lithology**.

Landform (morphology) simply relates to the shape of surface features (slopes, slope breaks) whilst lithology refers to the composition of a deposit and encompasses other elements such as colour, texture, sedimentology and fossil content.

An appreciation of both lithology and morphology helps the geologists to determine the basic building blocks of the geological map called **geological units**.

Using the landform and lithology elements, a third element – **process** (the mode of origin) – may be inferred. An understanding of the process by which a geological unit was formed is in most instances *essential* to superficial mapping. If geological processes are known and understood, this insight enables the geologist to more confidently establish the spatial and temporal associations and complexities between individual sediments and their respective morphological elements

In the early stages of mapping, the emphasis will be placed on observation:

- lithological descriptions at specific points (e.g. exposures, auger holes)
- recording landforms by means of form lines as interpretation of the process(es) responsible for lithology and landform evolves.

This mapping rationale and the BGS cartographic method of recording these qualifiers on the field map are shown in Figures 3.1 and 3.2, respectively.

The combination of landform, lithology and process leads to *interpreted* **morpho-litho-genetic units**, - mappable units that provide the basis for establishing a **local stratigraphy** (Figure 3.1).

The local stratigraphy is the minimum benchmark that the geologist should be aiming for. Without this basic superposition understanding any map produced merely displays the spatial distribution of geological units present. As mapping progresses the mapper will test and repeatedly revise this local stratigraphic sequence. Providing sufficient data exists, the next stage would be to incorporate this local stratigraphic model into its wider **regional stratigraphical** context, which in turn will involve **chronology** and **lithostratigraphy.** These elements contribute to the evolving conceptual model, towards the completed map and to a 3D (lithoframe) model.

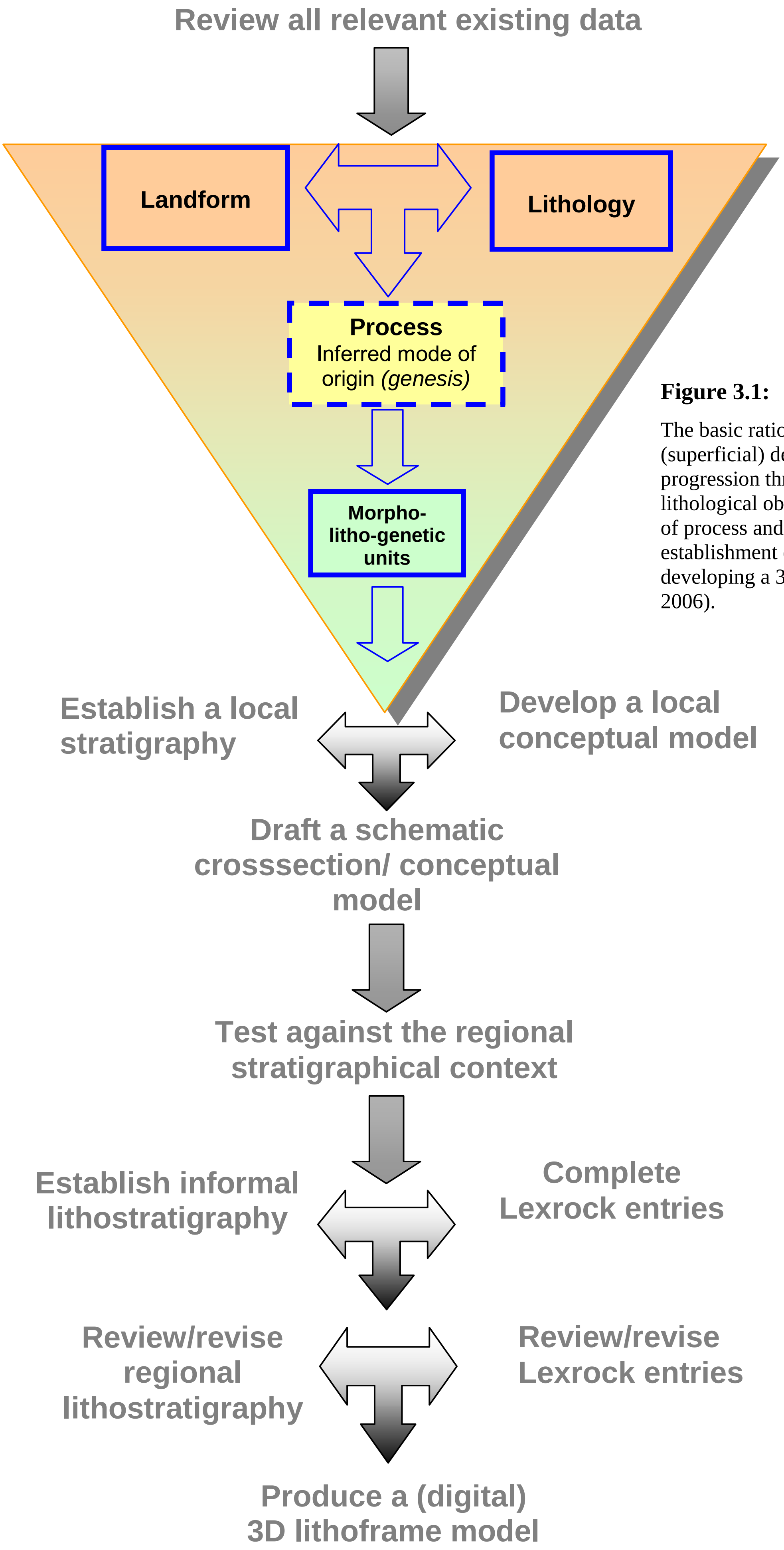
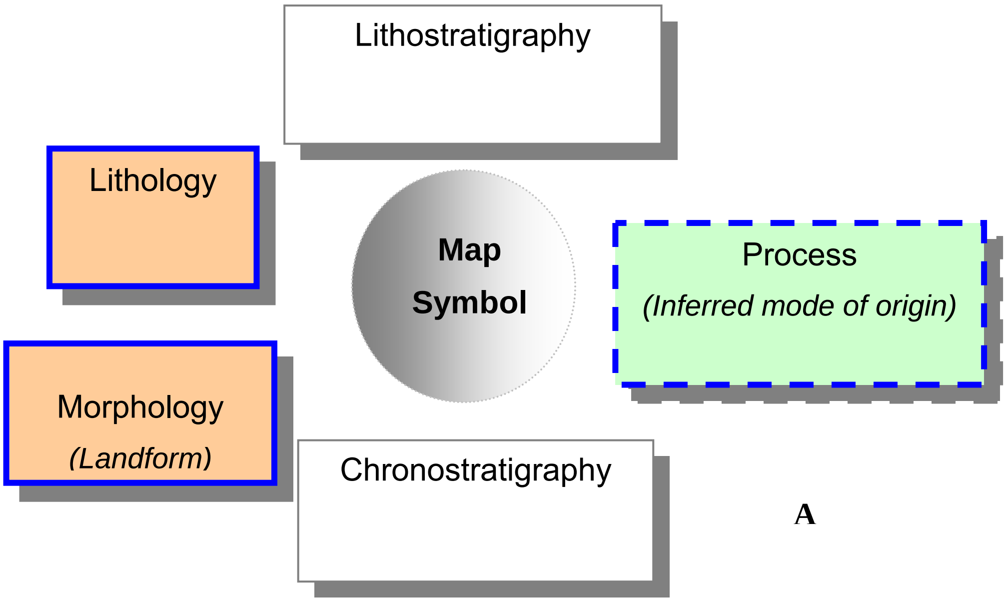


Figure 3.1:

The basic rationale for mapping Quaternary (superficial) deposits showing the progression through landform and lithological observations to the interpretation of process and genesis, leading to the establishment of a stratigraphy and ultimately developing a 3D model (from Booth and Lee, 2006).

3.2 REPRESENTING GEOLOGICAL UNITS ON A MAP

A mapped geological unit (see Section 3.1) must be defined in terms of its spatial extent (enclosed by a boundary line - see Section 3.3) Such spatially-defined geological units are in this digital age, referred to as **polygons**; within these, symbols characterizing the units as entities (e.g. till, river terrace etc) are placed. Where other qualifiers are known (lithology, associated landform stratigraphic name) these are shown as sidescript, subscript or superscript qualifiers (Figure 3.2). This symbol convention provides the reader with summarized geological information enabling an easily assimilated understanding of the *nature* of the mapped units.



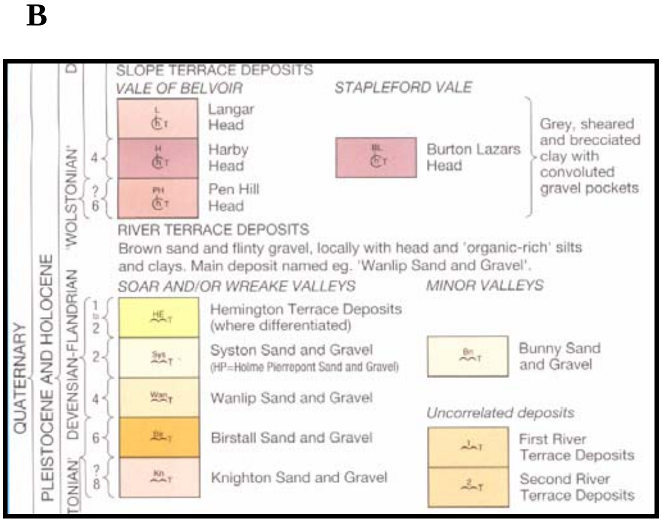


Figure 3.2:

A. The basic scheme for labelling mapped units whether morpho-litho-genetic symbols are used or formational terms are employed. Other possible attributes include sedimentological, biostratigraphical, hydrogeological and geotechnical characterization.

B. Examples of the scheme from published 1:50,000 scale geological maps

A guide to 'Basic Mapping Symbols' is currently provided by the 'Black Book' and this will be provided to as reference material you when you are about to undertake mapping as part of a project.

3.3 WHAT DOES A LINE ON A GEOLOGICAL MAP IMPLY?

A geological line on any geological map principally demarks one **geological unit** from another – effectively that the deposit at the line edge thins to a zero thickness. In reality, this definition is often let down by the geological practicalities of deciding upon the placement of the line, and cartographic limitations of drawing a line on a map since the visible representation will always appear to imply a degree of thickness. The scale of the map or section will of course determine this apparent thickness. There are several potential problems and issues that face the geologist regarding the positioning of lines, and these are outlined below:

What specifically can a geological line represent?

- A three dimensional geological boundary separating geological units.
- The 'top' and/or 'bottom' of a geological unit.
- The spatial extent of a deposit/unit = the locus of zero thickness
- A geological structure such as a fault.
- A time-related boundary – implying an event or a hiatus.

What other types of line are used in the mapping of Quaternary deposits?

Form lines may be used to define landforms as, for example, terrace outer edges and backfeatures, landslide scars, glacial meltwater channel margins and centre lines, eskers, drumlins, kettleholes. Such lines are subject to the same degree of error in placement as geological boundaries.

What types of evidence are used to position lines?

- observation of features
- slope breaks associated with features
- DEM slope analysis (NextMap)
- Stereo pair analysis of aerial photographs
- lithological observations derived from auger traverses and soil brash
- boreholes
- interpretation (best guess judgement)

How accurately are lines positioned?

Accuracy is a function of the scale of the map used, the thickness of the drawn line, the accurate drawing of the line, the accuracy of location in the field, the degree of interpolation between observations, the relative proportions of observation and inference used in determining the position of the line. For example, at 1:10,000 scale, the accumulated error will generally be ±15m (empirically determined), occasionally better and sometimes worse. At 1:25,000 scale it's probably about ±40m and at 1:50,000 scale ±75 to 80m.

Judgement

Judgement is an overriding factor when determining the existence and position of lines as, for example, in drawing a line representing gradational boundaries or uncertain boundaries. It almost goes without saying that judgement is likely to improve with experience!

Edge matching

Joining geological units across geological map boundaries can potentially lead to mismatches where the geological interpretations of fellow mapping geologists may differ from your own. Clearly, mismatches need to be addressed otherwise adjacent geological maps will not fit – something that no team effort should allow to happen. Common causes of edge matching problems are:

- the direction of map traverses across a map boundary.
- different geologists mapping to a different geological succession.
- inconsistent interpretation or definition of a particular geological unit.
- contrary interpretations (differing best guess judgements)

In the past, BGS adopted the policy of mapping a deposit where it is at least one metre thick (in some cases of convenience a one and half metre rule was applied), *however the QMT manual directs that this metre rule is abandoned.* In its place, manual directs that the project mapping team need to assess the **significance** of deposits mapped in respect of the overall purpose of the map. For example, a peat layer of 0.4 metres or less may be highly significant to an engineer assessing a site in terms of potential compressible strata. The mapping protocols adopted by the team should be recorded for users of the field map data.

3.4 ACCURATE POSITIONING

An essential skill associated with geological mapping is being able to accurately locate yourself on the topographic base map. Two main methods exist:

- pacing
- Global Positioning Systems (GPS)

3.4.1 Pacing

The pacing technique is an old-age method used to measure distance in the field; it has been largely superseded by GPS, but still remains the quickest and dependable way of field positioning, for example, along field boundaries.

Before applying this technique '*on the job*', it is necessary to determine the length of your stride. This can be done either by using a 100m tape and determining the number of paces required to walk along its length, or by pacing a short linear feature and measuring the distance on the topographic map. Most people will find that they have to walk rather more than 100 paces to cover 100 metres. It soon becomes a habit to count paces when surveying.

The problem with pacing is that you generally have to walk along field boundaries and then at right angles into the field to determine the position of any small pits or boundaries etc. which does prove time consuming. Another drawback is that if the ground is uneven (a ploughed field), it is most difficult to maintain a standard length of stride. With GPS it is possible to walk directly to the point of interest and thus reducing the distance walked and terrain irregularities are of no import.

3.4.2 Global Positioning Systems (GPS)

Global Positioning Systems or alternatively satellite positioning systems are now routinely used for location in the field. This is perhaps the one piece of equipment that has significantly speeded up field activities during the last 30 years. The small handsets currently used in the field are accurate to about 6m in the horizontal direction, which is usually adequate for most field mapping and locations can either be given as standard Longitude and Latitude readings or Ordnance Survey grid references. *The instruments are significantly less accurate for vertical height determinations*. There are two drawbacks to using GPS systems:

(1) the need to have at least one spare set of batteries – a good quality (e.g. Duracell, Ever Ready) set of 1.5v AA size batteries will typically give around 15 hours continual use;

(2) mechanical failure – several GPS's have broken down over the last couple of years and it can take several weeks for them to be repaired or replaced under warranty (hence the need to maintain your pacing skill!).

3.5 FIELD TECHNIQUES FOR MAPPING LOWLAND QUATERNARY DEPOSITS

If you have experience of geological mapping, you will have quickly realised that most of the techniques described within this manual are field mapping techniques that can be applied to many different types of geological mapping. In the following sections, you will learn about those techniques that are commonly employed when mapping lowland Quaternary terrains – see Figure 3.3. Some of these are described below.

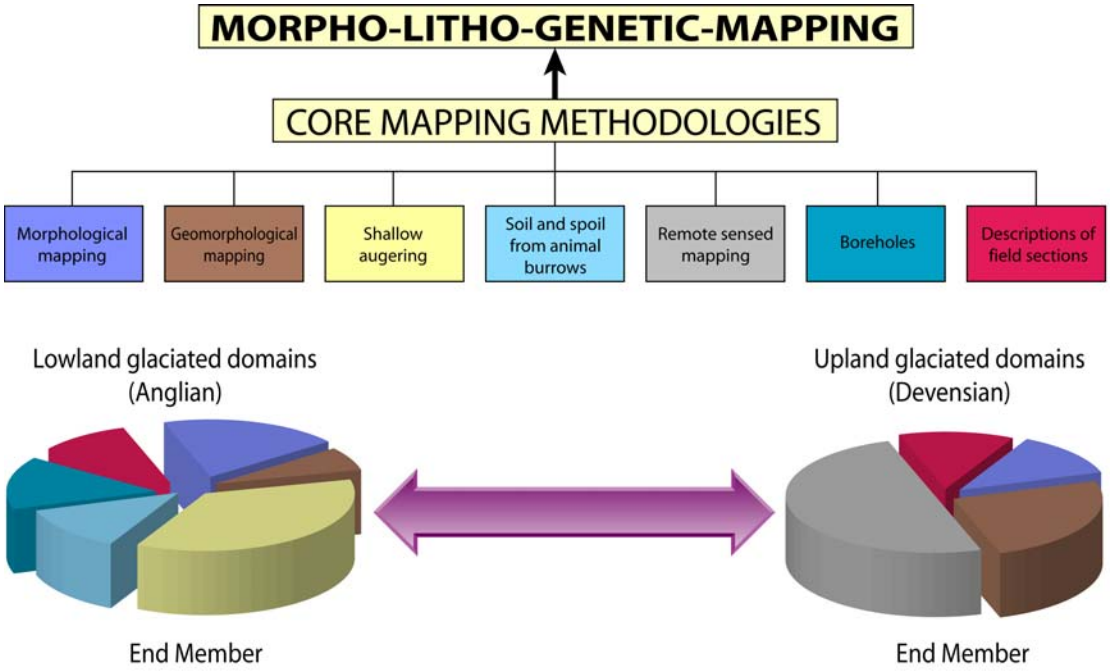


Figure 3.3: Seven core methodologies that underpin the BGS approach to Quaternary mapping (Booth and Lee, 2006). Of these, the most important methods for mapping in lowland Quaternary areas are morphological mapping, shallow augering and soil and spoil from animal burrows, and describing field sections. Remote sensed mapping is beyond the scope of this manual.

3.5.1 Morphological and geomorphological mapping

Morphological mapping is a classic method of landform mapping that lies upon the recognition and recording of observable changes in topography and surface form. Morphometric information, for instance, convex and concave changes of slope and the geometry of plateaux surfaces, gullies and ridges, is purely descriptive and based largely upon the judgemental recording of field and remote observations supplemented with occasional quantitative measurements (i.e. slope angle). The main morphological mapping symbols (form lines) used by BGS for this purpose are shown in Figure 3.4.

From a mapping perspective, it is perceived that morphometric changes may reflect changes in the underlying superficial geology - for example, a bed of sand sandwiched between two beds of more competent till, or a resistant bed of sand and gravel overlying a till. Consequently, lithological boundaries and geological lines may therefore correspond to changes in relief. Equally, it is possible that morphometric features may bear no resemblance to the underlying superficial geology and may instead relate to some form of post-depositional modification – this is especially the case in areas that have been subjected to periglacial processes.

Since morphological mapping is purely descriptive and not genetically interpretative, geological interpretations of morphological features will be based upon geological hypotheses developed by the geologist for an individual mapping area. It is critical therefore that these hypotheses and geological interpretations can evolve and are testable based upon field observations. As a consequence of this need for testing and re-evaluation, pure morphological mapping is perhaps best suited to areas where the relief and geology is not complex – for instance lowland areas.

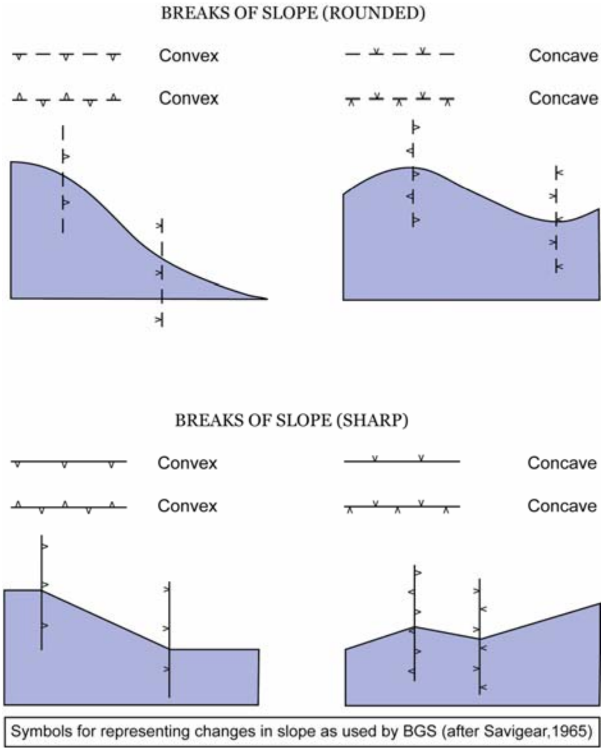


Figure 3.4: The primary morphological symbols for recording changes of slope.

Geomorphological mapping enhances the purely morphological approach, as it also involves determining the genesis of the observed landforms, taking into account lithologies and their spatial geometry (including stratigraphy). As sound interpretation is the key to the success of this method, it requires a good understanding of landform assemblages and their genesis, together with an appreciation of other appropriate field and laboratory techniques that might assist in interpretation. Whatever other methods are brought into the geomorphological survey (e.g. if remotely sensed data are available, they can serve to increase the rate of ground coverage and reduce field time), ground-truthing remains an essential element (e.g. to confirm remotely sensed interpretations, to observe sections and to record lithologies).

3.5.2 Shallow augering (Figure 3.5)

Augering underpins most superficial mapping except in those localities where the deposits comprise predominantly gravel or boulders or where the ground is impenetrably hard due to dryness. The method is routinely used in lowland Britain for establishing:

- lithologies in stratified sequences
- boundary positioning

It is very important to use the Dutch auger correctly to avoid back injury (see the Health and Safety field booklet). Ideally, the auger should be used in a vertical position. This should pose no problem to the taller members on the course, but for shorter individuals it will be more difficult. It is easiest to screw the auger in a few turns and then pull it out, examine the sediment and then repeat the operation. In stiff clays it may be necessary to ream out the hole occasionally, which will enable the auger to be extracted more easily. Some geologists like to mark the stem of the auger in 10 cm units with coloured tape or by 'engraving' so they can record depths and thicknesses more accurately.

Figure 3.5: Trainees being introduced to shallow augering.

In the field, farmers may ask you '…how many time do you auger?' and '…how deep do you auger?' There is no straight forward answer to this except to say that you auger as many times and deep as is required to resolve the geological problem. For example, on flat featureless terrain of uniform lithology, it may only be necessary to auger every 200m and down to 0.8m. By contrast, on an undulating hillside you may need to auger at a much higher resolution and to a greater depth (i.e. 1.3m or greater). If the geology and terrain are working in the geologist's favour, then boundaries may be fixed to an order of accuracy better than 5m. It is inevitable that in many instances, the accuracy will be far less than ideal, and will vary across the mapped ground due to such things as poor auger penetration and sample retrieval, or highly variable geology (e.g. tectonised glacigenics). Also, be aware that augers tend to push the larger stones aside so that deposits may appear to contain less gravel than is actually present…. so your lithological appreciation may well be misguided.

Generally speaking, two approaches to augering can be employed for boundary positioning (Figure 3.6). The initial approach is often to auger along a series of parallel traverses at intervals with auger holes separated by about 200m. If frequent variations in the geology are found or suspected it may be necessary to increase your frequency of augering. As boundaries between geological units are detected, the distance between auger holes should decrease so as to spatially constrain the boundary (i.e. boundary tracing). Geological boundaries can thus be interpolated between traverses, their positioning being guided by any other observations (e.g. slope changes) that have been made in the intervening ground and from contours on the base map. The often, close link between slope changes and geological boundaries is a particularly important mapping 'shortcut' once it has been recognised. Where the link is strong, walking along the feature whilst checking the relationship by judicious augering may be a preferable and time saving option to systematic traversing.

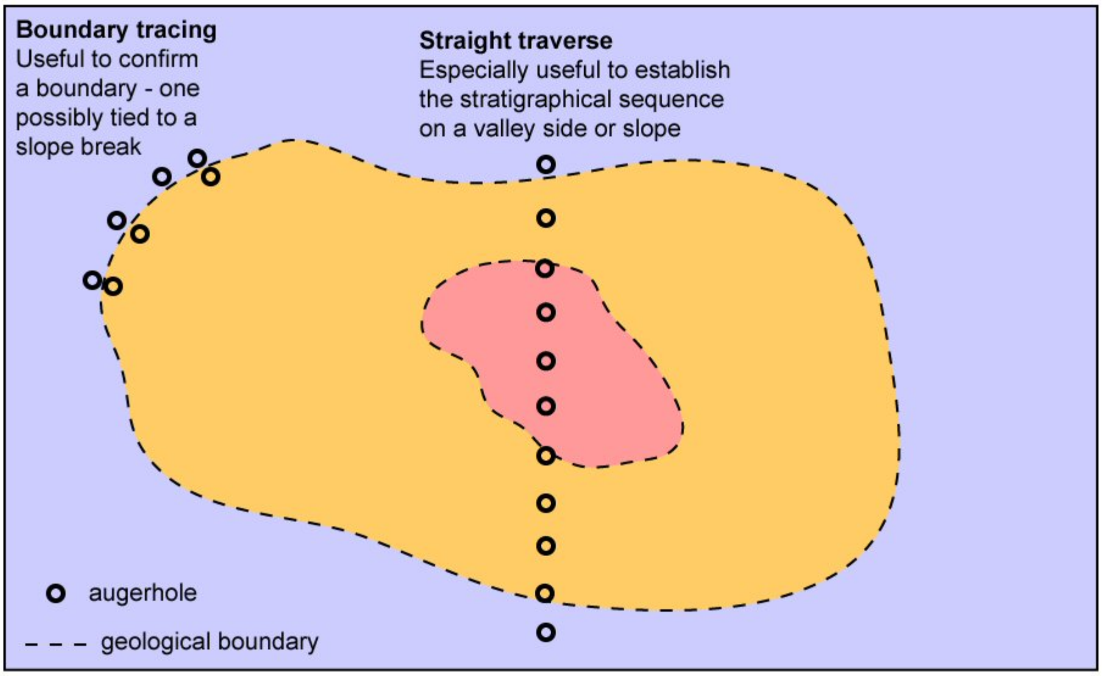


Figure 3.6: Two approaches to shallow augering and boundary positioning: (1) boundary tracing; (2) straight traverse.

Auger hole locations are often marked on the base map by a 'dot' with an abbreviated note alongside describing the lithologies encountered. BGS typically records *depth to* (from surface) in auger holes rather than the *thickness* of individual units, for instance silt to 0.5m, till to 0.9m, clay to 1.2m.

As familiarity with the terrain increases, geological and landscape subtleties often emerge and the significance of earlier observations becomes more apparent. This evolving understanding usually enables a reduction in augering frequency and leads to a more efficient mapping effort

3.5.3 Soil and spoil from animal burrows

Soil, especially over ploughed fields, and 'spoil' from animal burrows are often good indicators of the underlying geology. Although mapping of superficial deposits does not equate with formal soil mapping procedures, general observations on the textural properties of the soil should be made (e.g. whether sandy, clayey, peaty or stony). These observations may provide clues to the underlying 'parent' deposit and are thus a useful mapping aid.

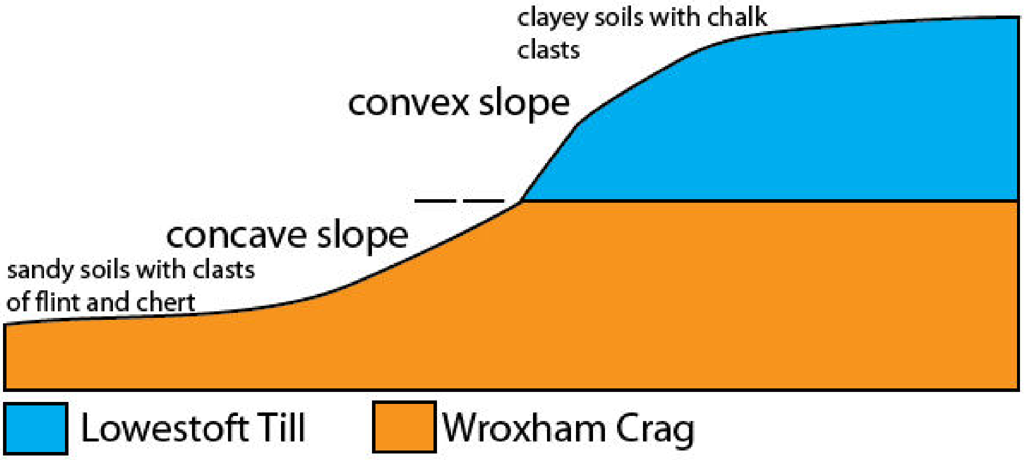


Figure 3.7: An example of soil texture and composition used in combination with slope breaks to determine the position of a geological boundary.

Stones or fragments observed on the soil/ground surface are frequently referred to by the term ‘brash’; these fragments are often derived from the underlying parent material. Changes in soil texture, spoil or brash may provide a strong indication that a geological boundary has been crossed. The postulated presence of a boundary can be tested and constrained by augering and looking for possible related slope breaks. By way of an example, the transition from the Wroxham Crag to the Lowestoft Till in central East Anglia, is marked by an abrupt change from light sandy soils with occasional flint and chert pebbles, to heavy clay-rich soils with abundant chalk. The sandy ground usually produces a concave slope whilst the till body tends to have a convex slope (Figures 3.7 and 3.8).

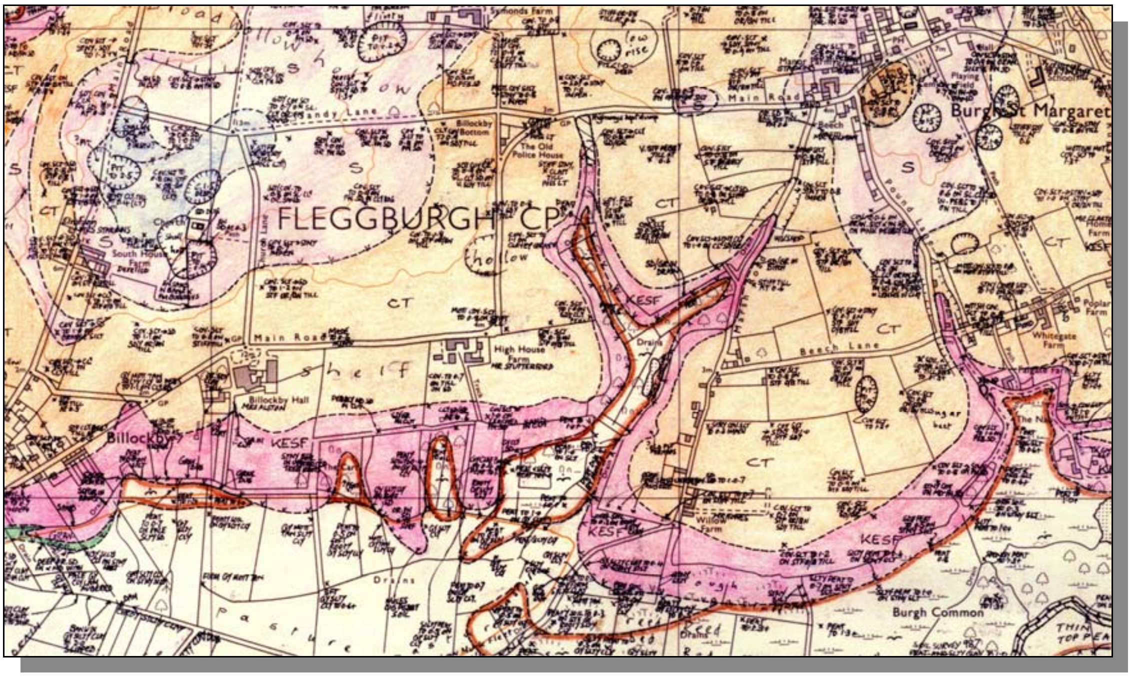


Figure 3.8: Map extract from a 1:10,000 scale fieldslip on the Great Yarmouth sheet. The fieldslip shows how slope breaks, auger holes and observations of soil brash have been used to constrain the geological boundaries.

Although soil, spoil and brash observations can be very useful, cultivation of the fields can in some cases produce some misleading results so a reasonable degree of caution needs to be exercised. Problems that may potentially be encountered include:

- ploughing or natural slope processes that may move material downslope over time
- soils may be especially stony in spring – the fine soil fraction having been washed away or into the substrate by wind and rain over winter months
- landscaping and the application of lime and hardcore will modify the soil characteristics
- soils used to grow carrots and potatoes are often destoned by machinery which sieves out the stones and redeposits them in rows alongside trenches.

3.5.4 Description of field sections

Recording and describing field sections (exposures) is an integral part of field observation. Sections can provide a wealth of lithological and stratigraphical information, as well as providing insights into the genesis and former dynamics of the geological sequence. Types of section that may be found include coastal cliffs and quarry faces, road and railway cuttings, ditches, trial pits and construction excavations. Sections may prove particularly hazardous; for example, the slopes may be unstable or have associated hazards e.g. passing vehicles or trains. Health and safety considerations are therefore of paramount importance, and risk assessments for working on sections should be carried out during the project planning phase. Further Health and Safety guidance for working on exposed sections can be found within:

ALDISS, D T. 2003. BGS Guidance Note: a safe system of fieldwork. *British Geological Survey Report* IR/02/094, 45pp. [\\kwsan\store\Publications\Documents\IR\2002\IR02094.pdf]

A standard for describing sites is set out in the *British Standard Code of practice for site investigations* (BS 5930,1999). However, depending on the requirements of the mapping investigation, it may be necessary to supplement this with additional information, as outlined in *The description and analysis of Quaternary stratigraphic field sections* (Jones et al., 1999). In general you will need the following items of standard equipment for investigating sections:

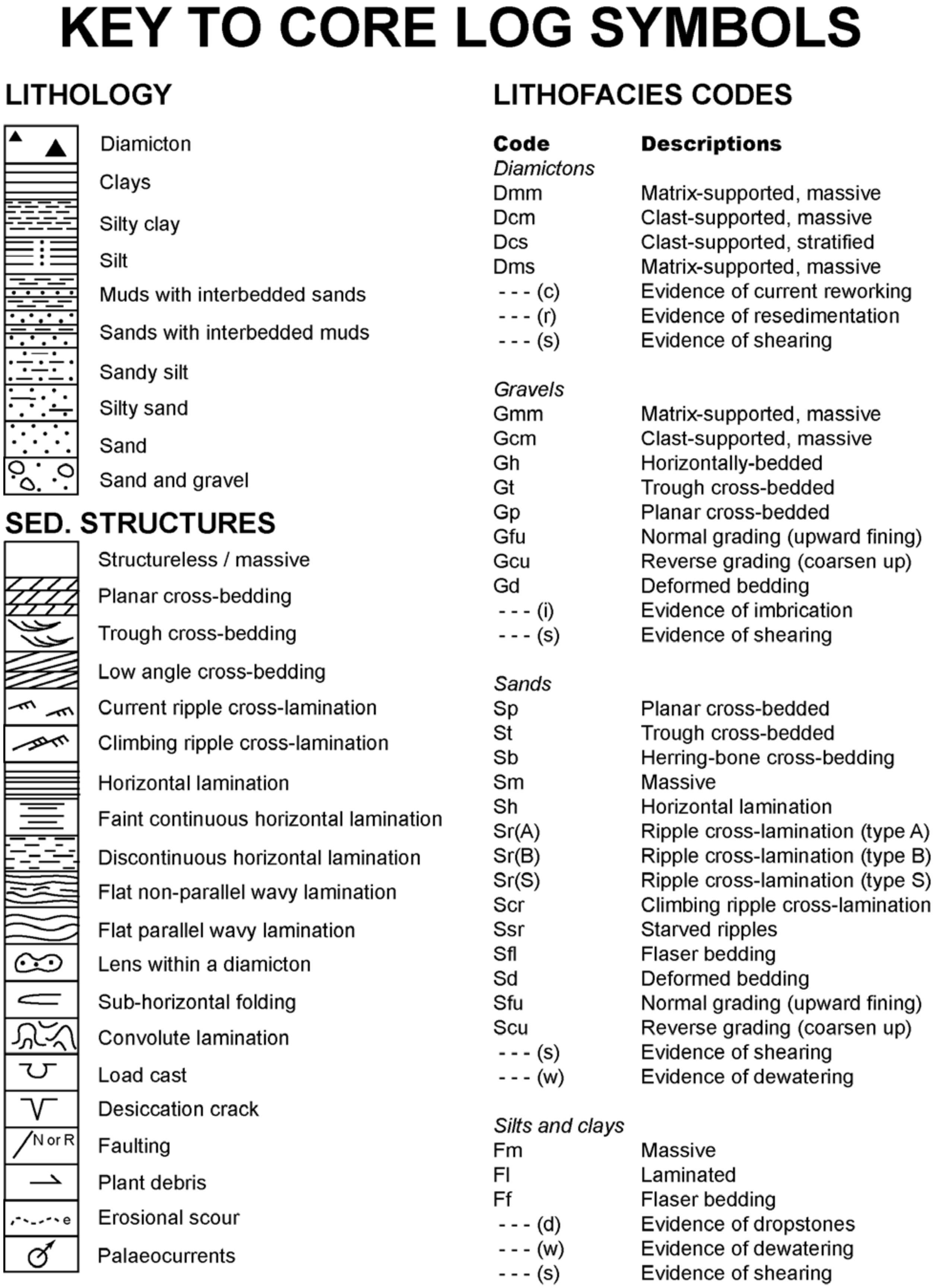
- Hard hat and high visibility jacket (ensure the colour is appropriate for the site)
- GPS for location (note: reliable readings are not always possible close to cliff faces)
- Spade, trenching tool and trowel for excavating and cleaning exposures
- 3m and 30m tape measure
- Field notebook or data cards, pencils and marker pens
- Grain size card – for grain size determinations
- Hand lens – for examining sediment grains and surfaces of larger clasts
- Camera – preferably digital
- Munsell Soil Color chart – a standard colour reference
- Compass clinometer – for palaeocurrent and clast fabric analysis and structural determinations
- Hydrochloric acid (diluted to 10%) – to test carbonate content
- Sample bags and labels – should you want to collect samples for analysis

The examination and recording of your observations within exposed sections should follow a hierarchical approach. This will be based firstly, upon simply recording your observations, and then interpreting these observations with respect to mechanism of deposition and finally environment of deposition (Table 3.1).

When making field sketches and sedimentary logs, it is common to summarise your observation using either a set of descriptive symbols that classify texture and sedimentary structures, and / or a series of descriptive lithofacies codes. There is no standard set of symbols and lithofacies codes however those shown in Figure 3.9 have been developed by the authors of this manual and include the most commonly occurring elements.

Activity	**Things to consider**	**Equipment**
1. Record the OS grid reference	Proximity to exposure face; are there features obscuring the GPS instrument from the 'sky'	• GPS
2. Clean the section		• Spade, entrenching tool or trowel
3. Make orientated and scaled sketches and photographs; draft sedimentary logs		• Field note book, data cards, pencil • Key in Figure 3.9
4. Identify the principal geological units	• Visual breakdown of the sequence exposed	
5. Describe the section and the geological units	• Bed / unit geometry • Sediment texture • Structure • Lithology and composition • Palaeocurrents • Level of consolidation • Clast fabric • Organic content • Chemical content	• Tape measure • Grain size card • Hand lens, hammer • Compass clinometer • Compass clinometer • Hand lens • Dilute HCl
6. Interpret the mechanism and dynamics of deposition, accretion / deformation	• Waterlain? • Windblown? • Sediment reworking	
7. Interpret the environment(s) of deposition / accretion / deformation	Are the sediments fluvial, shallow marine, subglacially derived?	

Table 3.1: Hierarchical approach to describing and interpreting sections.



Code	**Descriptions**
Diamictons	
Dmm	Matrix-supported, massive
Dcm	Clast-supported, massive
Dcs	Clast-supported, stratified
Dms	Matrix-supported, massive
- - - (c)	Evidence of current reworking
- - - (r)	Evidence of resedimentation
- - - (s)	Evidence of shearing
Gravels	
Gmm	Matrix-supported, massive
Gcm	Clast-supported, massive
Gh	Horizontally-bedded
Gt	Trough cross-bedded
Gp	Planar cross-bedded
Gfu	Normal grading (upward fining)
Gcu	Reverse grading (coarsen up)
Gd	Deformed bedding
- - - (i)	Evidence of imbrication
- - - (s)	Evidence of shearing
Sands	
Sp	Planar cross-bedded
St	Trough cross-bedded
Sb	Herring-bone cross-bedding
Sm	Massive
Sh	Horizontal lamination
Sr(A)	Ripple cross-lamination (type A)
Sr(B)	Ripple cross-lamination (type B)
Sr(S)	Ripple cross-lamination (type S)
Scr	Climbing ripple cross-lamination
Ssr	Starved ripples
Sfl	Flaser bedding
Sd	Deformed bedding
Sfu	Normal grading (upward fining)
Scu	Reverse grading (coarsen up)
- - - (s)	Evidence of shearing
- - - (w)	Evidence of dewatering
Silts and clays	
Fm	Massive
Fl	Laminated
Ff	Flaser bedding
- - - (d)	Evidence of dropstones
- - - (w)	Evidence of dewatering
- - - (s)	Evidence of shearing

Figure 3.9: Key symbols and lithofacies codes used for the describing of Quaternary sections (after Miall, 1978, Eyles *et al*., 1983 and Benn and Evans, 1998).

3.5.5 Other geological indicators within the field

Ditches

The presence of ditches usually indicates that the adjacent fields have poor natural drainage and are underlain by clay or silty or sandy clay. Ditches can be quite useful for augering in that they may give you a metre or so depth start! It is generally best to auger into the side of a ditch unless it has been very recently cleaned out. **Note**: beware of ditches polluted with slurry adjacent to farmyards and if in doubt avoid them! Ditches running down hillsides are a good place to determine the presence and thickness of any Head or Colluvium.

Small pits in fields

In ploughed in pits, an examination of the rim will often reveal some evidence of what was originally dug. Many pits have been backfilled over the years. This may be evident from a change in the soil colour, the presence of brick, concrete, etc. Many have been filled with the washings from sugar beet and these may not be obvious. Record the approximate depth of all pits as this may be important if the pits are later backfilled and development is planned.

Crop marks

In hot dry summers, crops growing on well-drained deposits such as sand and gravel often become stressed and their growth is retarded. This characteristic provides an invaluable indication of small, isolated patches of sand and gravel on till plateaux which otherwise probably would be missed.

Flora and fauna

The flora will often provide clues as to the nature of the underlying soils and superficial deposits. For example wild clematis (old man’s beard) tends to occur on calcareous soils so may be an indicator of chalk-rich till (or Chalk bedrock!). Heather, gorse and bracken are typically found on the more acidic soils so check for the presence of sand and gravel. Willows, sedges and mosses are generally associated with wet ground and commonly indicate the presence of alluvium and possibly spring lines.

3.5.6 Supporting methods

Boreholes and trial pits provide invaluable lithological, stratigraphical and other property information supporting field mapping. However, if they are to be funded by the project, they are an additional drain on project resources.

Boreholes

Boreholes are often the only way of obtaining information on the sediments at depths more than a few metres below the surface. A percussion ‘shell and auger’ rig is suitable for most Quaternary sequences apart from where coarse gravels are prevalent. Using this equipment it is possible to take undisturbed ‘U100’ ‘core’ samples of the more cohesive layers encountered. The borehole should normally commence in 10- or 8-inch diameter casing as this will enable samples to be collected that are large enough for laboratory analysis. Particularly deep holes should commence in 12-inch casing to allow reductions to be made as drilling proceeds. In non-cohesive sediments, samples should be collected at 0.5 or 1.0m intervals or where changes in lithology occur. Drilling is usually charged per metre and may range from £10 per metre for the first metres up to £50-60 per metre at depths of 40-60m. There is usually an additional mobilization fee to and between sites, which may be several hundred pounds per move.

Trial pitting

Trial pits provide a quick and relatively inexpensive way of obtaining sub-surface information. The hire of JCB-type excavator typically costs as little as £150 per day. However, *Health and Safety requirements* are making it increasingly difficult to excavate trial pits without placing shuttering within the excavations, which greatly increases the costs and also minimises the faces that are available for study. It is essential to check with the BGS Safety Advisor before hiring any equipment or embarking on trenching operations.

A detailed account of drilling and trenching is provided in the QMT manual.

Windpumps and handpumps

These may be associated with wells or former wells. It is worth checking with the farmer or landowner for information regarding why and how deep they were sunk; often there is an associated log, which may be made available for your purposes.

3.6 MAP DATA COMPILATION AND FAIR DRAWN MAP PRODUCTION IN THE OFFICE

Whilst you are participating in the course field modules, you will use Ordnance Survey topographic 1:10,000 scale base maps. These maps, referred to as *field slips*, are to record your geological observations and to place boundaries between the different geological units – you should regard these field slips as the geologist’s working notebook. As the mapping effort progresses, a wealth of data is encapsulated in the field slip which gives them a scientific, intellectual and monetary value far in excess of the value of the original document – so take care of them and make colour copies at the end of each week just in case they are lost or destroyed.

Experience has shown that many individuals despite having attended mapping training courses are still unsure of what is expected from them when they start on their first mapping project – what is the final output when field mapping is completed?

The purpose of mapping is to determine the sequence of geological units, their spatial distribution and geometric relationships and to characterise their physical properties. Depending on the project objectives, this may involve mapping all the geological units within a 1:10, 000 scale quarter sheet or the brief may be to map themes missed by previous surveys e.g. landslip, Head and Colluvium or Artificial Ground.

In the early days of mapping, many field geologists had excellent cartographic skills and their field slips are aesthetically pleasing to view. Not all of us are so gifted and inevitably field slips get grubby and often a little wet so it is not easy for anyone but you to decipher them – it is also true on some occasions long after the field season to question ‘what was that note I recorded?’ or why did I put that boundary there?’ This being the case, it is essential that the geological knowledge held on your field slips be transferred onto a fair-drawn base.

It is acknowledged that the SIGMA protocols are changing procedures towards complete digital capture of all field data. However, the basic directive stands, a fair drawn copy must be produced which depicts your intellectual understanding of the geology of the given area.

These fair-drawn maps are called ‘Standards’ a term from the past when the maps went through a checking process culminating in the Chief Geologist signing them off as the definitive map of the area. Depending on the District, around 25 1:10, 000 scale standards when ‘fitted’ (a process of making sure all the lines etc join) are collated to form the 1:50, 000 geological map.

It cannot be understated how important it is to record as much geological information on your field slips as possible. Unlike university research, field mapping does not normally allow repeated visits to locations. Not only do these field slips form the basis of your own geological interpretations, but also they should have sufficient detail in order that anybody else looking at them should be able to quickly understand what you have been mapping.

In essence:

- *you are expected to collect and display enough geological observations on your field slips to be able to justify your geological model and the positioning of geological boundaries.*
- *Do not expect anyone else to make a fair copy from your field slip …it is your responsibility.*

3.7 SUMMARY

This chapter provides the information on what data to collect, and how to record it within the field. You should now have a good general understanding of:

- the basic principles of mapping Quaternary (superficial) deposits
- representing geological units on a map
- what does the geological line on map imply?
- accurate positioning
- field techniques for mapping lowland Quaternary deposits.
- map data compilation in the field and fair drawn map production in the office

Now that you have been provided with the theoretical basics of mapping, the next stages will be to put what you have learnt into practice. The next chapters refer to the individual field-based modules within the training course.

4 East Midlands Field Module

The aims of this module are:

- to gain experience linking topographic features to evidence obtained from shallow augering and field brash.
- to introduce you to the mapping of low-profile landslips, head deposits and river terraces.
- to provide you with the basic skills for recognising and mapping artificial deposits.

Research questions:

- What is the relationship between river terrace altitudes and the Pleistocene drainage development of a region?
- How would I go about correlating several isolated river terrace deposits within the same river valley?
- What would happen to the pre-existing drainage when it is interrupted by an advancing ice sheet?

Selected references:

BRIDGLAND, D R. 1994. Quaternary of the Thames. *Geological Conservation Review Series,* No.7. (London: Chapman & Hall; Joint Nature Conservation Committee) – good for river terrace formation & correlation

CARNEY, J N, AMBROSE, K, BRANDON, A, ROYLES, C P, CORNWELL, J D, AND LEWIS, M. A. 2001. Geology of the country between Loughborough, Burton and Derby. *Sheet Description of the British Geological Survey,* 1:50 000 Series Sheet 141 Loughborough (England and Wales). – general geological background to the area

CARNEY, J.N. AND NAPIER, B. 2005. Geology-based methodologies for visualizing inland floodplains and understanding fluvial processes. *European Geologist,* No.20, 14-17.

MCMILLAN, A A. 2005. A provisional Quaternary and Neogene lithostratigraphical framework for Great Britain. *Netherlands Journal of Geosciences – Geologie en Mijnbouw,* Vol. 84-2, 87-107. – New Quaternary nomenclature for BGS.

MCMILLAN, A.A. AND POWELL, J.H. 1999. Classification of artificial (man-made) ground and natural superficial deposits: applications to geological maps and datasets in the UK: BGS rock classification scheme, volume 4. *British Geological Survey Research Report* RR-99-04.

RICE, R.J. 1968. The Quaternary deposits of Central Leicestershire. *Philosophical Transactions of the Royal Society of London,* Vol. 262(A), 459-508.

4.1 BACKGROUND

This part of the course is based at Keyworth, and the localities to be visited lie on the recently revised Melton (142) and Loughborough (141) sheets (Figure 4.1). Actual mapping will only be possible for a few hours, its aim being to demonstrate the importance of feature mapping, in addition to the use of the soil auger, in order to confirm the type of deposit that is present. The course will also include the recognition of features formed by natural and artificial deposits in urban, as well as rural situations.

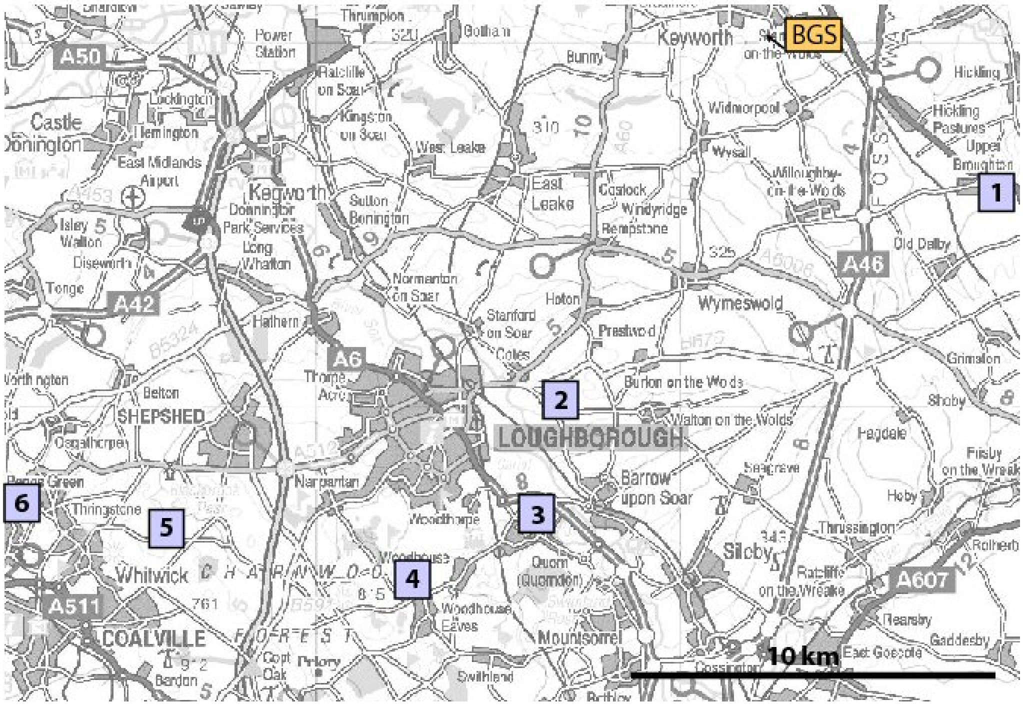
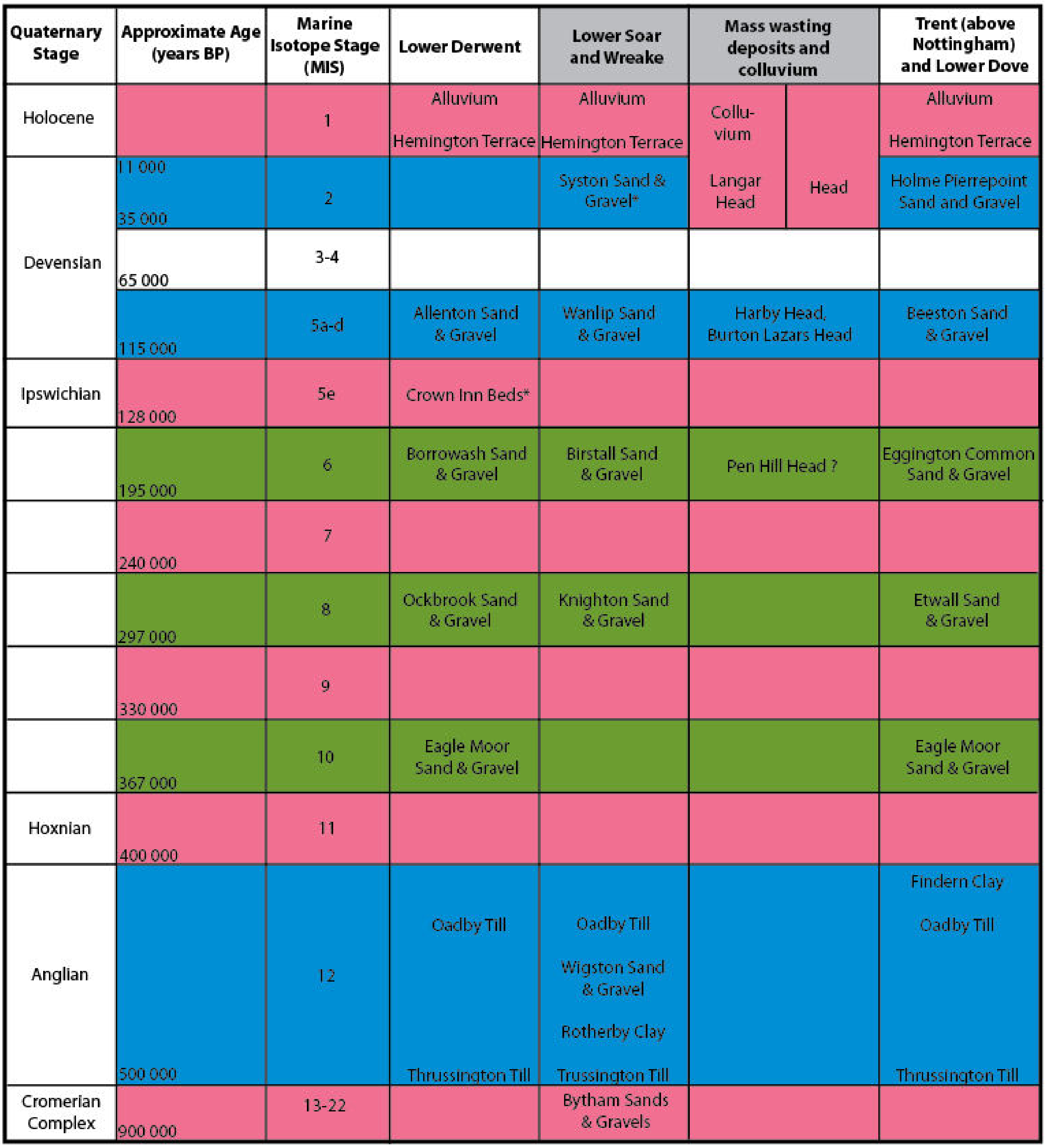


Figure 4.1: Location of sites to be visited in the Melton and Loughborough area.

4.2 GEOLOGICAL CONTEXT OF THE STUDY AREA

The East Midlands drift sequence spans a number of Quaternary episodes between the Anglian and Holocene stages. These stages are based on an oxygen isotope chronometric scale that has been deduced from the study of deep-sea cores and is constrained by a variety of absolute age-dating techniques. In the terrestrial context, absolute ages of deposits (e.g. river terraces) have been obtained from techniques such as: biostratigraphy (macro and micropalaeontology and palynology), and radiometric dating (e.g. C^{14} and U-Th series). Such studies have been carried out by universities and also by BGS; for example during the various mapping projects in central and eastern England. They emphasise the importance of recognising organic material, and its significance to age dating and correlation, when examining the generally rare exposures of Quaternary deposits in the field.



Quaternary Stage	Approximate Age (years BP)	Marine Isotope Stage (MIS)	Lower Derwent	Lower Soar and Wreake	Mass wasting deposits and colluvium		Trent (above Nottingham) and Lower Dove
Holocene		1	Alluvium Hemington Terrace	Alluvium Hemington Terrace	Collu-vium	Head	Alluvium Hemington Terrace
Devensian	11 000 35 000	2		Syston Sand & Gravel*	Langar Head		Holme Pierrepoint Sand and Gravel
	65 000	3-4					
	115 000	5a-d	Allenton Sand & Gravel	Wanlip Sand & Gravel	Harby Head, Burton Lazars Head		Beeston Sand & Gravel
Ipswichian	128 000	5e	Crown Inn Beds*				
	195 000	6	Borrowash Sand & Gravel	Birstall Sand & Gravel	Pen Hill Head ?		Eggington Common Sand & Gravel
	240 000	7					
	297 000	8	Ockbrook Sand & Gravel	Knighton Sand & Gravel			Etwall Sand & Gravel
	330 000	9					
	367 000	10	Eagle Moor Sand & Gravel				Eagle Moor Sand & Gravel
Hoxnian	400 000	11					
Anglian	500 000	12	Oadby Till Thrussington Till	Oadby Till Wigston Sand & Gravel Rotherby Clay Trussington Till			Findern Clay Oadby Till Thrussington Till
Cromerian Complex	900 000	13-22		Bytham Sands & Gravels			

Table 4.1: Quaternary deposits in the East Midlands showing the principal glacigenic, fluvial and mass-movement deposits, those of interest to this course are shaded grey. Pink highlight equates to interglacials; blue highlight to glacial; green to periglacial episodes. After Brandon (1999) and Carney *et al*. (2004).

The nomenclature, correlation and chronology of the drift sequence is summarised for the East Midlands in Table 4.1. The **Anglian** and **Devensian** stages bracket the two main glacial periods of the Quaternary, but it was only during the earliest, Anglian glaciation, that ice sheets covered the training area, depositing the locally thick tills, glaciofluvial sands and gravels and glaciolacustrine clays indicated at the foot of Table 4.1. During the late Devensian glaciation the ice sheets stopped well to the north, west and east of the area, which therefore sustained a very cold, tundra-like climate at that time. Between the two glacial periods there occurred warm temperate (interglacial) conditions and cold, periglacial conditions. All of these different climatic regimes have produced distinctive landforms, deposits and in some cases, landscape features. For example, many of the river terrace deposits, and slope head deposits, originated under successive periglacial climatic regimes.

Anglian Stage deposits were laid down during a widespread, lowland type of glaciation. They veneered a previously irregular topography, commonly thickening where infilling the original valleys. Many of these valleys were subsequently incised during post-Anglian erosion, leaving the glacial deposits as cappings to the interfluves where they now give rise to locally extensive plateaux. Such outcrops are characterised by a flat to gently domical surface, usually developed on till. Anglian glacigenic sequences are typically well stratified and are dominated by till. The various types of till are distinguishable on the basis of matrix colour and clast content, enabling them to be mapped out over considerable distances. Complexities tend to occur where the deposits infill palaeovalleys that were either excavated during the glaciation (e.g. tunnel valleys) or prior to it (pre-glacial palaeovalleys). As mapping proceeds these palaeovalleys become recognisable, their courses traced and their gradients worked out through the use of rockhead contour plots (i.e. contour maps based on elevations of the junction between Quaternary deposits and bedrock). In certain palaeovalley situations where sub-glacial waters flowed and were ponded, glaciolacustrine clay deposits are interstratified in the sequence.

This module will concentrate on the post-glacial deposits of the region. **River terrace deposits** generally comprise sand-rich, matrix-supported, trough cross-bedded gravels. They reflect late Anglian river basin initiation and post-Anglian to Holocene incision associated with the development of the Trent/Soar river systems. The terraces form parallel, sheet-like spreads of sand and gravel, rarely more than 5m thick. The terrace deposits were laid down during periods of aggradation, when deposition outpaced erosion, and only became terraced landforms when the fluvial regime was replaced by one of incision and down-cutting, in response to adjustments to base-level caused by relative sea-level falls. Because of the repeated cycles of fluvial incision and periglaciation, the preservation potential of a given terrace deposit is inversely proportional to its age. In order of decreasing age (and topographic elevation), the named terrace deposits of this area are: the Birstall, Wanlip and Syston sands and gravels (Table 4.1). The correlation and tentative assignment of terraces to various Marine Isotope Stages suggests that these deposits were typically laid down in periglacial climate regimes, probably as braid plains that filled most of the valley floor.

Altimetric information and constructed terrace long profiles are essential for correlating the more isolated terrace deposits (e.g. Bridgland, 1994). These data indicate between 3m and 7m of incision between the various terrace aggradations. Stone clasts in terrace deposits derive from reworking of the older Superficial Deposits and bedrock within the river catchment and the proportions of the main constituents vary between the valleys, although ‘Bunter’ pebbles and shattered flints are always prevalent, generally in similar proportions. Later head accumulation and cryoplanation can, however, modify the terrace form, the degree of cryogenic involution generally increasing with the age of the deposit.

Alluvium deposits in this area are of Holocene age. They represent the deposits of active floodplains, and thus have an obvious geohazard connotation in respect of past flooding and its likely recurrence in the future (Carney and Napier, 2005). It is therefore important to map alluvium accurately and to do this, some techniques will be discussed that will enable recognition of the wide range of geomorphological features to be found on floodplains. **Head*** and **landslip** deposits are widely distributed in the area, but commonly do not form obvious features. Both are manifestations of downslope mass movement, but whereas head is commonly a very subdued, mantling deposit, landslippage is recognised by a spectrum of very distinctive features.

* see Section 4.6.1 below

4.3 LOCALITY 1 – MAPPING OF LOW MAGNITUDE SLOPE INSTABILITY FEATURES

At this locality features formed by landslides will be viewed around Greenhill Farm [SK 6960 2830] and Broughton Lodge near Old Dalby, Vale of Belvoir (Figure 4.2). A short mapping exercise will illustrate the surveying of landslips. It should be stressed, however, that the mapping of landslipped terrains is an iterative process, involving the interpretation of 1:10,000-scale aerial photographs in the office and confirmation or 'ground truthing' during the field survey.

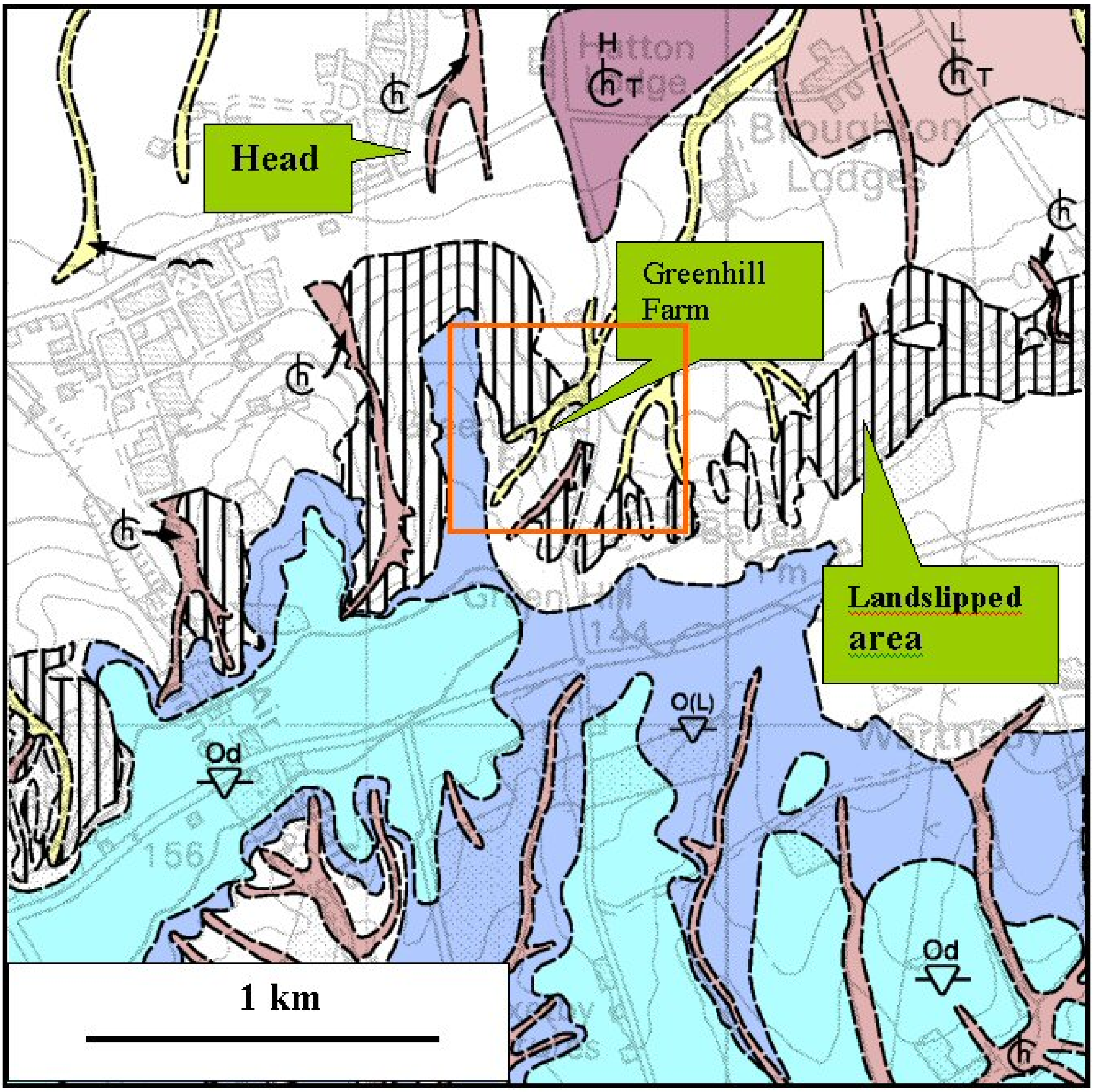


Figure 4.2: Quaternary geology around Greenhill Farm near Old Dalby. Outcrops are taken from from the Melton Mowbray 1:50k sheet (142). Od = Oadby Till; O(L) = Lias-rich variant of the Oadby Till.

The landslips near Old Dalby continue outside of the area shown in Figure 4.2, and are present along most of the length of a dissected, north-facing scarp slope developed on Lower Jurassic beds of the Charmouth Mudstone Formation. They have a clear topographical expression and can be identified on air photographs. Semi-circular back scarps characterise the tops of landslipped slopes, and distinct lobate flow-forms are developed in the toe-zones of the slipped areas. These mudflow lobes may merge imperceptibly down the slope, into blanket head deposits. Topographical analysis utilising the 5m contour intervals of the 1:10,000 Ordnance Survey map showed that the scarp has a uniform facet with a consistent slope angle, the median value of which is 6.3°. The slope is, however, incised by later erosion with mudflows emerging from the gullies so-formed.

4.4 LOCALITY 2 – MAPPING OF FLUVIAL TERRACES AND ALLUVIUM

This exercise will be carried out on ground occupied by a flight of river terrace deposits representing previous aggradations of the River Soar, a major tributary of the Trent. A combination of approaches is used to map terrace deposits: a) they are regarded as geological units ('deposits') characterised by a certain composition, and b) they are mapped by using as a guide, the distinctive suite of landforms (features) to which they give rise. An emphasis on feature mapping is necessary where terrace deposits occur in urban areas, as will be demonstrated later at locality 3.

Some of the principal features defining outcrops of fluvial terrace deposits (Figure 4.3) will be viewed.

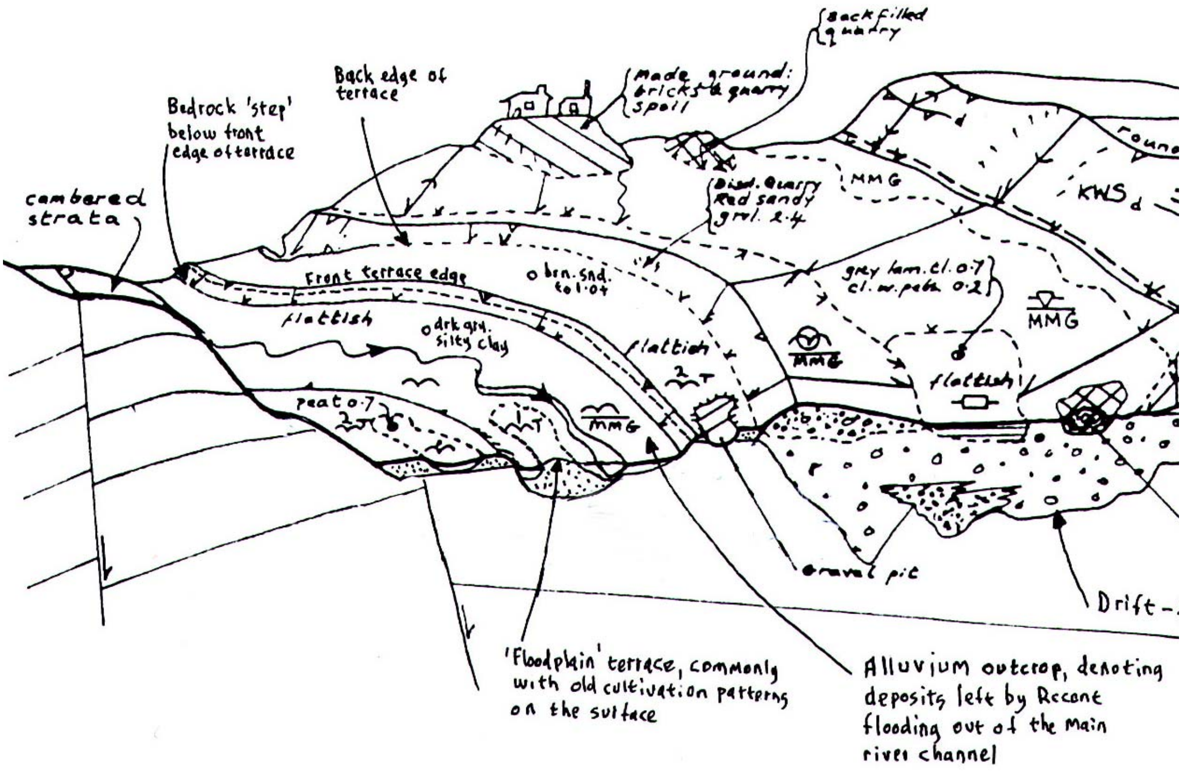


Figure 4.3: Schematic diagram showing Quaternary deposits and associated landforms.

These features include:

- *Terrace front edge*: a construction line, which can be shown on fieldslips by a crest-line symbol.
- *Bedrock 'step'*. This is the narrow bedrock outcrop that commonly occurs below the front edge of a 'perched' terrace that is significantly higher than adjacent fluvial deposits. In many cases the geological boundary line marking the base of the terrace deposit will be offset, down-slope, from the terrace front-edge (i.e. this boundary will form the top of the bedrock step). Note that the youngest and thus the lowest terrace deposit (the 'floodplain terrace')

commonly has a degraded edge against which the alluvium has lapped, with no bedrock step developed.

- *Terrace surface.* This highly planar landform appears to be flat, but where the outcrop is wide the terrace surface commonly rises very gradually, away from the axis of the valley and towards the terrace back edge. Soils on the terrace deposit are invariably sandy and pebbly, but very thin terrace deposits may show involution with the underlying substrate where periglacial modifications have occurred.
- *Terrace (or alluvium) back edge*. This is a construction line and geological boundary, taken at the concave break in slope marking the change from the flattish terrace (or alluvium) surface to rising ground of the valley side (or bedrock step of the next-highest terrace). This feature may be modified by the encroachment of material from the slope behind; for example, as a result of hill-wash, solifluction etc. Note that an alluvium back edge will also represent the outer limit of the active floodplain.

The features and deposits relating to river terraces and alluvium of the Soar valley are demonstrated in rural ground around Cotes Road, north of Barrow on Soar [SK 5685 1970], as shown in Figure 4.4. In this area the Cropwell Bishop Formation (CBp) of the Mercia Mudstone Group forms the bedrock, which is locally mantled by sands and gravels representing river terrace deposits. The oldest, highest and consequently the most degraded terrace forms a small capping consisting of deposits belonging to the Birstall Sand and Gravel.

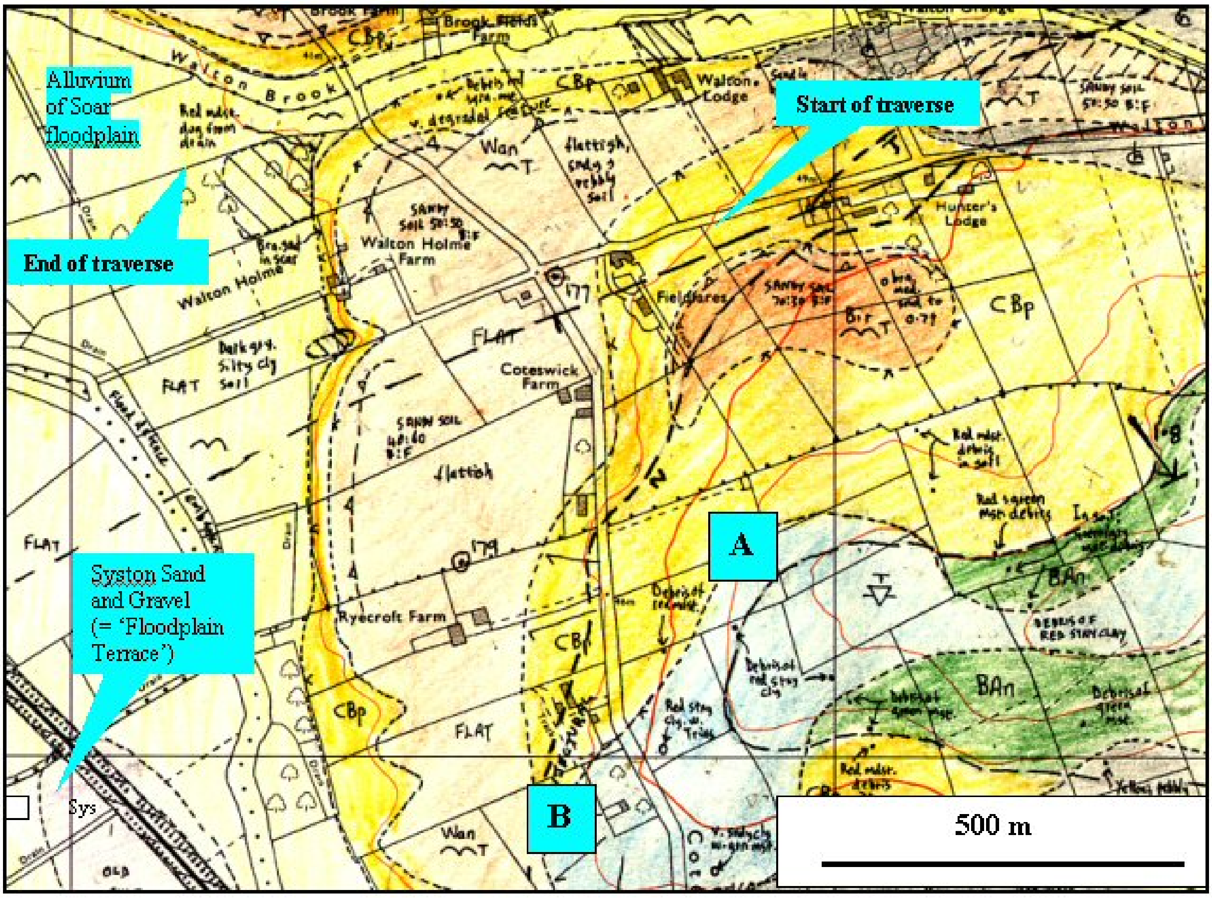


Figure 4.4: River terrace and other Quaternary features near Cotes Road. Extract of 1:10,000 field slip SK51NE/NW.

With reference to Figure 4.4, between points A and B, note the decline in rockhead elevation along the edge of the Thrussington Till outcrop (T), indicating that the base of the till slopes downwards, to the south-west. This mimics the slope of the modern valley of the Soar, suggesting that the till forms a veneer to a pre-existing (pre-Anglian) valley side.

- The front edge, flattish surface and back edge of the terrace feature formed by the *Birstall Sand and Gravel* outcrop (Bir), and the rock step of Cropwell Bishop Formation below it, will be viewed first.
- Down from the Birstall bedrock step, the back-edge of the next-youngest terrace, formed by he *Wanlip Sand and Gravel* outcrop (Wan), will be seen, as will the flattish surface of the Wanlip terrace.
- This exercise will conclude with a visit to the degraded front edge of the Wanlip terrace. Below the terrace deposit, the foot of the bedrock step is onlapped by the back edge of the modern *alluvium*. That boundary therefore marks the outer limit of the River Soar floodplain.

Aerial photographs (1:10,000 scale) can be used for ‘first-pass’ delineation of river terraces and floodplain boundaries; however, most features are of small magnitude (1-5 metres high) and any such interpretation will need to be verified in the field. Floodplain alluvium actually represents a complex association of deposits and landforms, commonly with a vertical topographical range of up to 2 m. The features formed by these deposits are invariably too subtle to be readily or quickly mapped out in the field, but if necessary (e.g. for a detailed study of a floodplain as part of a commercial or environmental project) the use of airborne laser microtopographical surveying (LiDAR), which has a vertical height resolution of only 15cms, should be considered (Figure 4.5).

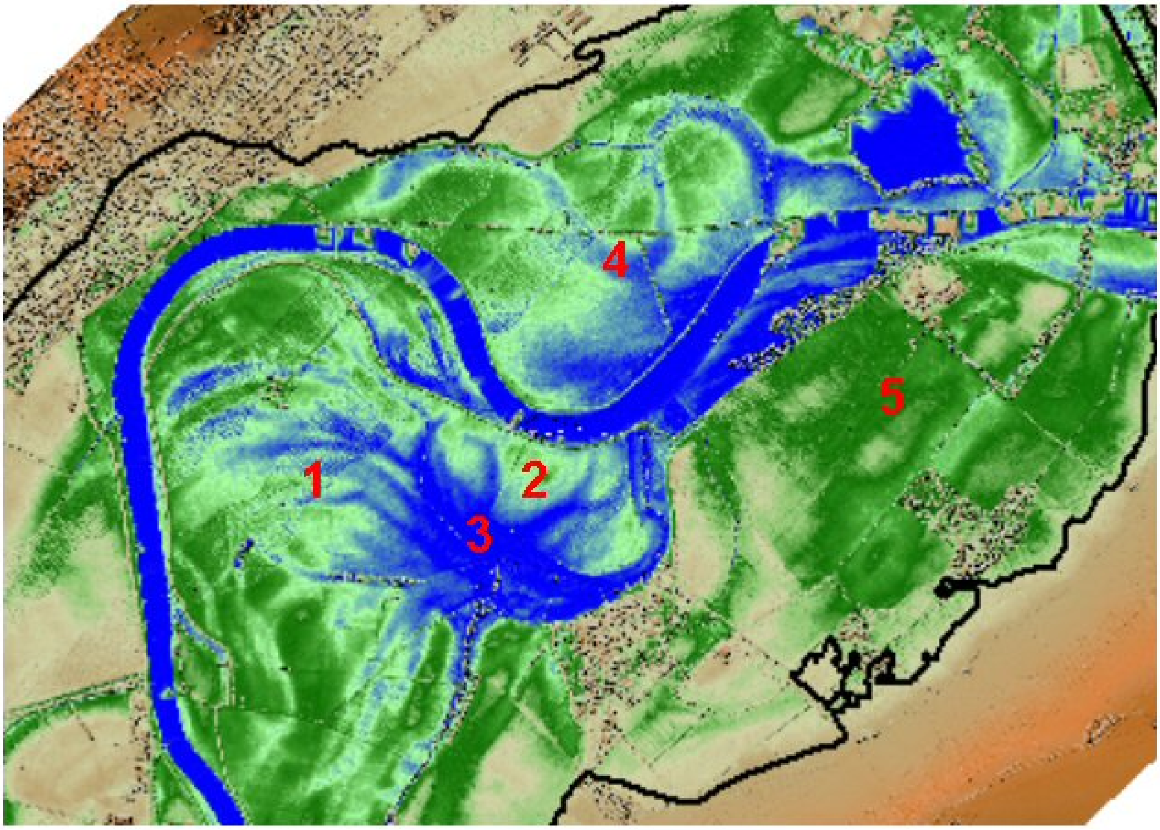


Figure 4.5: Example of a LiDAR topographical map of River Trent floodplain alluvium between Shelford and Gunthorpe, 9km east of Nottingham. Blue colours are low ground, pale to dark green represents progressively higher ground. 1: Arcuate gravel bars (point-bar complex); 2: Levee with crevasse channels; 3: Flood basin or backswamp; 4: Abandoned channel; 5 Higher ground of the floodplain terrace (from Carney and Napier, 2004). Source LiDAR imagery ©Environment Agency. BGS reprocessed image ©NERC. The copyright proprietors reserve all rights.

4.5 LOCALITY 3 – SURVEYING TERRACES IN AN URBAN SITUATION

The objective of this locality is to view and to map, on field slips provided, sand and gravel outcrops representing river terraces in the urban area of Quorndon (Figure 4.5). Starting in Spinney Drive [SK 5570 1640], the mapping exercise will demonstrate the importance of recognising, and following, constructional terrace features (e.g. front edge and back edge). It will include the mapping of *alluvium*, as well as landforms related to the *Syston*, *Wanlip* and *Birstall* terraces (Figure 4.6).

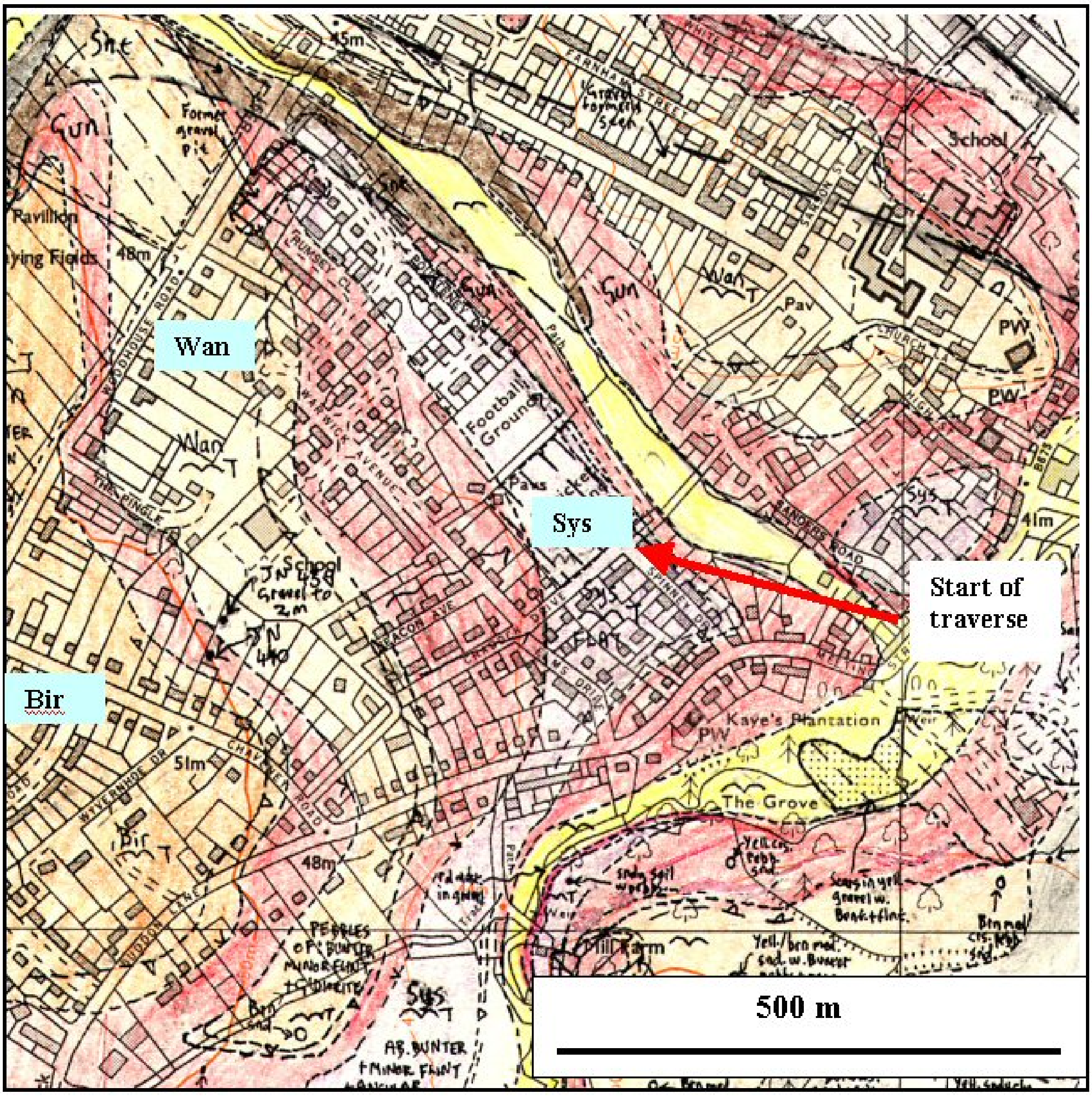


Figure 4.6: Upper map is extracted from 1:10,000 fieldslip SK51NE, showing outcrops of the Syston (Sys), Wanlip (Wan) and Birstall (Bir) terrace gravels to be surveyed during this exercise.

4.6 LOCALITIES 4 AND 5 – SURVEYING OF UPLAND HEAD DEPOSITS

West of Quorndon (locality 4), there will be an opportunity to view and debate the representation at different scales (Figure 4.7) of ‘upland’ head in Charnwood Forest. The debate *vis a vis* mapping-in or leaving out such deposits is continuing in areas such as the Scottish and Welsh highlands. The locality to be visited is a (hopefully) ploughed field at Woodhouse Eaves [SK 5260 1475].

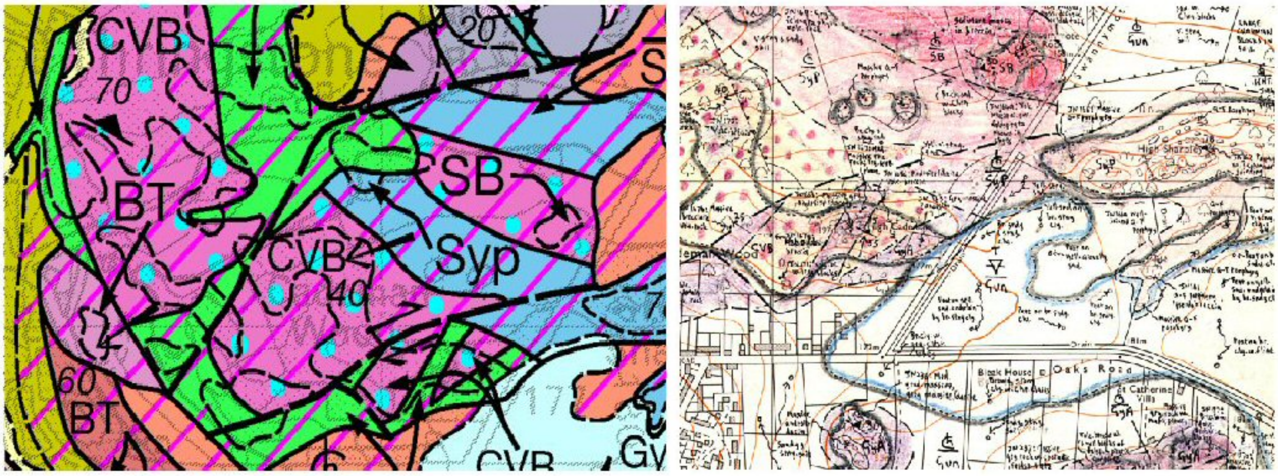


Figure 4.7: Left - 'transparent' representation of upland head (diagonal magenta lines) in Charnwood Forest. Extract from Loughborough 1:50,000 geological map sheet (141). Right - on this fieldslip [SK41NW] Thrussington Till (T; blue-fringed fields) and upland head (grey-fringed fields) are represented transparently so as not to obscure bedrock geology. Note the use of fraction symbols

Further into Charnwood Forest, near Mt St Bernard Abbey (locality 5), there is an example of how Quaternary deposits can be represented, by colour edging, in areas of complex bedrock geology (Figure 4.7: Right).

4.6.1 'Head' and 'colluvium' – some early definitions of the terms

These notes suggest that 'Head', a term currently in favour at BGS, has in the past been used synonymously with 'colluvium', both meaning deposits that have originated by the down-slope movement of loose material.

On the published Geological Survey maps of England a number of structureless deposits of different composition and irregular distribution have been given names as "Head" (of Devon), Pebbly Clay and Sand, Talus, Rainwash, Downwash Gravel, Coombe Rock or Coombe Deposits, Taele Gravel, and Angular Chert Drift. These deposits have several characteristics in common, and some similarities in mode of origin, as do certain other deposits hitherto included in: Alluvium, Plateau Gravel, High Level gravel, Pebble Gravel of Doubtful Age, Valley Gravel, Dry Valley Gravel, Brick-earth and Clay-with-Flints.

These superficial deposits in common with certain others now being mapped by the Survey are all of variable composition are derived from local formations (either bedrock or Superficial) and are clearly the result of slow flow from higher to lower ground, while oversaturated with water from melting snow or ice, rain, or lines of springs or seepages. They are commonly classed together under the general term "Head".

'Colluvium' is a general term applied by many workers around the World (e.g. Bates and Jackson, 1980) to any loose heterogeneous and incoherent mass of soil material and/or rock fragments deposited by rain-wash, sheet wash, *or slow continuous down slope creep*, usually collecting at the base of gentle slopes or hillsides. Turner (1996) adds that the terms colluvium and colluvial materials are used to refer to deposits that have been transported by gravity. The characteristics of colluvial materials vary according to the characteristics of the bedrock sources and climate under which weathering and transport occur. Generally, colluvium is weakly stratified and consists of a heterogeneous mixture of soil and rock fragments ranging in size from clay particles to rocks a metre or more in diameter. In cold climates, colluvium is affected by the presence of permanently frozen ground, or permafrost. Frozen ground conditions impede internal drainage and often lead to saturation of the surficial layers. Solifluction, the slow flowage of saturated surficial materials, produces characteristic lobate topographic patterns reflecting slope instability.

It seems clear from these definitions that at least some components of material known as ‘Head’, a term that has long been in favour at BGS, have in other parts of the World equated to ‘colluvium’, both meaning deposits that have originated by the downslope movement of loose material.

On some recent BGS maps, a distinction has been made between a) loose material that has collected in valley floors, usually by processes of hill-wash caused by deforestation and soil erosion, and b) slope-mantling deposits (head). This is good practice, as the two types of deposit will have different modes of origin. However, the valley-filling deposits have commonly been referred to as ‘colluvium’. In view of the wider uses of the latter term, discussed above, it now seems desirable that the term ‘colluvium’ should not be used for such valley floor deposits. Alternative names - such as simply ‘Valley Deposits’ - may be more appropriate, and this issue is currently under discussion.

Further reading:

BATES, R.L. and JACKSON, J.A. (eds). Glossary of Geology, 2nd Ed. American Geological Institute, Falls Church, Va., 751p. 1980.

TURNER, A.K. 1996. Colluvium and Talus. In: Landslide investigation and mitigation, A.K. Turner and R.L. Schuster (eds.) Special Report 247, Transportation research Board, National Research Council, National Academy Press, Washington D.C.

BALLANTYNE C K and HARRIS, C.1994. The periglaciation of Great Britain. Cambridge University Press. *Chapter 7. Periglacial mass wasting and slope evolution in lowland Britain.*

4.7 LOCALITY 6 – ARTIFICIAL GROUND IN THE LEICESTERSHIRE COALFIELD

The aim of this section is to very briefly introduce factors associated with the mapping of Artificially Modified Ground, taking as an example ground recently mapped in the now-derelict North-West Leicestershire Coalfield. Definitions of the various categories of artificial ground are given in McMillan and Powell (1999), and the types of hachuring used to represent them in the *Specifications for the preparation of 1:10,000 scale geological maps.* Artificial ground can be represented at various levels of detail (McMillan and Powell, 1999), but today a simple level of interpretation (‘Level 2’ of McMillan and Powell, 1999) is to be considered, as it is the most used given the time constraints usually imposed upon field mapping. Level 2 divides artificial ground into 5 main types:

- *Made Ground* – Areas where the ground is known to have been deposited by man on the former, natural surface (e.g. road embankments, colliery waste tips, constructional fill (landraise))

- *Worked Ground* – Areas where the ground is known to have been cut away (excavated) by man (e.g. road or railway cuttings, quarries)

- *Infilled Ground* – Areas where the ground has been cut away (excavated) and then had artificial ground (fill) deposited (e.g. partly or wholly backfilled quarries)

- *Landscaped Ground* – Areas where the original surface has been extensively remodelled, but where it is impractical or impossible to separately delineate areas of worked (excavated) ground and made ground.

- *Disturbed Ground* - Areas of surface and near-surface mineral workings where ill-defined excavations, areas of man-induced subsidence caused by the workings and spoil heaps are complexly associated with each other (e.g. collapsed bell pits and shallow mine workings)

All of these categories are mapped during the course of a 1:10,000 scale survey; however, on most published 1:50,000 geological sheets only the first three are shown.

On this course, we will concentrate on the more unusual and uncommon, but potentially hazardous, categories of artificial ground in the North-West Leicestershire Coalfield. This coalfield has experienced a long history of surface and underground coal extraction, with written records of such activity dating at least as far back as 1200 AD. Then, the main technique involved the sinking of numerous, shallow bell pits or pillar and stall workings into coal seams that were close to the ground surface.

By the 17th and 18th centuries, however, technology had evolved, enabling the sinking of larger, more discrete shafts to access the deeper seams. The 19th and 20th centuries saw the main phase of intermediate and deep mining, with the development of large colliery complexes around shafts whose locations were documented on Ordnance Survey maps. In the latter part of the 20th century, coal was extracted from large opencast pits, most of which are now fully restored.

With reference to Figure 4.8:

- ***Disturbed Ground*** on Coal Measures around Church Hill, east of Thringstone [SK 4178 1730]. Along this footpath, hummocky features are observed (‘A’ on Figure 4.8 - left), attributed to undocumented shafts or bell pits. There is also a NW-orientated ‘slack’ (‘B’), not obviously associated with stream erosion, which may be a subsidence feature. Also note scarplets on hill to left of road, below Church Hill.
- Further observations of ***Disturbed Ground*** **and** ***Made Ground*** on Coal Measures, around Pegg’s Green at Anchor Lane [SK 4150 1775]. In this field (‘C’; Figure 4.8 -left) observe hummocky featuring of Disturbed Ground, possible subsidence-induced damage to a wall, and small area of Made Ground at top of field.
- ***Disturbed Ground*** due to intensive bell-pitting [SK 4019 1717] around Coleorton (‘D’; Figure 4.8 - Middle). Discuss detection of undocumented larger shafts.
- ***Infilled Ground*** (‘E’ on Figure 4.8 - right) representing a fully restored open cast pit, and a domestic refuse landfill site near Lount [SK 3928 1916].

4.8 SUMMARY

On completion of this module, you have will have learnt the basics and gained experienced in:

- mapping river terraces and floodplain alluvium
- recognising types of mass-movement deposit (Head, Colluvium etc), and recording them
- recognising types of Artificial Ground and recording them

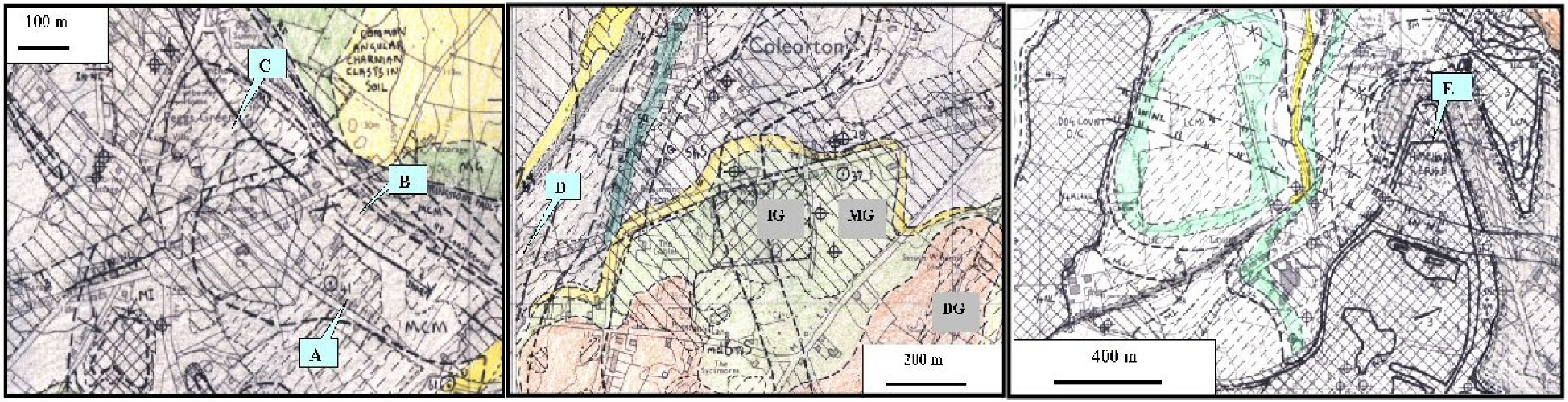


Figure 4.8: Left – disturbed ground around Pegg's Green, NW Leicestershire Coalfied (fieldslip for 1:10k sheet SK41NW). Middle: Fieldslip SK41NW portraying hachure symbols for use with Infilled Ground (IG), Made Ground (MG) and Disturbed Ground (DG). Right – detail from fieldslip SK31NE showing areas occupied by large, restored opencast coal workings (Infilled Ground Symbol).

5 Vale of York Field Module

The aims of this module are:

- To appreciate the overall character, size, relationships and environments of deposition of the Devensian glacial and proglacial deposits and landforms in the Vale of York.
- To compare the deposits and landforms with those seen in modern glacial and pro-glacial environments.
- Learn how to map features and soil, and record auger information to make a geological map of glacial and proglacial deposits.

Research questions:

- What interactions and deposits would you expect when an ice sheet advances into a pro-glacial lake?
- What would happen to the pre-existing drainage when it is interrupted by an advancing ice sheet?
- What retreat features would you expect during the wasting of a 30km wide lowland ice sheet?

Selected References:

COOPER, A.H. AND BURGESS, I.C. 1993. Geology of the country around Harrogate. *Memoir of the British Geological Survey*, England and Wales (Sheet 62).

EVANS, D.J.A. AND TWIGG, D.R. 2002. The active temperate glacial landsystem: a model based on Breidamerkurjokull and Fjallsjokull, Iceland. *Quaternary Science Reviews* 21, 2153-2177.

EVEREST, J.D. AND BRADWELL, T. 2003. Buried glacier ice in southern Iceland and its wider significance. *Geomorphology* 52, 347-358.

GAUNT, G.D. 1970. A temporary section across the Escrick Moraine at Wheldrake, East Yorkshire. *Journal of Earth Sciences* 8, 163-170.

JANSSON, K.N. 2003. Early Holocene glacial lakes and ice marginal retreat pattern in Labrador / Ungave, Canada. *Palaegeography, Palaeoclimatology, Palaeoecology* 193, 473-501.

5.1 BACKGROUND

During this module of the Lowland Quaternary mapping course, we will be investigating the landforms and sediments at the Devensian ice margin in the Vale of York (Figure 5.1). Day 1 will be spent examining the Quaternary history and landforms of the Vale of York. This will include looking at the morphology of marginal glacial drainage diversions, moraines, eskers and glacial lake deposits. During Day 2, we will study the types of sediments and landforms that are likely to be encountered during the mapping exercise the following day. This will include logging sections in quarries and trenches, augering and landscape interpretation. On the final day, Day 3, you will undertake an exercise mapping Holocene deposits and late-Devensian glacial and glaciolacustrine sequences, using augering and feature mapping techniques. The evening will be spent drawing up fieldslips and possibly viewing captured data in 3 dimensions.

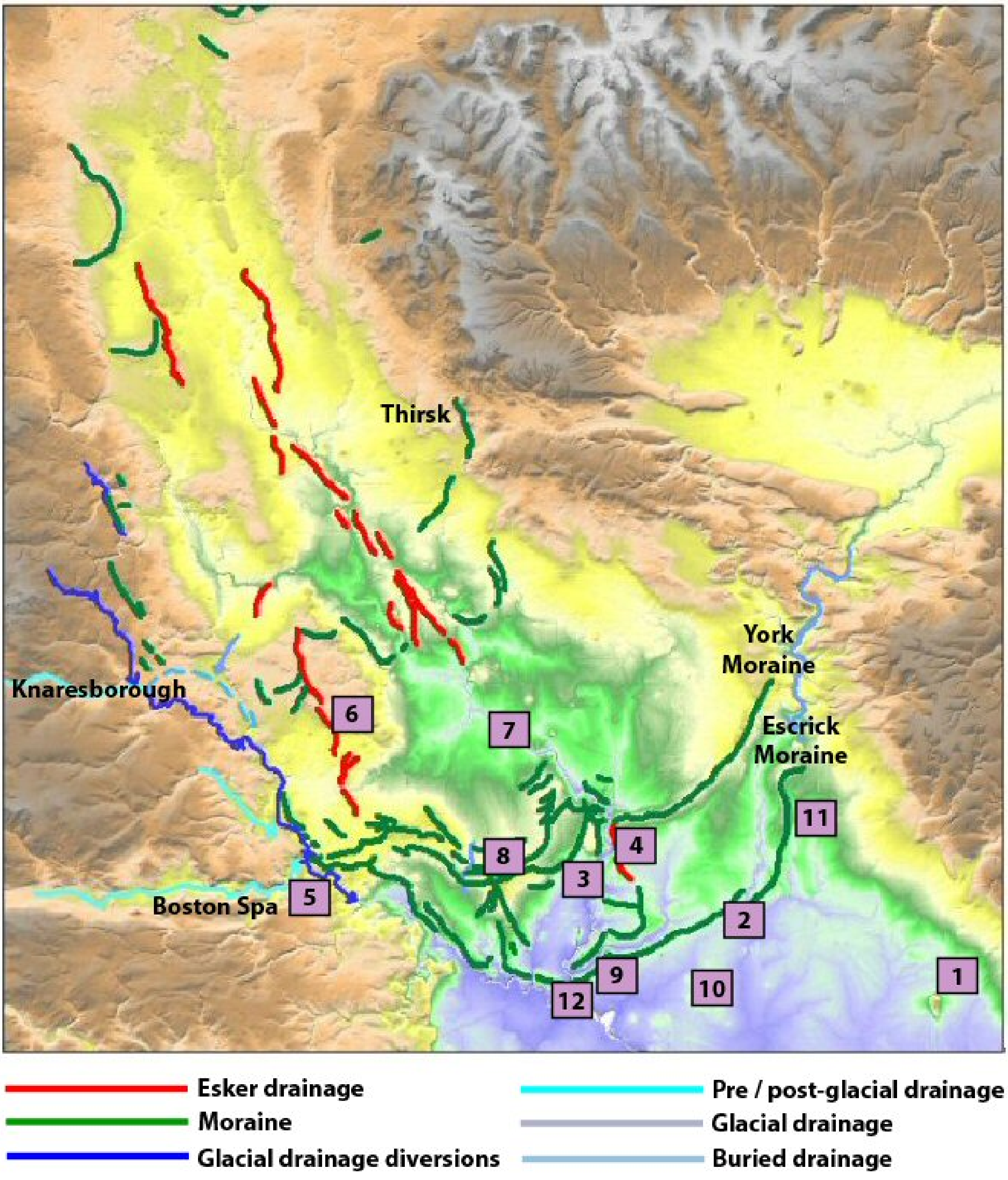


Figure 5.1: The main topographic and glacial features within the Vale of York. The numbers refer to localities visited during this three day section of the course.

5.2 GEOLOGICAL CONTEXT OF THE STUDY AREA

The pre-Devensian stages of glaciation, which probably affected the region, are hard to disentangle. Most of the pre-Devensian glacial deposits within the Vale of York probably date from the **Anglian** Stage, around 500 000 years BP when glacier ice reached southern England. Because of their considerable antiquity, the pre-Devensian deposits are now heavily dissected by erosion and only relics remain on the plateaux and elevated ground to the west, south and east of the Devensian ice-limit (Locality 1). These deposits vary considerably depending on the local bedrock, but generally include tills, sands and gravels plus valley fill deposits ranging from sandy clays to clays with local and exotic rock clasts. Many of the areas that were not glaciated are notable for the presence of gravel and boulder dreikanter or ventifacts, these are wind-worn faceted stones indicative of prolonged sand-laden wind erosion (possibly for just the Devensian at the margin of the ice or possibly for a longer period of time).

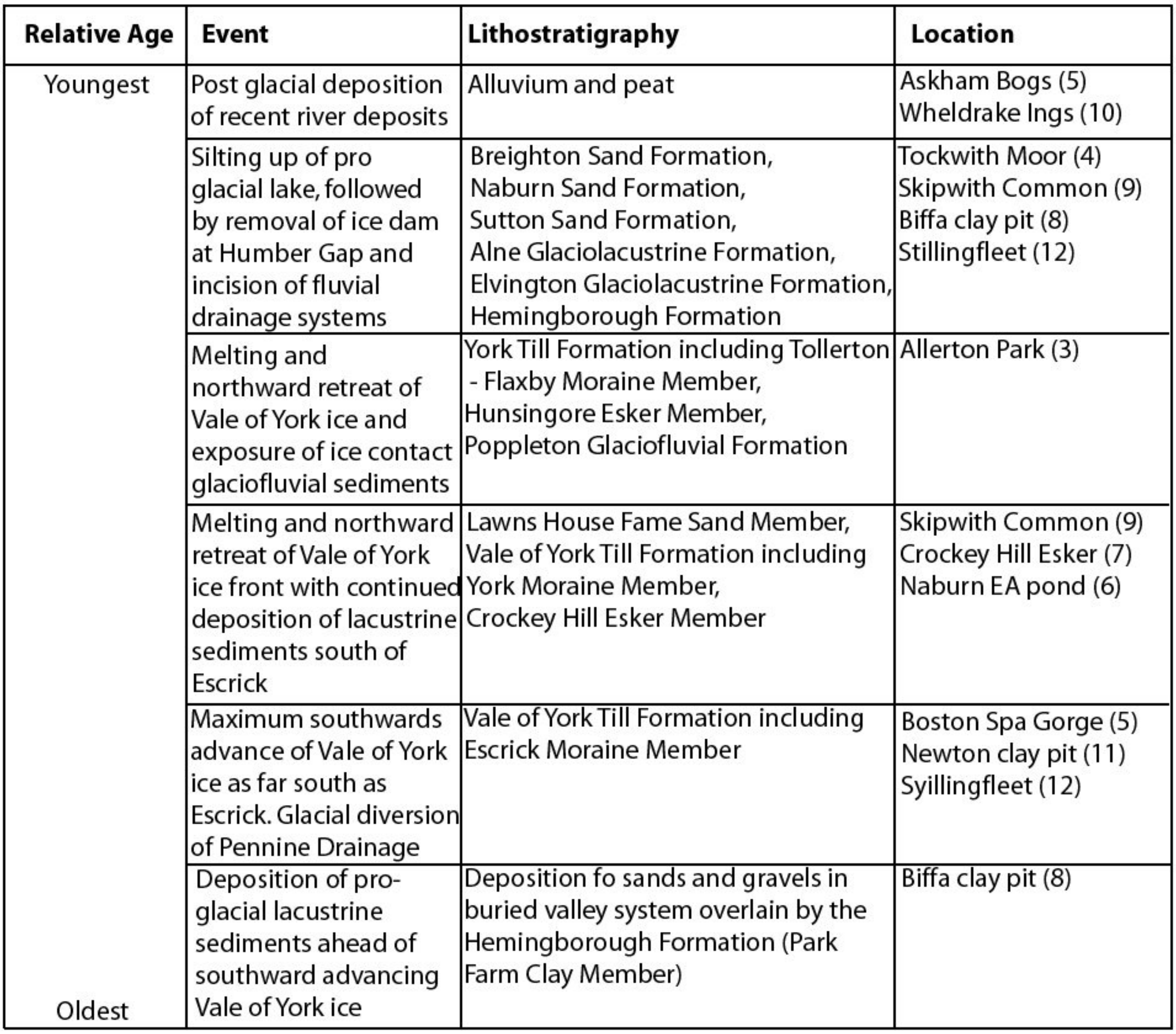
In the Wortley area of Leeds, [SE 2850 3310] ancient excavations in the Aire Valley yielded the remains of Hippopotamus preserved in clay dug from a terrace of the Aire. This deposit has been inconclusively carbon dated, but suggests an **Ipswichian** age for its occurrence indicating a warm temperate environment prior to the Devensian ice-age.

During the last, **Devensian** glaciation, ice covered most of northern Britain. The Pennines valleys were glaciated as far south as Leeds and a tongue of ice occupied the Vale of York. This ice appears to have been an amalgamation of North-Sea ice and ice from the Lake District that crossed the Pennines at Stainmore. The route of the ice movement is shown by the nature of the erratic clasts contained in the glacial till and the outwash deposits. In the west of the Vale of York these are dominated by Carboniferous sandstone and limestone. In the east more Jurassic and Chalk material is present. Within the Vale of York, the Devensian ice retreated as recently as perhaps 14 000 years BP, leaving extensive glacial and pro-glacial deposits behind.

Within the Vale of York ice advanced as far south as the Escrick Moraine (Table 5.1; Figure 5.2). At the same time, the North Sea ice advanced to Norfolk blocking the drainage out through the Humber gap. In front of the ice, glaciofluvial outwash deposits and pro-glacial lake deposits were formed in the dammed pre-glacial valley system. The large pro-glacial lake drained southwards down the Trent valley (in the opposite direction to the present drainage) and appears to have drained out through the Lincoln Gap.

As the ice built-up towards to the Devensian maximum, it overrode many of the pro-glacial deposits. In the west, it built up a marginal belt of gravels and till forming a lateral moraine. To the north of this, it formed a thin spread of gravely till to the west of the Knaresborough Gorge. The ice margin then retreated progressively northwards with intervening still-stands depositing the lobate Escrick Moraine, the York Moraine and the Flaxby-Tollerton Moraine. These moraines represent still-stands in the ice margin where the supply of sediment-laden ice was in equilibrium with the degree of melting or wasting. In many places the ice-sheet and moraine were “bulldozed” into pre-existing glaciolacustrine deposits forming thrust surfaces with the essentially flat-lying laminated clays immediately in front of the moraine.

The advance of the ice down the Vale of York blocked the pre-existing Pennine drainage. Numerous rivers were blocked and pre-existing valleys filled with glacial deposits. The River Nidd used to flow to the east of Knaresborough, but it was diverted to cut its present gorge to the west of Knaresborough. It was then diverted to flow through what are now valleys with insignificant



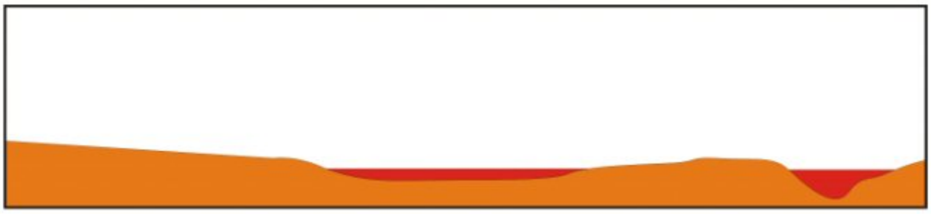
Relative Age	Event	Lithostratigraphy	Location
Youngest	Post glacial deposition of recent river deposits	Alluvium and peat	Askham Bogs (5) Wheldrake Ings (10)
	Silting up of pro glacial lake, followed by removal of ice dam at Humber Gap and incision of fluvial drainage systems	Breighton Sand Formation, Naburn Sand Formation, Sutton Sand Formation, Alne Glaciolacustrine Formation, Elvington Glaciolacustrine Formation, Hemingborough Formation	Tockwith Moor (4) Skipwith Common (9) Biffa clay pit (8) Stillingfleet (12)
	Melting and northward retreat of Vale of York ice and exposure of ice contact glaciofluvial sediments	York Till Formation including Tollerton - Flaxby Moraine Member, Hunsingore Esker Member, Poppleton Glaciofluvial Formation	Allerton Park (3)
	Melting and northward retreat of Vale of York ice front with continued deposition of lacustrine sediments south of Escrick	Lawns House Fame Sand Member, Vale of York Till Formation including York Moraine Member, Crockey Hill Esker Member	Skipwith Common (9) Crockey Hill Esker (7) Naburn EA pond (6)
	Maximum southwards advance of Vale of York ice as far south as Escrick. Glacial diversion of Pennine Drainage	Vale of York Till Formation including Escrick Moraine Member	Boston Spa Gorge (5) Newton clay pit (11) Syillingfleet (12)
Oldest	Deposition of pro-glacial lacustrine sediments ahead of southward advancing Vale of York ice	Deposition fo sands and gravels in buried valley system overlain by the Hemingborough Formation (Park Farm Clay Member)	Biffa clay pit (8)

Table 5.1: The Devensian and Holocene sequences in the Vale of York.

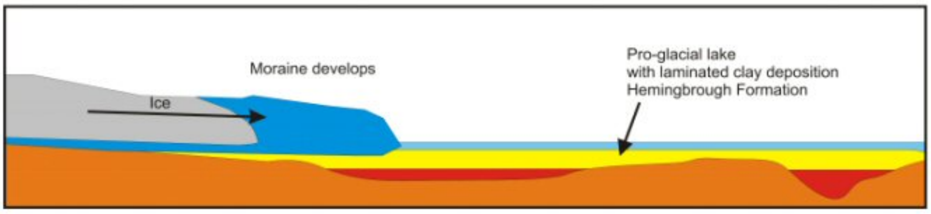
to join up with the River Wharfe just to the west of Wetherby. Here the drainage was also diverted around the south-west edge of the ice-sheet and Escrick Moraine incising the rock-cut gorge through Boston Spa. Upstream of this diversion the Wharfe valley is wide, downstream it is very narrow.

The vast amounts of meltwater draining from the ice-sheet formed en-glacial drainage systems that commonly became choked with sand and gravel (plus some laminated clay). Upon the ice-sheet melting, these choked drainage systems were left as ridges (eskers) of partially disturbed deposits. Where the drainage emerged from the ice-sheet (at the sides or in front) it commonly deposited terraces or fans of sand and gravel (such as at Pocklington and Linton upon Ouse). Where the drainage disgorged into glacial lakes, fans of sand and gravel formed with an upper surface approximating to the glacial lake water level. Glaciolacustrine deposits including laminated clay subsequently buried some of these fans.

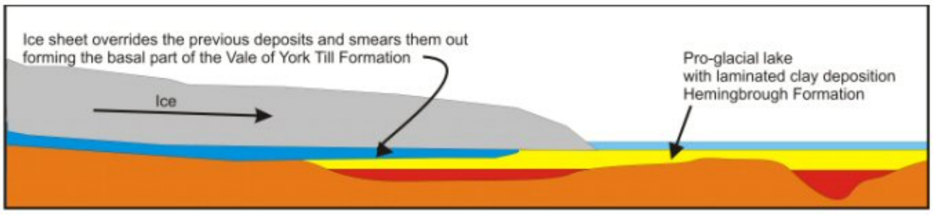
The pro-glacial lake deposits mainly comprise laminated silts and clays with inter-bedded and overlying sands, especially where marginal or ice-sheet drainage entered the lake. The ice-sheet of



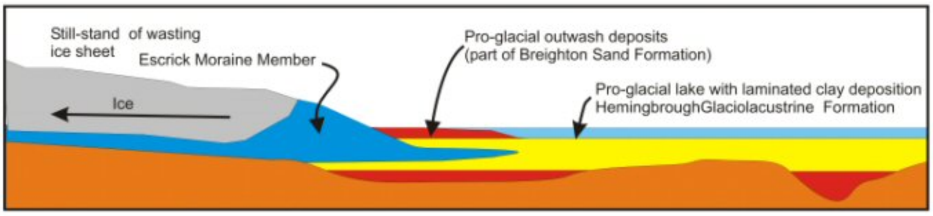
1.Pre-existing pre -Devensian topography and incision of drainage during the advance of the Devensian ice, deep weathering of the bedrock, topography partially filled in with fluvial and fluvio-glacial outwash and valley fill deposits.



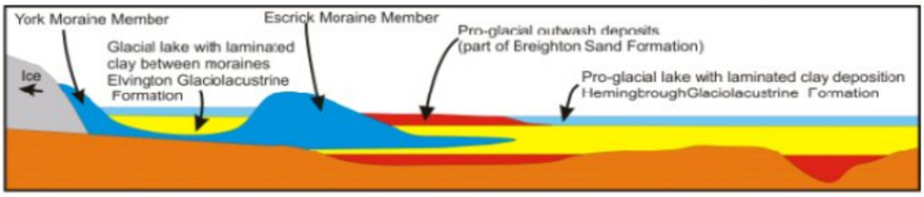
2 Ice advances over the pre-existing topography valley fill deposits, moraine develops at still-stands, pro-glacial lake with laminated clay deposits of the Hemingbrough Formation in front of ice sheet..



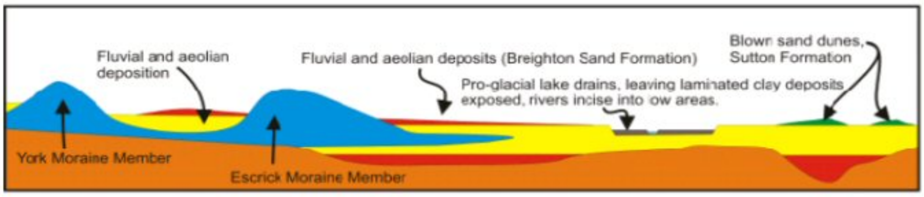
3 Ice advances over the pre-existing deposits smearing out the moraine forming part of the Vale of York Till Formation over the Hemingbrough Formation and possibly floating on the pro-glacial lake depositing dropstones from ice bergs.



4 Ice retreats, new pro-glacial lake develops and new moraine forms at Eskrick. Fluvio-glacial outwash and terraces spilling into lake.



5 Ice retreats, new pro-glacial lake develops and new moraine forms at York. Laminated clay lake deposits (Elvington Glaciolacustrine Formation) develops between the moraines and the Hemingbrough Glaciolacustrine Formation continues to be deposited in front of the Escrick Moraine Member.



6 Ice retreats completely, fluvial and aeolian pro-glacial lake drains and rivers become incised.

Figure 5.2: Glacial evolution of the Vale of York ice sheet and related proglacial deposits.

the Vale of York over-rode the early glacial lake so that laminated clay is found beneath the till in many areas. This early deposit of laminated clay is synchronous with deposits to the south where the glacial lake was not overridden. The moraines separate at least three glacial lakes that formed as the ice-sheet waned. The glaciolacustrine deposits to the south of the Escrick Moraine are the Hemingbrough Formation. Between the Escrick and York moraines there is the Elvington Formation and to the north of the York Moraine the Alne Formation.

During deglaciation, the ice retreated from the Humber Gap and the pro-glacial lake of the Vale of York drained eastwards into the North Sea. Extensive sand deposits were washed out across the floor of the recently drained lake and spreads of sand with gravel were deposited. As these deposits dried and the drainage became established, aeolian sand deposits were blown around the newly emerged lake bed forming subdued dunes of blown sand. Much of the drainage followed its previous course into the Vale such as around the front of the Escrick Moraine cutting into the glacial till, glaciofluvial outwash terraces and the associated glacial lake deposits. Other drainage followed its previous glacial course such as the River Ouse, which cuts through the York Moraine at a point near to where the glacial drainage used to emerge. The Rivers then incised their present flood plains with their flat alluvium and localised peat deposits in poorly drained areas.

5.3 LOCALITY 1 – HOLME ON SPALDING MOOR, CHURCH HILL [SE 8205 3892]

Church Hill is capped with a deposit of sand and gravel that contains numerous wind-blown cobbles and boulders. These are indicative of erosion by wind and have the typical form of dreikanter or ventifacts. The hill below the sand and gravel is Triassic Mercia Mudstone which weathers to a red soil. The flat low ground surrounding the hill is sand resting on glacial lake silts and clays. From Church Hill (if the weather is clear) there are good views over the Vale of York which allows an appreciation of the extent and low relief of the glacial and pro-glacial deposits.

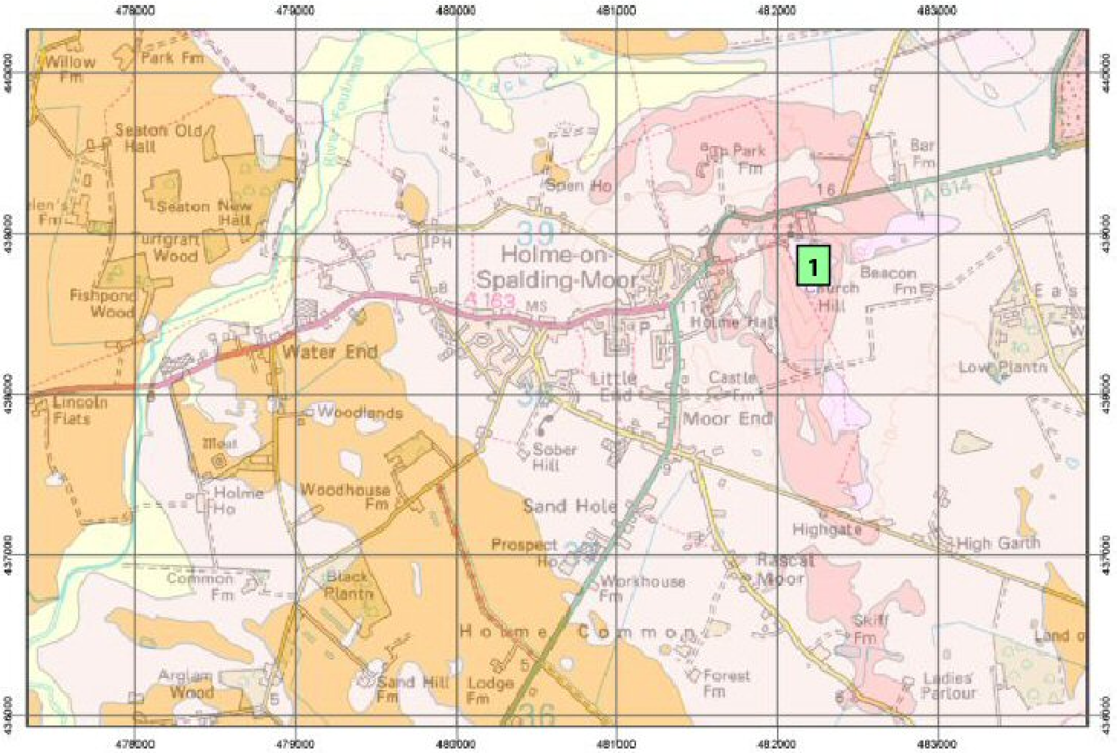


Figure 5.3: Church Hill south of the Escrick Moraine. Relics of pre-Devensian deposits cap the hill while the low ground is covered with flat sand resting upon glacial lake deposits.

5.4 LOCALITY 2 – WHELDRAKE INGS [SE 6900 4475]

At Wheldrake, the River Derwent has cut though the Escrick Moraine and runs in a narrow valley with a narrow flood plain (Figure 5.4). South of the moraine there are glacial lake deposits of the Hemingbrough Formation with overlying sands of the Breighton Sand Formation. North of the moraine there are slightly higher glacial lake deposits and sands. The alluvial deposits are wider south of the moraine partly because they have eroded into low-lying glacial lake deposits and partly because they have eroded into a sequence of fine-grained silty sand contained within the glacial lake clays, This is the Lawns House Farm Member and it separates the Thorganby Clay Member above from the Park Farm Clay Member below. This sand is water-saturated and prone to running and forms a geological hazard in the area.

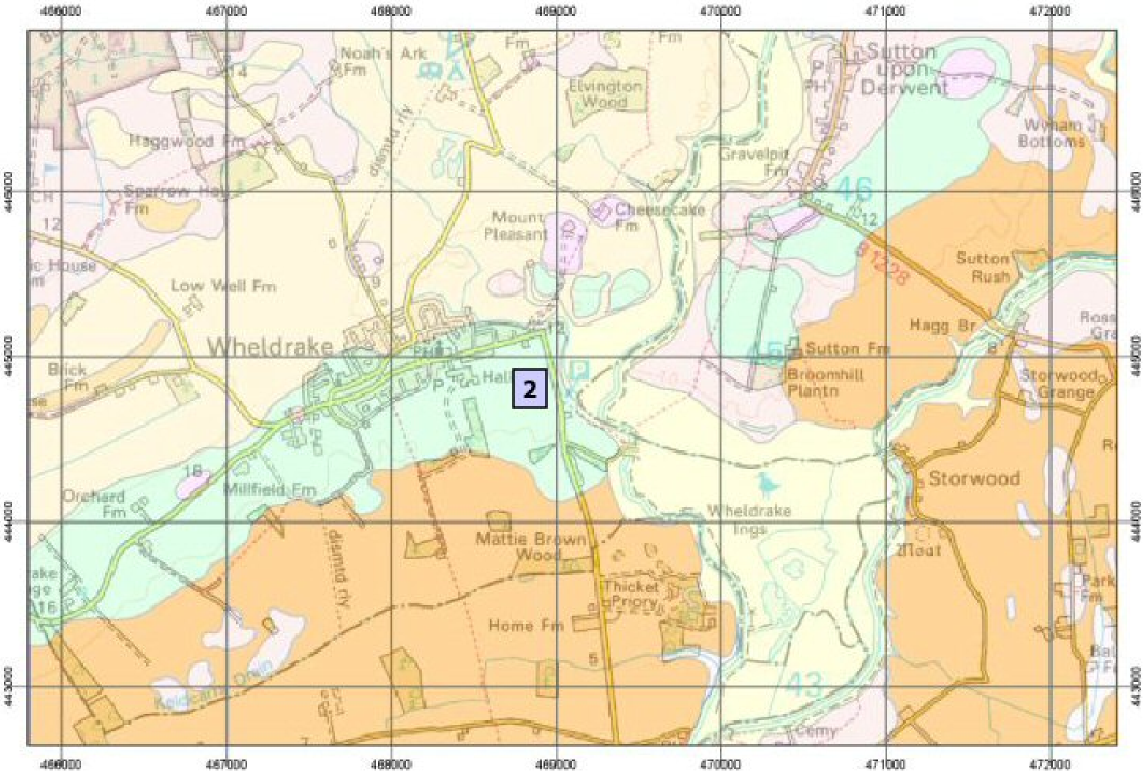


Figure 5.4: Wheldrake Ings. Alluvial deposits of the River Derwent where it has incised through the Escrick Moraine.

5.5 LOCALITY 3 – NABURN FLOOD RELIEF PONG [SE 5970 4520]

This pond (Figure 5.5) has been excavated on behalf of the Environment Agency in 2002 to retain inland floodwaters. The pond is *c*.6 metres deep and showed basal till of the Vale of York Formation overlain by the Naburn Sand Member of the Breighton Sand Formation. Slope failures along the edge of the pond indicate the contact between the two deposits.

5.6 LOCALITY 4 - CROCKLEY HILL ESKER [SE 6250 4650]

The Crockey Hill Esker deposits are up to 6 metres thick and forms a subdued ridge running in a north south direction in line with esker deposits further north. It comprises poorly sorted bedded and cross-bedded sand and gravel of predominantly Carboniferous origin. There is currently no exposure of these deposits but they have been extensively quarried along the road and at Crockey Hill itself.

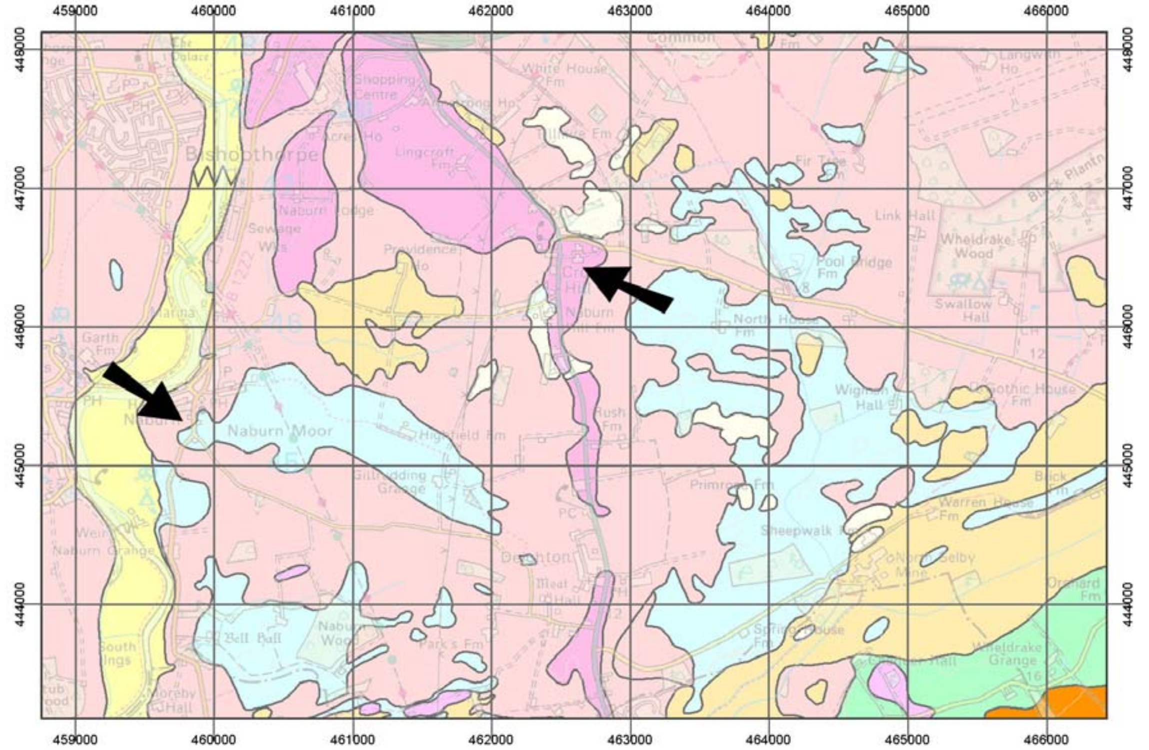


Figure 5.5: Extract from the revised 1:50k Selby map (Sheet 71) showing the position of the Naburn flood relief pond (3) and the course of the Crockey Hill Esker sand and gravel deposits along the A19 from Escrick to Crockey Hill.

5.7 LOCALITY 5 – BOSTON SPA, RIVER WHARFE GLACIAL DIVERSION [SE 4200 4600]

Before the Devensian Ice-age the River Wharfe occupied a wide valley that came down from the Pennines and spilled into the Vale of York. As the ice advanced it interrupted all the drainage and diverted the river around the margin of the ice causing it to cut a channel in the underlying Permian limestones and mudstones. A similar situation occurred at Knaresborough. Along the lateral margins of the ice sheet moraines developed and there are numerous overflow channels linking the rivers together. Drainage from the River Swale links with drainage from the Nidd, which in turn overflows along channels into the Wharfe before it enters the glacial diversion between Wetherby and Boston Spa. Note the wide flood plain to the west of Wetherby, the narrow gorge then the wide flood plain with outwash gravel terraces as the drainage enters what was the pro-glacial lake.

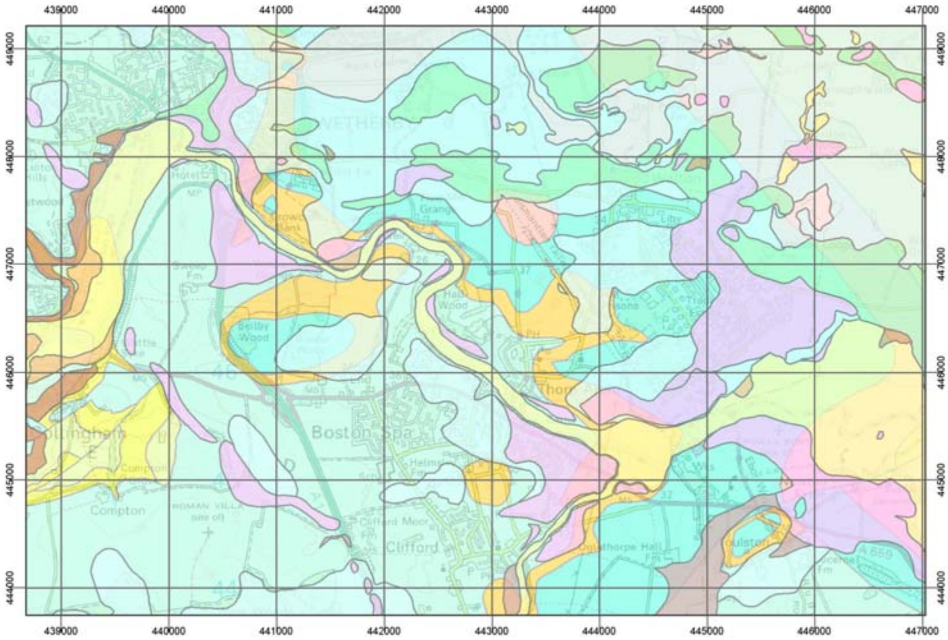


Figure 5.6: Extract from the Leeds DigMap50 model showing the diverted course of the River Wharfe from Wetherby through Boston Spa.

5.8 LOCALITY 6 – HUNSINGORE ESKER [SE 4100 5725]

The Hunsingore Esker represents a former drainage route for water and sediment within, below or upon the ice-sheet in the Vale of York. It can be traced for approximately 13km and comprises mainly sand and gravel with a small amount of laminated clay. The morphology of the esker is that of a sinuous ridge that runs in a north-north-west direction parallel to the main flow-direction of the ice. At Allerton Park this ridge stands about 15 to 30m above the level of the Sherwood Sandstone Group bedrock.

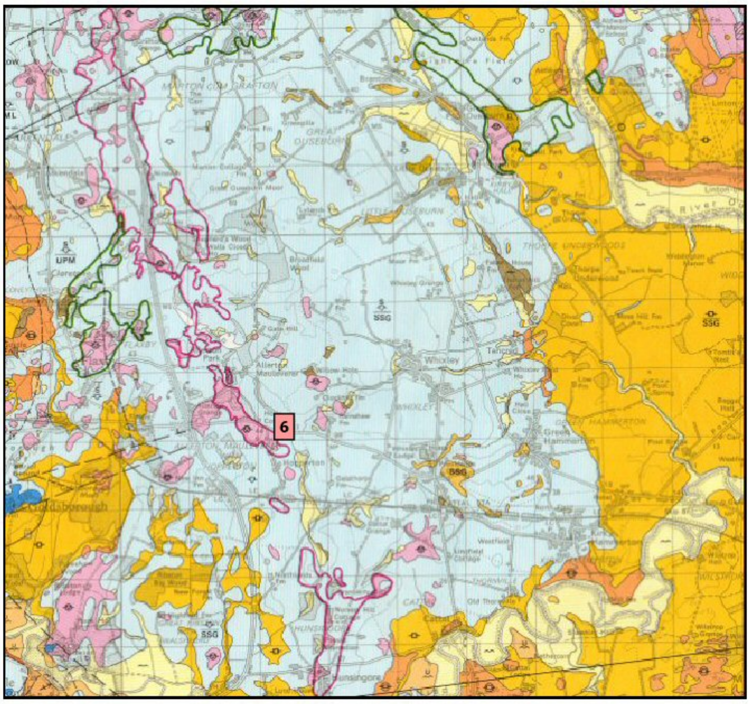


Figure 5.7: Extract from the Harrogate 1:50k map (Sheet (62) showing the position of the Hunsingore Esker and Flaxby-Tollerton moraine.

5.9 LOCALITY 7 - MONKTON MOOR, GLACIOLACUSTRINE DEPOSITS [SE 5125 5480]

Driving from Allerton Park the route descends from the till-covered and sandstone-cored ridge of the Hunsingore esker on to the low ground occupied by the glaciolacustrine lake of the Alne Formation (Figure 5.8). The area of this glaciolacustrine deposit is essentially flat around 14m OD, but rising up to 21m in some places.

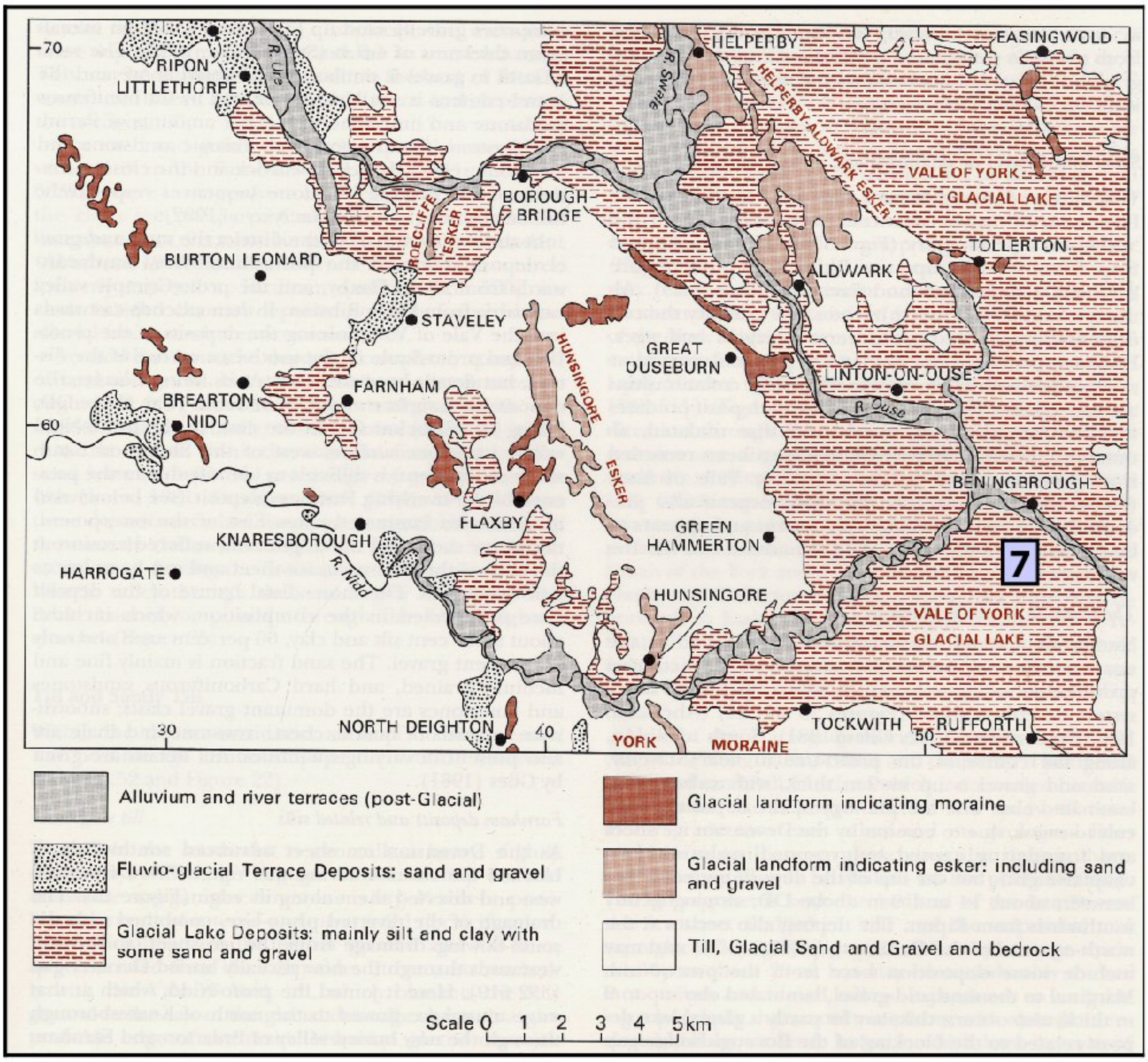


Figure 5.8: Present day distribution of glacial deposits and the extent of the Vale of York glacial lake (Alne Formation) impounded north of the York Moraine (from Cooper and Burgess, 1983).

5.10 LOCALITY 8 – YORK, ASKHAM BOGS AND YORK MORAINE [SE 5620 4790]

At the end of the Devensian, the area to the north of the York Moraine was a low wet area with very poor drainage. Consequently, a peat bog developed which is now called Askham Bogs. To the south of the bog, the York Moraine rises to a height of about 20m compared with the elevation of about 12m for the bogs themselves.

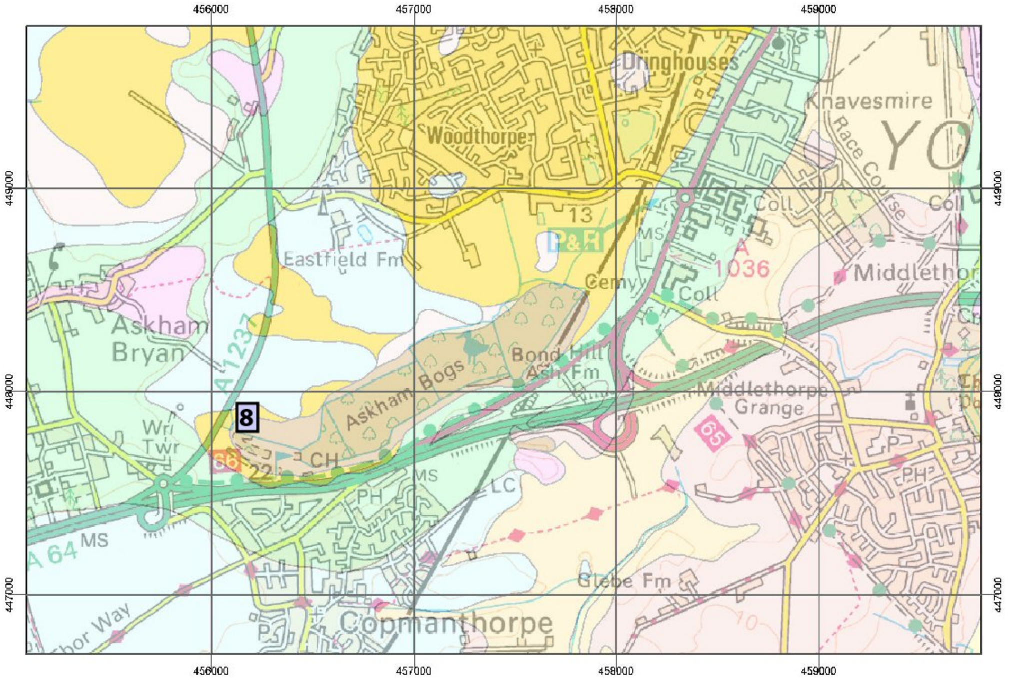


Figure 5.9: Extract from the Selby 1:50k map (Sheet 71) showing the position of the Askham Bogs to the north of the York Moraine.

5.11 LOCALITY 9 – BIFFA CLAY PIT, GLACIOLACUSTRINE SEQUENCE [SE 6210 4030]

To examine typical laminated glaciolacustrine silts and clays of the Hemingbrough Glaciolacustrine Formation (Figure 5.10), and to observe the contact with the overlying sands (Breighton Sand Formation). Detailed logging of section.

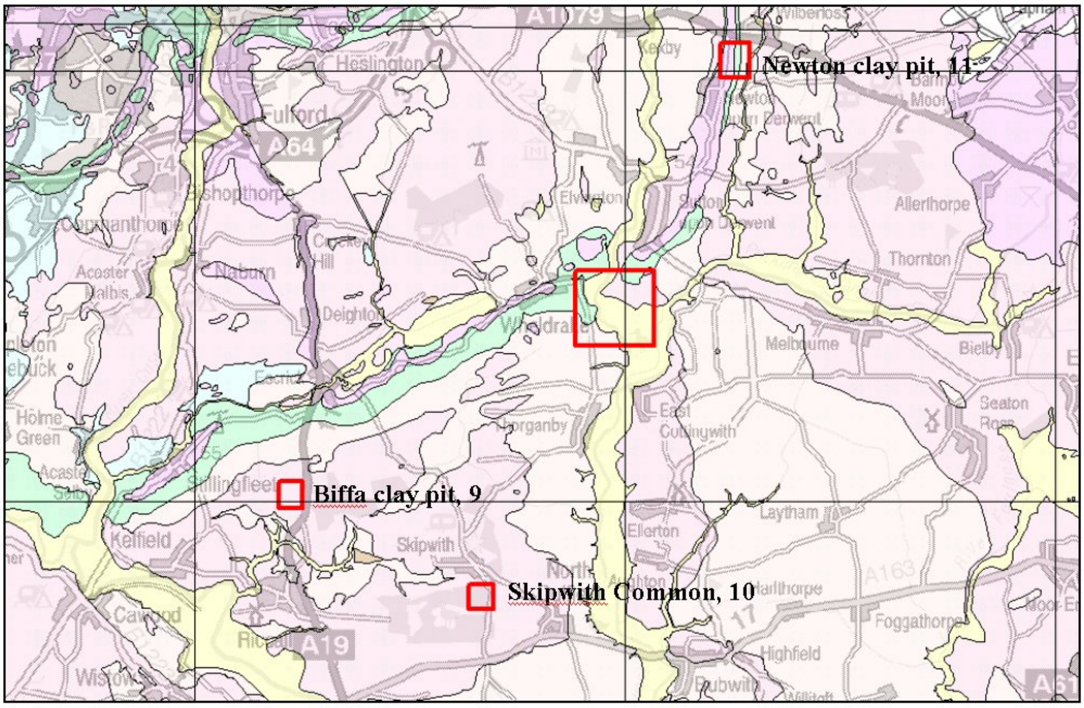


Figure 5.10: Extract from the Selby 1:50k map (Sheet 71) showing the location of sites 9-11.

5.12 LOCALITY 10 - LITTLE SKIPWITH [SE 6690 3780]

To examine latest glacial and/or post-glacial fluvio-aeolian sand including buried peat horizons (Breighton Sand Formation – Skipwith Sand Member) and evidence of former surface peat extraction (Figure 5.10). Deep augering and logging.

5.13 LOCALITY 11 - NEWTON CLAY PIT [SE 7240 5040]

To examine morainic tills, glaciotectonised lake sediments and fluvio-aeolian “cover” sands (Figure 5.10). Logging exercise of Breighton Sand Formation “cover sand” section.

5.14 LOCALITY 12 – STILLINGFLEET, MAPPING EXERCISE [SE 5950 4450]

The purpose of this locality is to complete a small mapping exercise developing upon the geological information and knowledge that you have developed from the previous localities. The location for this exercise is the land between Stillingfleet and Kelfield. A cross-section (Figure 5.12), a NextMap DSM (Figure 5.13) and LIDAR image (Figure 5.14) of the mapping exercise area are provided.

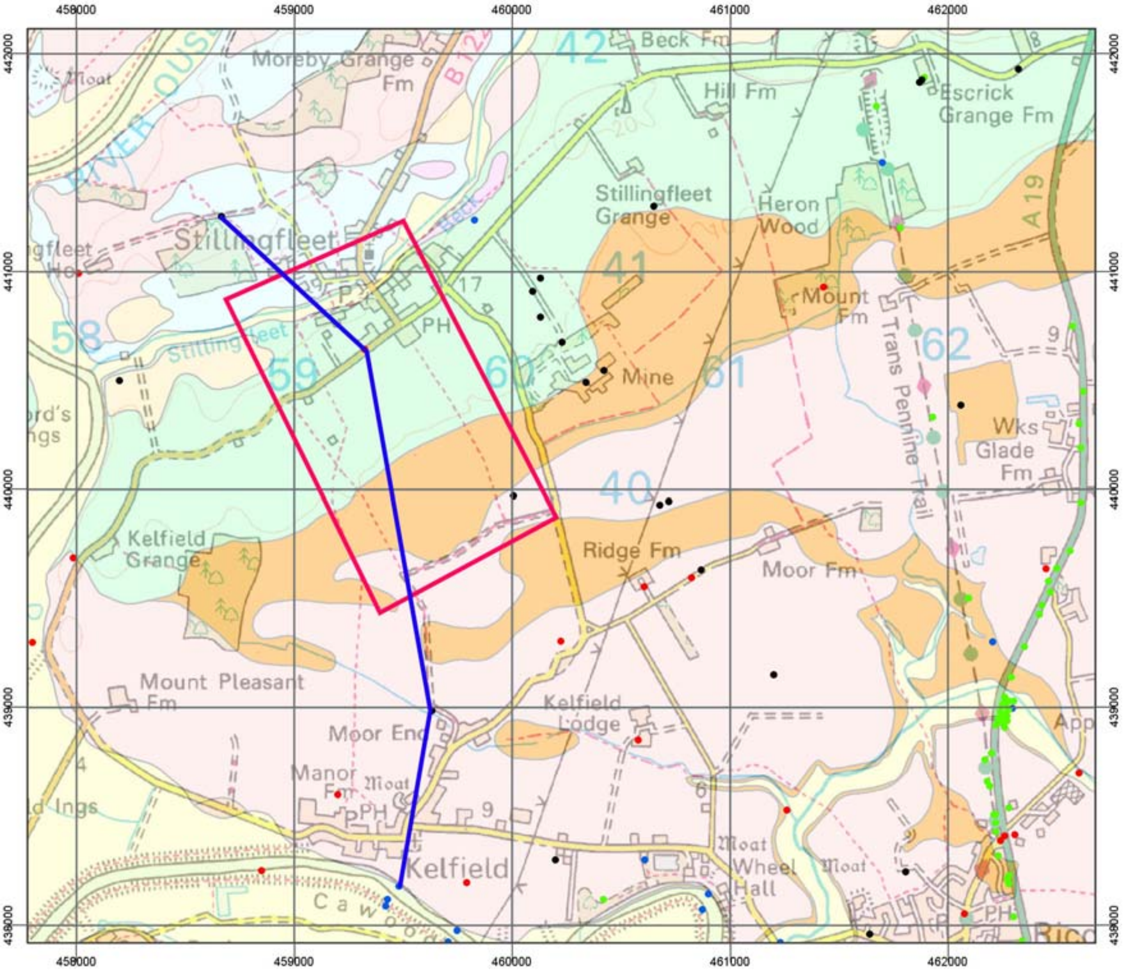


Figure 5.11: Map showing the geology and mapping exercise area (pink rectangle) near Stillingfleet to the south of York (1:50k Sheet 71 Selby; 1:10k Sheets SE54SE and SE53NE). The blue line follows a north-south section shown in Figure 5.12.

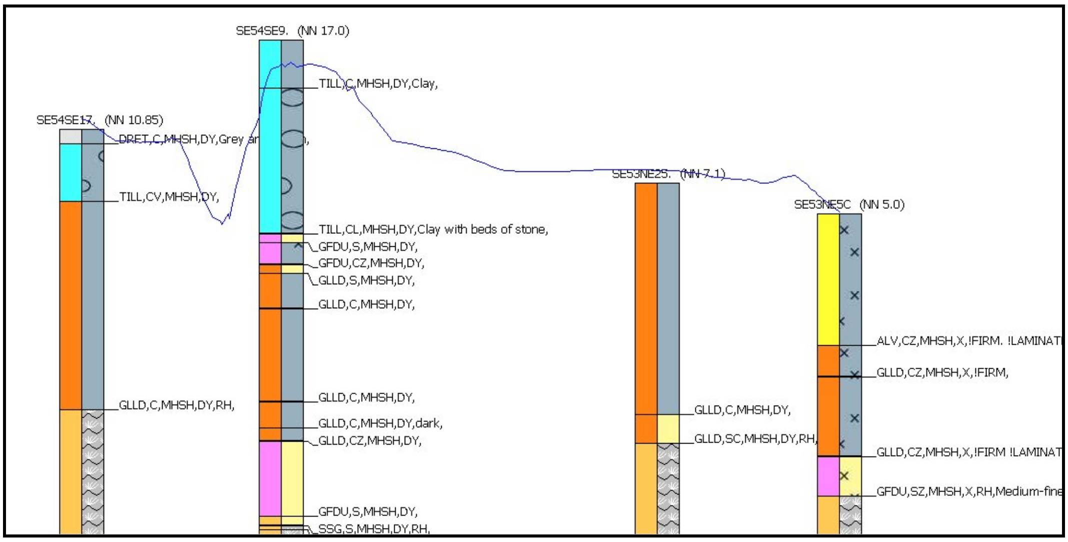


Figure 5.12: North-South cross-section across the mapping area using 4 existing boreholes. Till – blue; glaciolacustrine deposits (orange); basal glaciofluvial deposits (pink); Sherwood Sandstone (brown). The Blue Line Represents The DTM.

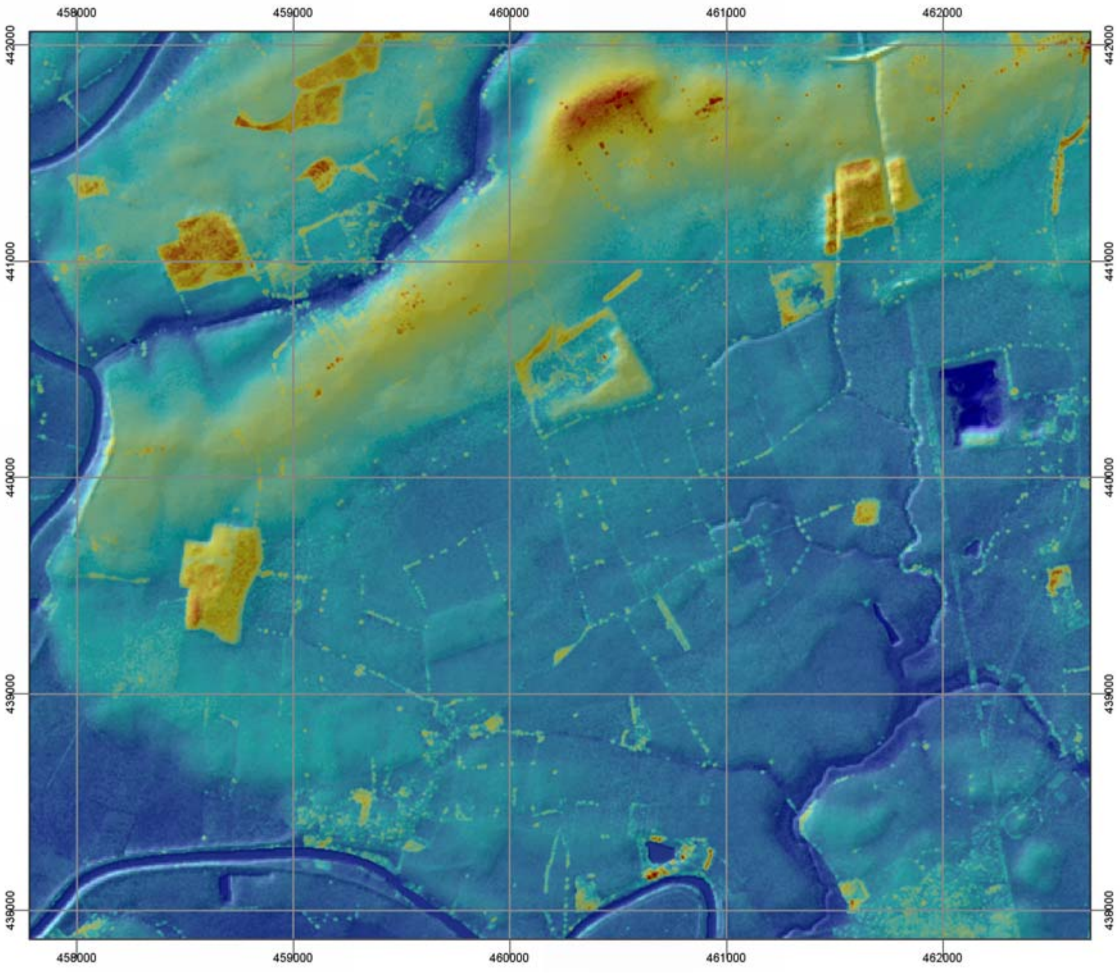


Figure 5.13: NextMap DSM 5m resolution dataset colour ramped 0-30m and 50% transparency over 4 degree shaded 10m resolution hillshade derived from the same dataset. Area depicted is the same as Figure 2.26. Note the presence of woods and trees, also at this scale of colour ramping the height of the crops show in some of the fields

Figure 5.14: LIDAR images of training area to be used during mapping showing the moraine high in dark green and floodplains in brown. (licensed by EA for training purposes only).

5.15 SUMMARY

On completion of this module, you have will have developed your basic mapping skills and gained further experienced in:

- the Quaternary and glacial history of the Vale of York
- recognising morainic and ice marginal landforms in a lowland Quaternary setting
- recognising sediments deposited at an ice margin ranging from tills to glaciolacustrine deposits
- mapping ice marginal successions and identifying links between surface form and geology

6 East Anglia Field Module

The aims of this module are:

- To relate an established stratigraphic model observable within coastal sections, to the mapping of a lowland area with little or no exposure of sediment.
- To gain and develop skills associated with shallow augering, recognising subtle landform features and soil composition, to assist in the construction of a geological map.
- To understand the practical problems associated with 'joining-up'
- To understand processes of glacial erosion and deposition and relate these to the geometry of glacial deposits.

Research questions:

- How has the palaeogeography of the study region area evolved during the Middle Pleistocene?
- What do the lithological properties of the tills tell us about their provenance and ice flow directions?
- What do spatial changes in the elevation of the base of the Lowestoft Till across the mapping area tell us about the pre-existing land-surface and processes of subglacial deposition?

Selected References:

ARTHURTON, R.S., BOOTH, S.J., MORIGI, A.N., ABBOTT, M.A.W. AND WOOD, C.J. 1994. *Geology of the country around Great Yarmouth.* Memoir of the British geological Survey, Sheet 162 (England and Wales).

HOPSON, P.M. AND BRIDGE, D.MCC. 1987. Middle Pleistocene stratigraphy in the lower Waveney Valley, East Anglia. *Proceedings of the Geologists' Association,* 98, 171-185.

LEE, J.R., BOOTH, S.J., HAMBLIN, R.J.O., JARROW, A.M., KESSLER, H.K.E., MOORLOCK, B.S.P., MORIGI, A.N., PALMER, A., PAWLEY, S.J., RIDING, J.B. AND ROSE, J. 2004. A new stratigraphy for the glacial deposits around Lowestoft, Great Yarmouth, North Walsham and Cromer, East Anglia, UK. *Bulletin of the Geological Society of Norfolk* 53, 3-60.

6.1 BACKGROUND

The area around Norwich and Great Yarmouth (Figure 6.1) has been chosen because it represents an excellent opportunity to firstly examine the Quaternary sequence in relatively well-exposed cliff sections, and secondly, to map the same sequence inland where there are few natural exposures.

During the afternoon of the first day, the group will examine coastal sections at Happisburgh. This will provide, in the form of an exercise and discussion, an introduction to the Quaternary geology of northern East Anglia as well as offering hands-on experience looking at formations and lithologies that you will encounter later in the week within the mapping area.

Days 2-4 will be spent within the mapping exercise area located adjacent to Rockland St Mary between Norwich and Great Yarmouth. The first day will be spent together as a group, looking at the various field techniques that can be used, whilst on days two and three, you will be subdivided into small groups and allocated individual mapping areas. Each group should aim to complete about one square kilometre of land. The aim is not to complete the mapping in the shortest time, but to gather as much information as possible within the period, and to interpret this information to produce a geological map. The information that you put on your field maps should enable the user to determine why you have put your geological boundaries in a particular position.

On Day 5, the party will return to Keyworth stopping off at three localities on the way (time and weather permitting) to examine some glacial sediments and landforms. These are West Runton, Weybourne and Wiveton Downs.

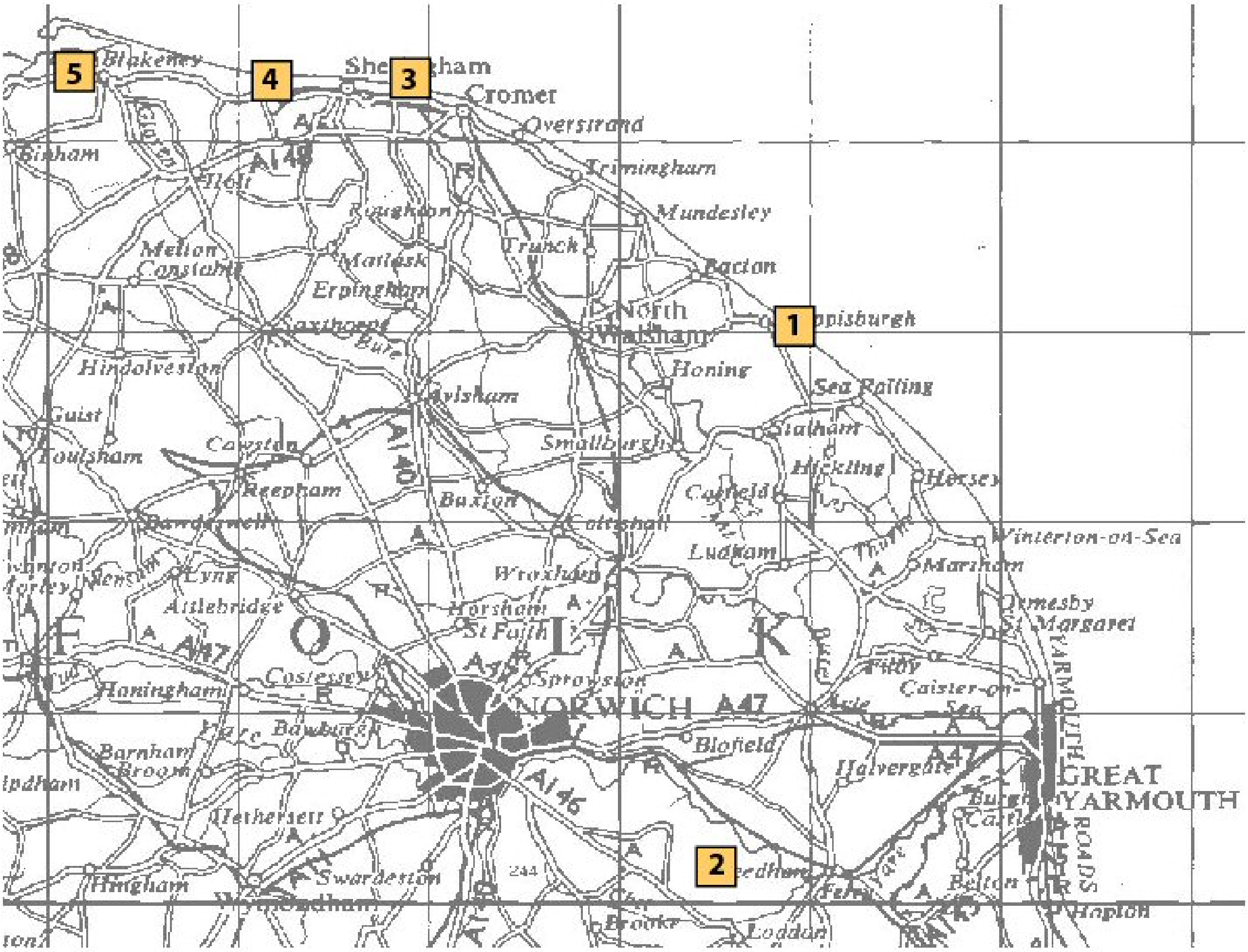


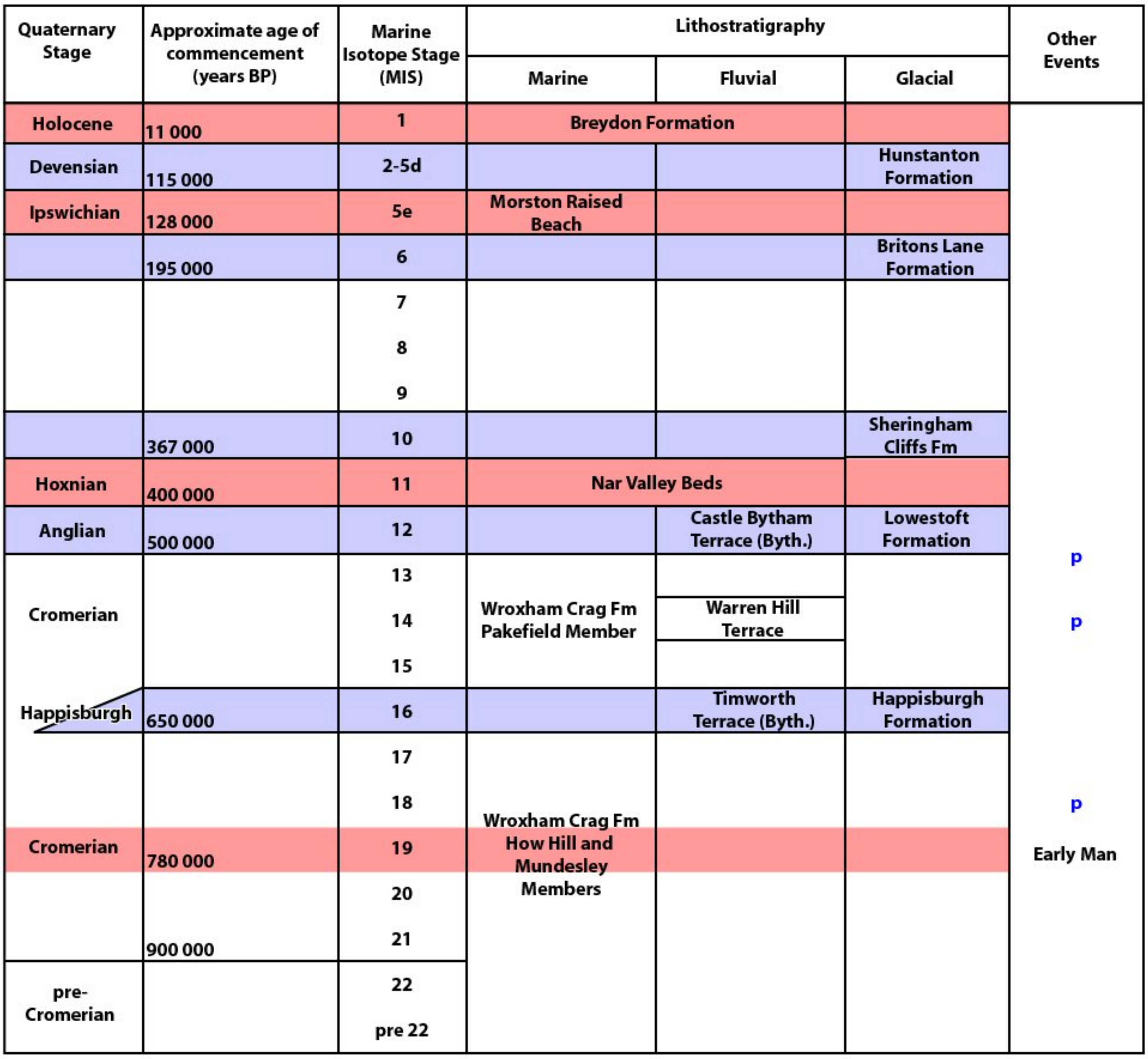
Figure 6.1: Location of sites to be visited in Norfolk. 1 – Happisburgh; 2 – Rockland St Mary; 3 – West Runton; 4 – Weybourne; 5 - Wiveton Downs.

6.2 GEOLOGICAL CONTEXT OF THE STUDY AREA

The Quaternary deposits within northern East Anglia comprise a sequence of pre-glacial shallow marine and fluvial sediments, overlain by a thick sequence of tills and associated glaciofluvial outwash deposits (Table 6.1). Post-glacial deposits include Head and the Breydon Formation, a Holocene sequence of inter-bedded peats and silts.

6.2.1 Pre-glacial deposits

The oldest deposits that will be seen during the mapping in Norfolk will be the sands and gravels of the **Wroxham Crag Formation** of the Crag Group. Note that although Quaternary in age, the Crag is regarded as Bedrock (Solid) by BGS. The sands and gravels of the Wroxham Crag are characterised by their significant content (up to about 25 per cent) of vein quartz and quartzite in addition to flint that is the dominant lithology. The quartz and quartzite have been brought into the Crag basin by the proto-Thames, the Bytham River and the Ancaster River that drained southern, midland and northern England prior to the Anglian glaciation. At the time the Great Yarmouth sheet was surveyed the sands and gravels of the Wroxham Crag were mapped as Kesgrave Formation – the fluvial deposits of the proto-Thames. More recent work has shown that the Thames did not flow this far north prior to the Anglian glaciation.



Quaternary Stage	Approximate age of commencement (years BP)	Marine Isotope Stage (MIS)	Lithostratigraphy			Other Events
			Marine	Fluvial	Glacial	
Holocene	11 000	1	Breydon Formation			
Devensian	115 000	2-5d			Hunstanton Formation	
Ipswichian	128 000	5e	Morston Raised Beach			
	195 000	6			Britons Lane Formation	
		7				
		8				
		9				
	367 000	10			Sheringham Cliffs Fm	
Hoxnian	400 000	11	Nar Valley Beds			
Anglian	500 000	12		Castle Bytham Terrace (Byth.)	Lowestoft Formation	
Cromerian		13	Wroxham Crag Fm Pakefield Member			p
		14		Warren Hill Terrace		p
		15				
Happisburgh	650 000	16		Timworth Terrace (Byth.)	Happisburgh Formation	
		17	Wroxham Crag Fm How Hill and Mundesley Members			
		18				p
Cromerian	780 000	19				Early Man
		20				
	900 000	21				
pre-Cromerian		22				
		pre 22				

Table 6.1: Stratigraphy of the Quaternary deposits in northern East Anglia. Pink highlighting indicates a demonstrated interglacial or temperate climate whilst blue shading indicates a demonstrated glacial climate. Within the 'Other Events' column, a blue 'p' refers to demonstrated periglacial episodes.

6.2.2 Glacial deposits – early stratigraphic models

Norfolk possesses some of the most extensive, thickest, and, by virtue of its long coastline, best exposed glacial sequences in the British Isles. These have traditionally been divided into three glacigenic formations, and in recent times these have been formally termed the 'North Sea Drift Formation', Lowestoft Formation, and Hunstanton Formation (Bowen, 1999). The North Sea Drift and Lowestoft formations were ascribed to the Anglian Glaciation (Marine Isotope Stage 12), while the Hunstanton Formation is ascribed to the Devensian Glaciation, MIS 2 (Bowen, 1999).

Banham (1968, 1988)	**Lunkka (1994)**
Lowestoft Till = Marly Drift	Lowestoft Till Formation, Marly Drift Member
Third Cromer Till	Cromer Diamicton Member, Mundesley Diamicton Member
Second Cromer Till	Walcott Diamicton Member
First Cromer Till	Happisburgh Diamicton Member

Table 6.2: The pre-Devensian till stratigraphy of North-East Norfolk according to Banham (1968, 1988) and Lunkka (1994).

The Anglian formations were believed to derive from two distinct ice sheets, the 'Scandinavian Ice Sheet', which entered the area from the north or north-north-east, and the 'British Ice Sheet', which entered from the west (Perrin *et al.*, 1979; Bowen *et al.*, 1986). In general it was believed that the deposits of the 'North Sea Drift Formation' were derived from the former ice sheet, since they were believed to be characterised by a suite of igneous and metamorphic erratics from the Oslofjord region, while the deposits of the Lowestoft Formation were derived from the latter ice sheet, and contain erratics derived from the Mesozoic outcrops to the north-west, principally the Chalk and Kimmeridge Clay. However, it has generally been believed that the two ice sheets co-existed (Hart and Boulton, 1991).

In north-east Norfolk, three tills were recognised within the 'North Sea Drift'. These were initially named the First, Second and Third Cromer tills (Table 6.2.; Banham, 1968), of which the middle one was noticeably more calcareous than the others. Alternative formal names were later assigned to these three tills by Lunkka (1994). The Lowestoft Formation was believed to overlie the North Sea Drift Formation, although in north Norfolk it was represented by the "Marly Drift", formed almost wholly of reconstituted Chalk, with little or no Jurassic content. A further unit of relevance here is the Briton's Lane Sand and Gravel, recorded by Banham (1968) as overlying the Lowestoft Formation.

6.2.3 Glacial deposits – new stratigraphic models

In recent years, logging of coastal sections and mapping of adjacent hinterland areas, combined with detailed lithological analysis of the geological units, have led to a complete re-appraisal of this stratigraphy. The critical stratigraphic observations include:

- Mapping in north-east Norfolk, confirmed by particle size, heavy mineral, calcium carbonate and clast lithology data, indicates that the Walcott Till (Second Cromer Till) correlates with the Lowestoft Formation in the south. This correlation of course demolishes the concept of the ‘North Sea Drift Formation’, since the Lowestoft Formation cannot co-exist in the middle of the ‘North Sea Drift Formation’.

- Mapping along the entire length of north Norfolk indicates that the “marly drift” is associated with the “Third Cromer Till” and not with the Lowestoft Formation; the “Third Cromer Till” and “marly drift” lie stratigraphically between the Lowestoft Formation and the Briton’s Lane Sand and Gravel.
- Finally, clast analysis has demonstrated that the First and Third Cromer tills of the old North Sea Drift Formation were deposited by the British Ice Sheet rather than the Scandinavian Ice Sheet as previously considered. Sporadic occurrences of Scandinavian lithologies occur within these deposits but are much more common and diverse within the Briton’s Lane Sand and Gravel.

As a result of our discoveries a new stratigraphy has steadily evolved (Hamblin *et al.*, 2000; Moorlock *et al*. 2002; Lee et al., 2004b), and our current stratigraphic and chronological model is shown in Table 6.3.

Formation	**Members**	**Proposed MIS age**
Holderness Formation		2
Briton’s Lane Formation	Briton’s Lane Sand and Gravel	6
Sheringham Cliffs Formation	Weybourne Town Till (“marly drift”) Runton Till and Bacton Green Till (3rd Cromer Till & “contorted drift”)	10
Lowestoft Formation	Walcott Till (2nd Cromer Till)	12
Happisburgh Formation	California Till Corton Till (1st Cromer Till) Happisburgh Till (1st Cromer Till)	16

Table 6.3. The revised stratigraphy proposed in this paper; the Devensian Holderness Formation is included for completeness. N.B. The youngest glacigenic deposits that we will encounter on the mapping course belong to the Lowestoft Formation, but detail on the younger glacigenic deposits is included for completeness.

6.2.4 Description and derivation of the pre-Devensian tills

The **Happisburgh Formation** includes several till members, the Happisburgh, Corton and California tills: the term Happisburgh Formation is preferred to Corton Formation used in the Great Yarmouth memoir (Arthurton *et al*., 1994) since the deposits are best exposed at Happisburgh, where both the Happisburgh and Corton tills are present and can be observed in superposition. The basal **Happisburgh Till** crops out between Happisburgh and Ostend and between Trimingham and Overstrand, and has been recorded as far west as Wickmere (between North Walsham and Cromer), while the overlying **Corton Till** crops out discontinuously from Corton to Happisburgh. Both are highly consolidated, matrix-supported diamictons with a matrix of clayey sand, and exhibit similar clast, heavy mineral, $CaCO_3$ and palynomorph content. The California Till is the upper till exposed in the cliff at California Gap. The massive Happisburgh Till is interpreted as a subglacial deformation till deposited by ice flowing from between northwest and northeast, whilst the Corton Till was deposited by a range of subglacial and subaqueous processes. At the units Corton stratotype locality, the till represents the subaqueous grounding-line position of the British Ice Sheet as its margins terminated within a standing body of water. The California Till at California Gap is a subaqueous gravity flow deposit. The tills are clast-poor, with most clasts smaller than 32mm. The clasts are dominantly rounded and angular flint, vein quartz, quartzite, chalk and shell, with less common Old and New Red Sandstone, Jurassic limestone, Magnesian Limestone, Carboniferous Limestone, coal, various metasediments, porphyry, basalt and dolerite, granite and granodiorite. This erratic suite is consistent with derivation from northern Britain.

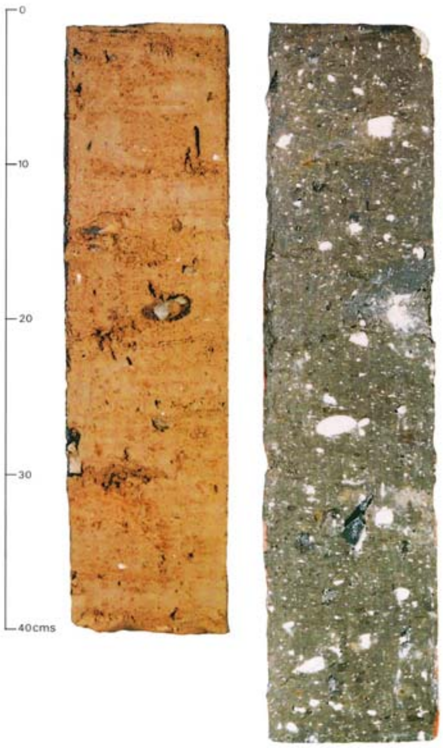


Figure 6.2: Core samples of till from the Happisburgh Formation (left) and the Lowestoft Formation (right). Note that the Happisburgh Formation till contains very few clasts of chalk whereas the Lowestoft Formation till contains abundant clasts of chalk

Allochthonous palynomorphs in the Happisburgh Formation tills include Westphalian spores (very common), Jurassic (variable), Cretaceous, particularly Lower Cretaceous dinoflagellate cysts, Cenozoic spores and pollen and Paleogene cysts. These associations confirm derivation from northern Britain and the North Sea, with the Cenozoic spores and pollen and Paleogene cysts deriving from the North Sea, Lower Cretaceous cysts consistent with the Speeton Clay of Yorkshire, and the Westphalian spores from north-eastern England or eastern Scotland, there being no Carboniferous outcrops between Norway and Norfolk.

The **Lowestoft Formation** tills differ from those of the Happisburgh Formation by their higher content of $CaCO_3$, both in the matrix and as chalk clasts (see Figure 6.2), lower sand and higher silt and clay content, and higher content of opaque heavy minerals and apatite. The typical lithology is dark grey or olive grey, silt and clay-rich, matrix-supported diamicton. The matrix is dominantly derived from the Kimmeridge Clay and other Mesozoic argillaceous rocks. Clasts are dominated by chalk (typically >80%), and flint, but also include other Mesozoic limestones and sandstones, quartz and quartzite, and a wide range of fossils from the Lower and Middle Jurassic (Lias to Kimmeridge Clay). The Walcott Till Member is interpreted as a sub-glacial deforming-bed till deposited by ice from the north-west, and it is clear from the overwhelming content of Jurassic and Cretaceous material that it derives from eastern and north-eastern England. Its spatial distribution in and adjacent to the field area for this module is largely confined to the plateau tops and interfluve areas (Figure 6.3).

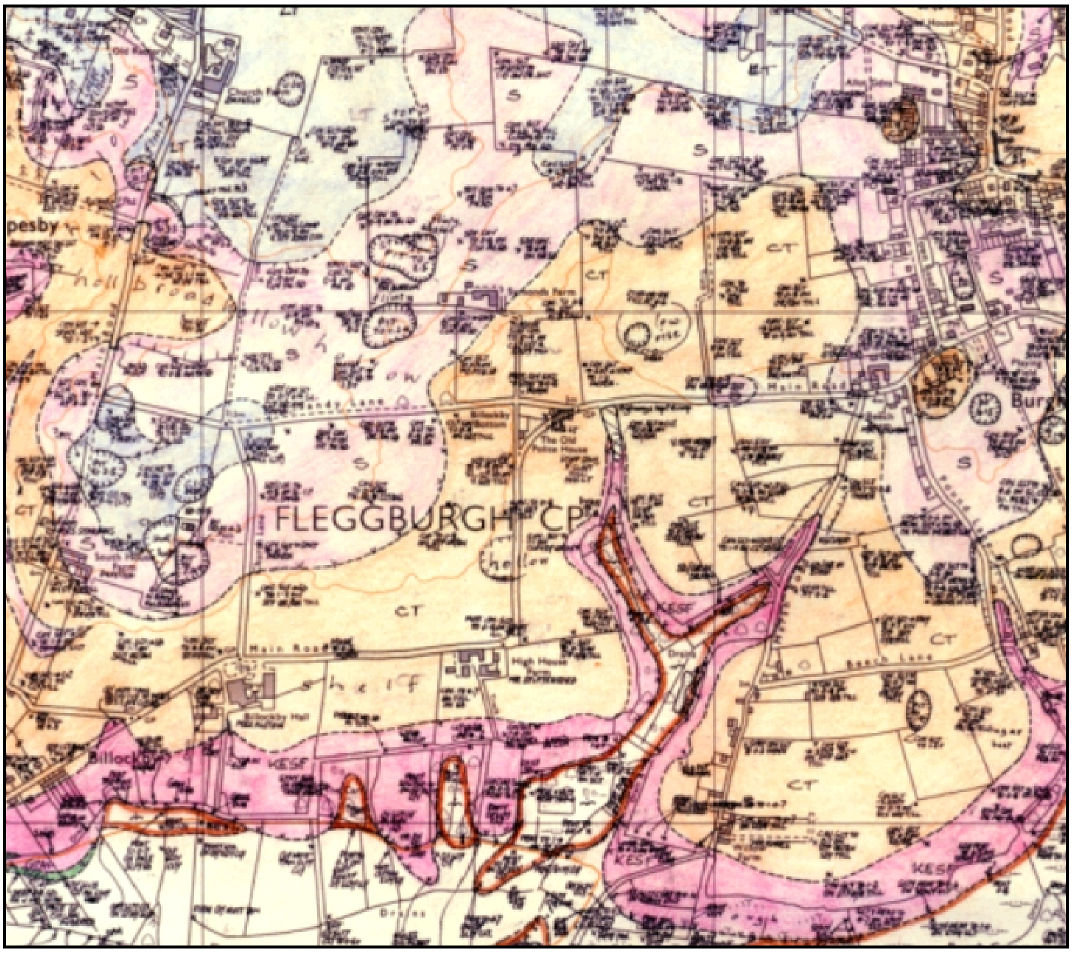


Figure 6.3: Extract from a 1:10k fieldslip near Great Yarmouth. Dark pink - Wroxham Crag Formation, orange – Corton Till Member, pale pink – Corton Sand Member, blue – Lowestoft Till, Uncoloured – Breydon Formation, Outlined with brown – Peat.

Allochthonous palynomorphs in the Lowestoft Formation confirm the derivation from eastern Britain. The till from the type site of the formation at Corton was dominated by dinoflagellate cysts from the Lower Kimmeridge Clay, with low proportions of Carboniferous and Callovian/Oxfordian palynomorphs and, surprisingly, no Cretaceous or Quaternary marker forms. Similar analysis of a sample of Walcott Till from Trimingham revealed an abundant palynoflora dominated by Jurassic species (72%), mainly Kimmeridgian and including diverse and abundant dinoflagellate cysts. Carboniferous spores accounted for only 2.8% of the sample, and again surprisingly, Cretaceous forms accounted for only 3.5%, with Quaternary, 20%.

The younger formations described below will not be seen during the course, but they are included for completeness.

The **Sheringham Cliffs Formation** includes both brown, sandy tills and “marly drift”. The former vary from heterogeneous assemblages including both massive, matrix-supported diamicton and beds of stratified sand with dropstones (Bacton Green Till Member) to massive diamicton (Runton

Till Member). Both tills contain rather more clasts than the Happisburgh Formation tills, but of similar lithologies: mainly flint, quartz and quartzite, sediments of Cretaceous, Jurassic, Permo-Triassic, Carboniferous and Devonian derivation, and igneous erratics of northern British derivation. It is interpreted as a subaqueous flow till (Lee, 2003).

The allochthonous micropalynology of the tills are dominated by Lower and Upper Jurassic forms, Toarcian and Kimmeridgian, with also consistently high populations of Westphalian and Lower Cretaceous forms, implying derivation from north-east England. Upper Cretaceous (Chalk) forms are consistently present in small quantities, while Palaeocene to Oligocene dinoflagellate cysts and Quaternary microplankton and miospores will derive from the North Sea.

The **“marly drift”** tills are pale grey or buff, massive, highly consolidated diamictons. They comprise almost entirely re-constituted chalk and black-hearted, fresh flints, with a minor Jurassic and Triassic input. This is reflected in their allochthonous micropalynology, which is dominated by Upper Cretaceous forms, with Carboniferous forms rare, and Jurassic forms rare to absent. Lee (2003) interprets these tills at Weybourne Town Pit and Trimingham as sub-glacial.

Traditionally the “marly drift” has been assigned to the Lowestoft Formation (Perrin *et al*., 1979; Lunkka, 1994; Bowen, 1999), in view of its high chalk content. However current BGS mapping shows that, throughout an outcrop extending from the north-east coast of Norfolk almost to Hunstanton, it is intimately associated with the Bacton Green Till. Together they form a major glacigenic complex which, at least in the east from the coast to Alby between North Walsham and Cromer, rests upon the Lowestoft Formation. The detailed relationships of the two facies vary considerably and form the subject of further study. In the north east, for instance at Trimingham, the brown sandy Bacton Green Till and the overlying “marly drift” form separate mappable units, while inland around Hanworth, the marly drift forms distinct masses within the massive Bacton Green Till. Within the Britons Lane borehole, a stratigraphic inversion with Bacton Green Till overlying Weybourne Town Till has been caused by ice marginal thrusting. At Weybourne Town Pit, the “marly drift” has incorporated lensoid masses of the brown sandy till as part of the subglacial deforming bed. An identical stratigraphic relationship has been recognised within adjacent coastal sections between Weybourne and Sheringham.

The **Briton’s Lane Formation** comprises sands and gravels which form a major outwash sandbur (**Briton’s Lane Sand and Gravel Member**). These deposits form the core of the Cromer Ridge, a gravel ridge over 100m high, with over 40m of bedded sand and gravel exposed in the quarry at Briton’s Lane. The mapping indicates that the formation includes the Blakeney Esker and kame terraces in the Glaven Valley. Analysis of the gravels at Briton’s Lane showed predominantly flint with significant amounts of quartzite, resistant Cretaceous rocks, Triassic red sandstone and igneous and metamorphic rocks, but an almost complete absence of Jurassic rocks and vein quartz. The igneous rocks include dolerite, rhomb porphyry, feldspar porphyry, granite, granodiorite, diorite and gabbro, with the rhomb porphyry proving derivation from the Oslofjord area of Norway. The metamorphic rocks were mostly schists with only a few samples of gneiss.

6.2.5 Chronology of pre-Devensian glaciations

The easiest formation to date is the **Lowestoft Formation**, traditionally ascribed to the Anglian glaciation, MIS 12, since this was the most extensive British glaciation and was correlated with the most prominent of the isotopic peaks representing magnitude of ice volume (Bowen, 1999). This has been confirmed by relating the glaciation to the terrace aggradations of the River Thames (Bridgland, 1994), demonstrating that the Thames was diverted to its present course by the Anglian ice sheet in MIS 12. More recently, organic deposits overlying the Lowestoft Till have been dated as MIS 11 at Hoxne, by radiometric dating

The **Happisburgh Formation** underlies the Lowestoft Formation, but traditionally it has been considered to date from the same glaciation, because of a lack of intervening interglacial deposits and in view of the model of co-existing ice-sheets (Hart & Boulton, 1991; Lunkka, 1994). However, this model has not been supported by our mapping and analytical work, and indeed the fact that the allochthonous palynology implies that the two formations have similar sources in north-east England and eastern Scotland make it unlikely, since this would require two very different deposits to derive from the same source area during the same glaciation. There are however a variety of indications that the formations represent separate glaciations. There is a strong unconformity between them, with the Lowestoft Formation resting on a deeply eroded topography cut in the Happisburgh Formation in southeast Norfolk. The Lowestoft/Walcott till is also much less weathered than the Happisburgh/Corton tills, which weather to form the "Norwich Brickearth". Also the Lowestoft Till incorporates clasts of calcrete derived from the Happisburgh Formation, implying a sufficient time gap between the two formations to allow calcrete to form within the Happisburgh Formation. Indeed analytical work examining the palaeoenvironmental signal from oxygen and carbon isotopes within these calcretes, suggests that they accreted under a more temperate non-glacial climate.

Recently, more compelling evidence has been found in the terrace deposits of the Bytham River, a pre-Anglian river which flowed from the English Midlands to the sea near Lowestoft until it was overrun and destroyed by the Lowestoft Formation ice advance during the Anglian. Large, angular erratic clasts of far-travelled rocks including mica schist, granite, Carboniferous limestone, dolerite and porphyry, glacially-derived heavy minerals and clasts of eroded and reworked Corton Till, have been recorded in the Kirby Cane Sands and Gravels, which form the third terrace of the Bytham River at Leet Hill (Lee *et al*., 2004a).

This third terrace is separated from the first Bytham terrace (associated with the Anglian Glaciation) by one major terrace aggradation and two major phases of fluvial incision plus several temperate alluvial deposits. Current models of river terrace development for mid-latitude lowland river systems suggest that river terraces aggrade during cold (glacial or periglacial) stages, downcutting and incision occurs at the transition from cold to temperate stages, and alluvial sedimentation occurs during temperate stages (Bridgland, 1994). If this model is applied to the Bytham River, it is possible to count back from the Anglian (MIS 12) and determine the age of the third terrace – MIS 16 (Lee *et al*., 2004a). This proposed age does raise a major problem with regard to microtine rodent stratigraphy, since *Arvicola terrestris cantiana* occurs in the Cromer Forest-bed Formation beneath the Happisburgh Till, and this is considered to have first appeared in MIS 15 (Preece, 2001). However, the correlation of stratigraphic sequences based upon the first and last appearance of biostratigraphic indicators and assemblages over wide spatial scales is considered ambiguous and this matter still needs to be fully resolved.

Our mapping has now demonstrated that the **Sheringham Cliffs Formation** is present throughout almost the whole width of North Norfolk, from the east coast almost to Hunstanton, and it is thus believed that this is the till present at Tottenhill near Kings Lynn (Rowe *et al*., 1997). At this site the till is recorded as passing upwards into laminated clays and sands and then peat, and radiometric age determinations on the peat indicate an MIS 9 age. It is thus proposed that the till at Tottenhill, and the Sheringham Cliffs Formation, are of MIS 10 age. This is in accord with an apparent lithological correlation between the Sheringham Cliffs Formation and the chalky Oadby Till of the English Midlands, which has been correlated with the terraces of the Thames catchment which are dated as MIS 10 (Bridgland, 1994). In the Midlands the terrace sequence only extends back to MIS 10 (Keen, 1999), implying that river development only began as the MIS 10 ice wasted. However this correlation is not guaranteed since the till outcrop at Tottenhill is not physically connected to the main outcrops of either the Bacton Green or Oadby tills, and the possibility must remain that the Sheringham Cliffs Formation belongs to MIS 12 and that the MIS 10 glaciation did not extend east of the low chalk escarpment which separates Tottenhill from the main Sheringham Cliffs Green Formation outcrop.

The **Briton's Lane Formation** rests upon a deeply eroded topography cut into the Sheringham Cliffs Formation, and differs from the pre-existing formations in that it retains constructional geomorphology in the form of the Cromer Ridge, the Blakeney Esker, and the kames in the Glaven Valley. This suggests that it is significantly younger than the Sheringham Cliffs and Lowestoft formations, since no such constructional geomorphology is found associated with British Anglian deposits in East Anglia or the Midlands. However it is not likely to be Devensian (MIS 2) since it is entirely unlike the Devensian glacigenic deposits which can be seen in Norfolk between Hunstanton and Morston. Thus it is proposed that it dates from MIS 6, which forms a major peak on the oxygen isotope scale, and that it correlates with the Basement Till at Bridlington and with the outwash gravels of the Tottenhill Member of the Nar Valley Formation in Norfolk. It is also correlated with the Dutch Saalian glaciation, which is age-constrained by MIS 7 and MIS 5e organic deposits. It is notable that the Dutch deposits are similarly of Scandinavian origin, and have similar landforms, including push-moraines on the scale of the Cromer Ridge.

6.3 LOCATION 1 – HAPPISBURGH CLIFFS [TG 381314 – TG 393305]

Happisburgh is located on the northeast Norfolk coast some 30km north of your mapping area near Norwich. The locality has been chosen because it offers an excellent opportunity to study some of the deposits that you will be mapping later in this module of the training course – thereby introducing you to the stratigraphy of the region and the properties of the geological units that you will be mapping.

The cliffs at Happisburgh stretch northwestwards between the car parks at Cart Gap and Happisburgh. At the southern end, the cliffs are 5-6m in height and protected by a range of coastal defences. After approximately 400m, the coastal defence disappear and a broad embayment opens up beneath Happisburgh lighthouse, stretching for some 600m to the village of Happisburgh where the cliffs gradually rise to a height of 8m. The cliff line in this embayment has receded about 105m between 1992-2004 and recent surveying shows that between September 2001 and September 2003, approximately 18km^3 of sediment has been lost along a single 100m section of cliff at approximately 9m per year (Poulton *et al.*, 2006). The Quaternary geology of the cliffs comprise a layer-cake sequence of tills separated by waterlain sediments and these were deposited within an ice-marginal locality (Lee, 2003).

At this locality, you will divide into small groups and each will be given a section of cliff to examine comprising different parts of the Happisburgh succession. A short document summarising the geological units that you have encountered will be provided upon completion of your exercise.

6.4 LOCATION 2 – ROCKLAND ST MARY, MAPPING EXERCISE [TG 330030]

Rockland St Mary (Figure 6.4) is the main location for this module of the mapping course. Following an introduction to the area and the mapping techniques that you may choose to employ, you will be subdivided into groups and given a small mapping area. As stated earlier, the task of each group is collect as much geological information as possible within the allocated time, in order to construct a geological map. An additional task is to liaise with adjacent groups to ensure that the stratigraphies and maps join up.

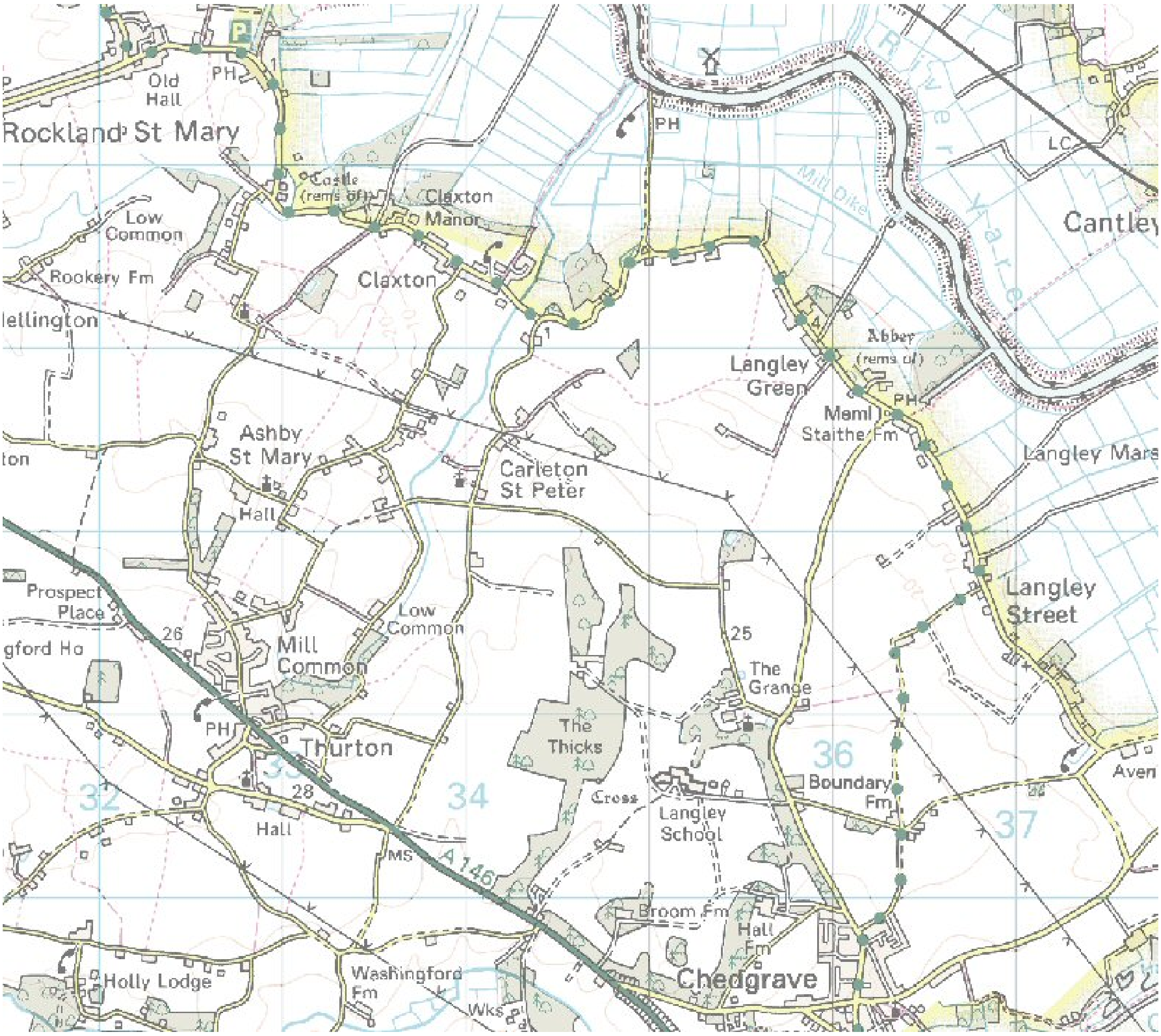


Figure 6.4: The mapping area for this module to the east of Rockland St Mary.

6.5 LOCATION 3 – WEST RUNTON [TG 185432]

West Runton is located some 10km west of the coastal resort of Cromer. At this site we shall examine some of the pre-glacial sediments including tidal marine sediments of the Wroxham Crag Formation, and alluvial deposits known as the Cromer Forest-bed. Overlying these are thick sequences of contorted glacial tills called the Runton Till and Bacton Green Till members of the Sheringham Cliffs Formation, and these in-turn are overlain by outwash deposits called the Runton Sand and Gravel Member (Britons Lane Formation). The relationship of the sands and gravels to the tills is also interesting and will be discussed. West Runton also provides the opportunity to view the spectacular chalk rafts – huge blocks of chalk that have been sheared off chalk bedrock by glaciers in the North Sea and transported southwards before being deposited in their present position. Intriguingly, in places you will see chalk bedrock overlying drift!

6.6 LOCATION 4 – FOX HILL, WEYBOURNE, CROMER RIDGE [TG 117430]

At Fox Hill, we will see the northern ice contact slope of the Cromer Ridge (Figure 6.5), a large polyphase push moraine complex that represents one of the most significant and distinctive landforms in northern Norfolk. The ridge is composed of thrust-stacked slabs of till and glaciolacustrine sediment with a thick pile of outwash sand and gravel situated on top.

Figure 6.5: The Cromer Ridge push moraine complex viewed from Beeston Hill on the eastern outskirts of Sheringham.

6.7 LOCATION 5 – WIVETON DOWNS, BLAKENEY ESKER [TG 032422]

At Wiveton Downs, we will be examining the form and sediments of the Blakeney Esker – one of the best preserved examples of an esker in lowland Britain. We will also discuss with the aid DTMs, how the geology and geomorphology can be mapped together in order to reconstruct the geological evolution and stratigraphy of the area.

6.8 SUMMARY

On completion of this module, you will have:

- developed and enhanced your understanding of the Quaternary evolvement of East Anglia
- constructed a geological map of an area of subdued relief using augering and soil brash
- gained an insight into the lithological and structural complexities of tills
- collaborated with adjacent mapping teams to ensure edge-matching between maps

7 Conclusions

You have now completed a two-week course in mapping Quaternary (superficial) deposits in Lowland Britain. We hope that you have found the course valuable and feel the areas that you have worked in over the duration of the course have provided you not just with a theoretical and practical basis for mapping of lowland Quaternary deposits, but also made you aware of the geological issues that you need to consider whilst constructing your geological map.

If you have completed and fully understood these exercises, you should now have a basic understanding of the following:

- gathering of geological information to aid mapping prior to the undertaking of fieldwork
- what is meant by a geological line and how to record geological information on a map
- a theoretical and practical understanding of the primary mapping techniques that can be utilised in the mapping of lowland Quaternary deposits
- the spatial and lithological complexity of Quaternary deposits
- how an understanding of genesis (how a geological unit was deposited) can contribute to the mapping model
- the range of Quaternary deposits that are present in Lowland Britain and their surface expression, either as landforms or by lithological clues such as ‘brash’; you have examined the following Quaternary deposits - shallow marine, river terrace deposits, alluvial floodplain, glacial tills, glaciolacustrine and glaciofluvial outwash, Colluvium, Head and Artificial Ground.

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