

# The Hydrogeological Classification of Superficial Clay:

Methodology of Map Production

British Geological Survey

R&D Technical Report W31



Further copies of this report are available from:



Foundation for Water Research, Allen House, The Listons,  
Liston Rd, Marlow, Bucks SL7 1FD. Tel: 01628-891589, Fax: 01628-472711



# The Hydrogeological Classification of Superficial Clay:

Methodology of map production.

M P Boland.

Research Contractor:  
British Geological Survey

Environment Agency  
Rio House  
Waterside Drive  
Aztec Drive  
Almondsbury  
Bristol BS12 4UD

R&D Technical Report W31



**Publishing Organisation.**

Environment Agency  
Rio House  
Waterside Drive  
Aztec Drive  
Almondsbury  
Bristol BS12 4UD  
Tel: 01454 624400 Fax: 01454 624409

NW-04/97-30-B-AYDF

**©Environment Agency 1997**

This report is the result of work jointly funded by the Environment Agency and the British Geological Survey. All rights reserved. No parts of this document may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior permission of the Environment Agency

The views expressed in this document are not necessarily those of the Environment Agency. Its officers, services or agents accept no liability whatsoever for any loss or damage arising from the interpretation or use of the information, or reliance on views contained herein.

**Dissemination Status**

Internal: Release to Regions.  
External: Release to Public Domain.

**Statement of use**

This report describes the methodology used in producing hydrogeological classification of superficial clay maps. The report should be used as a guide to the data interpretation method and assumptions in the map production process.

**Research Contractor**

This document was produced under R&D project W6/455 by:

British Geological Survey,  
Keyworth  
Nottingham NG12 5GG

Tel: 01159 363100 Fax :01159 363200

**Environment Agency Project Manager**

Mr Paul Birchall, Environment Agency, North West Region



# CONTENTS

## Executive Summary

<b>1.</b>	<b>Introduction</b> . . . . .	<b>1</b>
<b>2.</b>	<b>The Database</b> . . . . .	<b>2</b>
2.1	Data Entry . . . . .	3
2.2	Data Retrievals . . . . .	6
<b>3.</b>	<b>Map Production</b> . . . . .	<b>11</b>
3.1	Continuous clay thickness map . . . . .	13
<b>4.</b>	<b>Hydrogeological Classification of Superficial Clays map</b> . . . . .	<b>16</b>
4.1	Accompanying Solid and Drift Geology Map . . . . .	16
4.2	Main Map . . . . .	17
4.3	Representative Borehole Logs . . . . .	18
4.4	Figure A: Borehole site map . . . . .	19
4.5	Figure B: Drift Thickness . . . . .	19
4.6	Figure C: Laboratory and field measurements of hydraulic conductivity . . . . .	19
4.7	Figure D: Plot of laboratory hydraulic conductivity against porosity . . . . .	20
4.8	Figure E: Schematic cross-section . . . . .	20
<b>5.</b>	<b>Limitations</b> . . . . .	<b>21</b>
<b>6.</b>	<b>Recommendations</b> . . . . .	<b>22</b>
	Appendix A: Reports produced for East Anglia and Shropshire during the hydrogeological classification of clay projects . . . . .	24
	Appendix B: Sequence Query Language macro for retrieving continuous runs of clay from Access database . . . . .	26



Figure 1: Database form for entering data into Borehole table

Figure 2: Database form for entering data into Data table.

Table 1: Data fields in Borehole Table

Table 2: Data fields in Data Table

Table 3: Feedback from Environment Agency



## **EXECUTIVE SUMMARY**

Based on the understanding of clay hydrogeology developed during the "Hydrogeological classification of superficial clays" project a methodology was developed for presenting, in a map format, information required in interpreting the aquifer protection provided by superficial clay deposits.

The main objective was to produce 1:50000 scale hydrogeological classification of superficial clays maps for the Diss, Norfolk and Wem, Shropshire areas. The main component of each map was to be a 1:50000 scale contour map of clay thickness. The methodology of producing the map using PC based databasing and surface modelling computer packages was to be examined.

A database of borehole data held by the British Geological Survey was set up using the Access database package. The data was entered as it was recorded on the original log. No stratigraphical interpretation was added and no formalised system of entering lithological data was employed. The maximum thickness of continuous clay recorded for each borehole was retrieved from the database. The maximum thickness of continuous clay considered to be unweathered was also retrieved. This latter interpretation was based on the colour recorded in the log. A contour map was produced using the thickness of vertically continuous clay and the maximum thickness of unweathered clay were superimposed on the contour map as posted values.

This vertically continuous clay thickness map has been produced at a 1:50000 scale. Additional lithological and hydrogeological data has been presented as marginalia to this map to aid in the interpretation of the hydrogeology. This includes representative borehole logs, a borehole site map and drift thickness map, field and laboratory measured hydrogeological parameters and a schematic section through the drift sequence. A lithological interpretation based on remote sensing data is also shown on the Diss map.

The maps have been produced on transparent overlays to be used in conjunction with the existing 1:50000 scale Solid and Drift Geology maps.



The contours of vertically continuous clay thickness produced by the surface modelling package include a number of misinterpretations related to how the computer package handles the data. Although recognised, these errors have not been manually edited out of the final maps. The accuracy of the maps, and hence the validity of using this methodology, can therefore be further assessed once Environment Agency staff have had an opportunity to use the maps produced in decision making. A further refinement of the map, by delineating "hydrogeological domains", is recommended to aid interpretation of the maps.

Production of the continuous clay thickness map highlighted a number of shortcomings in the database design and recommendations regarding improvements in the database are made in the report.

**Key words:** Database, superficial clays, hydrogeological classification map, aquifer protection, fracturing, oxidation.



# 1. INTRODUCTION

This report describes the work carried out in producing the "Hydrogeological classification of superficial clays" maps for the Diss, Norfolk and Wem, Shropshire areas. The maps act as the synthesis of work carried out during a three year investigation into the hydrogeological classification of superficial clays. The principal objective of the study was to develop a cartographic methodology that would indicate the level of protection given to an aquifer by the superficial clays which overlie it. The new maps would provide information which would allow a more refined interpretation of the protection provided by the areas of black stipple delineated on the current 1:100000 scale vulnerability maps produced for the National Rivers Authority (NRA) by the British Geological Survey (BGS) and the Soil Survey and Land Research Centre.

The new maps correspond to the existing BGS 1:50000 scale Solid and Drift geology sheets 175(Diss) and 138(Wem). These sheets were selected because of their proximity to sites at which field tests were carried out and because of the volume and distribution of borehole data available for each area. The work incorporated into these maps has been previously reported in BGS Technical Reports and NRA Project Records. Map users are referred to these original documents for full descriptions of the work carried out (Appendix A).

This study into the methodology of producing "Hydrogeological classification of superficial clays" maps was carried out in two phases. Initially a computer database of all the available borehole data was created. This database was then used to create contour plots of hydrogeologically significant aspects of the drift deposits. These contour plots form the main element of the maps and are augmented by lithological and hydrogeological data relevant to the interpretation of the map.

## 2. THE DATABASE

The aim of this part of the superficial clays project was to determine whether maps could be produced by extrapolating hydrogeologically significant parameters measured in the field to large areas using existing data, primarily lithological data recorded in borehole logs.

A database was set up using the Microsoft Access package to handle borehole data. This PC based package was selected because of its relative low cost, widespread availability and its compatibility with other packages. This software is also the accepted standard within the Environment Agency.

The database contains two linked tables called Data and Boreholes. The data fields contained in each table are listed in Tables 1 and 2. The Boreholes table consists principally of borehole site information such as grid reference, borehole name, site O.D. etc. The Boreholes table also includes the BGS borehole registration number for each borehole. This field is also present in the Data table and acts as the link between the Borehole and Data tables.

**Table 1**      **Data fields in Borehole Table**

<b>Field Name</b>	<b>Field Size</b>
Borehole Number	9
Name	35
Eastings	Long Integer
Northings	Long Integer
NGR Precision	Integer
Ordnance Datum	Double
Quality	Double
Depth	Double
Drift Thickness	Double
Water Struck	Double
Water Level	Double

The Data table contains stratigraphical, lithological, colour and depth information from the borehole logs.

**Table 2 Data fields in Data Table**

<b>Field Name</b>	<b>Field Size</b>
Borehole Number	9
Stratigraphy	78
Lithology	78
Lithology Code	2
Colour	15
Colour Code	2
Fractured	
From	Double
To	Double
Thickness	Double
SPT	Double
CPT	Double
SO3	Double

The Borehole table for the Diss area contains 1104 boreholes with 5846 lines of associated lithological data held in the Data table. The tables for the Wem area holds 1005 borehole records and 4025 lines of associated lithological data.

## **2.1 Data Entry**

Data is entered using forms which show the data fields of each table. These forms are shown in Figures 1 and 2. The data tables are set up such that certain fields cannot be left blank e.g. Borehole number, and only certain input formats can be used e.g. Date as dd/mm/yyyy. The database fields were set up such that data could be entered as it was recorded on the original record. The only limit



on this was the number of characters which each field could accept e.g. the lithology field had a maximum size of 78 characters. This "freestyle" method of data entry, rather than a system of codes, meant that the original records did not have to be interpreted in terms of a set of acceptable codes. Thus data entry operators with limited geological knowledge can enter the data and the data entered is an accurate copy of the original. However complex logs, e.g. those with lithological descriptions greater than 78 characters in length, may still require an element of interpretation to assign information to the appropriate fields.

The data entered has not been systematically checked against the original paper records because of constraints on time and funding within the project. Thus the database has not been validated and may contain errors. These may take the form of typing errors, omissions or misinterpretations of the lithological log when transcribing it into the database. The data has been checked against the original records where unusual values are highlighted by the contour or posted value plots produced. However this procedure will not highlight errors where the stratigraphical, lithological or colour information in the database does not accurately reflect the original log.

**Recommendation:** Validation of the data entry should take place. Any interpretative data should be checked by a suitably qualified geologist.

## 2.2 Data retrievals

The clay map required the retrieval of thickness values for both weathered and unweathered clay from the database. This was done using the Query option in Access by specifying certain criteria to distinguish clay from other lithologies and unweathered clay from weathered clay.

Data relating to clay layers was retrieved by specifying certain criteria for the database field LITHOLOGY. It should be noted that grain size analysis showed the till to have a grain size range from silty clay to silty clay sand and thus lithologies within this range were retrieved. The criteria specified for lithology on both sheets were:

(Note: "\*" represents any character or characters)

**Acceptable**

\*clay\*

**Unacceptable**

\*clayey\*

\*with\*clay\*

\*and\*clay\*

\*,\*clay\*

\*,clay\*

\*in\*clay\*

\*+clay\*

Thus for example entries such as "silty clay" or "clay silt" would be retrieved as being suitable lithologies while entries such as "sand, clay" or "clayey sand" would not. However the range of lithological descriptions involving "\*clay\*", together with the difficulty in many cases in interpreting exactly what is meant by these descriptions, made retrievals difficult.

As well as the lithological descriptors outlined above it was found necessary on the Wem sheet to define criteria in both the LITHOLOGY and STRATIGRAPHY fields in order to retrieve clay entries. This was because of the use of the term "\*marl\*" to describe both clays within the drift sequence and calcareous mudrocks within the Pre-Quaternary sequence. Thus if the term "marl" in the LITHOLOGY field was associated with the term "Keuper Marl" in the STRATIGRAPHY field this layer was not incorporated into the clay thickness map. As with the term "clay", the range of descriptions involving "marl" meant that writing retrievals which captured all of the appropriate layers was probably not achieved. Additional terms entered against the LITHOLOGY field in retrievals of clay for the Wem Sheet.

**Acceptable**

\*marl\*

**Unacceptable**

\*marly\*rock\*

\*marl\*sandstone\*

\*marl\*SST\*

\*sandstone\*marl\*

\*rock\*marl\*

Additional terms entered against the STRATIGRAPHY field in retrievals of clay for the Wem Sheet.

### **Unacceptable**

Middle Lias

Keuper Marl

Rock

Sandstone

Keele Beds

Kinnerton Sandstone

Kuiper Marl

Lower Lias

Lower Sandstone

Mercia Mudstone

Sherwood Sandstone

Waterstone

Bunter Sandstone

Interpretation of the oxidation or weathering state of the clays was based on their colour. The criteria entered against COLOUR to retrieve unweathered clay were:

### **Acceptable**

\*brown\* in conjunction with \*grey\*

### **Unacceptable**

\*brown\*and\*grey\*

\*grey\*and\*brown\*

\*brown\* (on its own)

\*yell\*

\*red\*

\*orange\*

The map production process has identified a number of shortcomings in the database design. These have arisen because the range of properties to be shown on the hydrogeological classification of clay maps has evolved during the project through discussions with the Environment Agency end users of the map. Thus the retrievals necessary from the database in order to produce the required map changed and it was found that in some cases the original design of the database did not lend itself to the easy retrieval of the required data. The shortcomings include:

- As data has been entered in a "freestyle" rather than coded manner the large variety of lithological and colour descriptors used in the original lithological logs are present in the database. Thus queries to retrieve information are extremely complex and unwieldy.
- The summing of layer thickness where a number of successive layers of the same lithology but of a different colour occur proved problematical. If a lithological log records three successive clay layers, each 1m in thickness, with the first layer being orange in colour, the second being blue, and the third being orange then the thickness of the continuous clay layer is 3m, while the thickness of the unweathered clay layer, based on the clay colour being blue, is 1m. The database design did not allow the software to carry out a simple retrieval to sum the three layers. Initial retrievals of the maximum clay thickness in the sequence would arrive at a value of 1m.

This problem was overcome by constructing a small SQL (Standard Query Language) program to extract the necessary thicknesses. The SQL is given in Appendix B. After running a query to make a table of thickness of unweathered clay the program was run. The program compared the depths of bottoms of unweathered clays with the depth of the next thickness of clay in the same borehole. If they matched it stored a running total thickness for that clay. If the program encountered more than one thickness of clay separated by other strata it stored the individual thicknesses of clay encountered. It was then a simple task to find the maximum thickness. When it encountered a new borehole number it then stored the borehole number and the continuous thickness of clay found for the previous borehole along with the coordinates.

Due to the nature of the data being entered it would have been difficult to improve the database to avoid having to take this step. However if unweathered clay was coded as it was entered, the lithology code and colour code fields for the data table could have been utilised to flag unweathered clay at an earlier stage and a simpler retrieval mechanism used.

**Recommendation:** A coded system of data entry should be developed. The system should be designed such that the data retrievals required to produce the maps can be easily carried out.

- A problem arose on the Wem sheet which may occur on other Permo-Triassic aquifers. The term marl has been used as a lithological descriptor of both clay rich layers within the drift deposits and mudrocks within the Permo-Triassic sequence, principally the Keuper Marl. This particular problem was easily overcome where a stratigraphical unit was entered against the lithology. However this had only been done where the stratigraphy had been annotated to the original log. The interpretation of the stratigraphy of each borehole sequence is a time consuming process which requires a geologist with a detailed knowledge of the local sequence.

The lack of a stratigraphical interpretation on each borehole log inhibits the use of the database in terms of interpreting the three dimensional nature of the drift sequence as the relative stratigraphical position of some of the lithologies will be unclear. Thus to utilise the database to its full potential the borehole logs should be databased to stratigraphical level.

**Recommendation:** In future a full stratigraphical interpretation should be entered into the database

- An additional field indicating whether the borehole record is commercial-in-confidence should be added to the Borehole table.

**Recommendation:** Additional field to be added to Borehole table

### 3. MAP PRODUCTION

Throughout the course of the project Regional Hydrogeologists within the Environment Agency have been informed of progress and their comments and ideas have been sought to steer the final deliverables into a form which would be beneficial to them as end users, whilst still achieving the principal aims of the project. As a result the design and information contained on the clay classification maps has undergone refinement as a result of feedback from Environment Agency staff .

A primary concern from Environment Agency staff was that the original concept of producing a map showing vulnerability would be providing them with an interpretation of the data, rather than the data itself. It was universally accepted that for the clay maps to be a useful tool they should provide appropriate raw data which they could interpret themselves, based on their own knowledge and experience of the clays in their region. This should be supported with information generated from the project on hydrogeological properties such as permeability , clay content , particle size etc.

Table 3 shows the "wish list" generated by the Environment Agency which the map should aim to satisfy. Whilst it is accepted that all the comments are valid , it has not been practical to design a clay map based on all aspects raised. However , it is felt that at least 80%- 90% of comments and ideas have been progressed.

**Table 3          Feedback from Environment Agency Staff.**

- format of maps to be based on existing hydrogeological maps. This was a useful format for depicting a range of properties on a single map.
- Change the scale of the clay maps from the proposed 1 : 100000 to one of 1 : 50000. This would show sufficient resolution to make them useful whilst allowing them to be used in conjunction with existing drift maps.
- Use of transparent overlays was seen as a major benefit. Another reason for changing scales.
- Put as much information onto the maps as is practically possible .

- All information shown should be explained and cross referenced to the R&D records, or other sources.
- Can confidence limits be made regarding the contouring. i.e. changes in line thicknesses to represent high confidence and low confidence? Can zones be highlighted on the map if data is infrequent?
- Staff are interested in the full drift assemblages. Borehole records of key principal sites, in diagrammatical form, around the outside of the map so that the clays variability can be assessed.
- Borehole reference on the map so that they can look up the appropriate log record.
- Different label for boreholes down to rock head compared to shallow boreholes.
- Borehole distribution map useful.
- Identify separately those boreholes with QA associated with them.
- The amount of the marginalia should be big enough to support as much information as possible, but small enough so that the map can fit into standard size map cabinets.
- Show the Cover Sand as a light shading on the overlay, rather than in line work.
- What is the % coverage of unweathered till? This would be useful for recharge calculations.
- Maps need to be living documents which can be worked on. Therefore maps need to be protected, via a transparent film similar to the OS tourist information maps.
- There is a requirement that the data can be linked back to the vulnerability maps, which are currently being digitised. Is it possible that our maps/contours are digitised in the same format? (This was seen as a logical extension for future map production and a step nearer to producing a GIS system. Experience gained in this R&D project may well help to form the basis of future GIS projects.)
- Need to produce explanatory notes/guide to using the maps.
- Customise the maps to suit the regions in terms of contouring. Both Severn Trent (WEM) and Anglian (DISS) are interested in the total till thickness and unweathered till thicknesses. The format of the maps should be consistent across the country, but the clay information could vary depending on the requirements of the various regions.
- Important properties to be shown; Fissuring, Thickness, Rate of Penetration, Bulk Permeability

- The mineral assessment reports are used frequently for reference, can the R&D records and R&D note form a basic reference document?

### **3.1 Continuous clay thickness map**

The two hydrogeologically significant features of superficial clays which were to be shown on the classification map were the thickest vertically continuous clay layer within the sequence and the thickest unweathered clay layer in the sequence. The thickest single clay layer was selected over the total thickness of clay in the sequence because of the presence of preferential pathways, such as sand and gravel lenses, by which infiltration could bypass clay layers. Thus a single thick layer in a sequence may act as a more effective aquitard than a number of thin layers of equal or greater cumulative thickness distributed through the sequence.

Unweathered clay is considered to have a lower hydraulic conductivity than weathered clay due to the absence of the fracture pathways. The oxidation state is determined using the colour of the clay as recorded on the borehole logs. This is based on field observations which show that unweathered Lowestoft Till, for example, is a uniform dark colour such as grey, olive or blue, while oxidised tills have either a mottled appearance or are light colours such as orange.

The continuous clay contour map was produced using the contouring package Surfer. Three datasets, consisting of XY co-ordinates and a thickness value, were combined for contouring.

These were:

- Digitised boundary of the solid outcrop. The digitising software used was Jodphurs, a BGS in-house package which is available commercially. The package digitises lines as a series of XY co-ordinates. Each point on the line was assigned a thickness value of zero.
- Thickness of the maximum continuous clay layer, irrespective of its oxidation state, recorded in each borehole. This data was retrieved from the database.

- Those boreholes which did not intersect any clay. These boreholes were assigned a thickness value of zero.

The contours shown on the continuous thickness of clay map reflect the contouring packages interpolation between point values recorded at each borehole site and assumes a gradational variation in the measured properties. The contouring methodology treats the thickness data as if it relates to a single clay layer, although stratigraphically this is not what is present. No assessment of the lateral continuity of either the clay layers or the zones of oxidation has been attempted within the project. This limitation of the clay thickness contour must be fully appreciated by the map user.

**Recommendation** - The methodology of producing the continuous clay thickness map should be reviewed to see whether the map could be refined to indicate the probable lateral continuity of the point data on clay thickness and oxidation state.

The volume and quality of borehole data available affects the contour pattern produced in a number of ways:

- Uncertainty exists where the boreholes do not fully penetrate the drift sequence, as clay layers which are unaccounted for in the contour map may exist beneath the base of the borehole. However the contours based on the existing data indicate a level of protection which can only be improved by the existence of further clay layers.
- The contours produced reflect the data volume and distribution available to the contouring software and a number of artifacts are present in the contours related to this. This is most obvious around the buried valleys where the contouring package produces a "bullseye" effect around the extreme thickness values encountered. The contours also show a gradational change from thicknesses measured on the flanks to those from the valley fill. Neither of these contour patterns correspond to the geological interpretation of the data which would show contour values increasing rapidly at, and forming an elongate pattern parallel to, the

valley margins. This pattern could be imposed on the contour map by inputting a number of dummy values corresponding to the interpreted thickness at the valley margins and the valley centre.

The maximum thickness of unweathered clay recorded in each borehole is shown as posted values superimposed on the clay thickness contours. This provides a qualitative indication of the degree of weathering which has occurred and hence on the effectiveness of the clay layer as an aquitard.

The use of colour as an indication of oxidation state is dependent on these colours having been recorded, and recorded accurately, in the borehole logs. However many borehole logs do not record colour against lithology and thus the absence of a posted value does not necessarily mean that the entire sequence is weathered. Also the fact that colour is a subjective parameter means that the reliability of each interpretation must be accepted with some caution. Boreholes drilled as part of the BGS sand and gravel mineral assessment programme recorded colour using the Rock-Color Chart or "Munsell Color Chart" authorised by the Geological Society of America. The colour interpretation of these borehole logs will be therefore be more accurate. The location of these BGS boreholes is indicated both for the posted values on the main map and as part of the borehole location figure included in the map marginalia.

## **4. HYDROGEOLOGICAL CLASSIFICATION OF SUPERFICIAL CLAYS MAP**

The map provides a synthesis of the work carried out as part of the superficial clays project and aims to show the regional variation of one or more hydrogeologically significant features. The area of coverage selected corresponds to existing 1:50000 scale solid and drift geology maps. This has been done so that the new maps can be directly used as an addition to the already available geological information. Field studies were carried out to examine the hydrogeological nature of superficial clays overlying Chalk and Permo-Triassic aquifers and it was decided to continue this comparison between aquifer types to the map production. The two maps selected were Sheet 175 (Diss) on the Chalk aquifer and Sheet 138 (Wem) on the Permo-Triassic aquifer. Both areas contained a reasonable number of borehole records that were spread over the area rather than clustered.

As well as contoured data at the 1:50000 scale additional, more site specific data is included in the margins of the map. This information includes grain size, porosity and hydraulic conductivity data together with borehole logs indicating the lithological variability found in the sequence.

Each of the elements of the map is described below.

### **4.1 Accompanying Solid and Drift Geology Map**

The existing geological map should be used to determine information about the nature of the surface geology. The two areas selected demonstrate that the quality of the geological map which is to be used in conjunction with the "Superficial clays" overlay may vary considerably. The Diss sheet was remapped as recently as 1986, with the 1:50000 map being published in 1989. Thus the map reflects a recent stratigraphical interpretation based probably on most of the data currently available. The Wem sheet however was last mapped in 1911-22, the map being published at 1 inch scale in 1924. The solid geology was subsequently amended in 1963. The current map is a facsimile enlargement of the 1 inch map to 1:50000 scale, however this scale alteration has not been carried

out accurately and the map scale is approximately 1:49800. The "Hydrogeological classification of superficial clays" map has been produced to overlay the existing geology map and in the case of Wem the scale difference means that it cannot be directly overlaid onto a 1:50000 scale Landranger topographic map.

The Wem sheet is also an interpretation of the geology based on less data than is now available and using a less evolved understanding of the local geology e.g. no information derived from the BGS sand and gravel drilling programme will have been incorporated into this published map.

The fact that an area has not been recently surveyed means that the borehole logs are unlikely to be annotated with a stratigraphical interpretation. Thus no stratigraphy will have been loaded into the database, which limits its use in terms of interpreting the three dimensional geometry of the drift deposits.

The more modern geology maps give much more additional information in their margins, such as detailed cross sections and rockhead contour maps. This interpreted information should aid map users in conceptualising the local geology.

The two areas contrast in the extensiveness and lateral continuity of the surface drift deposits. The Diss area has a restricted area of Chalk outcrop, and extensive area of till, and two areas of more complex drift geology, one along the western margin of the sheet, and the other associated with the River Waveney along the southern margin of the sheet. The Wem sheet in contrast has much more extensive outcrop and more variable surface drift deposits.

## **4.2 Main map**

The principal element of the main map is the contour of continuous clay thickness, which is based on the thickest single clay layer recorded in each borehole. This contour was produced using the methodology described in section 3.1.

Although the contouring software has extrapolated between the thickness values as if they relate to a single layer, it should be noted that this is not what is happening in the drift sequence. The thickest clay layer in the sequence may occur at different levels in different parts of the area. This interdigitation of clay layers with possibly more permeable deposits may provide routes by which infiltration may bypass the clay layers. Further information on the three dimensional nature of the drift deposits will be derived from the representative borehole logs, drift thickness diagram and the cross sections shown on the Solid and Drift geology maps.

The maximum thickness of unweathered clay recorded in each borehole is shown as posted values superimposed on the clay thickness contours. This provides a qualitative indication of the degree of weathering which has occurred and hence on the effectiveness of the clay layer as an aquitard.

Field mapping on the Diss sheet identified the presence of a discontinuous 1m thick layer of well sorted sand which postdated the Lowestoft Till. The patchy nature of this thin deposit, termed cover sand, meant that it was not systematically mapped and has not been shown on the existing geological maps. However core drilled at the Uphall Farm site during this project showed the presence of a perched water table within the cover sand and oxidation of the underlying Lowestoft Till to a depth of 8m. Remote sensing techniques have been used to delineate areas of cover sand and these are shown on the map..

### **4.3 Representative Borehole Logs**

These borehole logs indicate some of the range of lithological variability that may occur. These logs are in no way a comprehensive guide to the complete range of lithological variability however. Together with the geological map they may provide an indication of the three dimensional lithological variation which might be expected at a given site. Other adjacent borehole information, as indicated by the borehole site map, which is held in the BGS archive should also be consulted.

#### **4.4 Figure A: Borehole site map**

This diagram shows the distribution of borehole information used in the production of the map. This provides a qualitative assessment of the reliability of the contouring at any point, based on data density. The quality and completeness of each borehole record is indicated by using different borehole symbols depending on whether the borehole fully penetrated the sequence and on whether the borehole was logged by the BGS. This latter point relates to the fact that the lithological colour descriptions in the BGS logged boreholes were made using a Munsell colour chart and thus interpretations of oxidation state based on colour can be made with some certainty.

#### **4.5 Figure B: Drift Thickness**

This contour map was produced using the contouring methodology described in section 3.1. The quality of the contours is dependent on the volume and distribution of data and on whether the boreholes fully penetrated the borehole sequence. The volume and distribution of data particularly affects the contour pattern where rapid changes in drift thickness occur e.g. along buried valleys. Both the position of the buried valleys and the drift thicknesses within them are highly conjectural.

#### **4.6 Figure C: Laboratory and field measurements of hydraulic conductivity**

These diagrams indicate the range of hydraulic conductivity values measured as part of the project at sites on the map areas. The variation in values against a logged borehole section is shown to indicate changes with depth/lithology/oxidation state. The difference between laboratory and field measured values from the same section are also shown, indicating the importance of the fracture permeability element which is missed by the laboratory tests.

#### **4.7 Figure D: Plot of laboratory hydraulic conductivity against porosity**

This diagram indicates how hydraulic conductivity changes with variations in porosity. The diagram includes both data generated as part of this project and values taken from existing site investigation reports. Hydraulic conductivity was measured using three different methods and the variation in results obtained by the different methods can be examined.

#### **4.8 Figure E: Schematic cross-section**

This schematic cross section shows some of the range of changes in lithology, thickness and oxidation conditions that may occur within the drift sequence. Oxidation may or may not occur both at the surface and base of the drift sequence. Oxidation may occur preferentially adjacent to certain lithologies or stratigraphical units. This schematic cross section should be used together with the actual cross sections shown on the geological map and the representative borehole logs to identify the possible range of three dimensional variation that might exist at a given site.

## 5. LIMITATIONS

A number of caveats about the accuracy of the vertically continuous clay contour map, relating to both the quality of the data used and the way this data was contoured by the software package, have been made in this report. These are repeated below and should be fully appreciated by the map user.

The contours produced reflect the data density and spatial distribution available to the contouring software and a number of artifacts are present in the contours related to this. This is most obvious around the buried valleys where the contouring package produces a "bullseye" effect around the extreme thickness values encountered. The contours also show a gradational change from thicknesses measured on the flanks to those from the valley fill. Neither of these contour patterns correspond to the geological interpretation of the data which would show contour values increasing rapidly at, and forming an elongate pattern parallel to, the valley margins. The contours shown on the continuous thickness of clay map reflect the contouring package's interpolation between point values recorded at each borehole site and assumes a gradational variation in the measured properties.

**Although the contouring software has extrapolated between the thickness values as if they relate to a single layer, it should be noted that this is not what is happening in the drift sequence.** The thickest clay layer in the sequence may occur at different levels in different parts of the area. No assessment of the lateral continuity of either the clay layers or the zones of oxidation has been attempted within the project. This limitation of the clay thickness contour must be fully appreciated by the map user.

The use of colour as an indication of oxidation state is dependent on these colours having been recorded, and recorded accurately, in the borehole logs. However many borehole logs do not record colour against lithology and thus the absence of a posted value does not necessarily mean that the entire sequence is weathered. Also unless the colour has been recorded using the Munsell system the description will be subjective and therefore the reliability of each interpretation must be accepted with some caution.

## **6. RECOMMENDATIONS**

This report outlines a methodology which allows borehole records to be easily databased. Data on clay thickness and oxidation state is retrieved based on criteria provided by field studies. A clay thickness map based on this data is combined with a range of laboratory and field measured hydrogeological parameters which relate to clay samples from the map area. A number of recommendations relating to the methodology of map production have been made through this report and these are repeated below. These recommendations relate principally to the databasing procedure as comments about the hydrogeological significance of the clay will be contained in R & D Technical Reports W28 and W29.

Conclusions and recommendations as to the value, applicability and validity of the maps which have been produced is best provided by the end users in the Environment Agency regional offices. As has been stated in this report comments on the process have been sought, and where possible acted upon, throughout this project. However the main assessment of the finished maps will be generated by their use.

The following amendments to the methodology should be considered:

- Validation of the data entry should take place. Any interpretative data should be checked by a suitably qualified geologist.
- A coded system of data entry should be developed. The system should be designed such that the data retrievals required to produce the maps can be easily carried out.
- A code should be entered against the clay lithologies to allow this retrieval to be carried out.
- In future a full stratigraphical interpretation should be entered into the database

- An additional field indicating whether the borehole is commercial in confidence should be added to the Borehole table
  
- The methodology of producing the continuous clay thickness map should be reviewed to see whether the map could be refined to indicate the probable lateral continuity of the point data on clay thickness and oxidation state.

## **Appendix A:**

### **Reports produced for East Anglia and Shropshire during the hydrogeological classification of clays project.**

#### **East Anglia.**

The hydrogeological classification of superficial clays: 1. Tills of East Anglia. *Environment Agency R&D Technical Report W28*

Busby, J.P., Peart, R.J., Meldrum, P.I. and Beamish, D. (1995) Hydrogeological classification of superficial clays: Apparent resistivity measurements from the Garboldisham , Norfolk pilot study area. *British Geological Survey Technical Report WN/95/11 : NRA Project Record 455/02E/NW*

Entwistle, D.C. (1994) The laboratory measurement of of hydraulic conductivity of glacial till from Norfolk and Essex. *British Geological Survey Technical Report WN/94/49C : NRA Project Record 455/02C/NW*

Hopson, P.M. and Morigi, A.N. (1993) Hydrogeological classification of superficial clays: Report on the detailed field mapping to characterise the till in Elmdon, Essex and Garboldisham, Norfolk pilot study areas. *British Geological Survey Technical Report WA/93/49 : NRA Project Record 455/02B/NW*

Inglethorpe, S.D.J. and Bloodworth, A.J. (1994) Definition and classification of till sequences from East Anglia as an aid to aquifer vulnerability assessment. *British Geological Survey Technical Report WG/94/19 : NRA Project Record 455/02D/NW*

Klinck, B.A. and Wealthall, G.P. (1995) The hydrogeological classification of superficial clays: East Anglian tills. *British Geological Survey Technical Report WE/95/37 : NRA Project Record 455/02A/NW*

O'Connor, E.A. (1994) Hydrogeological classification of superficial clays: Remote sensing investigations. *British Geological Survey Project Note RSG/94/3 : NRA Project Record 455/02F/NW*

Klinck, B.A., Barker, J., Noy, D.J. and Wealthall, G.P. (1996) Mechanisms and rates of recharge through glacial till: Experimental modelling studies from a Norfolk site. *British Geological Survey Technical Report WE/96/1*

### **Shropshire:**

The hydrogeological classification of superficial clays: 2. Tills of Shropshire. *Environment Agency R&D Technical Report W29*

Entwistle, D.C. (1996) Laboratory measurement of hydraulic conductivity of lodgement till and lacustrines from Shropshire. *British Geological Survey Technical Report WN/96/4C : NRA Project Record 455/03A/NW*

Inglethorpe, S.D.J., Evans, E.J. and Shaw, D.J.P. (1996) Mineralogical characteristics of samples of Shropshire Till: A factual report. *British Geological Survey Technical Report WG/96/4 : NRA Project Record 455/03C/NW*

MacDonald, D.M.J. (1995) Estimating groundwater recharge through glacial till at Bacon Hall, Shropshire. *British Geological Survey Technical Report WD/95/22 : NRA Project Record 455/03D/NW*

Wealthall, G.P., Brandon, A. and Klinck, B.A. (1996) The hydrogeology and hydrochemistry of glacial till and glacio-lacustrine sediments in Shropshire. *British Geological Survey Technical Report WE/96/6 : NRA Project Record 455/03A/NW*

## Appendix B:

### Sequence Query Language macro for retrieving continuous runs of clay from Access database

Option Compare Database 'Use database order for string comparisons

Function control\_function ()

    max\_thickness

End Function

Sub max\_thickness ()

Dim MyDb As Database, My\_set As Recordset, Out\_set As Recordset

Dim total As Double

Dim Flag As Integer

    Flag = 0

Set MyDb = DbEngine.Workspaces(0).Databases(0)

Set My\_set = MyDb.OpenRecordset("SELECT \* FROM UnweatheredClay ORDER BY  
[Borehole Number], [From]")

Set Out\_set = MyDb.OpenRecordset("Thickness")

My\_set.MoveFirst

Do Until My\_set.Nomatch

    BHID = My\_set![Borehole Number]

    top = My\_set![From]

    east = My\_set![Eastings]

    north = My\_set![Northings]

Debug.Print BHID

```
If BHID = BHIDB And bottom = top Then
Flag = 1
Else Flag = 0
total = thick
End If
```

```
Debug.Print Flag
```

```
BHIDB = My_set![Borehole Number]
thick = My_set![Thickness]
bottom = My_set![To]
```

```
If Flag = 1 Then
total = total + thick
Else total = thick
End If
```

```
Debug.Print BHIDB
Debug.Print thick
Debug.Print total
```

```
Out_set.AddNew
Out_set("[Borehole Number]") = BHID
Out_set("[Thickness]") = total
Out_set("[Eastings]") = east
Out_set("[Northings]") = north
```

```
Out_set.Update
```

```
My_set.MoveNext
```

```
Loop
My_set.Close
```

Out\_set.Close

End Sub

