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# Strategy, Location and Sampling of the Lias Group (2). Ground Movements: Shrink/Swell Project.

Urban Geoscience and Geological Hazards Programme  
Internal Report IR/03/074





BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/03/074

# Strategy, Location and Sampling of the Lias Group (2). Ground Movements: Shrink/Swell Project.

**K. A. Freeborough & L. D. Jones**

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# Foreword

This report is the published product of a study by the British Geological Survey (BGS). It refers to the work carried out on behalf of a Science Budget funded research project, under the Urban Geoscience & Geological Hazards Programme of the BGS.

# Acknowledgements

A large number of individuals in the BGS have contributed to the project. This assistance has been received at all stages of the study. In addition to the collection of data, many individuals have freely given their advice, and provided the local knowledge so important to the project. Key staff have helped to review draft chapters of this report. Of the many individuals who have contributed to the project we would particularly like to thank the following:

Prof. M. G. Culshaw  
Mr A. Forster  
Mr P. R. N. Hobbs  
Mr M. A. Sumblar

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# Summary

The authors published a report in 2002 describing the sampling of argillaceous formations of the Lias Group at twenty-eight sites in South Wales, Eastern and Southern England. This report forms an addendum to the original report and describes the sampling of further Liassic formations in the counties of Nottinghamshire and Lincolnshire.

Weathered and unweathered material was collected as undisturbed block samples and disturbed bulk samples from exposed faces. The samples were taken to give representative geotechnical properties of the lithostratigraphic formations of the Lias Group present at the sampling sites in a weathered and unweathered condition, if possible.

The location of each site is described briefly and is indicated on a 1:50K OS map base. The stratigraphic units present at the site are listed and the site indicated on a 1:50K geological map base. Photographs of sections and sampling sites are also present. The types of samples taken from each site are specified and difficulties regarding the sampling are indicated where appropriate.

# 1. Introduction

This report is concerned with the location, collection and sampling, by various methods, of test specimens from Nottinghamshire and Lincolnshire, for the determination of the shrinking and swelling properties of argillaceous formations within the Lias Group. It contains information relating to the sampling methods and the sample sites, descriptions and locations. All the samples were collected by members of the Shrink/Swell Project team of the British Geological Survey.

This work was carried out for the Ground Movements: Shrink/Swell Project (ESB8390006703), under the leadership of Lee Jones. This Science Budget funded research project forms a part of the Geohazards and Risk Sub-Programme, under Alan Forster, which itself forms part of the Urban Geoscience and Geological Hazards Programme, under Professor Martin Culshaw.

The main aim of the project is to determine the shrinkage and swelling properties of UK clays and mudrocks and to investigate the relationships between them. Thus leading to a better understanding of the shrink/swell behaviour for the user community. The formations that have been studied so far are the Gault Clay Formation, the Mercia Mudstone Formation and the Clays of the Lambeth Group.

## 2. The Lias - A Geological Background (M. G. Sumbler)

The Lias (or in strict lithostratigraphical terminology the *Lias Group*) comprises those predominantly argillaceous sediments of latest Triassic and Early Jurassic age found in and around the United Kingdom, and represents that period of geological time from about 180 to 205 million years before present. Onshore, the outcrop of the Lias extends from the coast of Dorset (Lyme Regis to Burton Bradstock) to Yorkshire and Cleveland (Ravenscar to Redcar), with outlying areas in Somerset and South Wales, although parts are concealed beneath Quaternary (drift) deposits. In general, the strata dip very gently towards the east or southeast beneath younger beds, and so the Lias is present at depth eastwards (downdip) of the main outcrop other than in the London area.

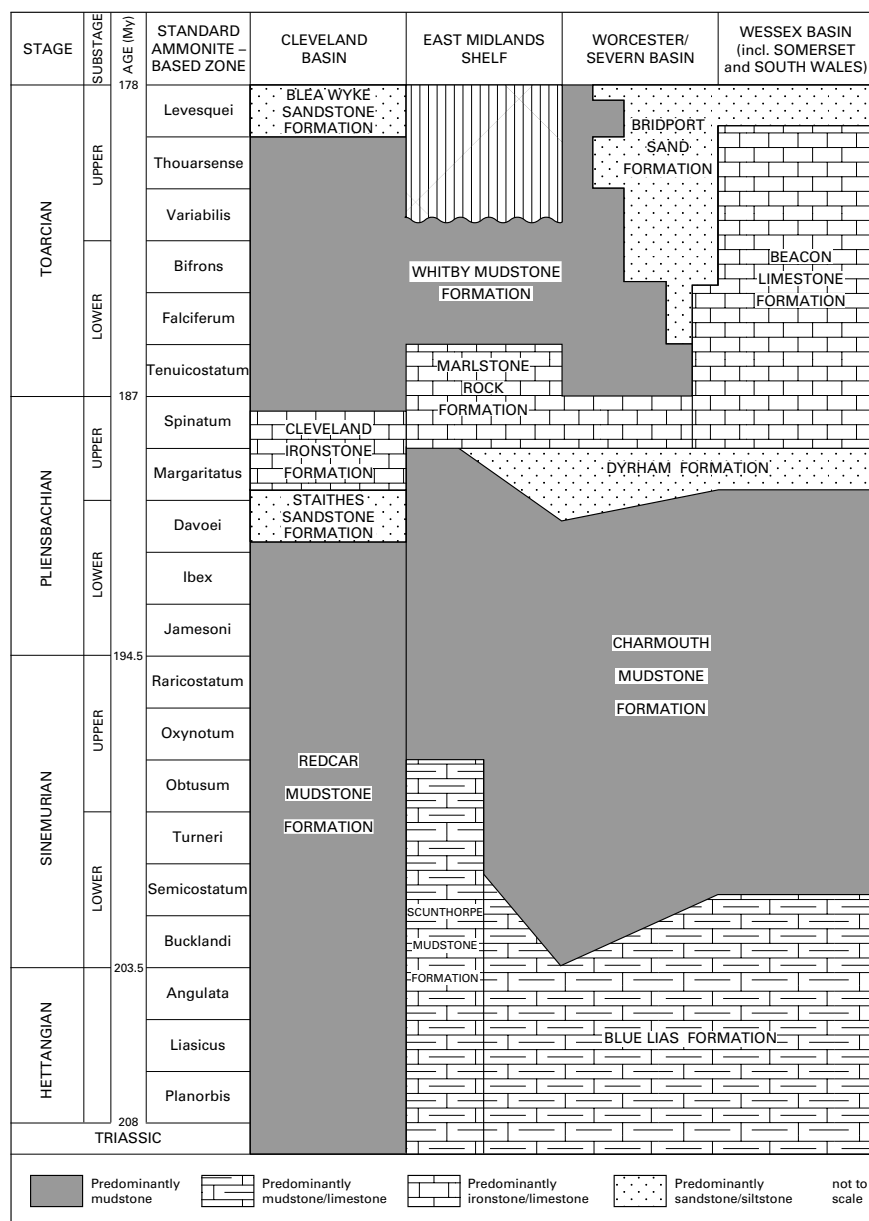
During the early Jurassic, the region that is now the UK lay somewhat closer to the equator than at present, probably at a latitude equivalent to the modern Mediterranean area. Accentuated by the presence of a large northern continental mass and the lack of a major North Atlantic Ocean at that time, the climate and seas which gradually overwhelmed the region were warm. The seas were shallow; even in the basins, it seems that sedimentation generally kept pace with subsidence so that the water was generally no more than a few tens of metres in depth. Away from the contemporary shorelines, conditions were remarkably uniform over the whole area of deposition so that many beds can be traced across large areas of the country.

Sediments, mainly muds, were washed into the seas by rivers on the adjoining land areas, building up the succession of Lias strata. Much of the succession is more or less

calcareous and limestone nodules or beds are developed at many levels most notably at the local base of the succession, having been deposited when the seas were particularly shallow. In some areas these basal beds include pebbly and shelly limestones evidently laid down close to the contemporary shoreline. Sands and silts may represent climatic events which washed coarser sediments into the sea and are also associated with two main periods of basin infill and general shallowing.

For purposes of stratigraphy, the ammonites are the most important fossils of the Lias, providing the basis for chronostratigraphical (age-based) classification, enabling correlation on a world-wide scale. The Lias has been divided up into some twenty zones and over 50 subzones based on ammonites (Figure 2.1); a typical ammonite zone represents about 1 to 1.5 million years.

**Figure 2.1 - Lias Stratigraphical Section**





### 3. Visit Strategy and Objectives

The work described in the Lias sampling report published in 2202 comprised the sample collection phase of the fourth stage of a study of the shrinkage and swelling behaviour of major UK clay formations. It dealt with the location, suitability, assessment and sampling of Lias Clay at sites in Eastern and Southern England and South Wales. The samples were taken from twenty eight pits, quarries, landfill sites or cliff faces in Northamptonshire, Warwickshire, Oxfordshire, Gloucestershire, Avon, South Glamorgan, Somerset, Dorset and North Yorkshire. Where possible at these sites an 'upper' (near surface) and a 'lower' (at depth) sample of the Lias Clay exposed by the quarrying operations was taken. The 'upper' site was intended to be representative of weathered, and the 'lower' site relatively unweathered, Lias Clay. Also, if there were several Lias stratigraphical formations within the sites an attempt was made to take samples from all of them. The geotechnical testing of these samples was carried out in the Geology, Geotechnics and Palaeontology laboratories (GGP) of the British Geological Survey (BGS).

After studying the initial report, a significant gap in the sampling was noted from the East Midlands Shelf basin and this report deals the location, suitability, assessment and sampling of the Lias succession from the five quarries visited in Nottinghamshire and Lincolnshire.

The East Midlands Shelf provides a succession of shallow marine deposits, characterised by a more or less complete Lias succession of moderate Thickness (typically 150 to 250m) The succession on the East Midlands Shelf thins southeast as the London Platform is approached. The main difference between the stratigraphy of this area compared with that of the Worcester basin to the south is the replacement of the Blue Lias formation by the Scunthorpe Mudstone Formation.

### 4. Contact and Schedule Information

#### *4.1. Visit Staff*

L. D. Jones	Geological Engineer
K. A. Rowlands	Environmental Geologist

#### *4.2. Organisations/Individuals Contacted*

##### Blue Circle (Barnstone Works)

Daniel Dolman – Environment Coordinator

##### C & G Concrete (Norton Bottoms)

Andrew Mosely – Unit Production Manager

##### Lafarge Redland Aggregates Ltd (Whisby)

Ian Pearson

# North Lincolnshire County Council (Conesby and Flixborough)

Vick Hodgson

Details of all of the sampling sites visited for the collection of Lias Samples throughout the outcrop, including those from the previous sampling report, are shown in Table 4.1. These include site location (OS National Grid and Sheet No.), site type, current owner, contact and initial visit date.

**Table 4.1 - Sampling Site Contacts**

Name	No.	Location	Sheet	Type	Company	Contact No.	Name	Contacted	Visit Date
<b>Northamptonshire</b>									
Sita Landfill, Brimworth	1.1	SP 757 720	141	Landfill	SITA	(01933) 680686	Sean Matty	10/07/2001	12/07/2001
Sidegate Lane, Finedon	1.2	SP 916 703	141	Landfill	SITA	(01933) 680686	Sean Matty	10/07/2001	12/07/2001
<b>Warwickshire</b>									
Rugby Cement, Rugby	2.1	SP 489 757	140	Cement Works	Rugby Portland Cement	(07966) 282575	Pete Klewitt	29/11/2001	04/12/2001
Southern Cement, Southam	2.2	SP 422 640	151	Cement Works	Rugby Portland Cement	(07966) 282575	Pete Klewitt	29/11/2001	04/12/2001
Edge Hill, Banbury	2.3	SP 375 474	151	Quarry	Hornton Quarries	(01295) 670238	Darren Haywood	30/11/2001	04/12/2001
<b>Oxfordshire</b>									
Hornton Grounds, Wroxton	2.4	SP 382 449	151	Quarry	Peter Bennie	(07860) 842855	David Jackson	29/11/2001	05/12/2001
Alkerton, Edge Hill	2.5	SP 395 429	151	Quarry	Peter Bennie	(07860) 842855	David Jackson	29/11/2001	05/12/2001
Sherington, Edge Hill	2.6	SP 359 435	151	Ex-Quarry	Peter Bennie	(07860) 842855	David Jackson	29/11/2001	05/12/2001
<b>Gloucestershire</b>									
Wingmoor, Bishops Cleeve	2.7	SO 946 272	163	Quarry	S. Grundon (Ewelme)	(01491) 834311	Toni Robinson	04/12/2001	06/12/2001
Robin's Wood Hill	2.8	SO 840 150	162	Ex-Quarry	Gloucester City Council	(01452) 303206	Tim Jenkins	29/11/2001	06/12/2001
Wellacre, Blockley	3.1	SP 181 371	151	Brick Works	Northcot Bricks	(01386) 700551	Roger Smith	28/11/2001	13/12/2001
<b>Avon</b>									
North Wick, Chew Magna	4.3	ST 585 657	172	Quarry	Reed Bros. & Bailey	(01225) 477528	Francis Bell	21/01/2002	23/01/2002
Stowey, Bishop Sutton	4.4	ST 598 587	172	Quarry	Stowey Stone Co. Ltd.	(01761) 452336	Site Manager	17/01/2002	23/01/2002
<b>South Glamorgan</b>									
Liswerry, Rhooose	4.1	ST 032 679	170	Quarry	Liswerry Lime Co.	(01446) 749322	Martin Brewer	17/01/2002	22/01/2002
Aberthaw, Barry	4.2	ST 038 672	170	Quarry	Blue Circle	(01446) 752300	Tony Dauncy	17/01/2002	22/01/2002
<b>Somerset</b>									
Waste Disposal, Dummer	3.2	ST 615 313	183	Landfill	Wyvern Waste	(01823) 324194	Martin Ellis	28/11/2001	14/12/2001
Handon Hill, Yeovil	4.5	ST 482 162	193	Quarry	Montacute Estates	(01902) 850077	Mike Lawrence	17/01/2002	23/01/2002
Downslade, Long Sutton	4.6	ST 455 269	193	Quarry	D. G. Mitchell	(01438) 274062	Mike Mitchell	18/01/2002	24/01/2002
Station, Somerton	4.7	ST 532 290	183	Quarry	Barham Brothers	(01438) 223538	Martin Butt	17/01/2002	24/01/2002
Lake View, Street	4.8	ST 548 304	183	Quarry	C. M. Pearce	(01438) 224033	Site Manager	17/01/2002	24/01/2002
<b>North Yorkshire</b>									
Kettlewell	5.1	NZ 831 153	94	Ex-Brick Pit	Scarborough District Council	(01723) 232589	John Woodhead	26/02/2002	04/03/2002
Runswick Bay	5.2	NZ 812 158	94	Cliff Face	Scarborough District Council	(01723) 232590	John Woodhead	26/02/2002	04/03/2002
Robin Hood's Bay	5.3	NZ 953 055	94	Cliff Face	Scarborough District Council	(01723) 232591	John Woodhead	26/02/2002	05/03/2002
Ravenear	5.4	NZ 980 016	94	Ex-Alum Pit	The National Trust	(01723) 870423	Mel Cunningham	26/02/2002	05/03/2002
Stoupe Beck	5.5	NZ 959 035	94	Cliff Face	Scarborough District Council	(01723) 232592	John Woodhead	26/02/2002	05/03/2002
<b>Dorset</b>									
Stonebarrow Hill	6.1	SY 370 930	193	Cliff Face	West Dorset District Council	(01305) 251010	Geoff Davis	26/02/2002	23/04/2002
Black Ven	6.2	SY 422 916	193	Cliff Face	West Dorset District Council	(01305) 251010	Geoff Davis	26/02/2002	24/04/2002
<b>Nottinghamshire</b>									
Barnstone Works,	7.1	SK 735 336	142	Ex-Quarry	Blue Circle Cement	(01949) 860301	Daniel Dolman	19/09/2002	01/10/2002
<b>Lincolnshire</b>									
Norton Bottoms, Newark	8.1	SK 867 360	127	Quarry	C & G concrete Ltd	(01636) 892220	Martin Blowers	19/09/2002	01/10/2002
Whisby, Lincoln	8.2	SK 896 668	114	Quarry	Lafarge Redland Aggregates Ltd	(01909) 537800	Ian Pearson	19/09/2002	01/10/2002
Conesby, Southorpe	8.3	SK 895 145	157	Ex-Quarry	North Lines County Council	(01724) 296085	Vick Hodgson	19/09/2002	02/10/2002
Flixborough, Scunthorpe	8.4	SK 877 142	157	Ex-Quarry	North Lines County Council	(01724) 296086	Vick Hodgson	19/09/2002	02/10/2002

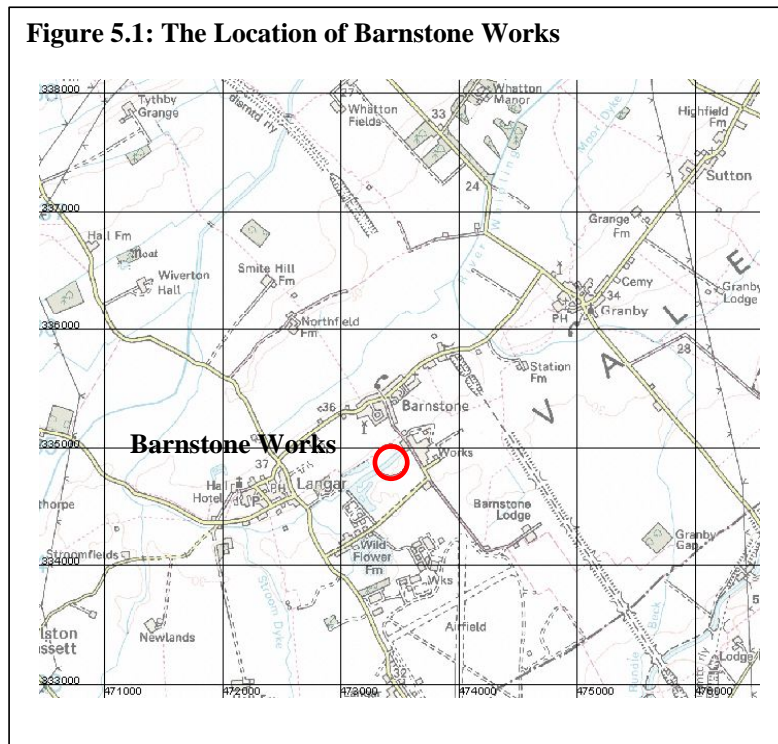
## 5. Site Locations and Sampling

On the 1<sup>st</sup> and 2<sup>nd</sup> of October reconnaissance field visits were made to five identified Lias locations in Nottinghamshire and Lincolnshire. A selection of disturbed samples but no undisturbed samples were taken at these visits. A return visit was made to two sites in Lincolnshire on the 10<sup>th</sup> March 2003. Further disturbed bulk bag samples and several large undisturbed blocks were extracted for index and strength testing

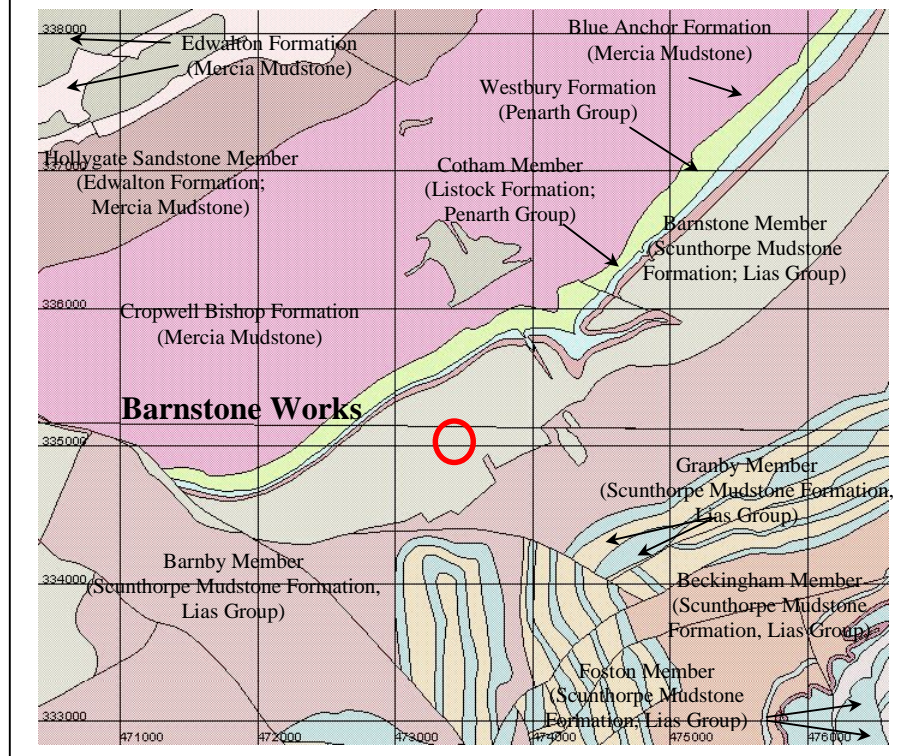
### 5.1. Barnstone Works

Barnstone works, Nottinghamshire, is owned by Blue Circle and is now a cement works. The sampling site is an ex-quarry that has since been flooded and is now used as a fishing lake. The site is located in the village of Barnstone approximately 6.5km to the south of Bingham, off the A52 (Figure 5.1). The excavation is located near the base of the Lower Lias, in the alternating shales and shelly-argillaceous partly concretionary limestone of the Barnstone Member (Hydraulic Limestones), of the Scunthorpe Mudstone Formation (Figure 5.2). The sampling site was located at SK 4735 3336, at an elevation of 25 m above Ordnance Datum (aOD) (Plate I). Samples were taken from the partially exposed succession on the south facing edge of the fishing pit, at a depth of approximately 0.2m below ground level (bgl) (Plate II). Access to the sampling site was good although as the site is a fishing lake extreme care had to be taken at the waters edge and large areas of the site were inaccessible.

The sampling visit to the cement works Barnstone, Nottinghamshire, took place on the 1<sup>st</sup> October 2002. At this time both undisturbed block and disturbed bag samples were taken for geotechnical index testing, SEM and XRD. Undisturbed sampling was not possible due to the extremely hard nature of the material at the accessed exposure and this limited access preventing the inspection of other potential sampling sites. No further visits to the site are planned.



**Figure 5.2: The Geology of the area surrounding Barnstone Works**



**Plate I – General View of Barnstone Works**





**Plate II – Sampling Site 1 (Barnstone Works)**

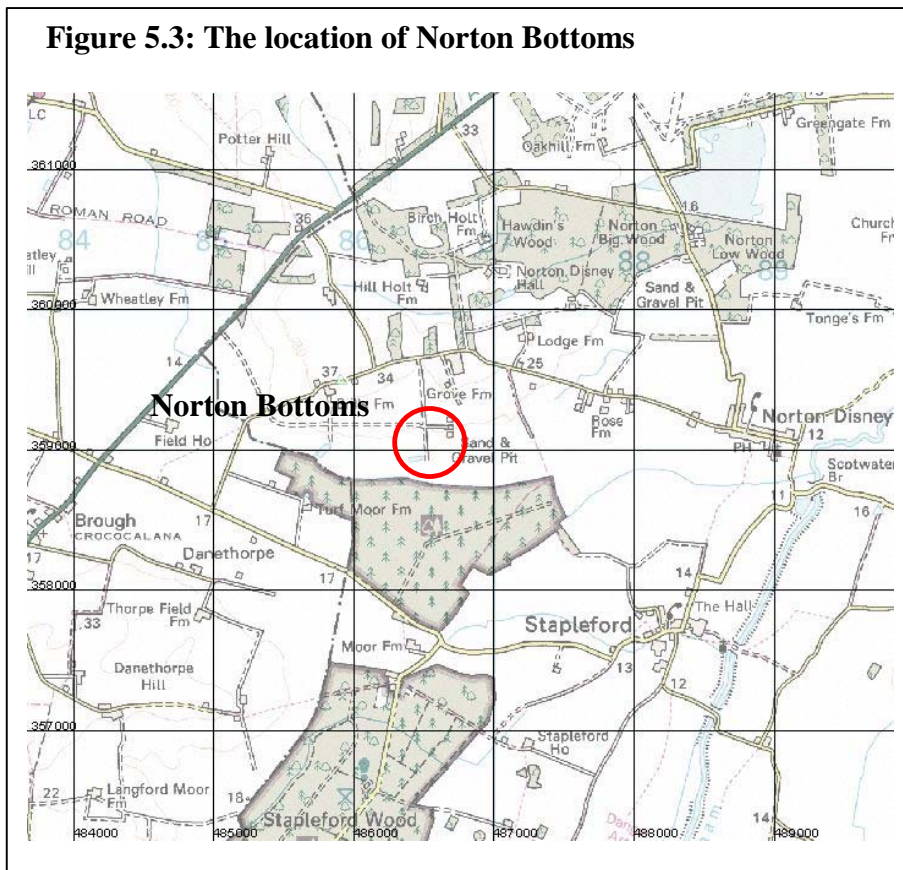


## 5.2 Norton Bottoms

The Norton Bottoms site, Norton Bottoms, Lincolnshire, is owned by C & G concrete Ltd and is an active sand and gravel quarry. The site is located approximately 5.5km north of Newark-on-Trent, 2km east of the A46 (Figure 5.3) and is located on the Scunthorpe Mudstone Formation of the Lias (Figure 5.4), which immediately underlies approximately 8m of Quaternary sand and gravel. The sampling site was located at SK 4867 3589, at an elevation of 20 m above Ordnance Datum (aOD) (Plate III). Samples of the Scunthorpe Mudstone Formation were taken from the Lias exposed at the quarry floor by the removal of the sand and gravel in the centre of the current excavation site. Samples were extracted from minor exposed areas alongside the current drainage channels (Plate IV), at a depth of approximately 1m below the quarry floor level (bql), 9m bgl. Access to the sampling site was good.

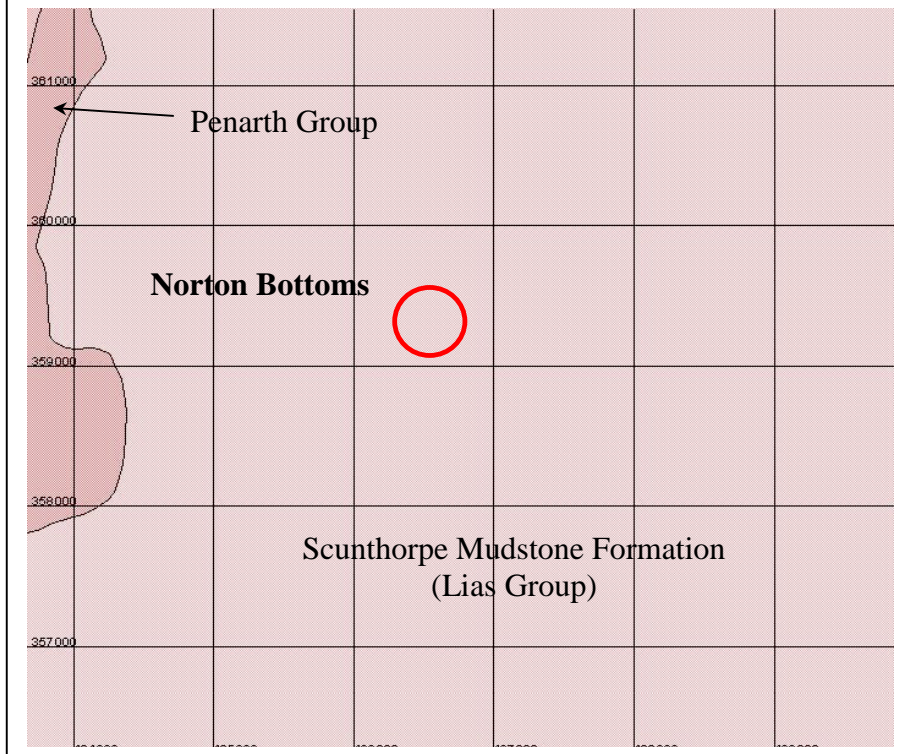
The sampling visit to the sand and gravel quarry at Norton Bottoms, Lincolnshire, took place on the 1<sup>st</sup> October 2002. At this time both undisturbed block and disturbed bag samples were taken for geotechnical index testing, SEM, XRD, analyses. Undisturbed sampling was not perceived to be possible at this site due to the potential compaction experienced, of the material being sampled by the quarry machinery. No further visits to the site are planned.

**Figure 5.3: The location of Norton Bottoms**





**Figure 5.4: The geology of the area surrounding Norton Bottoms**



**Plate III – General View of Norton Bottoms**



**Plate IV – Sampling Site 1, located at the edge of pictured Drainage Channel (Norton Bottoms)**



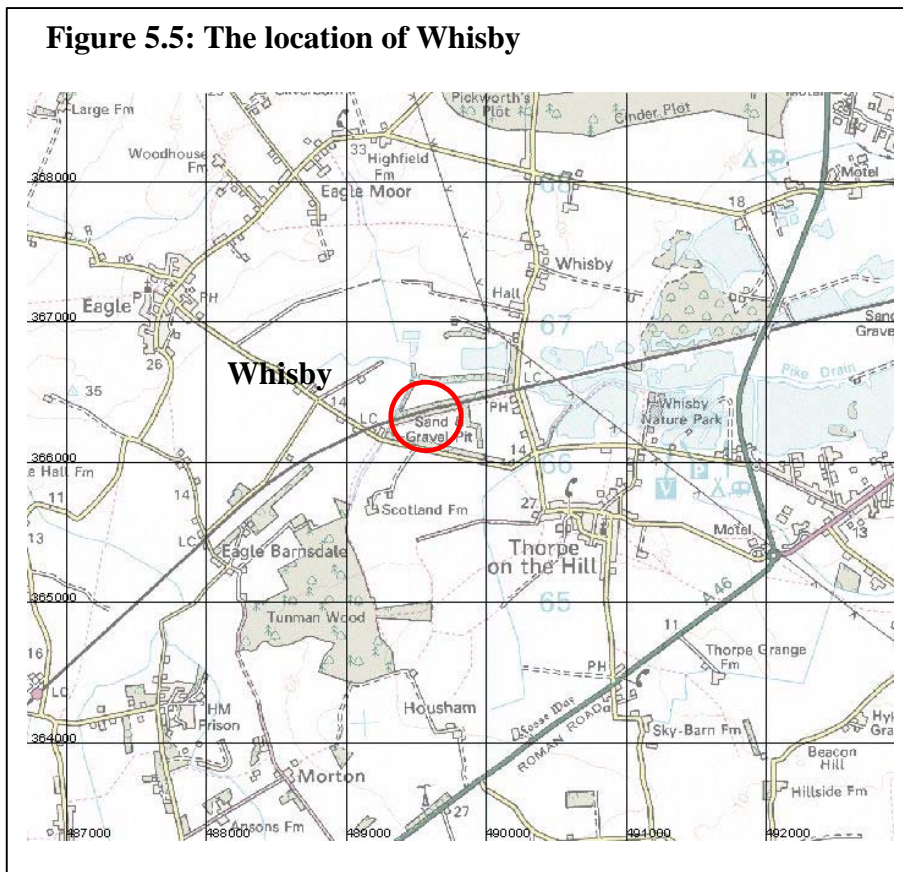


### 5.3 Whisby

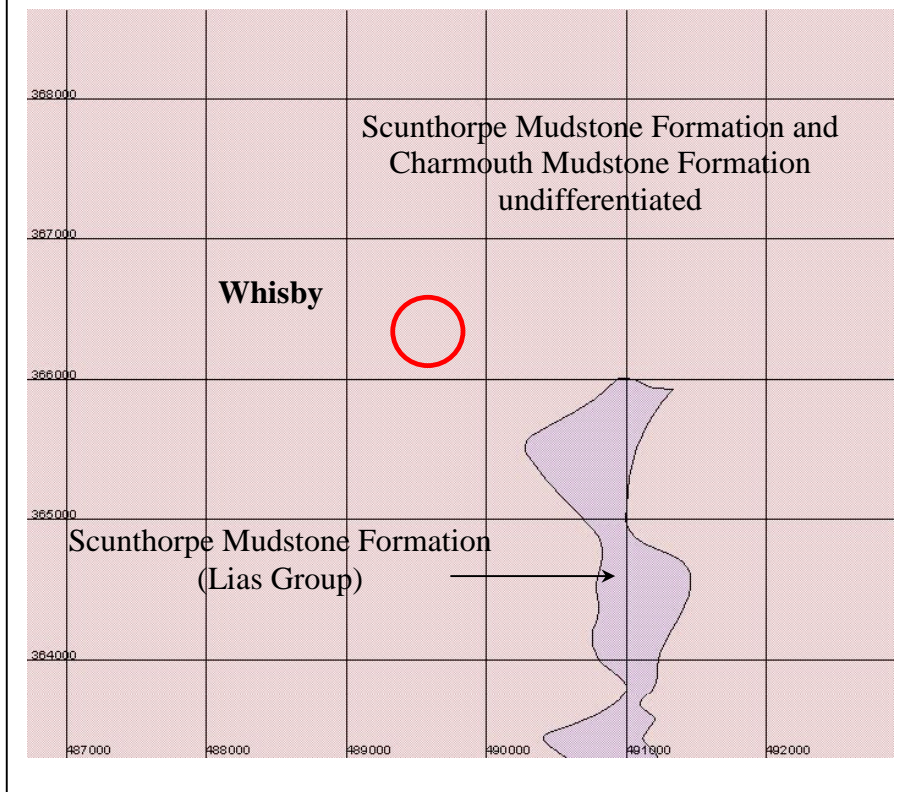
The Whisby site, Lincoln, is owned by Lafarge Redland Aggregates Ltd and is an active sand and gravel quarry. The site is located off the A46, approximately 3.5km west of Lincoln (Figure 5.5) and is situated on the Scunthorpe Mudstone formation of the Lower Lias (Figure 5.6), which immediately underlies approximately 10m of Quaternary sand and gravel. The sampling site was located at SP 4896 3667, at an elevation of 30 m above Ordnance Datum (aOD) (Plate V). Samples were taken from the Lias exposed at the base of the quarry by the removal of the sand and gravel in the centre of the site (Plate VI & VII), at a depth of approximately 1m bgl, 11 m bgl. Access to the sampling site was good although care was needed around the very wet areas of clay resulting in some potential sampling areas being inaccessible.

The sampling visit to sand and gravel quarry at Whisby, Lincolnshire, took place on the 1<sup>st</sup> October 2002. At this time both undisturbed block and disturbed bag samples were taken for geotechnical index testing, SEM, XRD, XRF and geochemical analyses. Undisturbed sampling was not perceived to be possible at this site due to the potential compaction and remoulding experienced of the material being sampled, by the quarry machinery. No further visits are planned.

**Figure 5.5: The location of Whisby**



**Figure 5.6: The geology of the area surrounding Whisby**



**Plate V – General View of Whisby Sand and Gravel Quarry**





**Plate VI – Sampling Site 1 (Whisby)**



**Plate VII – Close-up of shrinkage cracks in exposed Lias Clay (Whisby)**



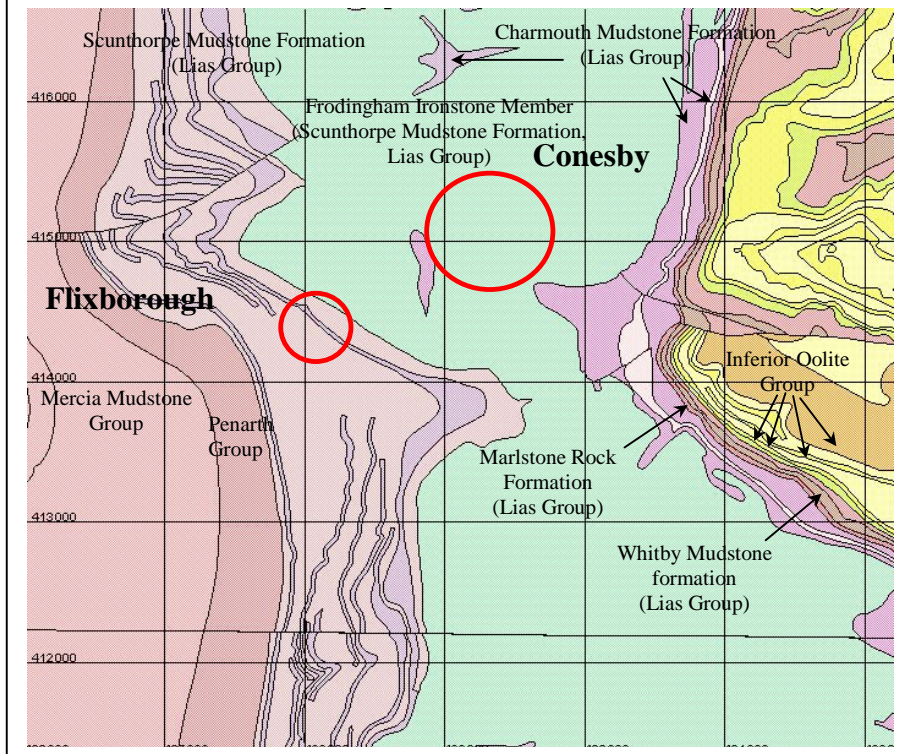


North Lincolnshire County Council now manages the Conesby site, Scunthorpe, Lincolnshire. The site used to belong to Corus steel works and is an old Ironstone Quarry. The old quarry site is being developed, using the area for the disposal of contaminated soils from a nearby enterprise park and including the construction of a clay lined waste management cell for landfill. The old quarry is currently also being extended further with the Ironstone being removed for road surfaces, and the Liassic mudstone for the lining of the cells. The area is eventually to be sealed and landscaped as a heath land habitat. The site is approximately about 2 km north of Scunthorpe (Figure 5.7) and the excavation is located in the Frodingham Ironstone member of the Scunthorpe Mudstone and the overlying Charmouth Mudstone (Figure 5.8). The site was located at SP <sup>4895</sup> <sup>2145</sup>, at an elevation of 30 m above Ordnance Datum (aOD) (Plates VIII & IX). Samples were taken from the east face of the recently extended cell (Plates X, XI & XII) at a depth of approximately 9 m below ground level (bgl), approximately 3m above the top of the Frodingham Ironstone. Access to the sampling site was good although care was needed around the very wet areas of clay resulting to some potential sampling areas being inaccessible.

**Figure 5.7: The location of Conesby and Flixborough Quarries**



**Figure 5.8: The geology of the area surrounding Conesby and Flixborough Quarries**



**Plate VIII – General view of Conesby Quarry before expansion works**





**Plate IX – General view of Conesby Quarry after initial phase of expansion works**



**Plate X – Close-up of Frodingham Ironstone (Conesby)**



**Plate XI – Sample Site 2 (Conesby- return visit)**



**Plate XII – Close-up Sampling Site 2 (Conesby)**





## 5.5 Flixborough

North Lincolnshire County Council now manages the Flixborough site, Scunthorpe, Lincolnshire. The site used to belong to Corus steel works and is an old Ironstone Quarry. It is currently being extended further with the Ironstone being removed for road surfaces, and the Liassic mudstone for the lining of the cells. The old quarry site is being developed and excavated, and is ultimately to be used as a business park. The site is approximately about 2 km north of Scunthorpe (Figure 5.7) and the excavation is located below the Frodingham Ironstone member within the Scunthorpe Mudstone (Figure 5.8). The site was located at SP <sup>4</sup>877 <sup>2</sup>142, at an elevation of 50 m above Ordnance Datum (aOD) (Plate XIII & XIV). Samples were taken from the north face of a trial pit and the recently extended cell at a depth of approximately 2 m below ground level (bgl), approximately 1.5m below the base of the ironstone (Plates XV, XVI XVII). Access to the sampling site was good although care was needed around the very wet areas of clay resulting to some potential sampling areas being inaccessible.

The initial sampling visit to the quarry at Flixborough, Lincolnshire, took place on the 2<sup>nd</sup> October 2002. At this time both undisturbed block and disturbed bag samples were taken for geotechnical index testing, SEM, XRD, XRF and geochemical analyses. A return visit to the site was made on the 10<sup>th</sup> March 2002, after further excavation and clearance was underway. Further disturbed bulk bag samples and undisturbed, orientated and carefully extracted large blocks for K<sub>0</sub> swelling (Triaxial) tests were taken. No further visits are planned.

**Plate XIII – General view of Flixborough Quarry before expansion works**





**Plate XIV - General view of Flixborough Quarry after initial phase of expansion works**



**Plate XV – Close up Sample Site 1 (Flixborough Quarry; initial visit)**





**Plate XVI – Sample Site 2 (Flixborough Quarry return visit)**



**Plate XVII – Close-up Sample Site 2 (Flixborough Quarry return Visit)**



## 6. Review of the Sampling Process

As a result of the previous sampling report and on examination of the location of the sampling sites, it was noted that there was a significant gap in sites around the Nottingham/Lincolnshire area. Three potential sites were quickly identified after publication of the previous report and it was planned that visits to these sites were in order, to obtain as representative coverage as possible within the constraints of time and funding.

Thus these three sites plus two further identified potential sampling sites were visited in the two counties; including one disused flooded limestone quarry, two active Quaternary sand and gravel quarries which overlay Lias deposits, and two former ironstone quarries that are currently being extended with intentions of redevelopment.

All of the sites provided sampling opportunities for disturbed bulk bag samples for remoulded tests, SEM, XRD, and XRF and geochemical analyses where applicable. Samples were successfully taken from the Scunthorpe Mudstone Formation; which includes the Barnstone Member (Hydraulic Limestones) and the Frodingham Ironstone Member, and the Charmouth Mudstone. Within the flooded fishing pit at Barnstone only limited access to the exposure was obtained in order to take these samples. The site at Norton provided good access although as the samples were taken from the Quarry floor potential of compaction by quarry machinery prevented undisturbed samples being taken. This was also the case for the site at Whisby, although access to areas around this site was limited due to the wetness of the underlying Liassic Sediments. Therefore, as noted above, sampling was again limited by health and safety implications at a couple of the sites.

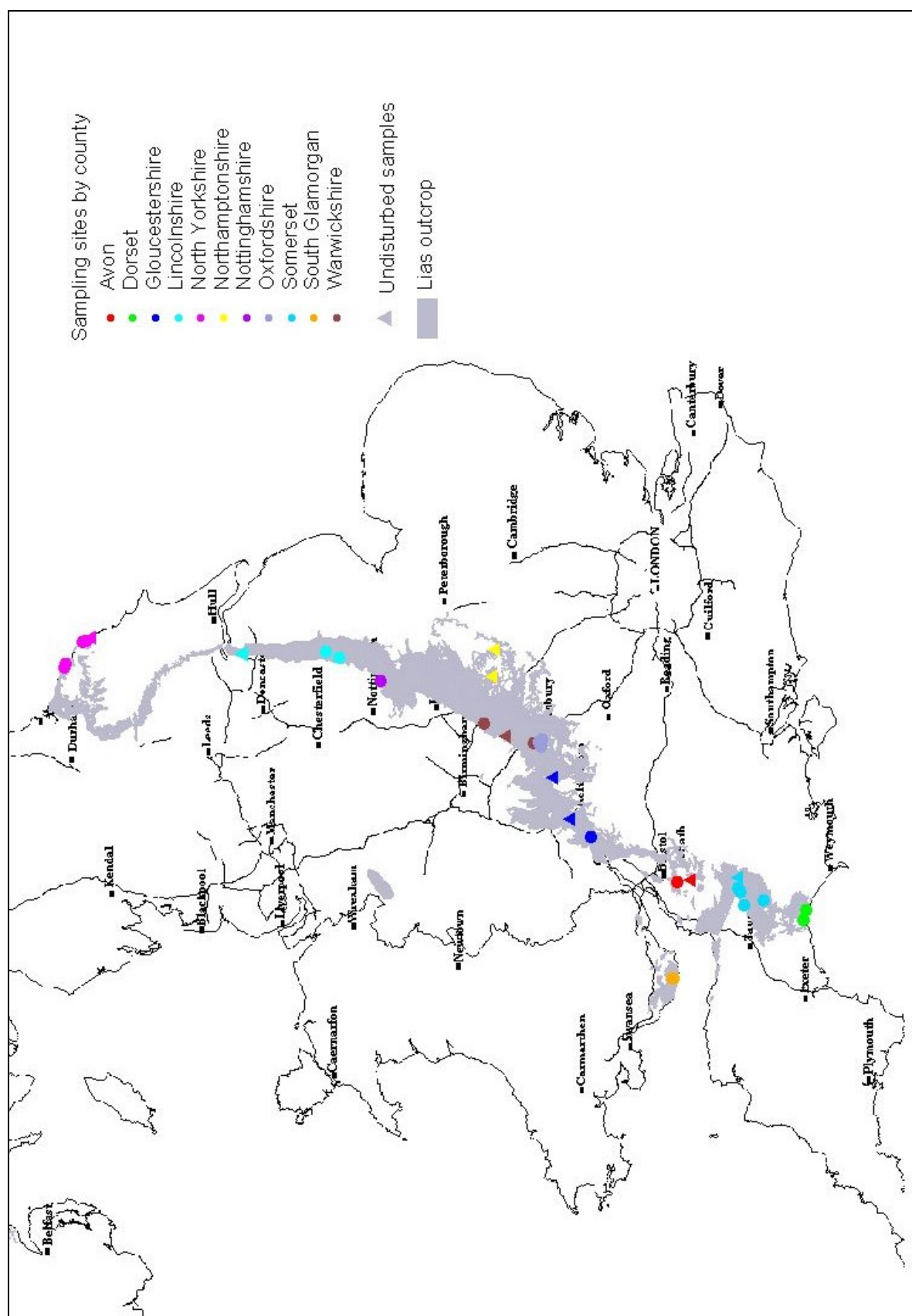
Undisturbed samples were obtained from two of the sites visited, Conesby Quarry and Flixborough Quarry, as a result of a return visit after the commencement of excavation works to expand the sites. Due to the fairly hard nature of the material and time restraints, these undisturbed samples were taken in the form of orientated and carefully extracted large blocks rather than in tins and boxes, wrapped in several layers of Clingfilm for transportation and storage. One of these samples was taken from the Scunthorpe Mudstone formation directly below the Frodingham Ironstone, and one from directly above the Ironstone, the Charmouth Mudstone Formation.

The visits to the sites described in this and the initial sampling report, now forms a complete sampling record across the Lias outcrop of the UK (Table 6.1 & Figure 6.1).

Table 6.1 Sample Details

Name	Location	OS Sheet	Type	Date	Formation	Member	Discovered		Undiscovered		Weathered	
							Large Bulk Sample	Small Bulk Sample	Large Block	Large Tin / Small Tin	Tube	Weathered / Unweathered
<b>Wharfedale</b>												
Sils Leiffa, Ewerth	SP 757 720	141	Lundell	12-Jul-01	Wharfedale Formation		✓	✓	✓	✓	✓	✓
Silgate Linn, Fenslon	SP 916 703	141	Lundell	12-Jul-01	Wharfedale Formation		✓	✓	✓	✓	✓	✓
<b>Yorkshire</b>												
Reddy's Cement, Pughy	SP 469 757	140	Cement Works	04-Dec-01	No Sample taken							✓
Southam Cement, Southam	SP 422 640	151	Cement Works	04-Dec-01	Blue Lias Formation		✓	✓	✓			✓
Edge Hill, Bury	SP 375 674	151	Quarry	04-Dec-01	Mudstone Rock Formation		✓	✓	✓		✓	✓
<b>Yorkshire</b>												
Horton Grounds, Wotton	SP 352 449	151	Quarry	05-Dec-01	Mudstone Rock Formation		✓	✓			✓	✓
Alberton, Edge Hill	SP 395 429	151	Quarry	05-Dec-01	Mudstone Rock Formation		✓	✓			✓	✓
Sharncliffe, Edge Hill	SP 359 435	151	Ex-Quarry	05-Dec-01	No Sample taken							
<b>Charnock</b>												
Waggon, Bishops Cleeve	SO 346 272	163	Quarry	06-Dec-01	Blue Lias Formation		✓	✓				✓
Robert's Wood Hill	SO 840 150	163	Ex-Quarry	29-May-02	Blue Lias Formation				✓			✓
				06-Dec-01	Lower Dyrham Formation							✓
				06-Dec-01	Upper Dyrham Formation							✓
				06-Dec-01	Mudstone Rock Formation							✓
				29-May-02	Dyrham Formation		✓	✓				✓
				13-Dec-01	Charnock Mudstone		✓	✓	✓			✓
<b>Don</b>												
North View, Charn Magna	ST 353 037	172	Ex-Quarry	23-Jan-02	No Sample taken							✓
Stoney, Bishop Station	ST 298 287	172	Quarry	23-Jan-02	Blue Lias Formation		✓	✓				✓
				23-May-02	Blue Lias Formation				✓			✓
<b>South Charnock</b>												
Laverney, Broom	ST 032 079	170	Quarry	23-Jan-02	Blue Lias Formation	Penbury Member	✓	✓				✓
Abertaw, Bury	ST 038 072	170	Quarry	23-Jan-02	Blue Lias Formation	Penbury Member	✓	✓				✓
<b>South</b>												
West Dip, 04, Damer	ST 615 313	183	Lundell	14-Dec-01	Charnock Mudstone		✓	✓				✓
Hindale Hill, Yowl	ST 482 162	193	Quarry	23-Jan-02	Budget Sand Formation		✓	✓				✓
Doncliffe, Long Station	ST 455 269	193	Quarry	24-Jan-02	No Sample taken		✓	✓				✓
Station, Swanton	ST 532 290	183	Quarry	24-Jan-02	Blue Lias Formation		✓	✓				✓
Lake View, Street	ST 548 304	183	Quarry	24-Jan-02	Blue Lias Formation		✓	✓				✓
<b>North Yorkshire</b>												
Kerfess	N2 831 153	94	Ex-Brick Pit	04-Mar-02	Cleveland Intrasite Formation							✓
Ruswick Bay	N2 812 158	94	Cliff Face	04-Mar-02	Wharfedale Formation							✓
Robert's Bay	N2 833 055	94	Cliff Face	05-Mar-02	Reddish Mudstone Formation							✓
Reverster	N2 800 016	94	Ex-Ash Pit	05-Mar-02	Wharfedale Formation	Alan Shale Member						✓
Strop's Bank	N2 859 035	94	Cliff Face	15-Apr-02	Wharfedale Formation	Alan Shale Member			✓			✓
<b>Don</b>												
Stonbury Hill	ST 370 350	193	Cliff Face	23-Apr-02	No Sample taken							✓
Seaton	ST 418 216	193	Cliff Face	23-Jul-02	Charnock Mudstone	Quern Amundale Beds	✓	✓	✓			✓
				23-Jul-02	Dyrham Formation	Byre Clay	✓	✓	✓			✓
				23-Jul-02	Charnock Mudstone	Redecliffe Muds	✓	✓	✓			✓
				23-Jul-02	Charnock Mudstone	Black Ym Muds	✓	✓	✓			✓
				23-Jul-02	Charnock Mudstone	Shale's With Reef	✓	✓	✓			✓
<b>Wharfedale</b>												
Burncliffe Quarry	SK 755 555	141	Ex-Quarry	01-Mar-02	Southbrough Mudstone	Burncliffe Limestone Member	✓	✓				✓
<b>Yorkshire</b>												
Norton Bottom, Newark	SK 867 360	127	Quarry	01-Oct-02	Southbrough Mudstone			✓				✓
Wharfedale, Lanch	SK 866 668	114	Quarry	01-Oct-02	Southbrough Mudstone	Frederick's Limestone		✓				✓
Croftley Quarry, Southbrough	SK 855 145	157	Ex-Quarry	10-Mar-02	Southbrough Mudstone		✓	✓	✓			✓
Plainsborough Quarry, Southbrough	SK 877 142	157	Ex-Quarry	10-Mar-02	Southbrough Mudstone		✓	✓	✓			✓

**Figure 6.1 – Sampling Site Locations across the Lias Outcrop**



## 7. Publications

Since the project started the following publications and reports have been generated:

### ***Papers:***

2000 Hobbs, P.R.N. and Jones, L.D. Clay Shrinkage Research at the British Geological Survey. *Proc. Slips, Shrinks and Swells - Clay Minerals and Geotechnics Conference. British Geological Survey, Keyworth. December 2000*

2000 Lu, P., Rosenbaum, M.S. and Jones, L.D. Fractal Behaviour of Particle Size and its Implications for Describing Volume-Change in Clays. *Proc. Slips, Shrinks and Swells - Clay Minerals and Geotechnics Conference. British Geological Survey, Keyworth. December 2000*

2000 Hobbs, P.R.N., Jones, L.D., Northmore, K.J. and Entwisle, D.C. Shrinkage Behaviour of some Tropical Clays. *Proc. Asian Conf. on Unsaturated Soils. Singapore. May 2000*

1998 Hobbs, P.R.N. and Jones, L.D. The Shrinkage and Swelling Properties of the Mercia Mudstone. *Proc. The Engineering Properties of the Mercia Mudstone. CIRIA Seminar. Pride Park, Derby. November 1998*

### ***Technical Reports:***

1999 Jones, L.D. and Hobbs, P.R.N. The shrinking and swelling properties of the Mercia Mudstone. *BGS Technical Report Series No. 98/14*

1998 Jones, L.D. and Hobbs, P.R.N. The shrinking and swelling properties of the Gault Clay. *BGS Technical Report Series No. 98/13*

1995 Hobbs, P.R.N. and Jones, L.D. Methods of testing for swelling and shrinkage of soils. *BGS Technical Report Series No. WN/95/15*

1995 Gostelow, T.P. Some geological aspects of clay swelling and shrinkage. *BGS Technical Report Series No. WN/95/16*

### ***Other Reports:***

2002 Rowlands, K.A. & Jones, L.D. Strategy, Location and Sampling of the Lias group, Ground Movements: Shrink/Swell Project. *BGS Internal Report Series No. IR/02/032*

2001 Jones, L.D. Determination of the Shrinking and Swelling Properties of the Clays of the Lambeth Group *BGS Internal Report Series No. IR/01/54*

2000 Gunn, D. A. and Jones, L. D. Automatic Shrinkage Limit Apparatus: System Control Software. *BGS Internal Report Series No. IR/01/48*

2000 Jones, L. D. Determination of the Shrinking and Swelling Properties of the Clays of the Lambeth Group. *BGS Internal Report Series No. IR/01/54*

2000 Jones, L.D. Results of a 'user' survey into the need for a greater understanding of shrink/swell behaviour. *BGS Project Note Series No. PN/00/03*

1998 Jones, L.D. Determination of the Shrinking and Swelling Properties of the Mercia Mudstone. *BGS Laboratory Report Series No. 98/03*

1998 Jones, L.D. Report on Visits to Lambeth Group Sampling Sites. *BGS Project Note Series No. 98/09*

1998 Jones, L.D. Sampling Techniques for UK Clay Soils. *BGS Project Note Series No. 98/06*

1997 Jones, L.D. and Cripps, A.C. Report on visit to various sites for sampling, for Mercia Mudstone Project (77BD). *BGS Project Note Series No. 97/10*

1996 Jones, L.D., Hobbs, P.R.N. and Cripps, A.C. Determination of the Shrinking and Swelling Properties of the Gault Clay. *BGS Laboratory Report Series No. 96/02*

1996 Jones, L.D. and Cripps, A.C. Report on Preliminary Visits to Various Sites for Project 77BH. *BGS Project Note Series No. 96/19*

1996 Jones, L.D. and Cripps, A.C. Report on Visit (and Sampling) to Arlesey and Leighton Buzzard Brickpits for Project 77BH. *BGS Project Note Series No. 96/17*

***Thesis:***

1999 Jones, L.D. A Shrink/Swell Classification for UK Clay Soils. *Nottingham Trent University, Department of Civil & Structural Engineering.*