Geodiversity Strategy
2022 - 26

Including the 3rd edition of Greater Lincolnshire Geodiversity Action Plan

Contents

Greater Lincolnshire Geodiversity Strategy
c/o Greater Lincolnshire Nature Partnership
Banovallum House
Manor House Street
Horncastle
Lincolnshire
LN9 5HF

01507 528398
info@glnp.org.uk

www.glnp.org.uk/our-services/geodiversity-strategy

Greater Lincolnshire Geodiversity Group

1st edition
December 2016
Edited by Fran Smith

2nd edition
September 2021
Edited by Charlie Barnes

Foreword

This new edition of the GLNP's Geodiversity Strategy highlights the importance of geodiversity to the health of our environment, and to everyone's wellbeing. Awareness of the importance of geodiversity is growing, which is one of the reasons a new strategy was needed.

This new edition continues to build on work arising from the previous Geodiversity Action Plan. It places great emphasis on geodiversity's relationship with biodiversity and its place supporting the delivery of other plans and policies, ensuring that we continue to develop a wider recognition of the value that geodiversity brings to our society, economy and environment.

Although much has already been achieved, many threats remain and resources are limited. For the most part the new strategy continues with established targets and actions as they remain the most important ways that have been identified to support and enhance Greater Lincolnshire's geodiversity.

It is true that challenges lie ahead, but this Strategy provides clarity, direction, and a framework for action. We want to build on our successes up to now, and with the strong partnership approach of the GLNP and the dedication of all of those who have contributed their time and energy to creating this Strategy, I look forward to seeing further achievements ahead.

David Hickman
Chair of the Greater Lincolnshire Nature Partnership

Acknowledgements

The Greater Lincolnshire Nature Partnership is grateful to the representatives and volunteers that contributed to writing the Geodiversity Strategy.

Working Group members:

Malcolm Fry (deceased)
Helen Gamble
Paul Hildreth
Sarah Smith
Jon Watson

Tim Langdale-Smith and the late John Aram must also be acknowledged for all their work on the original geodiversity audit that has been edited and included in this Strategy. Michael Ashton is thanked for providing comments for the 2nd edition of the Geodiversity Strategy.

****

Thanks also go to contributors of the 1st edition of the Lincolnshire Geodiversity Action Plan.

****

A Lincolnshire Limestone quarry © John Aram

1. Vision and aims

1.1 Vision statement

That Greater Lincolnshire's geodiversity assets are conserved, recorded, promoted, understood and enjoyed by all.

1.2 Aims

By working in partnership towards this vision, identifying priorities for action, and engaging with local stakeholders the Geodiversity Strategy aims to:

- Record and conserve the geodiversity of Greater Lincolnshire
- Ensure geodiversity is included in relevant plans and policies
- Raise awareness of the importance of geodiversity across all sectors
- Ensure delivery of geodiversity objectives through adequate funding

2. The role of the Geodiversity Strategy

2.1 The Geodiversity Strategy in context

This Strategy is an all-in-one document encompassing both a Local Geodiversity Action Plan (GAP) and a geodiversity audit. This ensures that all the crucial information on Greater Lincolnshire's geodiversity is in one place. A geodiversity audit presents a summary of the geodiversity resources of an area, highlighting areas of importance and also areas of concern. The aim of a GAP is to raise awareness of geodiversity and through the identification of local priorities enable delivery of national targets at a local level. Local GAPs contribute to the delivery of the UK GAP. Together an audit and a GAP create a coherent whole for geodiversity knowledge and action.

The Lincolnshire GAP 2010-2015 was delivered through a partnership. This has proven to be a successful way to focus resources and share best practice and over time the form of these partnerships has changed (see Figure 1). The Geodiversity Strategy continues to be delivered through this successful partnership method.

Through this collaborative partnership approach and the dedication of many individuals much has been delivered. Yet there is still much to do. Many topics within the 1st edition of the Lincolnshire GAP remained aspirational. This Strategy continues to refocus efforts in order to design more successful initiatives in the future and learn from those areas that have been delivered to ensure this knowledge can be shared.

Figure 1: The LBP to GLNP
The Lincolnshire GAP and the Geodiversity Group are an integral part of the Greater Lincolnshire Nature Partnership (GLNP) - previously known as the Lincolnshire Biodiversity Partnership (LBP). The LBP covered four work streams: the Biodiversity Action Plan (BAP); the Lincolnshire Environmental Records Centre (LERC); Local Sites and Geodiversity. LBP was the first partnership in the UK to be structured in this way. The GLNP is continuing to deliver in these four work areas but also has strategic priorities in other key areas. For more information see: www.glnp.org.uk

GLNP
GREATER LINCOLNSHIRE NATURE PARTNERSHIP

2.2 Why is geodiversity important?

Geodiversity is profoundly more important than most people realise. The rocks underneath us form the soils in which food is grown; they provide the clay to make bricks for houses (even the mug for your tea) and the gravel to make roads. Geodiversity is the source for fossil fuels which permeate our daily lives - from the petrol in our cars to the multitude of plastic items on which we depend. All of these areas form important businesses and both nationally and globally are huge industries and economic drivers.

Thinking more widely, the landscape around us is not only shaped by the rocks and minerals underneath it but the processes that have formed it. The plants and animals are influenced by the acidity or alkalinity of the

Figure 2: What is geodiversity?
Geodiversity is the variety of rocks, minerals, fossils, soils and landscapes, together with the natural processes which form them. It provides the key link between geology, landscape, biodiversity and people

rock and its ability to hold water – but the water isn't just important for our wildlife but geodiversity can also help to prevent flooding. Our human inspiration and ability to enjoy the world around us is as much governed by what we cannot see under the landscape as by what is growing on the surface. These contributions to our historic and cultural heritage, as well as education, sense of place and wellbeing are frequently overlooked.

Another frequently overlooked area is soil – the interface between geodiversity and biodiversity. The importance of soil in maintaining agricultural systems, storing carbon, filtering water and even regulating our climate is only just being realised. This strategy cannot address all of these aspects in detail but it must be remembered that geodiversity is not just about the 'rocks'.

Geodiversity can also help us plan our futures. By learning about how our environment has changed over millions of years through the fossil record and other clues in geology it is possible to construct scenarios of future climate. These will help us to determine how we need to live with the impacts of climate change and what those impacts are likely to be.

2.2.1 Ecosystem services

Geodiversity is an example of natural capital and as such provides society with services. Some of these are becoming increasingly obvious – but some are less apparent. These services are called ecosystem services and the National Ecosystems Assessment[1] places them in four categories, considering both the market and non-market benefits. This categorisation has been expanded by others to include a fifth knowledge category.

The following ecosystem services from geodiversity have been described[2]:

<u>Regulating</u>
- Atmospheric and oceanic processes e.g. the hydrological cycle
- Terrestrial processes e.g. the carbon cycle
- Flood control e.g. infiltration, sand dunes
- Water quantity and quality e.g. freshwater storage in aquifers, lakes and rivers

<u>Supporting</u>
- Soil processes e.g. soil profile development
- Habitat provision e.g. caves, salt marshes, terrestrial habitats
- Land as a platform for human activity e.g. building land
- Burial and storage e.g. landfill, oil and gas reservoirs

<u>Cultural</u>
- Environmental quality e.g. landscape character
- Tourism and leisure e.g. views, rock climbing
- Cultural and historic meanings e.g. folklore, sense of place
- Artistic impression e.g. sculpture, literature, music
- Social development e.g. field trips, tourism

[1] UK National Ecosystems Assessment, 2011. The UK National Ecosystems Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge.
[2] Gray, M., 2012. Valuing Geodiversity in an 'Ecosystem Services' Context. Scottish Geographical Journal, 128; 3-4.

Provisioning

- Food and drink e.g. mineral water, salt
- Nutrients and minerals for health growth
- Fuel e.g. coal, oil, gas, geothermal
- Construction materials e.g. stone, sand, gravel, cement
- Ornamental products e.g. semi-precious metals, gemstones
- Fossils

Knowledge

- Earth history e.g. evolution, extinction
- Understanding physical processes
- Geoforensics
- History of research
- Environmental research e.g. ice cores, sea level change
- Education and employment


Site visit at Welton le Wold quarry © LWCS

3. Challenges for geodiversity

Threats to geodiversity are insidious. This section highlights some principal areas of concern and section 4 describes the main ways of attempting to halt and reverse these impacts.

3.1 Losses through development

Geodiversity is unlike much biodiversity: once lost it cannot be recovered, mitigated for or compensated for. The same argument can be made of sites that are covered by development. Although the resource may be retained it is permanently inaccessible and it can be considered lost as future geologists and students cannot benefit from it. In this way losses through poorly planned development or lack of awareness are the largest threat to geodiversity.

3.2 Lack of management

While some geological assets may not need management, the vast majority will require some management in order to ensure the assets do not deteriorate. While individual rocks may be particularly hard and able to withstand erosion or the roots of plants, the whole rock face or feature must be considered. How often the site is visited and the safety of those visitors must also be a concern for management. A lack of management can therefore lead to a loss of geological interest at the site, a health and safety concern or lower awareness of the geological interest through reducing the accessibility of the geological feature.

3.3 Other threats

Other threats are more wide ranging and can be a double edged sword. One of the most concerning is the lack of awareness of geodiversity. Without interest in these sites, or geodiversity more widely, the sites and all that can be learnt from them is at risk. Lack of access to sites that are often working quarries is considered a threat in that knowledge and interest cannot be generated and shared. However, at the same time, too much access is likely to damage sensitive sites so there is a balance to be struck. The same can be said of the actual quarrying process; quarrying can be argued to remove and destroy the geodiversity resource. Yet it is the quarrying that has discovered the asset and may go on to discover even more interesting features.

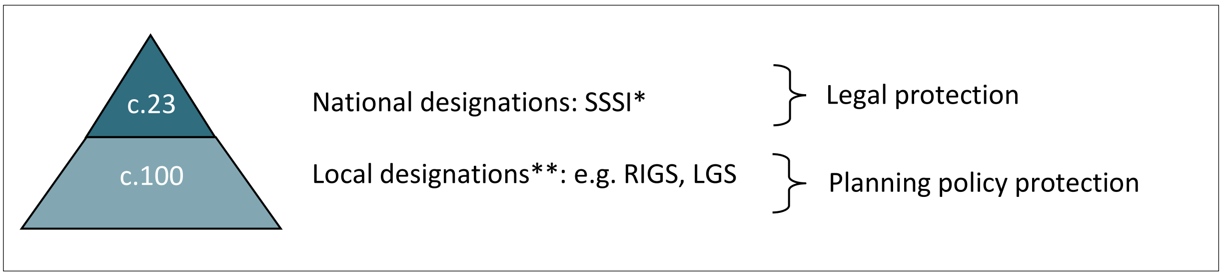
4. Geodiversity protection

Protection of geodiversity is through much of the same layered system of legislation and policy as biodiversity. However there are significantly more gaps in this system for geodiversity than for the biotic environment.

4.1 The protected sites system

The primary means of geodiversity conservation is protected sites. Unlike the more complex biodiversity system this has only a few layers, as exemplified in the pyramid below.

Figure 3: Hierarchy of protected sites



Numbers refer to approximate number of sites in Greater Lincolnshire and its adjacent sea.[3]

* See Appendix 1 for a list of Site of Special Scientific Interest (SSSIs).
** The administration of the Local Sites system in Greater Lincolnshire – Local Geological Sites (LGSs) and Regionally Important Geological Sites (RIGS) – is coordinated by the GLNP for local authorities. The guidelines for site selection were developed and approved by the GLNP in accordance with the 2006 Defra guidance[4].

The development of this system has taken many decades. Nationally the first serious attempts to identify important sites were undertaken between 1977 and 1990 with the Geological Conservation Review. This review highlights sites of stratigraphic significance in the record of British geological history and guided the designation of Site of Special Scientific Interest (SSSIs). SSSI designation represents the strongest (and only) statutory protection for geological features in the UK.

More locally, sites can also receive a measure of protection through planning policy. Each local authority holds a list of relevant sites that have been selected and designated by the local authority on the basis of local knowledge and geodiversity interest, along with information from the Geological Conservation Review. Over time, and in different areas, the terminology for such sites varied. In Greater Lincolnshire the first sites to be designated were known as Regionally Important Geological and Geomorphological Sites (RIGS). Later, following the publication of ‘Planning Policy Statement 9 Biodiversity and Geological Conservation’ in 2005, this was updated to Local Geological Sites (LGS) in line with the new guidance. Also at this time rigorous new guidance for the selection of sites was developed to ensure consistency.

---

[3] Lincolnshire Environmental Records Centre.
[4] Defra, 2006. Local Sites: Guidance on their Identification, Selection and Management.

Although LGSs do not have the same statutory protection as SSSIs, their incorporation by local authorities into their Local Plans will enable decisions on development to be made in the full knowledge of the geodiversity value of the site.

4.2 Legislation and policy outside protected areas

Specially protected areas cannot ensure the continued existence of all our geodiversity. In order to conserve areas outside of this, geodiversity conservation has to be integrated into other areas and sectors. This approach is still in its infancy for geodiversity but some important steps forward have been made.

4.2.1 National Planning Policy Framework

Revised in 2019 this relatively short document provides a system of guidance for local authorities on spatial planning. In this way it is a success that geodiversity is mentioned, albeit briefly. The areas in which geodiversity is considered are:

- **Paragraph 170a**: "protecting and enhancing valued landscapes, sites of biodiversity or geological value and soils; …"
- **Paragraph 170e**: "preventing new and existing development from contributing to, being put at unacceptable risk from, or being adversely affected by, unacceptable levels of soil, air, water or noise pollution or land instability."
- **Paragraph 174** states that Local Plans should protect and enhance biodiversity and geodiversity.
- **Paragraph 175b**: "development on land within or outside a Site of Special Scientific Interest, and which is likely to have an adverse effect on it (either individually or in combination with other developments), should not normally be permitted."
- **Paragraph 203**: "It is essential that there is a sufficient supply of minerals to provide the infrastructure, buildings, energy and goods that the country needs. Since minerals are a finite natural resource, and can only be worked where they are found, best use needs to be made of them to secure their long-term conservation."

4.2.2 Geoparks

This global designation is overseen by UNESCO and there are seven geoparks in the UK. Each one represents "single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development"[5]. The concept is bottom up, involving local people in the protection of the geological resource in a way that creates jobs and stronger communities. There are no Geoparks in Greater Lincolnshire at this time.

4.3 Power to the people

The effect individuals can have on geodiversity conservation is huge. It can be argued that individuals are the driving force of conservation in England, many of which lobby for positive policies and legislation for geodiversity protection. But the impact of individuals is wider; from comments on planning applications, to volunteering at a local reserve.

[5] UNESCO website, accessed 12/08/2016. www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/

Central to these actions by individuals is a personal connection with the natural environment. This connection is often first made in childhood and cemented by an inspirational experience. This Strategy hopes to ensure that more people continue to find inspiration in the geodiversity of Greater Lincolnshire.

5. Of the rocks and landforms

Greater Lincolnshire has a diversity of landscapes created from rocks, minerals and natural processes over time. It is this variety of landforms and rock types that creates the habitats and land uses we know today from the chalk of the Wolds to the intensive agriculture of the Fens and the distinctive spine on which Lincoln Cathedral sits. The following pages summarise this and are a condensed version of a geodiversity audit produced in 2010 and funded by the Aggregates Levy Sustainability Fund.

The boundaries of Greater Lincolnshire mimic geomorphological features which reflect the underlying geology. The natural dip of the strata to the east means that the rocks are younger from west to east and that along the north to south strike, lateral variations can be observed over a 100km long section.

This section describes the geology to be encountered in Greater Lincolnshire, with particular reference to geological exposures in the county that have been recorded as Local Geological Sites (LGS). At the time of writing a survey updating the last RIGS sites to LGSs is being completed.

5.1 The Triassic Period (252 - 201 Mya)[6]

Triassic rocks represent the oldest beds within the county of Greater Lincolnshire. They form part of a gently dipping sequence of more than 200m thickness that is largely concealed eastwards, down-dip, by the more recent deposits of the River Trent. They crop out at the surface on the Isle of Axholme, west of the River Trent, and in the A631 road cutting just east of Gainsborough. These beds belong to the Mercia Mudstone Group (previously known as the Keuper Marl). They have a very characteristic red colour and a predominantly clayey composition but some have been dolomitised and are greyish green. For the most part they were deposited in a shallow inland sea that occasionally dried out on the margins, when halite (rock salt) and calcium sulphate (gypsum) crystallised as the water evaporated in a hot, dry climate. In Melwood Quarry, between Owston Ferry and Epworth, bedding surfaces often show interesting sedimentary features such as ripple marks, salt pseudomorphs and, more rarely, rain prints.

The highest beds, formerly attributed to the Rhaetic, indicate changing conditions from a hot, arid climate to a more humid regime. Sea level rise led to the deposition of grey to black mudstones containing a marine fauna chiefly comprised of bivalves. Outcrops of these mudstones have been reported from the River Eau north-east of Scotterthorpe and from a pit dug at Blyton school. Both descriptions are of grey mudstones containing fish scales and other marine macrofossils.

5.1.1 Influence on the landscape

The Mercia Mudstone Group comprises relatively soft clays and fine silts which weather easily. They have subsequently been eroded to form nearly all the very flat low-lying ground adjacent to the Isle of Axholme. Locally they contain greenish grey siltstones and fine sandstones that are slightly calcareous or dolomitic and therefore more resistant to weathering. Known as the Clarborough Formation they are also relatively rich in thin fibrous

[6] Million years ago - time parameters are taken from the Geologic Time Scale Foundation (2012)

gypsum beds and tend to stand out as a topographic feature. At a much later date (see section 5.4.5) wind-blown sand derived from the west banked up against this line of higher ground to form the north-south ridge from Crowle to Haxey in what is otherwise a very flat landscape.

5.1.2 Economic uses

Beneath the Mercia Mudstone Group rocks of the Sherwood Sandstone Group occur at the surface further west in Nottinghamshire. Owing to the regional dip and its good permeability these rocks acted as an important self-filtering aquifer for the City of Lincoln late in the 19th Century. The deep borehole drilled by Victorian engineers near the Castle, and the resulting water stored in the adjacent water-tower, provided the city with pure water that was both naturally well-filtered and protected from surface water pollution by the thickness of the overlying impermeable mudstones of the Upper Triassic.

Until recently, to the south-east of Epworth, clays from the Mercia Mudstone Group were quarried for brick-making in a pit operated by Ibstock Brick from Leicestershire. In the later stages the clay was taken to Belton for firing, manufacturing facing bricks of differing pale colours, with the actual shade being controlled by the selection and blending of clays with differing calcite and dolomite contents.

5.1.3 Conservation

Permanent exposures in the Mercia Mudstones are increasingly rare, so the former brick-pits at Melwood and the sections in the former railway cuttings north of Haxey where red mudstones and thick seams of gypsum of the Clarborough Formation can be seen, take on greater significance.

5.2 The Jurassic Period (201 - 145 Mya)

The generalised Jurassic succession in Lincolnshire based on classifications published by the British Geological Survey[7] is shown in Figure 4.

The strike section extends along the length of Greater Lincolnshire, a distance of some 100km. Consequently there are significant changes in contemporaneous strata reflecting the difference in depositional environments at that time and controlled most strongly by the 'high' at Market Weighton. As a result, strata in the north are characteristic of a shallow coastal depositional environment compared to deeper water deposition further south.

5.2.1 Influence on the landscape

The underlying solid geology of Greater Lincolnshire dictates the pattern of the region's landforms. The north – south strike and consequent alignment of strata has produced a scarp and vale topography. The more resistant strata, mainly limestones, form ridges or blocks of higher ground. The gentle regional dip to the east gives each ridge a steeper west-facing slope, the scarp slope, and a corresponding gentle dip slope to the east. The mudstones and clays form broad vales in between. In the Scunthorpe area, Lias Limestone

---

[7] Table constructed from classifications included in the Memoirs for Sheets 80 and 89 (Kingston upon Hull and Brigg) published in 1982 and Sheet 127 (Grantham) published in 1999 and from the Regional Guide 2nd Edition "Eastern England from the Tees to The Wash" published in 1980.

bands, the Frodingham Ironstone and the Marlstone have produced a local set of scarp and vale features. The most striking of these lines of positive relief is that produced by the Lincolnshire Limestone. Geographically it has, conventionally, been divided into three areas:

- Humber – Lincoln Gap;
- Lincoln Gap – Ancaster Gap; and
- South of Ancaster Gap.

In the area north of the Lincoln Gap the easterly dip of the strata has created the west-facing scarp – the Lincoln Edge. The easterly dip reduces further south so that south of Lincoln the area on the now sub-horizontal dip slope is known as the Kesteven Plateau. Despite the relatively steep scarp slope there are no natural exposures, all of the rock being covered by post-glacial deposits, particularly the Coversands (5.4.4). Consequently, the distribution of exposures is controlled by quarrying activity and the economic value of the rock at any geographical location.

Figure 4: Generalised Jurassic succession

Stage	Group	Formation	Member/Unit (north)	Member/Unit (south)
Tithonian		Spilsby Sandstone	Lower Spilsby Sandstone	Lower Spilsby Sandstone
Kimmeridgian		Kimmeridge Clay	Elsham Sandstone	Kimmeridge Clay
			Kimmeridge Clay	
Oxfordian		Ampthill Clay	Ampthill Clay	Ampthill Clay
	Ancholme Clay	West Walton	West Walton Beds	West Walton Beds
		Oxford Clay	Weymouth	Weymouth
Callovian			Stewartby	Stewartby
			Peterborough	Peterborough
		Kellaways	Kellaways Sand	Kellaways Sand
			Kellaways Clay	Kellaways Clay
	Great Oolite	Cornbrash	Cornbrash	Cornbrash
Bathonian				
		Glentham	Blisworth Clay	Blisworth Clay
			Snitterby Limestone	Blisworth Lst.
		Rutland	Priestland Clay	Rutland
			Thorncroft Sands	(undifferentiated)
Bajocian	Redbourne	Lincolnshire Lst.	Hibaldstow Lst.	U. Lincs Lst.
			Kirton Beds	Ancaster Freestone
			Santon Oolite	
			Raventhorpe Beds	Collyweston Slate
Aalenian		Grantham	(undifferentiated)	(undifferentiated)
		N'ampton Sands	N'ampton Sands	N'ampton Ironstone
Toarcian	Lias	U. Lias Mudstone	U. Lias Mudstones	
Pliensbachian		Marlstone Rock	Marlstone	Marlstone
		Coleby/Brant Mudstone	Coleby Mudstones	Brant Mudstones
Sinemurian				
		Scunthorpe Mudstone	Frodingham Ironstone	Foston
			Scunthorpe Mudstones (undifferentiated)	Beckingham
				Granby
Hettangian				Barnby
				Barnstone

Sand/sandstone Mudstone Siltstone

Limestone Ironstone

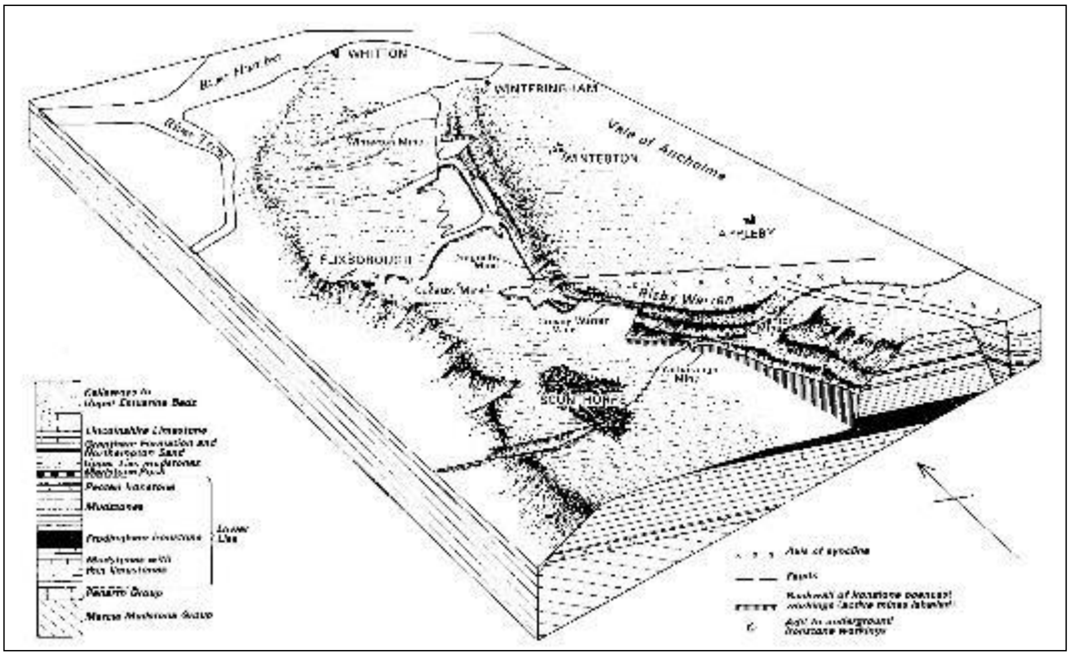
5.2.2 Economic uses

5.2.2.1 Ironstone

The Frodingham Ironstone is present in the north of the area and was the source rock for the ironstone quarrying industry at Scunthorpe as well as a significant local building stone (e.g. North Lincolnshire Museum). The industry is now in respite and many of the ironstone gullets are flooded (e.g. Bagmoor, Roxby, Winterton South). Crosby Warren and Yarborough Quarry are currently being filled in. Nevertheless, *in situ* sections of the Frodingham Ironstone and adjacent beds are still accessible at Conesby Quarry.

There are also underground workings at Dragonby and Santon mines. The general public will never be able to visit the mine but mining subsidence effects are pronounced and highly visible.

Figure 5: Block diagram of the Scunthorpe area showing the Frodingham Ironstone workings[8].



5.2.2.2 Aggregates, crushed limestone and building stone

There is a cluster of quarries around Cleatham (just north of Kirton Lindsey) where limestone and clay have been quarried as part of the cement manufacturing process. At Cleatham the quarries (Cleatham, Cliff Farm, Manton and Hibaldstow) exploited the Lincolnshire Limestone, with clay being won from Cleatham claypit, which is located just to the west of the village and therefore down the scarp face and in the underlying un-named, Lias mudstones. Manton Quarry has also supplied crushed limestone as aggregate.

South of the Lincoln Gap the Lincolnshire Limestone thickens and becomes suitable for quarrying to provide aggregate and a number of quarries are present from north to south and west to east across the dip slope. The most successful stone has been that from Ancaster which was able to take advantage of a good transport system to export its stone for buildings in Nottingham, Cambridge, Oxford and St. Albans.

---

[8] British Regional Geology, 1980. Eastern England from the Tees to The Wash. Second Edition.

The distribution of quarries exposes a considerable amount of limestone both along strike and dip and has allowed an understanding of the palaeogeography of the region during the Jurassic period.

5.2.2.3 Groundwater

The Lincolnshire Limestone is an important reservoir rock and comprises a series of aquifers separated by impermeable beds. Streams cutting down into these rocks produce a complex succession of aquifer and aquitard at outcrop, further complicated by overlying glacial deposits. Groundwater movement is to the east down the dip slope of the Lincolnshire Limestone and is almost entirely by fracture-flow along well-developed bedding planes and fractures. Most abstraction takes place to the east where the aquifer is confined by younger deposits and the confining pressure gives rise to artesian conditions. Locally the Lower Lincolnshire Limestone may be confined by the Crossi Bed. This Crossi Bed is a thin micritic limestone containing clay partings that is laterally extensive, and exhibits a distinctive brachiopod fauna at the junction with the Upper Lincolnshire Limestone.

5.2.3 Conservation

5.2.3.1 Lower Jurassic

The history of the Ironstone gullets around Scunthorpe is very important. Many of the gullets are now lost due to flooding but opportunities to preserve sections for future inspection and/or exploitation remain.

Lincolnshire Limestone forms Lincoln Castle © Lincolnshire County Council

There is an important exposure of the Lower Jurassic at the northern limit of Greater Lincolnshire, at Kell Well and Whitton Quarry, both of which expose the mudstones at their northern limit as they thin and become more limestone-rich against the Market Weighton high.

The iron ore rock store at Conesby is an unusual geological resource because the ironstone is highly fossiliferous and also accessible. The future of the store, now under the stewardship of North Lincolnshire Council, is however uncertain. The store has been pillaged by collectors and is becoming increasingly weathered and unstable.

5.2.3.2 Middle Jurassic

There are no natural exposures of the Lincolnshire Limestone. Consequently almost all knowledge of the Middle Jurassic strata in Lincolnshire is derived from boreholes, cuttings and quarries. The current trend in quarries is to exploit the void space for landfill and many quarries are destined to be filled. Restoration plans which include the maintenance of at least one quarry face are favoured.

5.2.3.3 Upper Jurassic

The relatively soft Upper Jurassic mudstones of the Ancholme Clay Group provide the bedrock of the Ancholme vale. There, mudstone is not naturally exposed and any exposures are restricted to the top of the Upper Jurassic where harder thin limestone beds form the foot of the Wold scarp. An exposure of the mudstones was, until Autumn 2020, present at the base of the very large quarry at South Ferriby where Ampthill Clay (Oxfordian) was overlain by an attenuated Kimmeridge Clay (Kimmeridgian) sequence.

The Elsham Sandstone is a locally restricted deposit extending from Barnetby northwards to Worlaby and is thus unique to north Lincolnshire. The only current exposure is in a disused and overgrown pit at Elsham where it contains Kimmeridgian ammonites.

Arguably the most important natural exposures are those with sections of the Spilsby Sandstone, a formation which spans the junction of the Jurassic and Cretaceous periods. Many small sections can be found including those at North Willingham, in the valley of the Nettleton Beck (south of Caistor), Hagworthingham and Somersby.

5.3 The Cretaceous Period (145 - 66 Mya)

This succession below is unique to Lincolnshire and represents a period of change from the preceding Jurassic mudstone deposition (i.e. deep sea) to that of marine regression and then, from the Tealby Limestone, transgression again. Natural exposures of the Lower Cretaceous are rare but there is ample borehole information to demonstrate a thinning of the succession northwards to Clixby just north of Caistor where Lower Cretaceous strata feather out against a structure, possibly a monocline. Changes of lithology also take place between south Lincolnshire and the Nettleton/Tealby area, a reflection of varying environments and water depth.

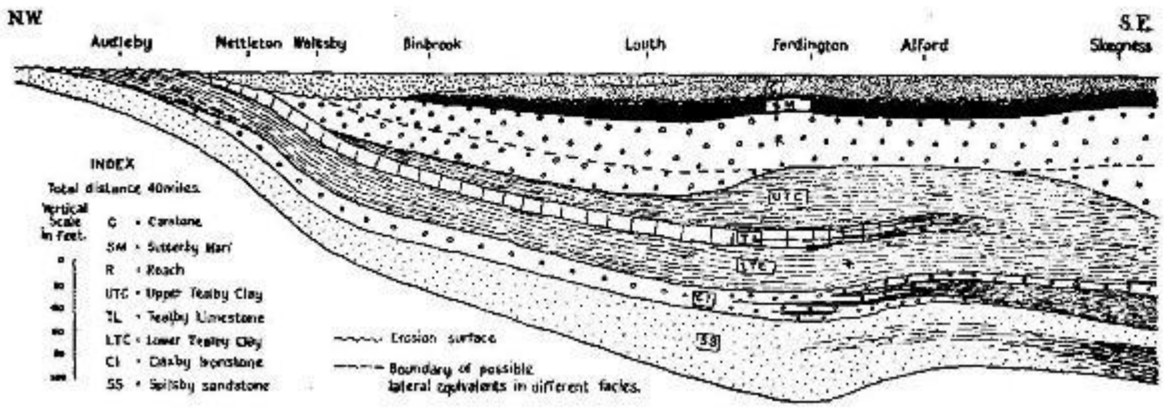
5.3.1 The Lower Cretaceous strata

Figure 6: The Lower Cretaceous strata

Nettleton/Tealby		**South Lincolnshire**	
Carstone	up to 6m thick	Carstone	up to 12m thick
Roach Formation	up to 12m thick	Sutterby Marl	2m thick
		Skegness Clay	2m thick
		Fulletby Beds	20m thick
		Upper Tealby Clay	up to 12m thick
Tealby Limestone	up to 5m thick	Tealby Limestone	10 to 40m thick
Lower Tealby Clay	up to 18m thick	Lower Tealby Clay	up to 13m thick
Claxby Ironstone	up to 8m thick	Hundleby Clay	up to 5.5m thick
Spilsby Sandstone	up to 11m thick	Spilsby Sandstone	up to 25m thick

The Spilsby Sandstone crops out in isolated roadside cuttings and former small quarries at Hagworthingham, Somersby, Stenigot and between Tealby and Bully Hill. Exposure of the rest of the succession is poor and, despite human activity in the Nettleton area to exploit the Claxby Ironstone, is often obscured by landslips on the steep west-facing slopes of the Wolds as on Nettleton Hill. Small outcrops of the Tealby Limestone can be observed in fields adjacent to the road from Claxby to Normanby-le-Wold and fragments of the limestone occur on ploughed fields at Nettleton Top.

Figure 7: Diagrammatic section showing relationships of the subdivisions of the Lower Cretaceous rocks[9].



5.3.2 Upper Cretaceous

During the Upper Cretaceous sea levels rose to over 200m higher than the present day covering all of eastern Britain. With the absence of high relief land to supply terriginous sediments, the sea accumulated pure carbonate deposits in an environment with higher global mean temperatures (+11°C) and atmospheric CO_2 levels up to four times higher than today.

The Red Chalk, though strictly a Lower Cretaceous deposit, is included in this section because it is conformable with, and an integral part of, the overlying Chalk Group. Chalk of the Northern Province is divided into six formations, in ascending order the Hunstanton, Ferriby, Welton, Burnham, Flamborough and Rowe Chalk formations. The Rowe Formation is nowhere exposed on land and, in Greater Lincolnshire, the Flamborough Chalk Formation has been proved only in boreholes buried beneath superficial deposits in the Grimsby area.

The Red Chalk, or Hunstanton Formation, comprises a series of red and yellow limestones with brick-red marls that have been stained by iron oxide leached from the underlying iron-rich strata to give the distinctive colouration. Several beds are relatively fossiliferous containing small belemnites (*Neohibolites minimus*) and species of the terebratulid brachiopod *Biplicatoria*, more frequently referred to as *Moutonithyris dutempleana*. Sections of Red Chalk are exposed at the Red Hill SSSI site, in Nettleton Bottom, on the west side of Nettleton Hill and at the base of Mansgate and South Ferriby Quarries.

Wood and Smith[10] identified reliable marker horizons throughout the Chalk in Yorkshire, Humberside and Lincolnshire and much of their nomenclature reflects local names. The Ferriby Chalk Formation is flintless but contains many thin and impersistent marl bands together with sand-textured chalks (Totternhoe and Nettleton Stones) and bands containing oysters. The Ferriby Chalk is exposed in several quarries along the west-facing scarp slope of the Wolds e.g. Bigby, Mansgate, Nettleton Bottom, Tetford Hill, Welton le Marsh and South

[9] Swinnerton, H.H. and Kent, P.E., 1981. The Geology of Lincolnshire. *Lincolnshire Naturalists' Union*.
[10] Wood, C.J. and Smith, E.G., 1978. Lithostratigraphical classification of the Chalk in North Yorkshire, Humberside and Lincolnshire. *Proceedings of the Yorkshire Geological Society.* **42**, 263-287.

Thoresby. Two bands of pink chalk, the Lower and Upper Pink Bands, are well developed at South Thoresby but become yellowish at Tetford Hill and absent north of Louth.

The boundary between the Ferriby and Welton Chalk Formations is marked by a series of dark coloured mudstones and siltstones, usually up to 70cm thick, known as the Variegated Beds. One of these beds, the Black Band, is particularly organic-rich and represents a minor extinction event. Pyritised fish scales and pyrite-filled burrows reflect the anaerobic conditions that must have been prevalent at the time. The Variegated Beds thin and become less distinct south of Louth. At Tetford Hill they are reddened and at Welton le Marsh they are represented by two thick greenish grey marls.

The Welton Chalk Formation contains harder chalks than the underlying Ferriby Formation with distinct, regionally persistent marl seams and flint bands. The flints of the Welton Chalk Formation are characteristically isolated nodular or burrow-filled. Exposure is mainly restricted to quarries such as Mill Hill at Claxby St. Andrew, Mansgate, Bigby, Barton upon Humber and the huge active workings of Singleton-Birch at Melton Ross but the A15 road cutting before the Humber Bridge approach road near Barton offers a continuous section through the topmost beds and the junction with the overlying Burnham Chalk Formation.

The Burnham Chalk Formation contains the first courses of continuous tabular flints and the large masses known as paramoudras. One of these tabular bands, the Ludborough Flint, is up to 30cm thick and very pale grey. There are also thick marl seams (e.g. North Ormsby Marl up to 12cm thick) and a shell-rich bioevent, the Ulceby Oyster Bed, from which a fish tooth has also been collected. Exposure is limited to former quarries at North Ormsby, West Ravendale, Wold Newton and Ulceby Vale with the highest beds exposed in Greater Lincolnshire occurring in overgrown quarries at Great Limber and Barrow on Humber.

In contrast to the region's Jurassic strata, where there is significant lateral variation in the depositional environment, lateral variations in the Cretaceous strata are subtle and it is the vertical section that is of most interest.

5.3.3 Influence on the landscape

The NW-SE trending scarp of the Lincolnshire Wolds is created by the more resistant Cretaceous strata compared to the underlying Jurassic mudstone. The various resistant layers of the Lower Cretaceous can be discerned in roads rising up the scarp face, particularly North Willingham Hill.

The scarp extends north into Yorkshire and has been breached by the Humber Estuary so that the north boundary of Lincolnshire comprises a north-facing Chalk coast, albeit only 2km long and concealed by Quaternary deposits.

The dip slope comprises almost 8km of the open rolling greensward of the Lincolnshire Wolds, dissected by pre-glacial and post-glacial river valleys, of such geomorphological magnificence that the area has been designated as an Area of Outstanding Natural Beauty.

The north easterly dip decreases southwards so that, at the southern edge of the Wolds near Spilsby, the dip slope has broadened and become concealed beneath Quaternary deposits.

5.3.4 Economic uses

5.3.4.1 Building stone

Use of the rock as a building stone has been common place given the extensive outcrop. The Spilsby Sandstone, which weathers to a distinctive green, has been used for churches such as at North Willingham. Limestone within the Tealby Formation has also been used locally (e.g. Nettleton village) and as far away as Irby on Humber. Chalk and flint built houses are rare, particularly in comparison to central East Anglia though the now disused church above the village of Barnetby le Wold is largely constructed of chalk.

The Lias clay was used for local brick-making until the 1920s. Waddington brick pit was a classic example that has since been lost to history and geology due to filling in and redevelopment. Similarly, former brick pits in the area between Sleaford and Bourne which used mudstones from the Oxford Clay Formation are now overgrown or filled.

5.3.4.2 Ironstone

The Lower Cretaceous Claxby Ironstone, which varied between 20% to 30% iron, was mined from 1928-1969 at Nettleton mine and remnants of the mining operation can still be discerned on the west side of Nettleton Hill and in Nettleton Bottom. The Roach was not mined despite analyses indicating a higher grade (c. 33% iron) than the Claxby Ironstone.

5.3.4.3 Aggregates, building stone and cement

Compared to the Jurassic limestones in Greater Lincolnshire, the Cretaceous strata have little value for crushing to be used as aggregate. Some production was achieved at Mansgate Hill and from flint-rich chalk at Ulceby Vale.

Tealby Limestone at Tealby village © Malcolm Fry

Chalk is predominantly exploited for its high pure lime content. When crushed to a fine powder is has been added to land to reduce the acidity, or used as a whitener. Roasting the chalk in a kiln (calcining), creates quicklime (calcium oxide) which at first was used to make mortar and cement but has since found a number of essential uses in industry.

Chalk quarries are distributed across the Wolds dip slope, with a particular concentration along the Humber Estuary near South Ferriby, where the coastal waters made bulk transport economic and allowed the quarries to prosper. Middlegate Lane Quarry, at South Ferriby, and Mansgate Hill Quarry, at Caistor, both extend down through the Chalk. The extensive workings at Melton Ross produce a variety of lime products.

5.3.4.4 Groundwater

The Chalk is a significant aquifer – the pumping station at Elsham is one of the largest in Europe. Groundwater is provided by fracture and fissure flow, and then from within a zone of 30m above and below sea level representing an area that was subject to freeze/thaw weathering during the previous Ice Ages that created the discontinuity pattern.

5.3.5 Conservation

The Lower Cretaceous strata are rarely exposed. The observation and recording of temporary exposures would aid with the understanding of the early Cretaceous.

The Environment Agency will not allow chalk quarries to be filled with waste if there is a risk of contamination to the chalk groundwater. The risk is great so many quarries remain unfilled.

Furthermore, chalk forms near-vertical faces that weather relatively quickly, producing a scree slope and preventing vegetation overgrowing the faces. Consequently there are many good exposures of the chalk succession. Unfortunately the exposure of the succession is not complete and there are gaps that may only be exposed temporarily and should, therefore, be observed and recorded.

5.4 Quaternary Period (2.6 Mya - Present)

The Quaternary period includes all the deposits formed during the last 2.5 million years, including those formed under climates ranging from warm temperate, through tundra to fully glacial. In Greater Lincolnshire they include gravels, sands, silts, clays, peats, and glacial till (previously called 'boulder clay') that cover a large proportion of the present land surface and extend eastwards on the floor of the North Sea.

There is little evidence in the region for any deposits from between the start of this period and about 600,000 years ago, although sediments from the ocean floor indicate that globally there were several glacial and inter-glacial events (known as Marine Isotope Stages or MIS) during this time.

Few deposits can definitely be attributed to a time before the Anglian glaciation (MIS12) when, about 440,000 years ago, glacial ice covered England as far south as North London and Bristol. Beneath the Anglian till in the south of the region there are older linear strips of river gravel and sand that were deposited along the courses of earlier eastward flowing rivers including the Bytham River.

The Anglian ice sheet entered Greater Lincolnshire from the north-east before developing a more direct north-south flow as it thickened and became less influenced by the underlying topography. The varied rocks and fossils that it brought into the region as erratics were mainly from Cretaceous and Jurassic rocks, but with less common rocks and fossils from the Carboniferous and older rocks from further north. Released from melting ice these materials were transported as sand and gravels that spread along river courses as fluvio-glacial deposits and into lower areas to form in lakes where they settled as lacustrine deposits. Combined with a lower global sea-level during a glacial period, the vast quantities of melt-water were able to carve deep valleys across the landscape during both advance and retreat stages of the ice sheets. The thick deposits of sands and gravels found along the course of the Bytham River probably date from the advance stages of the Anglian glaciation when, with its headwaters in Leicestershire, cutting eastwards across the Kesteven Plateau it escaped southward across East Anglia and possibly joined the ancient River Thames before entering the North Sea. In the chalk uplands similar sand and gravel deposits in the floor of a large inter-glacial valley at Welton le Wold are overlain by at least two different tills and may be the results of glacial retreat or advance stages between the Anglian and the Devensian (MIS2) glaciations.

Since the Anglian glaciation the region has experienced a number of alternating cold and warm climates that have dramatically modified the surface features. The last glacial advance that occurred during the Devensian glaciation(s), 30,000 to 15,000 years ago only reached into the extreme northern and eastern areas of the region. At Welton le Wold there is strong evidence for further glacial events and the deposition of at least two different tills between the Anglian and Devensian glaciations. Precise dating of these deposits to particular stages known from the MIS record in deep sea sediments and their relationship to similar deposits in other parts of Great Britain is currently under study and subject to conjecture and debate.

With the melting back of the Devensian ice sheet to the north about 14,500 years ago, the Flandrian stage (MIS1) has seen progressive global sea-level rising. Initially it drowned the forests and grasslands that had developed on the till and fluvial deposits of 'Doggerland' during the milder climate as the ice retreated, but now lie beneath the North Sea. The Humber Estuary and The Wash also progressively formed in the lower parts of the region's largest rivers as sea-level started to rise. This also reduced the gradient and hence the energy of the region's rivers, causing the deposition of sand and gravel up-stream and increasing flooding, with silt and clay sediments in suspension spreading over the adjacent flood-plains.

For more than three thousand years humans have been modifying these effects, with increasing success as technology has developed. In the Bronze and Iron ages extracting salt from sea-water along the coast involved 'trapping' high spring-tide water behind clay banks. During the Roman period the Carr Dyke was cut along the western side of the Fens to serve as a cut-off or catch-water drain and in the process to serve as a canal to Lincoln. On many occasions from the Medieval period until last century progressive 'reclamation' of salt-marshes by the adjacent parishes by building 'new sea-walls' extended their area further into The Wash. Large areas of freshwater marshes between the southern end of the Wolds and the 'siltlands' to the south, were only enclosed and drained during the 18th and early 19th Centuries. On the south banks of the Humber many parishes until recently used 'warping' with fresh-water alluvium to improve the agricultural potential of the acid peat soils in low-lying areas. Following the development of Victorian resorts along the Lincolnshire coast the natural defences of sand-dunes and beach materials were supplemented with wooden groynes and concrete promenades, before a mixture of 'hard' engineering solutions including steel-sheet piling and reinforced concrete, were used in the aftermath of the 1953 East Coast Floods. Most recently the 'soft' engineering solutions have involved beach nourishment, using sands dredged from off-shore sandbanks. Inland, in an attempt to reduce flood risk, many rivers have been straightened, banks raised and more powerful pumping stations have been built, along with a greatly improved system of waterway maintenance.

5.4.1 Glacial Till

Till of different types and ages and varying in thickness from tens of metres to a few centimetres is widespread over the county. The most extensive deposit is the Anglian Till, characterised by its pale grey to bluish grey fabric weathering to a yellowish brown colour, with an abundance of rounded chalk pebbles and angular flint erratics. It also contains fewer limestones, ironstones, mudstones and sandstones, mainly of Cretaceous and Jurassic ages, but with some Carboniferous and Triassic materials, plus rare igneous and metamorphic rocks including meta-quartzites and vein quartz pebbles. Where it is found in the most extensive areas on the Kesteven Plateau it is quite uniform in colour and composition indicating that it is the dissected remnants of a once continuous deposit formed during a single glacial event.

Younger tills, particularly in the Wolds and adjacent areas, have been described and attributed in the past to a Wolstonian glacial event about 200,000 years ago (possibly MIS6). Named after local places where they were studied, the Welton and Calcethorpe Tills both have an abundance of chalk and flints, with a very small non-Cretaceous content. An analysis of the orientation of elongated pebbles in these deposits suggests that they were transported in an ice-stream flowing almost directly from the north-north-west along the alignment of the Wolds. A post-Anglian age for gravels and sands from beneath the Welton Till has recently been supported by the dating of sand grains using Optically Stimulated Luminescence at Oxford University Laboratories, providing dates of between 300,000 and 400,000 years (=Hoxnian, MIS11).

The Wragby Till, varying between 5m and 15m in thickness is recorded in the Ancholme valley as far south as Woodhall Spa, but is more problematic. Usually a dark grey colour when fresh, the matrix is predominantly Jurassic clay, with gravel and sand-sized pieces of chalk, flint, sandstone, siltstone and larger septarian nodules. Large blocks of Lincolnshire Limestone and Spilsby Sandstone also occur as erratics in this till, reflecting an ice-stream flow along the strike of the Upper Jurassic-Lower Cretaceous boundary in the Ancholme valley south of the Humber. Several authors, including Perrin, Rose and Davies (1979)[11], have correlated the Wragby Till with the 'chalky tills' of East Anglia and hence given it an Anglian (MIS12) age. In the absence of controlled dating or relationships it is equally possible that they are the lateral equivalent of the Welton Till and post-Anglian in age.

The youngest glacial till to be found in Greater Lincolnshire is of Devensian (MIS2-3) age deposited between 30,000 and 15,000 years ago by an ice sheet that moved down what is now the North Sea from Scotland and northern England. Close to its southern limit the ice sheet was restricted from inland movement by the Wolds, banking up along a buried cliff-line on their eastern side before rounding the southern end and terminating as a moraine found at West Keal, through Stickney and Boston, to the North Norfolk Coast near Hunstanton. This ice sheet also pushed up the Humber estuary as far as Winteringham

[11] Perrin, R.M.S., Rose, J. and Davies, H., 1979. The distribution, variation and origins of pre-Devensian tills in eastern England. *Phil. Trans. Roy. Soc.,* Series B. **287**, 535-570.

before turning south. It deposited a terminal moraine across what is now the Ancholme valley at Horkstow. South Ferriby Cliff, on the south bank of the Humber estuary, provides sections where peneplaned and cryoturbated bedrock can be seen in contact with Devensian glacial deposits. Named the Marsh Till by Straw (2005)[12], it is a silty to sandy clay that weathers to a reddish-brown colour, with very mixed erratics of Jurassic, Permian, Carboniferous and Devonian aged rocks and fossils including several of boulder size. Chalk and flint are much less common compared with the older tills and there are usually granites and schists from Scotland. In the 19th Century a large block of distinctive granite from the Lake District was found in the till during the excavation of Grimsby docks indicating that ice from the Lake District had crossed the Pennines through the Stainmore Gap and merged with North British ice in the North Sea area. Larvikite, a rare rock type from the Oslo Fjord area of southern Norway, is frequently found in the till beneath the submerged forests on the Lincolnshire coast. Possibly Scandinavian ice mixed with, or replaced, Scottish ice in the last stages of the Devensian glaciations. Alternatively it is possible that the late Devensian ice was re-working deposits from an earlier Scandinavian ice sheet.

5.4.1.1 Influence on landscape

Where the till is thick or extensive it frequently masks the characteristics of the bedrock beneath. In the Wolds areas where till covers chalk and sandstone, soils are heavy and were agriculturally less productive so left under woodland. Similarly in the extensive areas of till over the limestone on the Kesteven Plateau, large areas of woodland originally formed the Forest of Kesteven, with wooded parklands and forestry plantations a feature of the present landscape.

5.4.1.2 Economic uses

Due to its frequent and varied erratic content economic use of the clays was very limited with some local use for brick-making. In areas where very chalk-rich tills lay over Spilsby Sandstone they were used as a source of lime for improving acid soils in the immediately surrounding area.

5.4.1.3 Conservation

Lacking coastal exposures, and with no modern economic extraction, any sections in the tills are rare and of great value in illuminating the Pleistocene history of the region. The most significant exposures in the earliest recorded glaciation of the area are those in the Bytham valley where sand and gravel are currently being extracted from beneath a till cover. Also on the Kesteven Plateau, several of the active limestone quarries have to remove till as a surface overburden deposit, offering further opportunities to add to the understanding of the Anglian glacial deposits. In the Wolds, the former extensive sand and gravel pits at Welton le Wold penetrated three different tills above the deposits, providing controversial evidence for glaciations between the Anglian and Devensian cold stages. Further along the Bain valley former and current sand and gravel workings at Biscathorpe, Donington on Bain, Woodhall Spa and Tattershall all show significant relationships between the sand and gravel deposits and glacial tills.

Continuing extraction of these deposits offers the best opportunities for a better understanding of their characteristics and origins. In some cases small faces might be retained in restoration schemes at the end of the working life of individual quarries or pits.

---

[12] Straw, A., 2005. Glacial and pre-glacial deposits at Welton-le-Wold, Lincolnshire. *Studio Publishing Services, Exeter.*

Lincolnshire Wildlife Trust purchased part of the geological SSSI at Welton le Wold as a Geological Reserve and owns Stanton's Pit, a reserve in the Bytham valley where sand and gravels were worked from beneath the Anglian till.

5.4.2 Fluvioglacial Gravels and Sands

Sand and gravel deposits associated with the advance and retreat of glacial ice across and into the region are considered together. This includes some that may have been deposited directly from the ice in sub-glacial channels as well as those deposited sub-aerially from melt-waters. In turn these become less easily distinguished from normal fluvial deposits progressively further downstream as melt-water influence, strong seasonal variations and the excessive supply of sediment decreases with distance downstream and milder climate. Often well bedded with cross-bedding and cut-and-fill structures they also tend to vary rapidly laterally and down-stream, grading into glacio-lacustrine clays and fine sand where ice-dammed lakes occurred. Ice-wedge casts and cryoturbation layers frequently occur at one or more levels within them indicating the severity of the climate during breaks in their deposition.

Since a high proportion of the material will have been derived directly from the rocks eroded by the glacial ice the pebble content of the sand and gravels will depend on which glacial advance event the deposits are associated with. This is well illustrated by the differences between the almost pure angular flint gravels below the Welton Till at Welton le Wold and the nearby deposits at South Elkington which have very mixed lithologies including a high proportion of older rocks derived from Northern England and Scotland found within the Marsh Till.

5.4.2.1 Influence on landscape

Extensive areas of fluvioglacial sands and gravels are not common in the county since many of them were restricted laterally by the rivers' valley sides. To the west of the Winteringham moraine, a series of shallow sand and gravel pits has been dug into the irregular surface topography on the south bank of the Humber, exposing complex variations in the pro-glacial deposits. More extensive areas of current workings occur in the Ancholme valley west of Barnetby le Wold, where the superficial deposits give rise to free draining acid soils and scrubby woodland in contrast with the heavy clay soils developed on the bedrock of the Ancholme Clay Group.

5.4.2.2 Economic uses

Derived from different tills, the sand and gravels have very varied compositions and hence economic value. Those derived from chalk or limestone rich tills are susceptible to frost damage and generally unsuitable for use in concrete but find a market for bulk fill and foundations.

5.4.2.3 Conservation

Continuing extraction of these deposits offers the best opportunities to develop understanding of their characteristics and origins. In some cases small faces might be retained in restoration schemes at the end of the working life of individual pits.

5.4.3 Fluvial Gravels and Sands

Fluvial sand and gravels are generally distinguished from fluvio-glacial deposits by their occurrence as flights of terraces along the main present-day river valley routes and a lack of association with glacial tills. With the highest level terraces being the oldest and the present-day flood-plains of the rivers being the youngest, they formed under a range of conditions including changing sea-levels and isostatic uplift following the unloading of major ice sheets over the region. Not surprisingly they show great variations over the area as a consequence of the variety of local bedrocks and superficial geology, the availability of different sizes of materials and lithologies from derived secondary sources.

5.4.3.1 Influence on landscape

As linear strips above the floodplains of modern rivers they often form flatter ground with different soils and drainage characteristics from the surrounding bedrock areas. Where they are less confined they tend to form extensive areas of free-draining acid soils that have low agricultural value. Often they are left under woodland or scrub, but many of the region's golf-courses including those at Woodhall Spa, Kirkby on Bain, Rauceby and Branston, are located on these deposits. Many of the former sand and gravels pits in the Lincoln Gap, including several within the built-up area of the City, are now flooded and have a wide range of recreational uses as well as providing landfill sites. Along the western margin of the Fenland, extensive areas of sand and gravels lie beneath the soil or a thin covering of alluvium and peat which previously supported a natural fenland carr vegetation.

5.4.3.2 Economic uses

Depending upon their varied lithologies and grain sizes sands and gravels from river terraces have been worked for a variety of purposes for many years. The former course of the River Trent through the Lincoln Gap is marked by an extensive spread of sands and gravels that are currently being extracted, with flooded former workings now used as nature reserves, water-sports and recreation areas. With suitable lining some former pits close to Lincoln have been used for licensed land-fill sites. Along the western edge of the southern Fenland, extensive areas of fluvial sand and gravels indicate where the Rivers Welland and Nene spread deposits over the mudstones of the Ancholme Clay Group. There are active quarries between Baston and Market Deeping with more workings planned.

5.4.3.3 Conservation

Lincolnshire Wildlife Trust owns and manages several former sand and gravel pits in the Lincoln Gap deposits at Whisby, in the lower Bain Valley, near Market Deeping and another in the Belton Sand and Gravel deposits in the Ancaster Gap near Rauceby. Many of the former fluvial sand and gravel pits have also proved attractive as fishing lakes and country parks.

Continuing extraction of these deposits where they occur offers the best opportunities for a better understanding of their characteristics and origins. In some cases small faces might be retained in restoration schemes at the end of the working life of individual pits.

5.4.4 Coversands

Widespread aeolian or 'wind-blown' sands are known as 'coversands' in most of Lincolnshire. They are often very thin and may be included in the finer upper layers of fluvial deposits. Exceptions occur at the foot of the north-south topographic ridges formed by more resistant lithologies, where several metres of well-sorted fine-grained sand may have been trapped. Although their uneven surface topography may resemble that of linear dunes, only rarely are dune-bedding features seen. Frequently they form gentle concave slopes at the foot of west-facing scarps having been picked up from unvegetated areas of sands and blown eastwards by the prevailing winds. Many of these deposits have been dated to the

Devensian when extensive areas of fluvio-glacial river deposits were forming across large areas of the county and pro-glacial lakes were drying-up. Other coversand materials formed under similar climate conditions associated with earlier glaciations may occur but are not easily recognised because of their distribution and subsequent weathering.

5.4.4.1 Influence on landscape

Banks of aeolian sands lie along the foot of most west facing scarps in the county where they help to mask the breaks in slope where bedrock geology changes. Contrasting light sandy soils were often left under woodland, or used as warrens in earlier times, but now they often provide scrubby areas of heathland, with silver birch and coniferous woodlands that are important recreation areas. In the western part of Greater Lincolnshire more extensive areas of low agricultural value lying over these deposits are now planted with coniferous woodlands.

5.4.4.2 Economic uses

Because it is generally very well sorted and under sparse vegetation these deposits have long been used for building sand. At Messingham and a few other sites the sands are almost entirely composed of chert and quartzite with a lack of fines (= particle size fraction of an aggregate which passes the 0.063 mm sieve). They have been suitable for use as refractory sands and in the manufacture of coloured glass.

5.4.4.3 Conservation

Active quarrying tends to produce fresh sections and increase the material available for study in order to better understand these deposits and their characteristics. In some cases small faces might be retained in restoration schemes at the end of the working life of individual pits.

Lincolnshire Wildlife Trust and local authorities now own a number of sites of previous workings in coversands for their environmental and recreational value; e.g. Moor Farm (Kirkby on Bain) and Atkinson's Warren (Scunthorpe). A vast range of flora and wildlife is to be found in the varied acid and calcareous, dry and wet habitats offered by the former workings. Rare birds including the nightjar and hen harrier mix with the more common green woodpeckers and woodlarks, whilst many varieties of butterflies, reptiles, flowering plants and grasses can be seen in an increasingly rare habitat.

5.4.5 Head

The product of rock decomposition and mass movement under periglacial conditions, only the thicker deposits are generally recognised owing to their frequent incorporation in landslip materials and blown sands. The composition of Head is as varied as the rocks from which it is derived but lack of sorting or structure, is rarely consolidated to any degree and deposits are usually less than 2m in thickness.

5.4.5.1 Influence on landscape

Masking slopes and thickest at their foot and in valley floors these deposits tend to have a micro-effect on landscapes. Solifluction lobes may be seen on a number of west- or north-facing slopes near Lincoln where the down-slope movement of material has broken or disturbed the vegetation cover. Because of their clay content they may also form deeper and less well drained soils at the foot of valleys in chalk and limestone areas.

5.4.5.2 Economic uses
Deposits of Head have no economic value and are consequently rarely seen in section.

5.4.5.3 Conservation
Since there are no extraction sites in Head deposits it is difficult to have a conservation policy. Where they are being cut through, as on the Lincoln northern by-pass and the Leadenham by-pass, any opportunities to measure, sample and study these materials should be taken since they have considerable importance on slope stability and related engineering properties.

5.4.6 Peat

There are extensive peat deposits in the county. They occur in the north-west, along the south bank of the Humber estuary and the Lower Trent valley, and in the south-east, around the Fens and Lower Witham valley.

The earliest evidence for peat formation may be seen at several places along the coast at low Spring tides when the remains of an old buried forest peat can be seen capping Devensian-aged Marsh Till. Radio-carbon dating suggests that peat formation had started around 7,000 years ago as a result of a wetter climate that was conducive to raised bog development in low-lying areas and a sharply rising mean sea-level; from -9m to -3m between 7,000 and 6,000 years ago. This was followed by a steady rise, with levels varying around those at the present day for most of the last 3,500 years. The peat deposits in the Isle of Axholme and Crowle Moor date from this phase when a rapidly rising water-table was conducive to the formation of raised bog.

As sea level continued to rise following the establishment of salt-marshes around The Wash, marsh-forming conditions started to move inland depositing silts and clays, with tidal creeks now filled in with fine sand showing as roddons. Consequently Fenland peats started to form again around 3,500 years ago. Woodland areas around the Wash again became water-logged as sea-level rose, with a fen carr of birch and pine that had recolonised the area becoming waterlogged and helping to form a further peat bed.

5.4.6.1 Influence on landscape
The northern peat deposits relate to more extensive areas of peat in the Humberhead Levels (Thorne, Crowle and Hatfield Moors plus smaller turbaries) that have both been a wilderness and an economic resource for centuries. Previously as wet and semi-permanently waterlogged woodlands, they had largely been worked around their margins for much of this time, until the modern demand for horticultural peat led to massive extraction and the associated destruction of large areas of this increasingly rare habitat.

The Fenland peats, include those of the Lower Witham valley, contribute to the rich pattern of the Fens with deep fertile soils well suited to intensive agricultural practices. As a consequence of drainage, most of these peat areas have started to dry out leaving them vulnerable to soil-blow in the event of dry spring conditions when there are no crops protecting the soil.

5.4.6.2 Economic uses
Originally used as a source of fuel for the adjacent settlements, the most recent use has been for horticultural peat. Where soils are developed on the peat they may be used for intensive crops such as celery.

5.4.6.3 Conservation
Pressures from conservation groups led to the cessation of extensive commercial peat extraction within the Humberhead Levels and the establishment of the Humberhead Peatlands National Nature Reserve. Restoration is underway with the aim of re-establishing conditions suitable for peat formation on Thorne, Crowle and Hatfield Moors. Within Greater Lincolnshire, the Wildlife Trust and North Lincolnshire Council own and manage peatland sites.

Buried peats beneath the silts and alluvium around The Wash provide vital evidence of changes in sea-level over the last few thousand years. It is important that key sites in this area are recognised and protected from destructive actions for future research. Natural England recently designated a number of such sites in the Lincolnshire Fenland as Geological SSSIs for these purposes, at least one of which is associated with the pioneering work in this field in the 1970s by Professor Ian Shennan[13] of Durham University.

5.4.7 Silts

Forming a crescent of slightly higher land around The Wash, marine silts deposited in salt-marshes and tidal creeks, impeded natural drainage from the higher ground to the west resulting in large areas of fen on the northern and western sides.

5.4.7.1 Influence on landscape
Despite only standing a few metres above the former coastal marshes to the seaward and the fresh-water fens on the landward side, the silts provided a route-way between these areas and slightly better drained land that was suitable for settlement. Consequently there is a chain of mediaeval settlement every few miles along the 'siltlands' around The Wash from Long Sutton to Skegness. The progressive construction of new sea-walls in these settlements, combined with increasing salt-marsh accumulation, allowed progressive reclamation, over many centuries, of half-mile wide strips of land towards The Wash and adding to the land area.

5.4.7.2 Economic uses
The soils developed on these reclaimed marshes are some of the most productive in Britain. Near Boston they are used to specialise in growing green vegetable crops including Brussels sprouts, cabbages and cauliflowers for the UK market. Near Spalding, the silt soils are used for bulb-growing and soft fruit production with daffodils taking over from tulips as the main bulb-field crop. In both areas the extensive use of greenhouses and scaled-down agricultural machinery allows the glass-house production of early crops that command the highest prices.

5.4.7.3 Conservation
Since there are no extractive industries working these deposits it is again vital that temporary sections produced during the cutting or maintenance of field or carrier drains are inspected and recorded.

---

[13] Shennan, I., 1986. Flandrian sea-level changes in the Fenland I: The geographical setting and evidence of relative sea-level changes; *and* Flandrian sea-level changes in the Fenland II: Tendencies of sea-level movement, altitudinal changes, and local and regional factors. *Journal of Quaternary Science.* **1**, 119-153 and 157-179.

5.4.8 Alluvium

Extensive areas of alluvium occur along the modern flood-plains of the region’s larger rivers. The most extensive deposits lie along the south bank of the Humber near Barton upon Humber where they are mainly a greyish brown silty clay up to 8m thick.

5.4.8.1 Influence on landscape

Generally they form very flat land on floodplains adjacent to rivers that may be subject to irregular flooding by river water. The areas along the south side of the Humber and very close to sea-level were also subject to marine flooding helping to form estuarine deposits locally more than 8m thick.

5.4.8.2 Economic uses

Along the south bank of the Humber downstream from Goole these estuarine clays have proved very suitable for brick and tile making for several centuries. The large rectangular flooded areas near the Humber Bridge were the sites of alluvium extraction. Whilst evidence and remains of old works are numerous, only William Blyth’s Hoe Hill Tile Works is still producing the traditional red clay pantiles.

5.4.8.3 Conservation

Since there are no current major extraction sites it is not possible to develop a conservation strategy for these deposits. There may be scope here for joint conservation projects with industrial archaeologists and historians at some future date. Many of the pits are nature reserves or SSSIs and are within or adjacent to the Humber Estuary SSSI, where the range of habitats support a variety of birds, including internationally import populations of a number of species.

6. Planning and taking action for geodiversity

This section covers more of the 'nuts and bolts' of geodiversity action; moving into the action plans that represent the GAP section.

6.1 The UK GAP context for Local GAPs

The 1st edition of the Lincolnshire GAP was produced before the UK GAP, but looked towards a national structure. With this national context the 2nd edition was more closely focused to ensure that delivery at the local level is also delivering for the national. In this way the relevant actions from the UK GAP are shown alongside the Greater Lincolnshire actions.

6.1.2 Criteria for developing action plans

The purpose of a GAP is to focus effort and to prioritise action. Therefore it is important to have criteria for developing action plans, otherwise it would be too easy to lose sight of the purpose and develop too many action plans. This Strategy includes only four plans as it recognises these are key areas in which to take action forward and yet even these remain aspirational to a degree.

6.1.3 Plan structure

Each action plan follows the same format to ensure consistency for the reader. Each plan is kept short as the required detail for action is not necessary in the plan. Actions are as 'SMART' as possible with the understanding that many actions are aspirational.

SMART: Specific, Measurable, Achievable, Realistic, Time-limited

The key to the tables is as follows:

Item	Explanation
Ref	Action reference, so that progress against each action can be tracked and measured
GAP	Action from the UK GAP
LAs	Local authorities
PBs	Public bodies such as Natural England
LMs	Land managers and owners, these are also business owners
NGOs	Non-governmental organisations, including charities. All museums in Greater Lincolnshire are included under this heading as is the work of the Geodiversity Group
I&Cs	Individuals and communities
£	Funders

6.1.4 The role of local groups

This Strategy is particularly strong as the partnership of organisations and individuals involved in its development, delivery and monitoring is part of a larger partnership: the GLNP (see Figure 1 – page 2).

In Greater Lincolnshire this Strategy and its action plans are supported and primarily delivered by the Geodiversity Group. This Group are local experts made up of volunteers and professionals with knowledge of the local area. With the support of the GLNP the Group has taken on the responsibility of working on the priorities, reporting on progress and updating the plans as necessary. This collaborative working has proven successful in delivering action in the 1st edition of the Lincolnshire GAP as best practice and information could easily be shared between group members.

6.1.5 Monitoring and reporting

All Partners will be responsible for reporting contributions towards targets and actions at least annually (April each year). The GLNP Team will collate information and produce summary reports. It is important that progress is recorded annually at the local level to help identify gaps in delivery and priorities for action. This system makes it possible to collate information on progress towards the UK GAP, recognising the contribution that local action makes to the bigger picture of geodiversity delivery.

6.2 Progress 2017-2021

Figure 8: Status of 2nd edition Geodiversity Action Plan targets

As the chart shows the total number of achieved actions is low, however the context of the 2nd edition Geodiversity Action Plan must be remembered. Actions were taken primarily voluntarily and by staff in addition to their 'day job'.

	Total	Percentage
Achieved	3	17
Some progress	13	72
Not achieved	2	11
Total actions	18	100

7. Geodiversity conservation

7.1 Current status in Greater Lincolnshire

There are currently 100 Local Geological Sites recorded in Greater Lincolnshire, with 39 surveyed in the last 10 years. Of these, 10 are recorded as being in positive conservation management, often only needing minimal management to maintain this status. There are also a number of sites (9) which have not been surveyed recently because access has not been possible for a variety of reasons. The condition of these sites is unknown.

Some progress has been made with a few sites where the Geodiversity Group has been consulted by landowners with regards to suitable restoration plans. This has meant that access to these sites will be available once current quarrying and other uses cease.

7.2 Threats in Greater Lincolnshire

Greater Lincolnshire has little in the way of natural exposure of its geology and there is a heavy reliance on artificial exposures in quarries and cuttings. This poses a significant threat to geodiversity as quarries eventually close and may be used as landfill. Many sites have been lost as they have been infilled and the exposures hidden whilst others have been lost as a result of work on coastal defences.

Quality of exposure is also an issue in quarries and cuttings as the rocks weather and the exposure degrades. Quarries can also become overgrown with vegetation which makes access to exposures difficult. Attempts to improve access to geodiversity with the creation of rockstores has also become an issue with the illegal access to and collecting from such sites.

Quarries may be seen as a liability by some landowners and this also poses a threat to the geodiversity of the Greater Lincolnshire area. Access to some quarries is denied and in other cases the ownership of the quarry cannot be traced making access problematic. The issue of illegal/unauthorised use of quarries has also meant that some landowners have introduced a ban on activities. Other sites are also in use for other purposes which can conflict with their geodiversity interest e.g. motor sports or shooting.

Some sites have also been lost having been restored to agricultural use. While this is especially true of small aggregate workings in largely agricultural environments, it must also be remembered that these sites are opportunities to record geodiversity that otherwise would not be seen.

7.3 Aim

To record and conserve the geodiversity of Greater Lincolnshire

7.4 Targets and actions 2022-2026

Target	Greater Lincolnshire actions	Relevant national actions	Who can help					
			LAs	PBs	LMs	NGOs	I&Cs	£
GAP_C_1	To survey and designate sites of interest	GAP: Designate areas of local geodiversity importance as Local Geological Sites (or their equivalent) and Local Nature Reserves GAP: Continue to map the distribution of the UK geodiversity and use a range of tools to present and interpret the mapped information	✓			✓		
GAP_C_2	To ensure no net loss of important geodiversity sites Suggested actions: Produce a database of sites including condition; identify SSSIs that require management to bring features into favourable condition; work with landowners to bring sites into favourable condition	GAP: Maintain and update information on locally important geodiversity site networks GAP: Identify and document new localities important to our understanding and interpretation of geodiversity		✓		✓		

<table>
<tr><th rowspan="2">Target</th><th rowspan="2">Greater Lincolnshire actions</th><th rowspan="2">Relevant national actions</th><th colspan="6">Who can help</th></tr>
<tr><th>LAs</th><th>PBs</th><th>LMs</th><th>NGOs</th><th>I&Cs</th><th>£</th></tr>
<tr><td>GAP_C_3</td><td>Identify where features and access can be improved on LGSs and investigate opportunities for improvement. Suggested actions: Produce a database to identify where work is needed to bring sites into favourable condition; liaise with site owners/managers to secure improvements works and access</td><td rowspan="2">GAP: Advocate good practice for geodiversity conservation across a range of sectors including transport, housing, mineral extraction and waste.
GAP: Advocate policies and environmental assessment methods that accommodate and plan for geodiversity enhancement and mitigation
GAP: Develop consistent and simple messages that support the wider recognition of geodiversity and develop initiatives that promote geodiversity
GAP: Establish sustainable management within locally designated geodiversity sites and areas that maintain and enhance the features of interest
GAP: Identify where using geodiversity information is important to Ecosystem Services including soil formation, flood management, pollution control, mineral resources and the enjoyment of our environment</td><td>✓</td><td></td><td>✓</td><td>✓</td><td></td><td></td></tr>
<tr><td>GAP_C_4</td><td>Further opportunities on new sites for protection of geodiversity Suggested actions: Work with quarry operators and industry to establish communication; work with planners to ensure restoration plans take account of geodiversity</td><td>✓</td><td></td><td>✓</td><td>✓</td><td></td><td></td></tr>
</table>


Fossil shells in Marlstone at Harlaxton Church © Fran Smith

8. Geodiversity in policies and plans

8.1 Current status in Greater Lincolnshire

The GAP 1st edition was circulated to all relevant planning authorities. The Geodiversity Group contributed to the consultation on the Lincolnshire Minerals and Waste Plan. Members of the Geodiversity Group have responded to planning requests either through the Lincolnshire Wildlife Trust, as concerned individuals or at the direct request of officers within local authorities.

8.2 Threats in Greater Lincolnshire

It is not clear if geodiversity issues have been embraced by all of the relevant authorities, and where they have, a watching brief must be kept as plans/policies change over time. Not all relevant planning requests are seen by the Geodiversity Group. There is generally no direct contact between the Geodiversity Group and the planning authorities within Greater Lincolnshire.

8.3 Aim

To ensure geodiversity is included in relevant plans and policies

8.4 Targets and actions 2022-2026

Target	Greater Lincolnshire actions	Relevant national actions	Who can help					
			LAs	PBs	LMs	NGOs	I&Cs	£
GAP_P_1	Review existing policy documents to determine whether appropriate policies exist to safeguard geodiversity	GAP: Identify policy and guidance that should include or reference geodiversity	✓	✓		✓		
GAP_P_2	Provide support and advice to enable policy changes to safeguard geodiversity Suggested actions: Produce model policies and circulate; officer to meet with representatives to engage interest	GAP: Work with relevant government departments, authorities and other organisations in order to secure wider geodiversity policy inclusion. GAP: Respond to relevant consultation advocated geodiversity inclusion in development and delivery of strategic documents and overarching policy. GAP: Integrate geodiversity within other environmental agenda, strategies and action plans, including the European Landscape Convention.	✓	✓		✓		
GAP_P_3	Provide specialist, site specific advice to planners in relation to individual planning applications Suggested actions: Produce a series of factsheets for policymakers; officer is available to provide specialist advice; ensure one face is retained in quarry restoration plans	GAP: Demonstrate how to use geodiversity information to better understand, plan for and mitigate the effects of climate change, coastal erosion and flooding GAP: Identify and better understand geodiversity in relation to other interest areas such as wildlife sites, the built and historic environment, landscape and the marine environment	✓	✓	✓	✓		
GAP_P_4	Monitor success of geodiversity awareness in policies		✓			✓		

9. Raising geodiversity awareness

9.1 Current status in Greater Lincolnshire

The Geodiversity Group has raised awareness within Greater Lincolnshire by producing leaflets which explain geodiversity issues. Members of the Geodiversity Group have also maintained a presence at the Lincolnshire Show to introduce the general public to geodiversity issues. Some members of the Group have also been responsible for events to interested groups within Greater Lincolnshire.

The Group has also drawn the attention of the GAP 1st edition to the relevant authorities within Greater Lincolnshire.

9.2 Threats in Greater Lincolnshire

The personnel who have developed the initiatives outlined above are largely volunteers and there is a need to attract new members to the Group in order to widen awareness amongst the general public. There is currently no paid officer responsible for geodiversity.

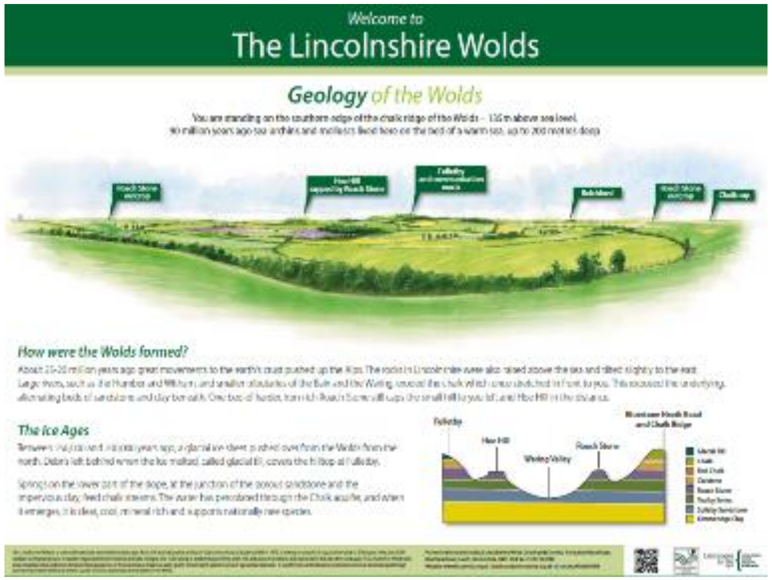
The attitudes of authorities within Greater Lincolnshire to geodiversity are not always clear.

A number of the museums have now closed or are under threat from funding cuts and access to their collections may become more difficult or problematic.

9.3 Aim

To raise awareness of the importance of geodiversity across all sectors

9.4 Targets and actions 2022-2026



Raising awareness through interpretation panels© LWCS

Target	Greater Lincolnshire actions	Relevant national actions	Who can help					
			LAs	PBs	LMs	NGOs	I&Cs	£
GAP_A_1	Identify existing geodiversity resources in museums and other collections	GAP: Audit and maintain records of geodiversity in public collections (including collections of specimens, published material, photographs and other geodiversity ephemera)				✓		
GAP_A_2	To raise awareness among local authorities and professional partners Suggested actions: Contact local authorities, new and existing partners and industry representatives highlighting the GAP and LGS process, directing them to the website, literature and specialist advice available; promotion of specialist advice available via officer	GAP: Demonstrate the socio-economic benefits that geodiversity brings for people and the cultural services it provides across a range of sectors and social agenda (for example contributing to sense of place and a healthy lifestyle) GAP: Develop consistent and simple messages that support the wider recognition of geodiversity and develop initiatives that promote geodiversity GAP: Identify where using geodiversity information is important to Ecosystem Services including soil formation, flood management, pollution control, mineral resources and the enjoyment of our environment.	✓			✓		
GAP_A_3	Raise awareness with landowners and managers Suggested actions: Develop factsheets of the special qualities of key geodiversity features and tie in with agri-environment practices and grant schemes; utilise site meetings and key farmer events to promote factsheets and encourage site visits.	GAP: Share good practice and experience for the establishment and delivery of Local Geodiversity Action Plans and organisational / company Geodiversity Action Plans. GAP: Share good geodiversity conservation practice through publication of guidance, case studies and articles / papers in a range of journals, magazines and newsletters and through the internet.	✓	✓	✓	✓		

Target	Greater Lincolnshire actions	Relevant national actions	Who can help					
			LAs	PBs	LMs	NGOs	I&Cs	£
GAP_A_4	Raise awareness across all levels of education Suggested actions: Provide teacher training days and literature on the geodiversity of Lincolnshire; provide information on sites where educational groups are welcome	GAP: Maintain and develop the role of geodiversity across all relevant subjects.	✓			✓		
GAP_A_5	Raise awareness with individuals and communities Suggested actions: Develop, expand and promote the Geodiversity section on the GLNP website, with associated printed literature, utilising links with existing and potential partner websites and newsletters; undertake events and open days to promote geodiversity; provide and promote geodiversity exhibitions; demonstrate the links between geodiversity, biodiversity and landscape	GAP: Develop consistent and simple messages that support the wider recognition of geodiversity and develop initiatives that promote geodiversity. GAP: Connect and involve communities in their surrounding geodiversity (including museum collections) in simple, accessible and innovative ways GAP: Encourage arts-based organisations and groups to use geodiversity as an inspiration and connection to the world around us, our cultural history and lives.	✓			✓		
GAP_A_6	Encourage appropriate access for the benefit of education and awareness Suggested actions: record and study temporary sections as they become available to fill gaps in knowledge	GAP: Increase the number of people undertaking volunteer work for geodiversity GAP: Increase access, through management, so more people can experience and understand our geodiversity			✓	✓		

10. Geodiversity organisation and funding

10.1 Current status in Greater Lincolnshire

Geodiversity in Greater Lincolnshire is based around the umbrella organisation of the GLNP. It consists of a group of volunteers who meet twice a year to discuss geodiversity issues. The meetings are coordinated and supported by the GLNP. The Geodiversity Group has supported the continuing recording of Local Sites and has also supported the re-survey of sites previously designated as RIGS. The Geodiversity Group has also supported the publication of leaflets which explain aspects of the geodiversity of Greater Lincolnshire. Funding for these initiatives has been via the auspices of the GLNP.

10.2 Threats in Greater Lincolnshire

The Geodiversity Group is a voluntary group and as such needs to consider widening its membership to sustain its activities into the future.

As the Geodiversity Group relies heavily on the GLNP for coordination and funding, the future shortfall in funding of the GLNP must be considered as a threat to geodiversity.

10.3 Aim

To ensure delivery of geodiversity objectives through adequate funding

10.4 Targets and actions 2022-2026

Target	Greater Lincolnshire actions	Relevant national actions	Who can help					
			LAs	PBs	LMs	NGOs	I&Cs	£
GAP_F_1	Partner organisations have endorsed the strategy	GAP: Work with relevant government departments, authorities and other organisations in order to secure wider geodiversity policy inclusion.	✓			✓		
GAP_F_2	Seek opportunities for funding for the delivery of the Geodiversity strategy Suggested actions: funding for an officer, funding for specific targets/actions, funding for surveys	GAP: Increase available funding for geodiversity from grants givers, sponsors, statutory agencies, local authorities and other organisations and industries. GAP: Develop and share guidance and experience on funding sources for geodiversity and the process of application	✓	✓		✓		✓
GAP_F_3	Explore opportunities for incorporating geodiversity into other projects and funding proposals Suggested actions: work with Partners to see the links between their work and geodiversity	GAP: Encourage integrated management of geodiversity within sites and areas designated for other interests, including biological SSSIs, Local Wildlife Sites, protected landscapes and Scheduled Ancient Monuments. GAP: Use geodiversity to support sustainable tourism.	✓	✓	✓	✓		✓
GAP_F_4	Develop project plans that could be used by volunteers or as dissertation topics to further the strategy	GAP: Maintain and develop the role of geodiversity across all relevant subjects. GAP: Encourage increased participation in geodiversity-related degrees. GAP: Increase the number of people undertaking volunteer work for geodiversity.				✓		

11. Glossary of terms

Alluvium – Unconsolidated sedimentary deposits of rivers, coastal marshes (marine and alluvium) and lakes (lacustrine) produced during the Quaternary Period.

Ammonites – A group of extinct free swimming coiled marine cephalopod molluscs which showed rapid evolution during the Mesozoic era.

Anaerobic – Conditions which are characterised by a lack of oxygen.

Aquifer – A rock which has the ability to hold and store water because of its relatively high porosity and permeability.

Aquitard – A rock which prevents the movement of water because of a lack of porosity and permeability.

Artesian – Water reaching the ground surface under the natural pressure of an aquifer.

Bed – A unit of sedimentary rock usually contained between planes of weakness (separation planes) or other rock types.

Belemnites – A group of extinct free swimming marine cephalopod molluscs probably distantly related to modern day cuttlefish and squid.

Biodiversity – The variety of plant and animal life in the world or in a particular habitat, a high level of which is usually considered to be important and desirable.

Bioevent – A record, illustrated by fossil content, of sudden and significant change in fauna and/or flora.

Boreholes – Holes drilled into the ground by a drilling rig for a variety of purposes: water supply, hydrocarbons, engineering data, minerals, scientific research.

Boulder clay – Replaced by the term Glacial till.

Brachiopod – A group of now rare marine shellfish characterised by two unequal valves and bilateral symmetry.

Calcareous – Any deposit which contains significant, but not necessarily dominant, calcium carbonate ($CaCO_3$).

Calcite – The crystalline form of the mineral composed of calcium carbonate ($CaCO_3$).

Carbonate – Any mineral salt with the CO_3 anion (negatively charged particle).

Carr – From the old Norse for a waterlogged wooded terrain. Nowadays riverside areas in broad valleys that have been drained for agriculture.

Chalk – A unique, very pure, limestone that has formed largely from the accumulation of the exoskeletons of zooplankton under greenhouse conditions (Late Cretaceous).

Chert – Cryptocrystalline silica which breaks with a conchoidal fracture. Occurs as a subsidiary deposit in some sandstones and limestones.

Clay – A deposit consisting of very fine particles (less than 2 microns diameter).

Conformable – The relationship between successive layers of sediment which have not been interrupted by periods of erosion or tectonic activity.

Coversands – Deposits of wind-blown sand which accumulated in a cold, dry climate probably at the end of the last (Devensian) glacial period.

Cryoturbation – Process of repeated freeze-thaw activity resulting in the destruction of sedimentary structures such as bedding and the deformation of rock fabric.

Cuttings – Fragments of rock produced by drilling which are brought to the surface by returning drilling mud.

Dolomite (dolomitic/dolomitised) – A double carbonate of magnesium and calcium ($CaMg(CO_3)_2$) associated with evaporite deposits and often called a dolomitic (or magnesian) limestone. It can be distinguished from limestone ($CaCO_3$) by not fizzing with dilute hydrochloric acid until the acid is warmed. Sediments such as siltstones and sandstones may be cemented by dolomite precipitating from pore water in which case they are said to have been dolomitised.

Ecosystem services – Generically, the benefits humans receive from the natural environment. See section 2.2.1.

Erratics – Rocks and fossils which have been transported from their areas of occurrence and deposited, usually by glacial activity, elsewhere.

Exposure – A locality where a geological feature can be examined because it is visible. Some are only available for a short time (e.g. pipeline trenches) and are referred to as temporary exposures.

Facies – Rocks with a characteristic of their conditions of formation and which may contrast with contiguous deposits.

Flint – Cryptocrystalline silica (SiO_2) formed within chalk sediments and found as isolated rounded (=nodular), tubular (=burrow-filled) or as continuous sheets (=tabular).

Fossiliferous – Rocks, usually sedimentary, which contain relatively high concentrations of fossil material.

Geodiversity – The variety of earth materials, forms and processes that constitute and shape the Earth, either the whole or a specific part of it. Relevant materials include minerals, rocks, sediments, fossils, soils and water.

Geodiversity Action Plan – A plan which sets out actions to conserve, enhance and promote the geodiversity of a particular area, usually based along local authority boundaries such as a county.

Geomorphology (geomorphological) – The study of landforms and the processes involved in the shaping of the Earth's surface.

Glacial – Of or connected to the work of ice.

Glaciation – Processes and actions associated with cold climates in particular those of ice.

Glacial till (till) – An unstratified deposit carried and laid down by a glacier. It consists of sand and clay and gravel and boulders mixed together. Produces a good soil for arable farming. Previously termed Boulder Clay.

Glacio-lacustrine – Of or associated with lakes formed by melting ice during periods of cold climate.

Gullet – A long, deep and narrow trench or pit produced by the process of quarrying for ironstone.

Gypsum – The crystalline form of the hydrated form of the mineral calcium sulphate ($CaSO_4$). The non-hydrated form is called anhydrite. Both are evaporite minerals produced by the gradual drying up of a shallow sea basin or temporary lake.

Halite – The crystalline form of salt (Na_2CO_3), another evaporite mineral.

Ice age – Any period of time when conditions were sufficiently cold and dry to bring about permafrost conditions and consequent lowering of sea levels, irrespective of whether a particular location was covered by an ice sheet.

Ice-wedge casts – In areas of permafrost, ice wedges form when water freezes in cracks in surface sediments. At the onset of warmer conditions, the wedges melt and the space is filled with sediment from the surrounding walls.

Inter-glacial – A period of time between two episodes of extremely cold climates.

Isostatic uplift – The upward recovery of an area of land following its depression caused by the weight of ice experienced during an 'ice age'.

Limestone – A sedimentary rock comprised of >50% calcium carbonate ($CaCO_3$).

Lithologies – The characteristic 'signatures' of different rock types.

Marker horizons - beds of rock which, by their character or content, make them clearly identifiable in a thick succession of sediments.

Marl – A sedimentary rock which is a mixture of lime ($CaCO_3$) and clay minerals.

Micrite (micritic) – A term used in the classification of limestone lithologies to describe a rock formed from the accumulation of lime mud or ooze.

MIS – Marine Isotope Stages are alternating warm and cool periods in the Earth's paleoclimate deduced from oxygen isotope data which reflect changes in temperature. The present day is MIS 1.

Monocline – A geological fold structure with one limb only.

Moraine – A mound composed of glacial debris deposited at the margin of a glacier or ice sheet.

Mudstone – A sedimentary rock predominantly composed of particles less than 0.0039mm (=3.9µm) diameter .

Palaeogeography – The geography of a given area at any given time in the past.

Paramoudras – Large masses of flint found at certain levels within the Chalk (mainly the Burnham Chalk Formation) and thought to be the sites of burrowing lifeforms that have attracted the aggregation of silica.

Periglacial – Referring to or associated with processes taking place at the edges of an ice sheet or glacier, characteristically where freeze-thaw conditions take place.

Pseudomorph – A mineral or sediment that occupies the space left previously by another mineral in its diagnostic crystal shape.

Pyrite (pyritised) – A mineral consisting of iron sulphide (FeS) commonly called Fool's Gold that is often associated with anaerobic conditions. It can form metallic, pale gold crystals or aggregates or, when finely disseminated, give mudrocks a bluish colour.

Quartzite – A sedimentary rock consisting of sand-sized grains held together by a silica cement. Also used for a metamorphic rock dominated by quartz crystals.

Rain prints –Small, shallow depressions formed in soft sand or mud by the impact of falling rain.

Refractory sands – Sands that can withstand the temperature of liquid metal being cast without breaking down. Steel casting needs a sand that will withstand 1,500°C (2,730 °F). Sand with too low refractoriness will melt and fuse to the casting

Regression – Withdrawal of conditions from an area for example the lowering of sea levels producing shallower water or dry land environments.

Roach – A sequence of iron-rich sedimentary rocks up to 11m thick which in the area between Tealby and Caistor replace the Upper Tealby Clay.

Roddons – Silt and sand which was deposited in the channels of tidal creek systems cut into clay during the mid-to late Holocene. Human activity, such as agriculture and drainage, has caused an inversion of topography so that the former channel deposits now stand out as positive features.

Salt-marsh – An area of coastal grassland that is regularly flooded by seawater.

Sandstone – A sedimentary rock containing particles of between 0.0625mm and 2mm diameter held together by a “cement” of varying composition.

Septarian (nodules) – Relatively hard rounded masses of sediment occurring in softer rocks and displaying cracks (=septaria) filled with minerals such as calcite.

Site of Special Scientific Interest (SSSI) – The national suite of sites providing statutory protection for the best examples of the UK's flora, fauna, or geological or physiographical features. These sites are also used to underpin other national and international nature conservation designations. Currently designated under the Wildlife and Countryside Act 1981.

Solifluction lobes – The fronts of material, often tongue-shaped, that has flowed down slope following a trigger (e.g. heavy rainfall or rapid thaw) causing slope failure.

Strata (stratum)– Distinct layers or beds of sedimentary rock with well-defined boundaries.

Strike – A line drawn at right angles to the direction of dip of strata. Exposed beds will appear to be horizontal in a strike section.

Succession – The order of beds or strata which represent a period in geological time at a particular locality.

Superficial deposits – Sediments that today cover the solid geology. Broadly speaking, deposits that have formed during the Quaternary period.

Terrigenous – Derived from a land mass.

Transgression – The gradual ingress of conditions to an area as for example a rise of sea level would cause flooding of coastal margins and deepening of shallow water environments.

Turbary – The legal right to cut turf or peat for fuel on common ground or on another person's ground.

An erratic © John Aram

12. References

Some of the following references contain weblinks that were correct at the time of writing. If you require assistance in locating any of these documents please contact the GLNP by emailing info@glnp.org.uk.

British Regional Geology, 1980. Eastern England from the Tees to The Wash. Second Edition.

Defra, 2006. Local Sites: Guidance on their Identification, Selection and Management.

Gaunt, G. D., 1982. Geology of the Country Around Kingston-upon-Hull and Brigg: Memoir for 1:50 000 Geological Sheets 80 and 89 (England and Wales) (Geological Memoirs & Sheet Explanations (England & Wales))

Gradstein,F., Ogg, J., Schmitz, M and Ogg, G. 2012 Geologic Time Scale Foundation. Elsevier

Gray, M., 2012. Valuing Geodiversity in an 'Ecosystem Services' Context. Scottish Geographical Journal, **128**; 3-4

Kent, P. E., 1981. Eastern England from the Tees to the Wash (British Regional Geology)

Perrin, R.M.S., Rose, J. and Davies, H., 1979. The distribution, variation and origins of pre-Devensian tills in eastern England. *Phil. Trans. Roy. Soc.,* Series B. **287**, 535-570.

Shennan, I., 1986. Flandrian sea-level changes in the Fenland I: The geographical setting and evidence of relative sea-level changes; *and* Flandrian sea-level changes in the Fenland II: Tendencies of sea-level movement, altitudinal changes, and local and regional factors. *Journal of Quaternary Science.* **1**, 119-153 and 157-179.

Straw, A., 2005. Glacial and pre-glacial deposits at Welton-le-Wold, Lincolnshire. *Studio Publishing Services, Exeter.*

Swinnerton, H.H. and Kent, P.E., 1981. The Geology of Lincolnshire. *Lincolnshire Naturalists' Union*.

UK National Ecosystems Assessment, 2011. The UK National Ecosystems Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge.

UNESCO website, accessed 12/08/2016. www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/

Unknown. 2011. UK Geodiversity Action Plan (UKGAP) – A framework for enhancing the importance and role of geodiversity www.ukgap.org.uk

Wood, C.J. and Smith, E.G., 1978. Lithostratigraphical classification of the Chalk in North Yorkshire, Humberside and Lincolnshire*. Proceedings of the Yorkshire Geological Society.* **42**, 263-287.

Appendix 1: List of SSSIs

The following is a list of SSSIs designated for their geological interest in Greater Lincolnshire and correct at the time of publication. Some sites may also be biological SSSIs and have other designations such as SAC, SPA, RAMSAR etc.

Site Name	Notification Date	Area (ha)	Site Code	Grid Ref
Benniworth Haven Cuttings SSSI	01/04/1986	2.49	S1004363	TF 228 823
Castle Bytham Quarry SSSI	01/06/1984	5.51	S1002829	SK 989 179
Castlethorpe Tufas SSSI	14/04/1989	0.49	S1003978	SE 980 076
Chapel Point-Wolla Bank SSSI	18/07/2002	39.67	S2000261	TF 560 741
Cliff Farm Pit SSSI	01/01/1985	1.13	S1002062	SE 940 009
Conesby (Yorkshire East) Quarry SSSI	25/04/1996	0.92	S2000024	SE 902 147
Copper Hill SSSI	01/03/1986	6.64	S1002907	SK 978 426
Cowbit Wash SSSI	16/06/1999	9.07	S2000265	TF 240 191
Dalby Hill SSSI	01/04/1986	0.23	S1003348	TF 409 695
Gibraltar Point SSSI	01/07/1988	598.24	S1004400	TF 565 592
Greetwell Hollow Quarry SSSI	01/06/1984	59.32	S1003018	TF 003 721
Harrington Hall Sand Pit SSSI	01/04/1986	0.08	S1003423	TF 361 719
Horbling Fen SSSI	16/06/1999	15.11	S2000264	TF 153 352
Humber Estuary - 2000480 SSSI	03/02/2004	37,000.60	S2000480	TA 232 155
Hundleby Clay Pit SSSI	01/04/1986	0.76	S1003379	TF 382 660
Kirmington Pits SSSI	01/10/1986	9.09	S1003116	TA 102 117
Manton Stone Quarry SSSI	01/02/1986	17.47	S1003157	SE 939 024
Metheringham Heath Quarry SSSI	01/07/1984	12.94	S1004063	TF 053 615
Nettleton Chalk Pit SSSI	01/05/1984	8.08	S1004128	TF 125 981
Risby Warren SSSI	01/07/1986	157.11	S1003381	SE 923 136

South Ferriby Chalk Pit SSSI	01/08/1987	84.96	S1003474	TA 001 201
Welton-Le-Wold Old Gravel Pits SSSI	01/10/1986	3.39	S1002608	TF 281 883
Winceby Rectory Pit SSSI	01/07/1987	0.04	S1003399	TF 320 685

Geodiversity Strategy 2022-26

Greater Lincolnshire Nature Partnership
Banovallum House
Manor House Street
Horncastle
Lincolnshire
LN9 5HF

Tel: 01507 528398
Email: info@glnp.org.uk
Web: www.glnp.org.uk

1st edition
December 2016
Edited by Fran Smith

2nd edition
October 2021
Edited by Charlie Barnes

Achieving more for nature

www.glnp.org.uk

GREATER LINCOLNSHIRE NATURE PARTNERSHIP