

East Anglia

REGIONAL GEOLOGY



Contents

- 1** Introduction
 - Subregions
 - East Anglia: summary of the regional geology
 - Available information for this region
- 2** Rock type
 - Younger sedimentary rocks
- 3** Older sedimentary rocks
 - Basement rocks
- 4** Rock structure
 - Groundwater
 - Resources
- 5** Natural processes
 - Further information
- 6 - 13** Figures
- 14 - 15** Glossary

Clicking on words in [green](#), such as [sedimentary](#) or [lava](#) will take the reader to a brief non-technical explanation of that word in the Glossary section. By clicking on the highlighted word in the Glossary, the reader will be taken back to the page they were on.

Clicking on words in [blue](#), such as [Higher Strength Rock](#) or [groundwater](#) will take the reader to a brief talking head video or animation providing a non-technical explanation.

For the purposes of this work the BGS only used data which was publicly available at the end of February 2016. The one exception to this was the extent of Oil and Gas Authority licensing which was updated to include data to the end of June 2018.



Introduction

This region includes the counties of Norfolk, Suffolk, Cambridgeshire and parts of southern Lincolnshire and eastern Bedfordshire. The region includes the adjacent [inshore](#) area which extends to 20km from the coast.

Subregions

To present the conclusions of our work in a concise and accessible way, we have divided the region into 3 subregions (see [Figure 1](#) below). We have selected subregions with broadly similar [geological attributes](#) relevant to the safety of a GDF, although there is still considerable variability in each subregion. The boundaries between subregions may locally coincide with the extent of a particular [Rock Type of Interest](#), or may correspond to discrete features such as [faults](#). Although screening has focused on the [200 to 1,000m depth range](#), which is consistent with the [Implementing Geological Disposal White Paper](#) and [National Geological Screening Guidance](#), we recognise that some rock types may be suitable as host rocks where they occur at depths greater than 1,000m.

East Anglia: summary of the regional geology

What follows is a summary of the geology of the region, emphasising the [geological attributes](#) that are relevant to meeting the safety requirements for a GDF. Information about the geology of the region has been summarised by the British Geological Survey (BGS) in a [Technical Information Report \(TIR\)](#) on which this summary is based. This information comes from [geological mapping](#), [geophysical surveys](#) and [boreholes](#).

Available information for this region

The surface geology of the region is known from coastal cliffs, shallow [boreholes](#) and man-made excavations such as quarries or road cuttings. At greater depths, below about 250m, there are observations from about 50 deep boreholes distributed fairly evenly across the region. The deepest of these were drilled to more than 1,000m depth, mostly in search of water or [hydrocarbons](#). This information is supplemented by [geophysical investigations](#) including studies of the Earth's gravity and magnetic fields and [seismic](#) surveys. There are a number of shallower boreholes that provide information on the [groundwater](#) above 200m, but very little information within and deeper than the [depth range of interest](#) for a GDF, 200 to 1,000m below [NGS datum](#).



Rock type

In order to describe the rocks present in the region we have divided them into 3 main groups: **younger sedimentary**, **older sedimentary**, and **basement** rocks. These are summarised in [Figure 2](#), which is a simplified rock column showing the oldest and deepest rocks at the bottom, with progressively younger rock units towards the top. [Figure 3](#) is a geological map of the region showing where the major rock units occur at the surface. [Figures 4](#) and [5](#) present schematic vertical cross-sections through the region. Within the 3 groups, individual rock units have been identified as **Rock Types of Interest** for the development of a GDF; **Higher Strength Rock (HSR)**, **Lower Strength Sedimentary Rock (LSSR)** and **Evaporite**. [Figures 6a](#) to [6c](#) show where in the region there are likely to be Rock Types of Interest for the development of a GDF within the **depth range of interest**.

Younger sedimentary rocks

The youngest rocks in the region, such as the Crag Group **sediments** that form the sea cliffs along much of the coast of the eastern subregion, are restricted to the shallow subsurface, above the **depth range of interest** and are not discussed further here. Beneath the Crag Group, the Triassic, Jurassic and Cretaceous sediments (approx. 65 to 250 million years old) comprise limestones, sandstones and mudstones, comparable to those seen along the coasts of Dorset and North Yorkshire. In western and northern parts of the area, a continuous Jurassic-Cretaceous sequence is capped by the Chalk Group (shown in green on [Figures 4](#) and [5](#)). Beneath the south-east of the region, however, Jurassic rocks are absent with the Cretaceous Gault Clay Formation and Chalk Group sediments resting directly on older **basement** rocks.

There are several rock units in the younger **sedimentary** rock sequence that contain thick, extensive mudstone layers and are likely to have potential as **LSSR** hosts. Some of them occur at the surface in the western part of the region and all are well known from drilling across a large part of the region. They include:

- The Gault Clay Formation, which occurs within the depth range of interest in the central and south-eastern parts of the region, is between 10 and 20m thick.
- The Kimmeridge Clay, Ampthill, West Walton, Kellaways and Oxford Clay Formations, which form a sequence of Jurassic mudstones over 200m thick in the north-west of the region, although they reduce in thickness significantly towards the south-east.
- The Lias Group, which contains several mudstones interbedded with minor sandstones and limestones. It reaches 230m thickness beneath the north Norfolk coast and, like the younger Jurassic mudstones described above, occurs only within the depth range of interest in the north and west of the region.



- The Mercia Mudstone Group, which is dominated by mudstone and siltstone with units of **evaporite** minerals off the coast. It is present at depth across the north of the region and, close to the coast and in the inshore area, attains a thickness of between 200m and 500m.
- The Bunter Shale Formation of the Bacton Group, which typically comprises silty mudstone, with thin siltstone units, and minor **dolomite** and **anhydrite**. It is present only in the **inshore** part of the region where it underlies the Sherwood Sandstone Group/ Bunter Sandstone Formation and is likely to reach 100m thickness within the depth range of interest.

Although thick salt layers are present off the coast in both the Mercia Mudstone Group and the Zechstein Group, the BGS considers that these only occur either more than 20km from the coast beyond the inshore area or below 1,000m and therefore they are not **Rock Types of Interest** for this region.

Older sedimentary rocks

Sedimentary rocks of Devonian age (approx. 360 to 420 million years old) have been encountered in boreholes at Soham and near Wyboston, in the south-west of the region, and rocks of Carboniferous age are known from boreholes along the north Norfolk coast. These are referred to here as older sedimentary rocks and include mudstones, limestones and sandstones (shown in orange and brown in **Figures 4 and 5**). They are highly **compacted** compared to the **younger sedimentary rocks** above and are underlain by basement rocks. The Warwickshire Group is a potential **LSSR** host.

Basement rocks

Within the **depth range of interest**, the oldest rocks beneath East Anglia are of Silurian to Cambrian age (approx. 420 to 540 million years old) and they form the basement (shown in blue, red and grey on **Figures 4 and 5**) to the overlying sedimentary rocks. Some of these basement rocks have potential as **HSR** host rocks. They are not exposed at the surface in this region, but many of the same rock units occur at the surface in other regions, such as Central England and the Welsh Borderland. Some have been found in deep boreholes across the region but others are thought to be present only on the basis of geophysical surveys. They fall into 3 main categories:

- **Granites** or similar rocks, formed from the solidification of magma below ancient volcanoes. Their presence is inferred from geophysical measurements and comparison with the Central England region to the west.
- Volcanic rocks, including Precambrian (more than approx. 540 million years old) felsic **tuffs**.
- Sedimentary rocks composed of mudstones, siltstones and sandstones that were deposited across the region during Cambrian to Silurian times. In some parts of the region the mudstones may have been folded and **metamorphosed** and may be **slaty**.

Further investigations would be needed to determine whether any of these basement rocks would be suitable as HSR hosts.



Rock structure

Only 3 major faults have been identified in the region to date (Figure 7), although it is likely that there are other major faults which affect the older sedimentary and basement rocks, but not the overlying younger sedimentary rocks. Such faults are known from adjacent regions but there is no existing information here. Faults may act as barriers to or pathways for groundwater movement, depending upon their characteristics, and the siting of a GDF would need to take account of them. There is no major folding in this region.

Faults occur on a diverse range of scales, from centimetres to kilometres, and the subsurface is criss-crossed by networks of numerous individual faults. However our work includes only those faults identified by the BGS with throws (vertical offset) of 200m or more. This is because the data available to the BGS are not able to resolve all faults consistently, across all thirteen regions, with throws less than 200m.

Groundwater

There is very little information on groundwater in the depth range of interest for a GDF, 200 to 1,000m below NGS datum, although there is information on groundwater in aquifers above 200m. The region contains several principal aquifers including the Crag Group, the Chalk Group and several older sandstones and limestones within the younger sedimentary rock sequences. Groundwater contained in these aquifers is likely to be separated from the groundwater at greater depth by the low permeability LSSR layers, even where these layers are not thick enough to host a GDF. The Sherwood Sandstone Group and Carboniferous Limestone aquifer are principal aquifers in those parts of this region where they are buried at sufficiently shallow depth. Where these aquifers are more deeply buried the groundwater has not been sampled but it is likely to be ancient saline water rather than potable water as the aquifers are not directly connected to the surface and therefore not recharged.

Water with salinity similar to sea water was found at a depth of 400m in the Chalk Group in north-east Norfolk. The water is believed to be virtually unchanged since the rocks were deposited (more than approx. 65 million years ago), indicating hydraulic separation between the water at the base of the Chalk Group and the shallow groundwater in this area. Groundwater from depths greater than 400m is unlikely to be suitable as drinking water anywhere in the UK¹.

There are no thermal springs in the region to suggest rapid flow of deep groundwater to the surface.

Resources

Although shallow resources such as chalk, building stone and sand have been exploited for hundreds of years there is no history of resource extraction below 100m in this region. There are also no known hydrocarbon or mineral resources below 100m. There are several small areas (approximately 1km²) where the presence of deep exploration boreholes would need to be considered in the siting of a GDF, shown in Figure 8.

¹ Water Framework Directive UK TAG. Defining and reporting on groundwater bodies, 2012.



Natural processes

The UK has low levels of [earthquake activity](#) and correspondingly low seismic hazard. Earthquakes are seldom large enough to be felt and the ground surface is not known to have been broken by [active faults](#). Relatively few earthquakes have been recorded in East Anglia compared with other parts of mainland Britain. There are no records of earthquakes with a magnitude of 4.0Mw or greater. A magnitude 3.7Mw earthquake 30km west-south-west of Norwich in 1994 was felt in and around Norwich. Earthquakes off the coast include the 5.9Mw Dogger Bank earthquake of 1931, the largest recorded earthquake in Britain, with an [epicentre](#) around 120km east of Flamborough Head.

Whilst the design of a GDF will need to consider the potential impact of earthquakes, there is no evidence that future seismicity anywhere in the UK would preclude its development.

The region was affected by the Anglian and Devensian continental-scale glaciations during the last two and a half million years, although East Anglia is situated beyond the limits of highland and lowland-scale glaciations. The precise siting and design of a GDF would need to consider the potential impacts of glaciation and permafrost during future continental scale glaciations. These include increased [erosion](#) and changes to groundwater movement.

The extensive low-lying coastal area of East Anglia is susceptible to future [groundwater](#) changes in response to sea level change. The precise siting and design of a GDF would therefore consider the potential impacts of sea level change.

Further information

More information about the geology of the region can be found in the [BGS Regional Summary](#), with additional detail in the [BGS Regional Guide](#). This also provides details about many of the sources of information underpinning the [TIR](#).



Figure 1 Subregions of the East Anglia region as defined for the purpose of National Geological Screening.

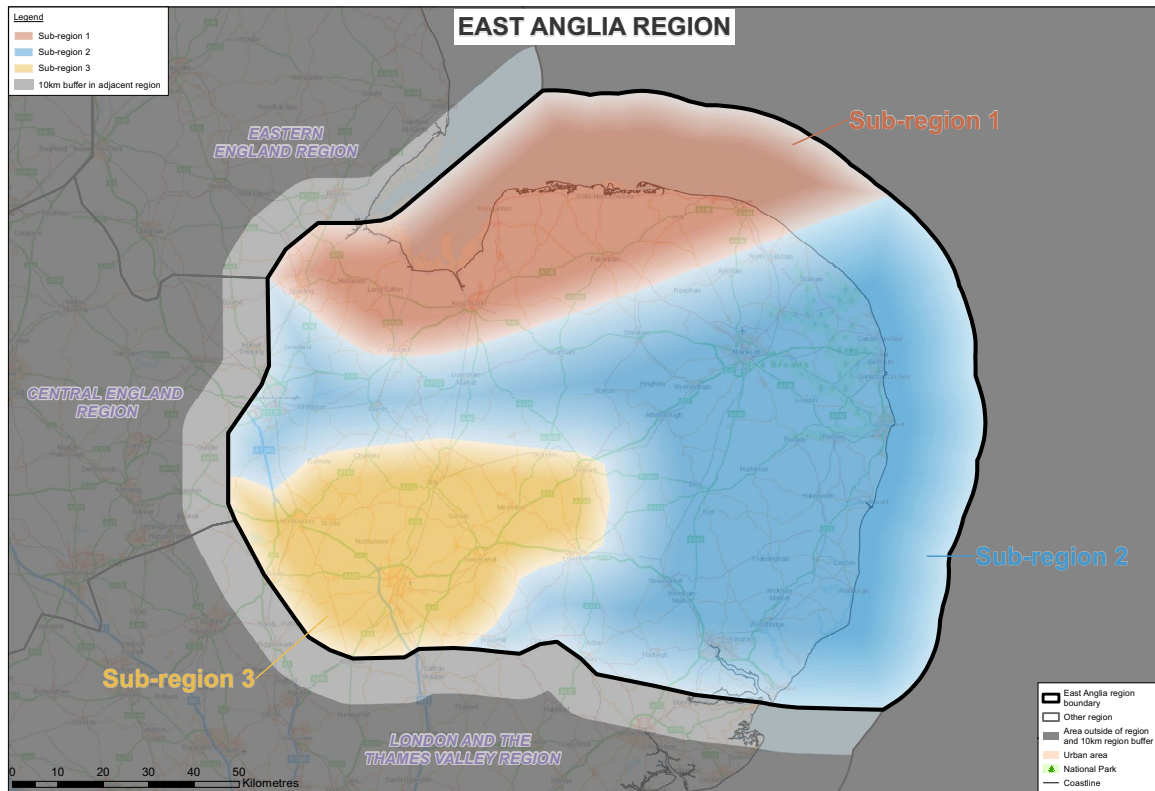




Figure 2 Table illustrating the sequence of the major rock units present in the East Anglia region and their possible significance for the siting of a GDF ².

	Geological Period (age in millions of years)	Geological Unit	Dominant Lithology	Rock types of interest		
				LSSR	HSR	Evaporite
Younger Sedimentary Rocks	Neogene (2.6 - 23.0)	Crag Group	Not applicable as not in depth range of interest	Not applicable as not in depth range of interest		
	Palaeogene (23.0 - 66.0)	Thames Group Lambeth Group Thanet Sand	Not applicable as not within depth range of interest	Not applicable as not in depth range of interest		
	Cretaceous (66.0 - 145.0)	Chalk Group	chalk			
		Gault Formation (Hunstanton Formation in north Norfolk)	mudstone and siltstone (red chalk in north Norfolk)	✓		
		Carstone Formation	sandstone			
		Lower Greensand Group	sandstone with siltstone, limestone and mudstone			
		Lower Cretaceous sediments including Skegness Clay, Roach, Dersingham and Sandringham Sands Formations	sandstones, siltstones and mudstones			
	Jurassic (145.0 - 201.3)	Kimmeridge Clay Formation	mudstone and siltstone	✓		
		Amptill Clay Formation	mudstone and siltstone	✓		
		West Walton Formation	mudstone and siltstone	✓		
		Oxford Clay/Kellaways Formation	mudstone, siltstone and sandstone	✓		
		Great Oolite Group (including Blisworth Limestone)	mudstone, limestone and sandstone			
		Inferior Oolite Group (including Lincolnshire Limestone Formation)	limestone, mudstone, siltstone and sandstone			
		Lias Group	mudstone, siltstone, limestone and sandstone	✓		
	Triassic (201.3 - 251.9)	Mercia Mudstone Group (Haisborough Group inshore)	mudstone, siltstone and sandstone with halite and anhydrite	✓		
		Sherwood Sandstone Group (Bacton Group inshore)	sandstone, siltstone and mudstone	✓ (inshore only)		
	Permian (251.9 - 298.9)	Zechstein Group	mudstone, sandstone, siltstone, conglomerate (onshore) with limestone, rock salt and anhydrite inshore			
Rotliegendes Group						

² Gaps in time in this column with no rock types shown either represent periods when no rocks were being formed or indicate that the rocks formed during these periods have subsequently been removed by erosion



Figure 2 Cont'd

	Geological Period (age in millions of years)	Geological Unit	Dominant Lithology	Rock types of interest		
				LSSR	HSR	Evaporite
Older Sedimentary Rocks	Carboniferous (298.9 – 358.9)	Warwickshire Group	siltstone and sandstone with subordinate mudstone	✓		
		Carboniferous Limestone Supergroup	limestone, sandstone and mudstone			
	Devonian (358.9 – 419.2)	Undifferentiated	mudstone, siltstone, sandstone and conglomerate			
Basement Rocks	Silurian, Ordovician and Cambrian (419.2 – 541.0)	Intrusive igneous rocks	granite (inferred from geophysics only)		✓	
		Lower Palaeozoic sedimentary rocks	weakly metamorphosed mudstone, siltstone and sandstone, with associated igneous rocks			
	Proterozoic (Pre-Cambrian) (older than 514.0)	Avalonian basement rocks	tuffs and ignimbrites		✓	

Figure 3 Generalised geological map showing the distribution of rock units in the East Anglia region. The inset shows the extent of the region in the UK. The bold black lines give the locations of the cross-sections shown in Figures 4 and 5. See Figure 2 for the key to the rock types shown.

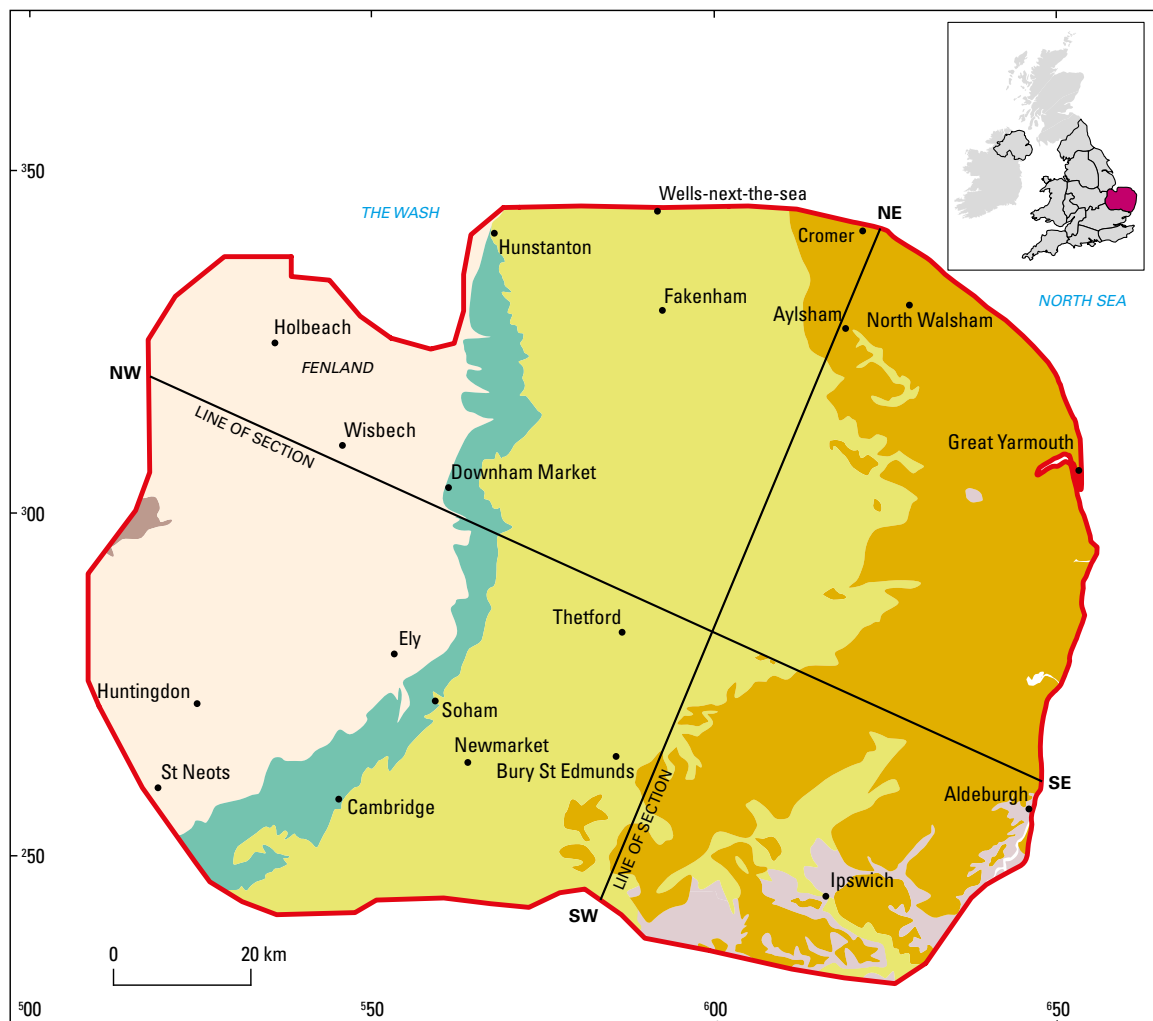




Figure 4 South-west to north-east schematic cross-section through the East Anglia region. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types shown.

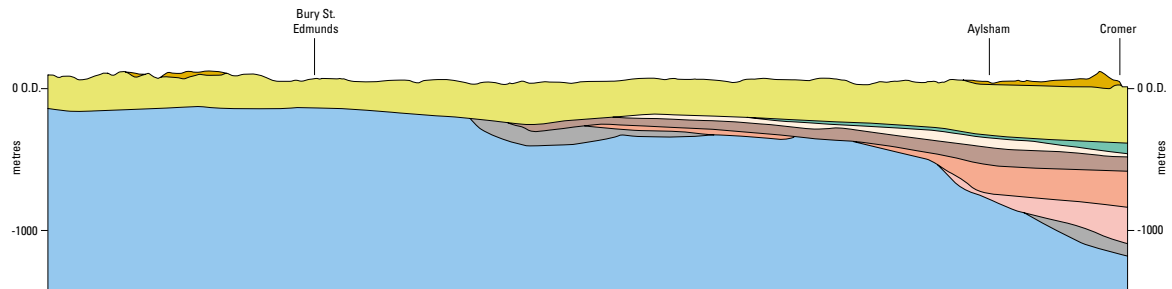


Figure 5 North-west to south-east schematic cross-section through the East Anglia region. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types shown.

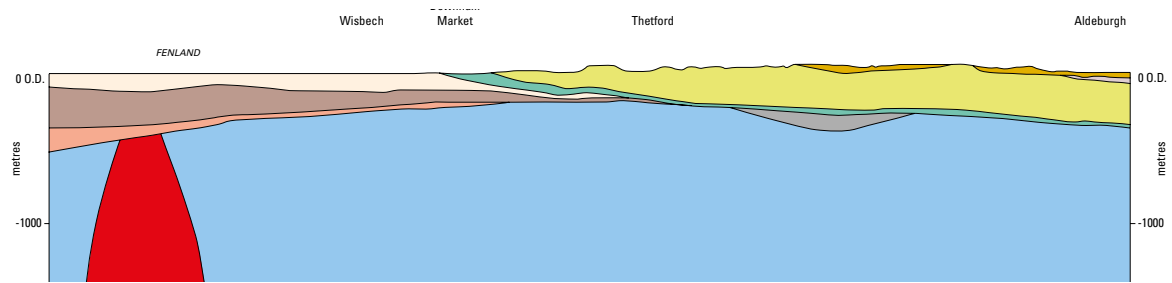




Figure 6a The areas of the East Anglia region where any of the 3 Rock Types of Interest are present between 200 to 1,000m below NGS datum.

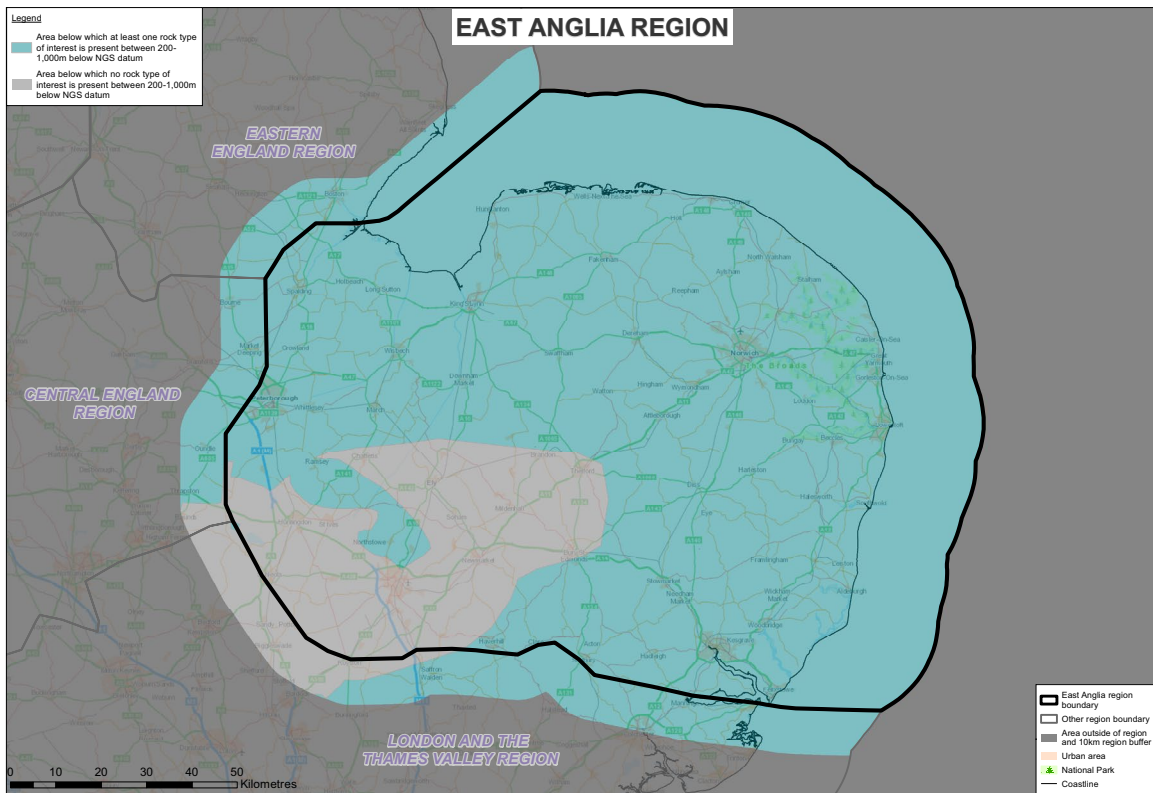


Figure 6b The areas of the East Anglia region where Lower Strength Sedimentary Rock Types of Interest are present between 200 and 1,000m below NGS datum.

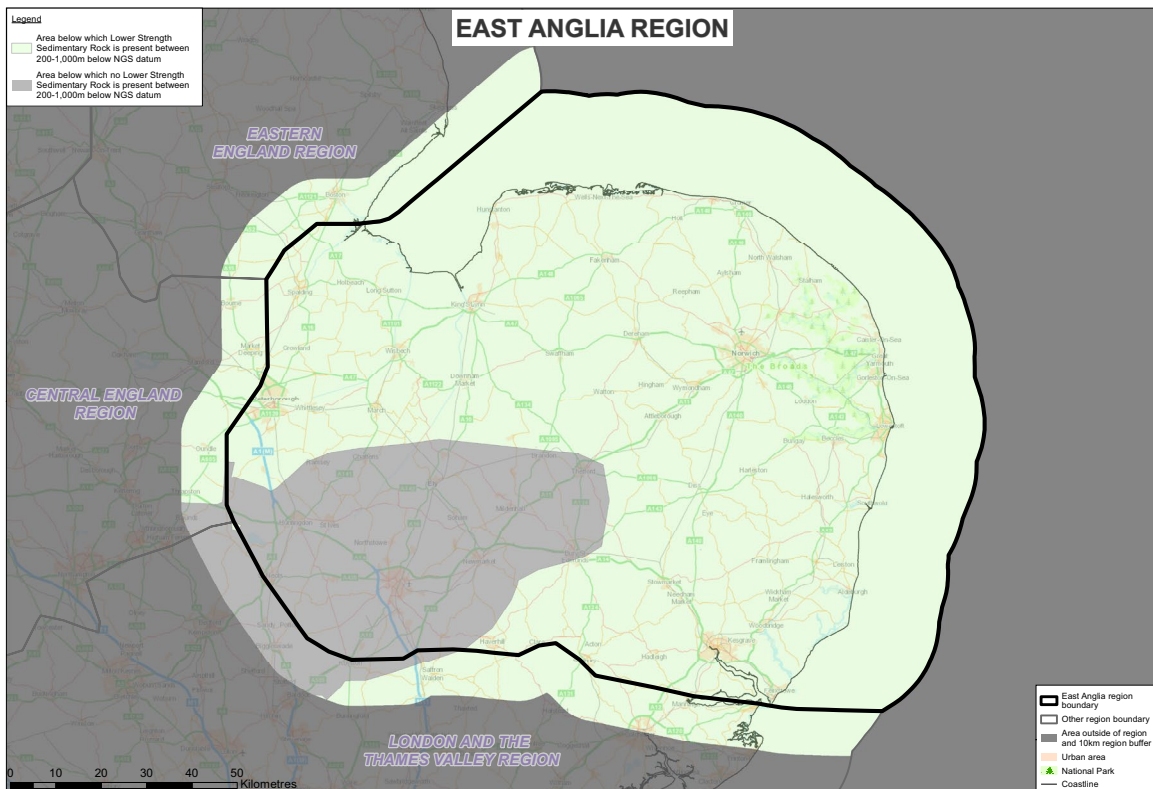




Figure 6c The areas of the East Anglia region where Higher Strength Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

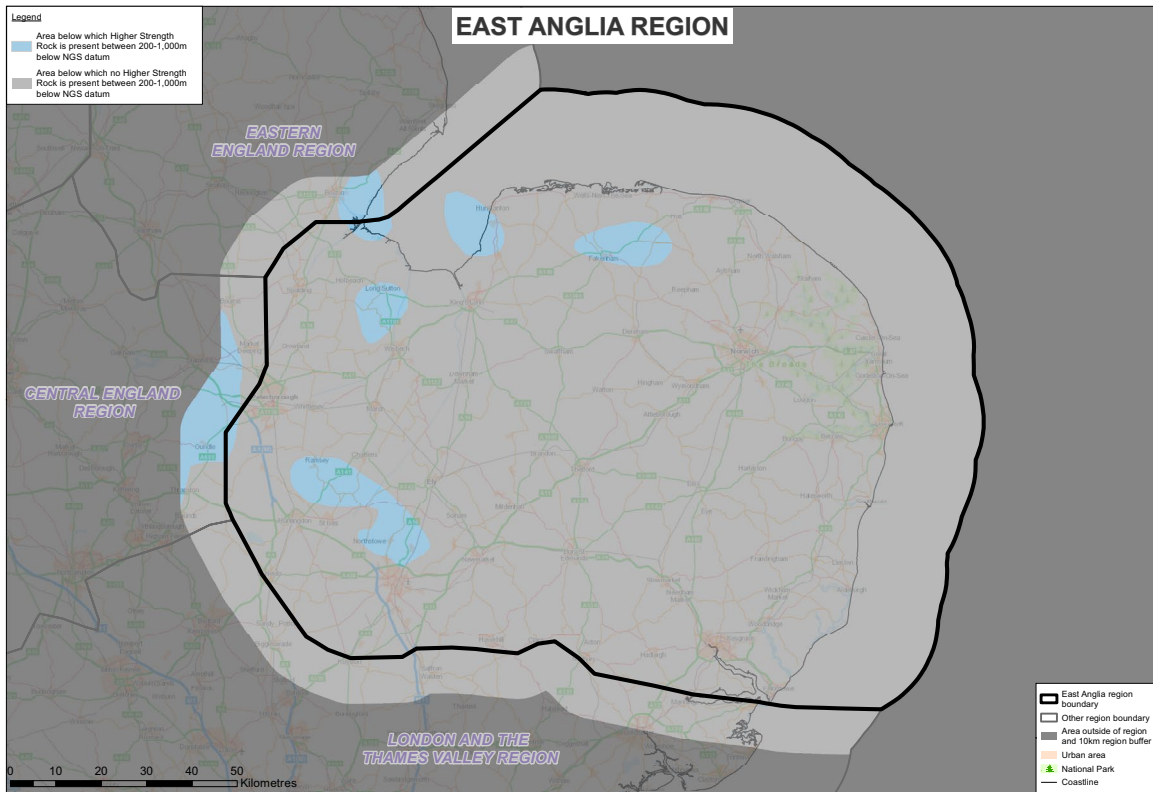


Figure 7 Location of major faults in the East Anglia region.

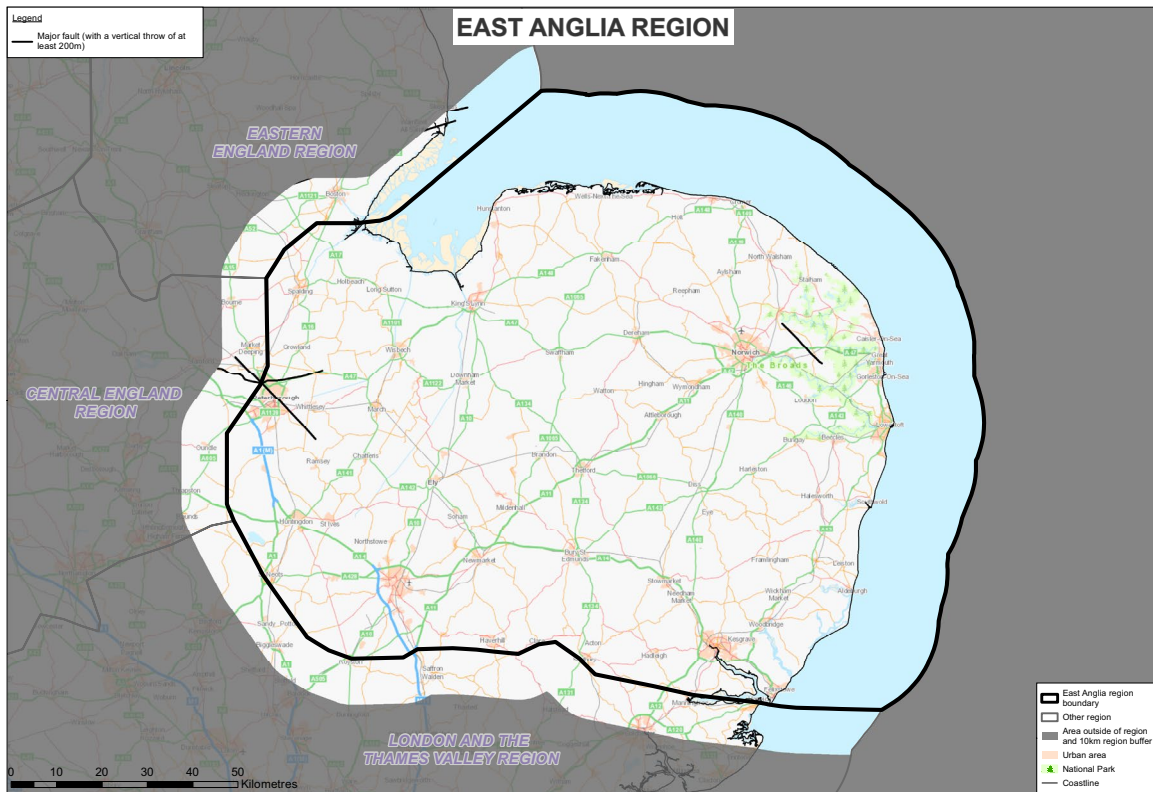
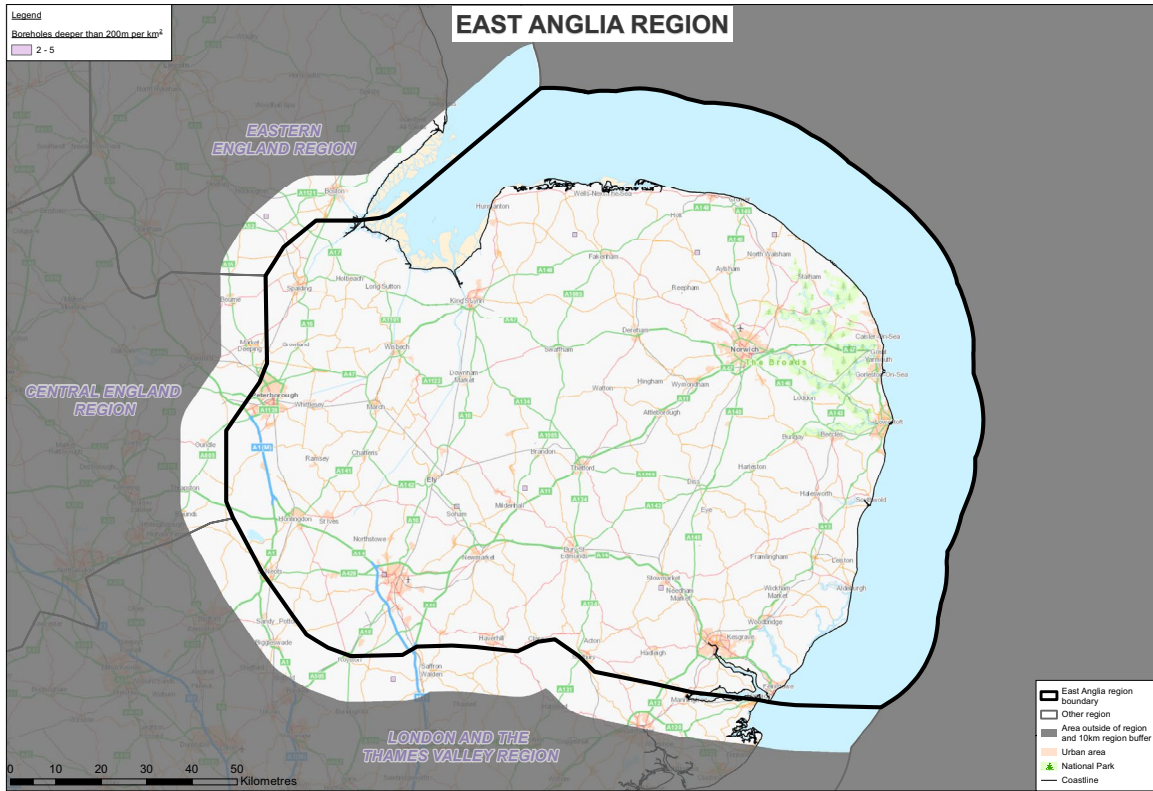




Figure 8 Areas in the East Anglia region with concentrations of deep exploration boreholes.





Glossary

Active faults

A fault that has moved once or more in the last 10,000 years and is likely to become the source of an earthquake at some time in the future.

Anhydrite

A calcium sulphate mineral that forms from the evaporation of salty seas. It contains no water and occurs at greater depths and higher temperatures than gypsum.

Aquifers

Aquifers are rocks that contain freshwater in pores and/or fractures and whose porosity and permeability are sufficiently high to make the extraction of groundwater possible.

Compacted

The action of squeezing as sediments become more deeply buried. Like wringing a sponge, compaction leads to loss of pore water and reduction of pore spaces between rock grains.

Dip

The angle, or slope of a plane, such as sedimentary layering, measured relative to the horizontal.

Dolomite

Magnesium carbonate mineral which often is found in limestones.

Epicentre

The point on the surface of the Earth above the focus of an earthquake. The hypocentre of an earthquake is the point underground where the earthquake occurs.

Erosion

The process by which the land surface is worn down, mainly by the action of rain, rivers, ice and wind leading to removal of huge volumes of soil and rock particles.

Evaporite

The generic term for rock created by the evaporation of water from a salt-bearing solution, such as seawater, to form a solid crystalline structure. Gypsum, anhydrite and halite are all types of evaporite.

Granites

Pale-coloured, coarse crystalline igneous rock rich in silica, sodium, calcium and potassium.

Hydrocarbon

A compound of hydrogen and carbon. Hydrocarbons are the chief components of oil and natural gas.

Lithology

The physical properties of rock types

Metamorphosed

A rock that has undergone change due to the action of temperature and pressure.



Potable

Water that is of drinkable quality.

Principal aquifers

An aquifer classified by the Environment Agency as: "rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage." They represent the most important aquifers in terms of water supply or base flow.

Saline

Containing salt (e.g. seawater is saline).

Sediments

Solid fragmented material, such as silt, sand, gravel and other material (including chemical precipitates, like salt), deposited in rivers, lakes, seas and oceans. Generally, the material that accumulates has originated from the weathering of other rocks. This material is often transported by erosion and deposited in layers. Sediments form the building blocks of sedimentary rocks (see below).

Sedimentary

A type of rock resulting from the consolidation of material that has accumulated in layers to form gravel, sandstone, mudstone and limestone. The layers may be built up by movement from erosion (e.g. by rivers, the sea or wind) or by chemical precipitation. Generally, the material that accumulates has originated from the weathering of other rocks. Sedimentary rocks constitute one of the three main classes of rocks identified by geologists, the others being igneous and metamorphic.

Seismic

Shaking in the earth's crust due to natural earthquakes.

Slaty

Distinctive way in which slate rocks split into very fine sheets.

Tuff

Fine-grained rock formed from compacted ash ejected during explosive volcanic eruptions.



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