

Summary of evidence: Geodiversity

1. General introduction

This summary sets out Natural England's assessment of the evidence relating to geodiversity and its conservation and management. It provides a statement of the current evidence base, presenting:

- what we know (with supporting data and key references);
- areas that are subject to active research and debate; and
- what we do not yet know from the evidence base.

It also provides information on Natural England research and key external research programmes to show how we are seeking to fill gaps.

This summary forms part of a suite of summaries covering all of Natural England's remit. The summaries are not systematic reviews, but enable us to identify areas where the evidence is absent, or complex, conflicting and/or contested. These summaries are for both internal and external use and will be regularly updated as new evidence emerges and more detailed reviews are completed.

2. Introduction to geodiversity

Geodiversity can be defined as *"The natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes"* (Gray, 2013). It forms, underpins and shapes the landscapes, biodiversity and dynamic natural environment on which we all depend.

Natural England has a statutory role in conserving and managing geodiversity. This is delivered through conservation and management of geodiversity Sites of Special Scientific Interest (SSSIs) and National Nature Reserves (NNRs), and more generally through provision of evidence and context to support the work of geoconservation groups managing Local Geological Sites, Global Geoparks and a World Heritage Site and through activities such as the preparation of National Character Area (NCA) profiles designed to assist in delivering integrated conservation at a landscape scale.

Geodiversity is an integral part of the natural environment and an understanding of geodiversity and an application of geodiversity evidence can play a major role in developing an ecosystem approach, delivering and enhancing ecosystem services, developing and informing approaches to climate change adaptation and delivering landscape scale approaches to nature conservation.

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Geodiversity is considered in the summary of evidence below under the following headings:

- Geodiversity resource.
- Conservation of geodiversity.
- Use of geodiversity to provide benefits for society.
- Wider application of geodiversity expertise.

3 Geodiversity resource

We know that:

3.1 England is extremely geodiverse and this geodiversity plays a major role in shaping the wide range of landscapes, habitats and land use that characterise England. England is made up of a vast diversity of rocks, minerals, fossils, soils, landforms and physical processes and a remarkably complete sequence of rocks spanning the last 700 million years. The completeness of the geological succession provides us with a record of Earth history and enables us to understand the evolution of England's landscapes and biodiversity and the nature and consequences of past environmental and climatic change, and human occupation. The nature and distribution patterns of England's geodiversity is described and illustrated in a wide range of maps and memoirs produced by the British Geological Survey www.bgs.ac.uk.

3.2 Understanding and managing our landscapes, biodiversity and the needs of society in both the terrestrial and marine environment requires an understanding of geodiversity and in particular geomorphological processes. The strong links between geodiversity, the natural environment and landscape character are clearly illustrated by the distribution patterns seen on geological maps, soil maps and in the National Character Area (NCA) descriptions and maps of England <http://publications.naturalengland.org.uk/map?category=587130>.

3.3 Geodiversity is important in providing or underpinning a wide range of ecosystem services of value to society. These include coastal and river flood buffering, aquifers and water supply, growing media for food and spectacular and inspirational landscape features (Webber *et al.* 2006; Gray 2011; Gordon & Barron 2011; Gray *et al.* 2013) and over 30 values of geodiversity have been proposed including cultural value, economic value, functional value and scientific value (Gray 2004, 2012; Gray *et al.* 2013). Geodiversity needs to be taken into account in describing and managing ecosystem services and the environment more widely.

3.4 The geodiversity of England, and indeed the UK, is extremely important for both science and education. The UK is the birthplace of the science of geology, and numerous divisions of geological time, rock formations and concepts were first defined here. Consequently, many terms and definitions in international use today (eg the Bathonian, Oxfordian, Wenlock and Devonian divisions of geological time and rock) relate to, and were named after, rocks and sites in England. Thus, many English sites and areas are now internationally important reference sites, conferring considerable international and national scientific, educational and heritage value to the conservation of geodiversity in England.

3.5 Our geodiversity and in particular many designated geodiversity sites contain evidence that enable us to understand how earth systems work and change. It records the dynamics of landscape and habitat change and the impact of climate change. It holds the key to answering many of the questions about the speed, magnitude and trajectories of future change.

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Areas that are subject to active research and debate:

3.6 The role and significance of geodiversity in taking an ecosystem approach and in underpinning and providing ecosystem services. A conceptual framework for taking account of geodiversity within an ecosystem approach to the management of the natural environment has recently been proposed (Gordon & Barron 2012; Gray *et al.* 2013) but still needs to be applied and tested.

3.7 The value of geodiversity in providing a temporal context for future climate change as well as informing our work on climate change adaptation. Unique geological archives preserve a record of past climatic and landscape changes that provide an important and valuable context for predicting the impacts of future climate change. Evidence for biological and landscape responses to past climate change can make a valuable contribution to our adaptation work such as identifying potential climatic refugia for flora and fauna.

3.8 The distribution and conservation importance of geomorphological features and processes in the wider landscape. Whilst we know a great deal about geodiversity within SSSIs, a little about geodiversity within Local Geological Sites, and have British Geological Survey maps that describe the distribution and nature of geology in the wider landscape, there is little map-based information on the distribution and nature of geomorphological features and processes outside of designated sites. A project to address this, in terms of producing geomorphological summaries, by NCA, has recently concluded its initial pilot phase and is being led by the British Society for Geomorphology and partner universities in association with end user communities such as government environmental and conservation agencies, civil engineering companies and major landowners (Hooke and Smith 2012). More work to spatially recognise the distribution of geomorphological features and processes and understand their change over time is required.

What we don't know:

3.9 The contribution of geodiversity in providing and underpinning ecosystem services and the value of the ecosystem services provided by or underpinned by geodiversity. Although the goods and services, and to some extent the economic benefits, arising from geodiversity have been described (Gray 2004, 2011; Webber *et al.* 2006; Gordon & Barron, 2011; Gray *et al.* 2013), thinking in this area is underdeveloped. More work is required to describe and value the contribution of geodiversity to the provision of ecosystem services and in taking an ecosystem approach to managing the natural environment. In particular, we need to apply and test, on the ground, newly developed frameworks for including geodiversity in the ecosystem approach. There are a number of evidence gaps in the UK National Ecosystem Assessment relating to geodiversity, and specifically geomorphological processes, the contribution of non-renewable resources and understanding long-term trends (Gray *et al.* 2013; Dearing *et al.* 2012).

4 Conservation of geodiversity

We know that:

4.1 Geodiversity has been recognised as an integral part of the natural environment throughout the history of statutory nature conservation in England (Prosser 2008, 2013). The National Parks and Access to the Countryside Act 1949 and all subsequent nature conservation legislation in the UK, including the Wildlife and Countryside Act 1981, the Countryside and Rights of Way Act 2000 and the Natural Environment and Rural Communities (NERC) Act 2006, have defined nature

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as relating to ‘flora, fauna, or geological or physiographical [now referred to as geomorphological] features’.

4.2 Internationally and nationally important geodiversity features have been identified and are protected as Sites of Special Scientific Interest (SSSIs). Internationally and nationally important geodiversity sites have been identified through the Geological Conservation Review (GCR) (Ellis *et al.* 1996; Ellis 2011), a systematic and rigorous audit process involving external specialists with a wide-range of expertise. Approximately 1,700 GCR sites have been identified in England. These GCR sites have been notified within approximately 1200 Sites of Special Scientific Interest (SSSIs) (Natural England 2008). The GCR is maintained through an interagency process involving Natural England, Natural Resources Wales and Scottish Natural Heritage, and publication of GCR site descriptions continues in the Proceedings of the Geologists’ Association.

4.3 86% (by number rather than area) of geodiversity SSSIs are in favourable or unfavourable recovering condition (Natural England 2008). In recent years, difficulties in securing funding for the management of geodiversity SSSIs, due to eligibility issues around the use of agri-environment funds, have caused problems in maintaining the percentage of geodiversity SSSIs in favourable condition. The recent emergence of the Conservation and Enhancement Scheme has, however, gone a long way in addressing this potential resource gap.

4.4 County-based, non-governmental and usually voluntary geoconservation groups exist in most English counties and play a critical role in the identification, management and promotion of non-statutory Local Geological Sites. These groups are often known as Regionally Important Geological Sites (RIGS) groups or local Geology Trusts and are represented nationally / multi-regionally through one of two umbrella bodies, GeoConservationUK www.wiki.geoconservationuk.org.uk/index.php5?title=Main_Page or the Geology Trusts www.thegeologytrusts.org/pub/. They play a central role in Local Sites partnerships identifying Local Geological Sites and notifying them to planning authorities for conservation and management in line with Defra guidance on Local Sites (Defra 2006; Whiteley & Browne 2013).

4.5 3828 Local Geological Sites have been identified and notified to planning authorities and, for the 2112 sites on which we have condition data, 1612 sites (76%) are in ‘favourable’ condition (as of November 2013) (source: Natural England’s Local Geological Sites Database).

4.6 The threats to geodiversity features and the technical means of safeguarding, managing and monitoring geodiversity SSSIs and Local Geological Sites are well understood. Detailed generic guidance on the conservation, management and monitoring of geodiversity exists (Prosser *et al.* 2006; RSNC 1999) although this now needs to be updated to take account of potential impacts from climate change (Brown *et al.* 2012) and other new pressures and threats as they arise.

4.7 There is a wide range of sites, in addition to SSSIs and Local Geological Sites that are designated for their geodiversity. These include: 5 National Nature Reserves (NNRs) declared primarily for their geodiversity, and a further 40 NNRs that include geodiversity SSSIs; 73 Local Nature Reserves with geodiversity interest (14 purely geological); 2 Global Geoparks, some Scheduled Monuments with Quaternary or early human interest, and the Jurassic Coast World Heritage Site in Dorset and Devon (Prosser 2013).

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4.8 Geodiversity and its conservation will be affected by climate change and in particular by society's response to it. We know, at a relatively high level, the likely impacts of climate change on geodiversity, the management responses that may be required and the evidence gaps that will need to be filled (Prosser *et al.* 2010; Brown *et al.* 2012).

Areas that are subject to active research and debate:

4.9 The geodiversity sites to be included within Marine Conservation Zones (MCZs) and how best to monitor and manage them. We know the nature and distribution of the submarine geodiversity features that we would wish to see considered for inclusion within Marine Conservation Zones, and the sites most suitable for inclusion within MCZs have been identified by Brooks *et al.* (2009). There is still uncertainty as to which MCZs will be designated (Burek *et al.* 2013) and the most effective methods of monitoring and managing marine geodiversity are still being developed.

What we don't know:

4.10 The current state (in terms of an overview) of the suite of English geodiversity SSSIs, GCR sites and Local Geological Sites in terms of understanding which 'site types' are in favourable condition, which are not, and which remedies are required to deliver favourable condition in different parts of the country. Pulling together and analysis of the data available is required to produce a geodiversity 'state of' report to inform future management intervention.

4.11 The new GCR sites and their scientific descriptions that we need to add to the GCR coverage to ensure that advances in science are taken into account and that the GCR and the SSSI and NNR series it underpins are up to date and scientifically robust and that we have the evidence to designate more geodiversity SSSIs and NNRs. For example, we are aware that the Holocene GCR network is probably not fit for purpose and the new thinking and newly identified sites associated with early human occupation of Britain are not adequately reflected in the GCR.

4.12 The conservation management requirements and prescriptions needed to address new threats and impacts that have recently emerged or known impacts that have grown in significance. In addition to the new impacts on geodiversity features and sites arising from climate change we need to know about impacts from fossil and mineral collecting, rock meshing, slope stabilisation, fracking, vandalism and destructive excavation / burrowing by wild mammals such as rabbits and badgers. Generic guidance on this is required to support delivery in area teams and by external partners.

4.13 The latest scientific research and interpretation of each individual geodiversity SSSIs and site specific issues relating to the most effective management prescriptions for each SSSI. Although we have high quality GCR data, science continues to advance and there is considerable scope to be more up-to-date with our site-based scientific knowledge and to develop more detailed management plans to reflect this scientific understanding. Updated Site Management Briefs, better geographic information on GCR sites and greater use of our photographic archive to understand and manage change would also enhance delivery.

4.14 The full detailed scientific descriptions of some hundreds of the GCR sites that underpin our SSSIs. We have (brief) GCR descriptions for all SSSIs but are still waiting for the full descriptions to be made publicly available for many sites. Although around 90% of GCR sites have had their descriptions published, there are six networks of sites (Portlandian - Berriasian, Marine Lower

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Cretaceous, Variscan to Alpine Structures, Pliocene Vertebrates, Quaternary of Southern England and Quaternary of East Anglia and the Midlands) where site detailed descriptions are awaited. These are now being prepared for phased publication over the next 5 years in the Elsevier journal Proceedings of the Geologists' Association.

4.15 The nature and condition of the full suite of Local Geological Sites – although we are now able to report on this for many counties of England this data is incomplete and currently no mechanism for update has been established.

4.16 The conservation importance and condition of geodiversity in the wider landscape. There has been no comprehensive conservation audit of geodiversity outside of SSSIs and Local Geological Sites. In particular, geomorphological features and processes are not well audited.

4.17 The potential of environmental land management schemes in delivering management of geological and geomorphological features within SSSIs, on local sites, or within the wider landscape, and the mechanisms through which this could be achieved. Land management schemes have not been applied to the conservation of geodiversity and an exploration of how this could come about is now timely.

4.18 The impacts of climate change and the socio-economic response to climate change, on geodiversity sites, features and processes. In particular, we need to know, on a range of spatial scales, what these impacts will be, where they are likely to occur and the geodiversity 'site types' most likely to be affected. We also need to develop and test, through piloting, new geoconservation techniques that will be effective in the light of the anticipated impacts of climate change (Prosser *et al.* 2010, Brown *et al.* 2013).

4.19 Evidence-based principles and guidelines to enable geodiversity to be taken account of and conserved as an integral part of climate change adaptation strategies. As well as the development and piloting of new geoconservation techniques, in particular with regard to active processes, this will require a greater understanding of the constraints and uses of spatially defined designations in the conservation of geodiversity in a changing climate (Prosser *et al.* 2010; Brown *et al.* 2013).

4.20 The degree to which national and local planning policy is succeeding in delivering geoconservation - for example, the effectiveness of the National Planning Policy Framework in delivering geoconservation and recognising geodiversity in initiatives such as those relating to green infrastructure. The degree to which implementation of the Marine and Coastal Access Act (2009) is delivering geoconservation.

5 Use of geodiversity to provide benefits for society

We know that:

5.1 Geodiversity sites and features occur across the marine, coastal, rural and urban environments, providing or underpinning many ecosystem services of significant value to society (Gordon & Barron, 2011; Gray 2011, Gray *et al.* 2013). These sites include SSSIs, NNRs, Local Geological Sites, LNRs, World Heritage Sites and Global Geoparks with associated partnerships and projects such as the English Geodiversity Forum, GeoConservationUK, Geology Trusts, European Geopark Network, Jurassic Coast World Heritage Site, Geodiversity Partnerships and Chalk East all

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working to provide environmental, social and economic benefit and services from these sites (see Prosser 2013; Anderson & Brown 2010). Key services provided include buffering against coastal and fluvial flooding, formation of soil as a growing media, water storage through aquifers and locally characteristic building stone that helps to create a sense of place.

5.2 Geodiversity sites and groups are of increasing importance in providing opportunities for education, engagement and tourism. The Jurassic Coast World Heritage Site, European Geoparks in the North Pennines and Torbay and the urban Wren's Nest NNR all use geodiversity to provide education resources that attract students, school visits, geological societies and the general public (see www.unesco.org.uk/uploads/Wider%20Value%20of%20UNESCO%20to%20UK%202012-13%20full%20report.pdf; Worton & Gillard 2013). Many Local Geological Sites are also interpreted and used for education purposes (see www.ukrigs.org.uk/esos/wiki/index.php5?title=Main_Page). Opportunities for engagement include whilst Barrow Hill and Tansey Green SSSI and LNR in Dudley, West Midlands, a hill formed from ancient volcanic rock, is being used as a walking route for recovering heart patients. In addition, groups such as the Geologists' Association, RIGS groups and Geology Trusts provide many people with opportunities to engage in their local community, to undertake outdoor education and recreation and to volunteer and participate in conserving the natural environment (Anderson & Brown 2010; Miles 2013; Whiteley & Browne 2013). Geodiversity acts as a, sometimes unconscious, draw for many visitors to tourist destinations with iconic scenery (eg chalk cliffs of Kent and Sussex, the Jurassic Coast of Dorset and the Whin Sill of northern England) and for many visitors to National Parks, Areas of Outstanding Natural Beauty (AONBs) and NNRs. Geotourism, is a proven contributor to the economy of a number of places including the Jurassic Coast of Dorset and Devon, the Isle of Wight and Dudley, West Midlands (Webber *et al.* 2006) and to England's two Global Geoparks (the English Riviera and the North Pennines) www.globalgeopark.org/aboutGGN/list/index.htm.

5.3 There are many untapped opportunities to achieve more for the natural environment through greater recognition, promotion and interpretation of geodiversity (Anderson & Brown 2010; Stewart & Nield 2013).

What we don't know:

5.4 How the public perceive and value geodiversity, as part of their local environment and as a contributing factor to their sense of place, recreational activities and enjoyment of the landscape. This could be addressed through adding questions to the Monitor of Engagement with the Natural Environment (MENE) survey. We also need to know more about how we can secure inclusion of geodiversity as part of interpretation strategies by conservation bodies, land management organisation and local authorities as this will help to promote a holistic understanding of the natural environment.

6 Wider application of geodiversity expertise

We know that:

6.1 Earth systems and processes (coastal, fluvial, mass movement, hydrological, hydrogeological and soil) are fundamental to the functioning of the natural environment and to the delivery of outcomes across Natural England's business. They determine the hydrological regimes that support ecosystems and habitats and through soil and soil formation, they determine the distribution of habitats and agricultural land use. Applying an understanding of these processes will inform the management of our coastlines, estuaries and river systems.

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6.2 The application of an understanding of past climate change can help us to understand and plan for adaptation to current and future climate change. Climate change is not a new phenomenon – it has been happening throughout geological time. During the last 2.6 million years, known as the Quaternary or Ice Age, the earth has experienced repeated abrupt and rapid climate change. These climatic changes and their impact on the environment have been recorded in geological ‘archives’ such as ocean and lake sediments and ice cores. Through studying these ‘archives’, it is possible to understand climate and environmental change far beyond the limits of human experience and the instrumental record. Hindsight from past environmental records and evidence of past climate-environment-human/biological interactions can enable us to understand complex processes, assess natural versus human-induced variability and, in turn, improve our understanding of resilience and vulnerability and thereby improve climate change adaptation in the future.

Areas that are subject to active research and debate:

6.3 How best to apply an understanding of past climate change and the environmental response to it to develop strategies for climate change adaptation. Initially, we need to know the impacts of climate change on geodiversity itself and to develop adaptation strategies that account for the needs of geodiversity sites and in particular geomorphological processes. We also need to be considering how we manage geodiversity and biodiversity SSSIs, and landscapes and the wider environment in the face of climate change, to deliver multiple outcomes including coherent ecological networks (Brazier *et al.* 2012).

What we don't know:

6.4 The most effective means of applying Earth system science to the delivery of Natural England's environmental objectives. This is likely to be through integrated approaches to landscape scale conservation, in using geosciences to underpin management of resilient habitats or in planning for climate change adaptation and building adaptive capacity.

6.5 How best to apply geodiversity expertise in taking an ecosystem approach and in understanding and describing the contribution of geodiversity to ecosystem services. In particular, we need to learn through applying an ecosystems approach (with geoscience integrated into it) on the ground. Landscape scale projects such as Nature Improvement Areas offer an opportunity to pilot such work.

7 Current Natural England projects

7.1 We are developing a method to make information about our current evidence projects available to everyone. In the meantime a list of Natural England's evidence projects relating to geodiversity that were current in 2014 can be seen on the National Archives at:
<http://webarchive.nationalarchives.gov.uk/20140711133551/http://www.naturalengland.org.uk/our-work/evidence/register/landscapevidence.aspx>.

7.2 Conservation and management of geodiversity features. Research, evidence gathering and provision of information to support the on-going management and provision of integrated technical advice on geodiversity. This includes small projects around the management of the GCR data for England, publication of guidance on fossil and mineral collecting and reviewing existing technical guidance related to managing geodiversity.

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7.3 Overview and condition of Local Geological Sites. This project is gathering data on the number, nature, location and condition of Local Geological Sites and will provide a long-term source of data from which to report on the condition of Local Geological Sites in England. It is currently operating on a care and maintenance basis due to resource constraints.

7.4 Investigating the value of palaeoecological refugia in identifying areas that could potentially provide refugia suitable for ecological restoration. A pilot project reviewing the potential of palaeo archives to indicate suitable refugia for species under changing climates. The main outputs will include a literature review, an objective evaluation of the potential of palaeo archives as well as recommendations about how to move thinking forward. This project feeds into other projects analysing modern ecological data.

7.5 Transferring management methods to deliver ecosystem services: Ecosystem Services Transfer. Opportunities for taking account of geodiversity in delivery of ecosystem services. In terms of geodiversity we are undertaking a retrospective review of the Bassenthwaite Pilot and produce some guiding principles for including geodiversity in an ecosystem approach.

8 Key external research programmes

8.1 Beach Management manual update (CIRIA) This manual, published in 2010, addresses beach management as a whole, recognising its multiple functions, and represents a major shift from previous approaches that focused on engineering interventions to beaches. Project funders, including NE, CIRIA and other partners and interested parties are now discussing additional guidance and updating case studies to sit alongside the manual.

www.ciria.org/service/knowledgebase/AM/ContentManagerNet/ContentDisplay.aspx?Section=knowledgebase&ContentID=17714

8.2 Bridging the Gap Network (University of Hull). To facilitate knowledge exchange between academics studying long-term ecological change (palaeoecology) and conservation practitioners, to determine how palaeoenvironmental records could contribute to conservation and management of landscapes, ecosystems and biota. Natural England has been engaged with this project and has offered support as an end user/steering group member in the latest application to the Natural Environment Research Council (NERC). The project aims to facilitate knowledge exchange and the development of a mutual research agenda.

8.3 English Heritage's work on the Palaeolithic. In particular implementation of their Thematic Research Strategy for Prehistory, www.english-heritage.org.uk/professional/research/strategies/research-strategies/prehistoric/.

8.4 The Geological Conservation Review (GCR). Although no longer led by the JNCC, GCR information, which underpins the selection of all geological and geomorphological SSSIs in England, can still be accessed on a website previously populated by JNCC, namely www.thegcr.org.uk/. Natural England, Natural Resources Wales and Scottish Natural Heritage now jointly oversee the GCR.

8.5 The Physical Landscape of Britain and Northern Ireland project which was initiated on behalf of the British Society for Geomorphology and is being led by the University of Liverpool and Kingston University. This seeks to provide a synthesis of geomorphological data in the UK. The project will provide a single point of access to information on the physical landscape of Britain and Northern Ireland,

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increase knowledge and awareness of geomorphology and identify evidence gaps to direct future research activity. Initial pilot now concluded (Hooke and Smith 2012) and next steps are being planned in conjunction with key end users.

8.6 PAGES - Past Global Changes. Part of the International Geosphere-Biosphere Programme.

This includes the **PHAROS programme** - Past Human-Climate-Ecosystem Interactions which seeks to understand ecosystem change on different timescales, and spatial scales from local to global. It seeks to understand the impact of human activities and climate change and the relationship of these impacts with internal system dynamics. It is looking at how sensitive or resilient modern ecosystems are to human stresses and climate change, and appropriate management strategies (Dearing *et al.* 2006).

8.7 BRITICE-CHRONO is a NERC funded consortium of 40+ scientists involving a systematic campaign to date material and better define the rate at which the last British-Irish ice sheet collapsed during the last ice age.

This data will be used to place current ice sheet changes (eg Greenland) into a longer-term context and produce computer models to predict ice sheet activity in the future that will likely have significant impacts on our landscapes and society. Samples will be collected from a range of sites (including geological SSSIs) and contexts across the UK and the adjoining seas. May produce new information on existing SSSIs and new sites may be discovered through their work. Also results from the offshore component may inform marine geoconservation.

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