

Annual science review

2016–2017



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**British
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



Foreword

by John Ludden CBE, Executive Director

Dear colleagues

I am very pleased to write the forward for the annual review of BGS activities in 2016/17. At the end of the year BGS staff numbers were 632 following a staff restructuring programme. This has ensured that we have people with the right skills to drive forward our strategic science priorities and retain our excellence as a geological survey. We will build on this in 2017/18 when for the first time in a decade we will be seeking to increase our headcount.

We finished the year with a small surplus on a total budget of £50.2 m (including £3.78 m capital). The foundations were laid for us to become more independent in that our parent body, the Natural Environment Research Council (NERC)

accepted that BGS public-good funding should be ring-fenced and evaluated independently of the research base. We will appoint a BGS board in 2017/18.

Through the NERC, the BGS has secured £31 m to install two UK Geoenergy Observatories. We are proceeding with planning for one site in Glasgow, which will have a focus on passive geothermal heat in a regenerating urban environment. A second site is planned for the Ince Marshes area of Cheshire. It will provide scientific information vital for the optimising and environmental monitoring of several subsurface, low-carbon energy solutions (shale gas, carbon capture and storage, deep geothermal, energy storage and waste management).

We also laid the foundations of a programme of Official Development Assistance (ODA) to which we will dedicate £7.4 m over the next three years. This will provide support for scientific research, underpinning datasets and capacity building

with a focus on sustainable development in East Africa, subsurface modelling in major south-east Asian conurbations, and global geo-risk analysis.

The demands of the UK Geoenergy Observatories programme, the ODA funding, and a further £2.8 m set aside for innovation funding will mean that we will have less flexibility in spending on UK regional activities in coming years. Nonetheless, as outlined in this annual review, we are continuing to undertake numerous high-impact activities in the UK and globally.

Some of these activities provide important baseline information for future resource development. Of note are the 21st Century Roadmap and large petroleum systems datasets of the North Sea for the Oil and Gas Authority, and the baseline monitoring of groundwater and air quality in areas of potential shale gas exploration. Our minerals work is now focused on critical metals and, as featured in this review,

we are investigating mining from deep-sea resources.

Infrastructure remains a focus of BGS activity such as our research on stability monitoring of infrastructure routes and the new datasets that have been developed (for example BGS Civils, Propbase, and coastal vulnerability). Internationally, infrastructure involves work on Earth observation and monitoring including the LANDSLIP project, which will help to develop landslide risk assessment and early warning systems in India. We have an ongoing commitment to understanding, and thus mitigating, natural hazards around the world.

We maintain discovery science via research grants, for example, in past environmental climate change, which are generally in collaboration with universities. Our NERC managed facilities continued to work well through an ongoing review process, which is now delivering more focused and strategically grouped NERC facilities.

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Introduction

As a world-leading geological survey, our vision is to be a global geological survey, working with new technology and data to understand and predict the geological processes that matter to people's lives and livelihoods.

Our focus remains on public-good science and research to understand earth and environmental processes. This is combined with an emphasis on three challenges:

- decarbonisation of power production, heat, transport and industry
- environmental change adaptation
- natural geological hazard and risk

However, we are undergoing a time of intense transformation, with a much stronger emphasis on the technological developments that are driving us to a new form of geological survey. This is evident in the presence of a data section in this review for the first time, and we are leading the world's surveys in many aspects of this field. In addition, numerous international opportunities are presenting themselves with the prospect of a greater global impact than ever before.

We have also been enhancing our regional delivery for England, in addition to that which is already in place for Scotland, Wales and

Northern Ireland. Specifically, we now provide a south-west England focus from our Cardiff office, in addition to a south and south-east England regional geology hub, a Midlands (including East Anglia) hub and a northern England hub from our Keyworth office.

This is a time of much change for the BGS but our key strengths still remain. These strengths include:

- nurturing our people
- developing our partnerships
- 3D geology and the national geological database
- remaining a trusted, independent voice



Finnarts Bay, Loch Ryan. Flute casts on the base of a greywacke bed. P008425.

National

The BGS undertakes a great deal of public and national-good science activities, all of which have a direct, positive impact on every aspect of UK society. These include providing advice on the sustainability of the nation's energy and mineral resources, monitoring and predicting the effects of environmental change in the UK, and providing data and knowledge for the nation's geological framework.

Environmental baseline monitoring

We are continuing to monitor baseline environmental conditions in relation to potential shale gas development in two areas of the UK: Fylde in Lancashire and the Vale of Pickering in North Yorkshire. Although the issue of shale gas has attracted considerable national and media attention, our independence from industry and regulators ensures that our science

outputs are evidence based and impartial. The programme, involving collaboration with the Universities of Bristol, Birmingham, Manchester and York as well as Public Health England, includes monitoring of seismicity, ground motion, atmospheric composition, soil gas, and quality of groundwater and surface water. Information collected from the monitoring programme is freely available via the BGS website.

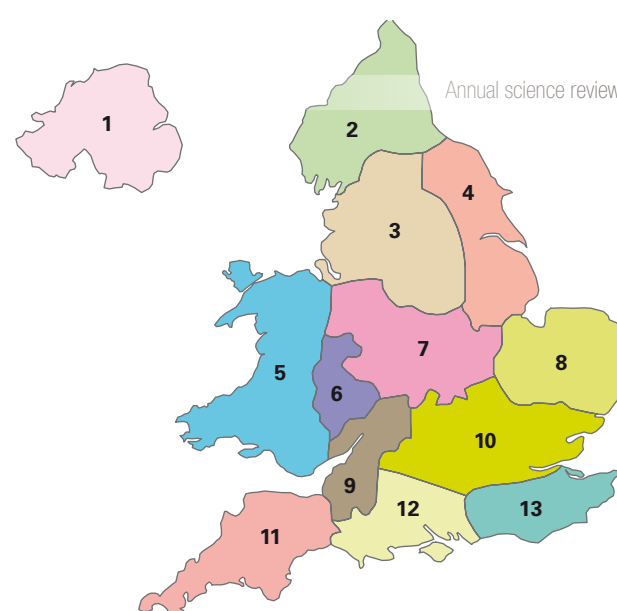
To enhance access to the data, our scientists have developed an online portal. In addition to traditional field measurements, sensors have been deployed in the field areas to provide continuous monitoring. Data is transmitted to the BGS by telemetry and then automatically

Did you know?

We have mapped the subsurface stress levels of the UK, which will help develop guidelines for hydraulic fracturing.



Installing a telemetry system for groundwater baseline monitoring.



- | | |
|------------------------------------|--|
| 1. Northern Ireland | 8. East Anglia and adjoining areas |
| 2. Northern England | 9. Bristol and Gloucester region |
| 3. The Pennines and adjacent areas | 10. London and the Thames Valley |
| 4. Eastern England | 11. South-west England |
| 5. Wales | 12. The Hampshire Basin and adjoining area |
| 6. The Welsh Borderland | 13. The Wealden district |
| 7. Central England | |

Regions used in the BGS National Geological Screening project.

uploaded to the data portal in real time or at daily intervals. The portal uses zoomable maps to place the monitoring in geographical and geological context. Live, interactive plots of individual sensors can be used to see the behaviour of environmental parameters over time and files of raw data are available for download.

National geological screening

The UK does not yet have a long-term disposal facility for high-level radioactive waste accumulated since the 1950s from power generation, medicine, research and defence-related nuclear programmes. Most of the waste can be disposed of safely in facilities on the surface but a long-term solution is still needed for the

most radioactive waste, some of which will remain hazardous for up to a million years.

The UK Government's policy is that higher-activity waste should be managed through geological disposal at depths of between 200m and 1000m below the surface. The UK's diverse geology provides many geological options for the deep disposal of radioactive waste. As holders of much of the authoritative and existing information on British geology, we have undertaken an assessment of the subsurface, focusing on aspects that are relevant to the long-term safety of a geological disposal facility (GDF). This includes the distribution of rocks with low groundwater flow and geological

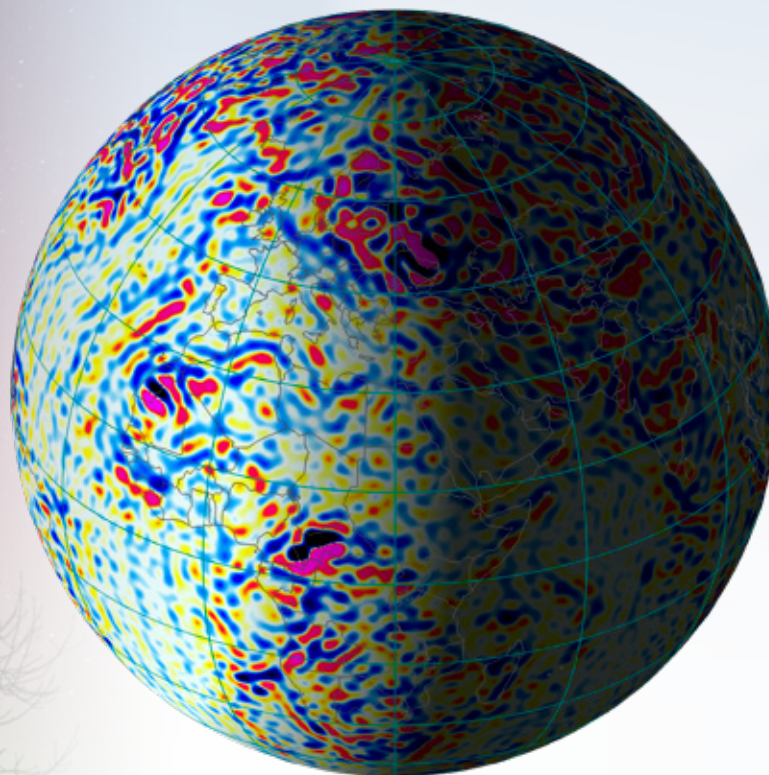
features that may influence the movement of groundwater from GDF depths to the surface environment. It will help us to judge the likely effect of future climatic changes and to understand the distribution of minerals, hydrocarbons and other resources that may affect the likelihood of future civilisations inadvertently drilling or mining their way into the waste. The outputs of geological screening will be used as a basis for engaging with communities wishing to understand more about the potential of their area to host a GDF.

Global geomagnetic model

The BGS global geomagnetic model (BGGM) is widely used in the oil industry for directional drilling with

Did you know?
We are a key provider of geological data that ensures the responsible development of the UK's offshore oil and gas resources.

measurement-while-drilling (MWD) magnetic survey tools, and has been a standard since the early 1990s. The tools measure the direction of the well-bore relative to the direction of the local geomagnetic field and help navigate wells towards small targets in congested fields. The local geomagnetic field and associated uncertainty are determined using the BGGM, and the MWD data can then provide the drilling location and error ellipsoid.



The vertical component of the Earth's crustal magnetic field.

Due to the unpredictable nature of the magnetic field arising from complicated processes in the Earth's core, the BGGM is updated every year. Data for the model is provided by the European Space Agency (ESA)'s Swarm mission and the network of geomagnetic observatories. We run or support over five per cent of global observatories and play a significant role in collation and quality control, primarily through our involvement in INTERMAGNET. A major part of the modelling effort each year is separating out the signals that vary on different spatial and temporal scales and combine in

any magnetic field observation. These signals come from the Earth's core, magnetic materials in the crust and magnetospheric and ionospheric currents driven by the Sun.

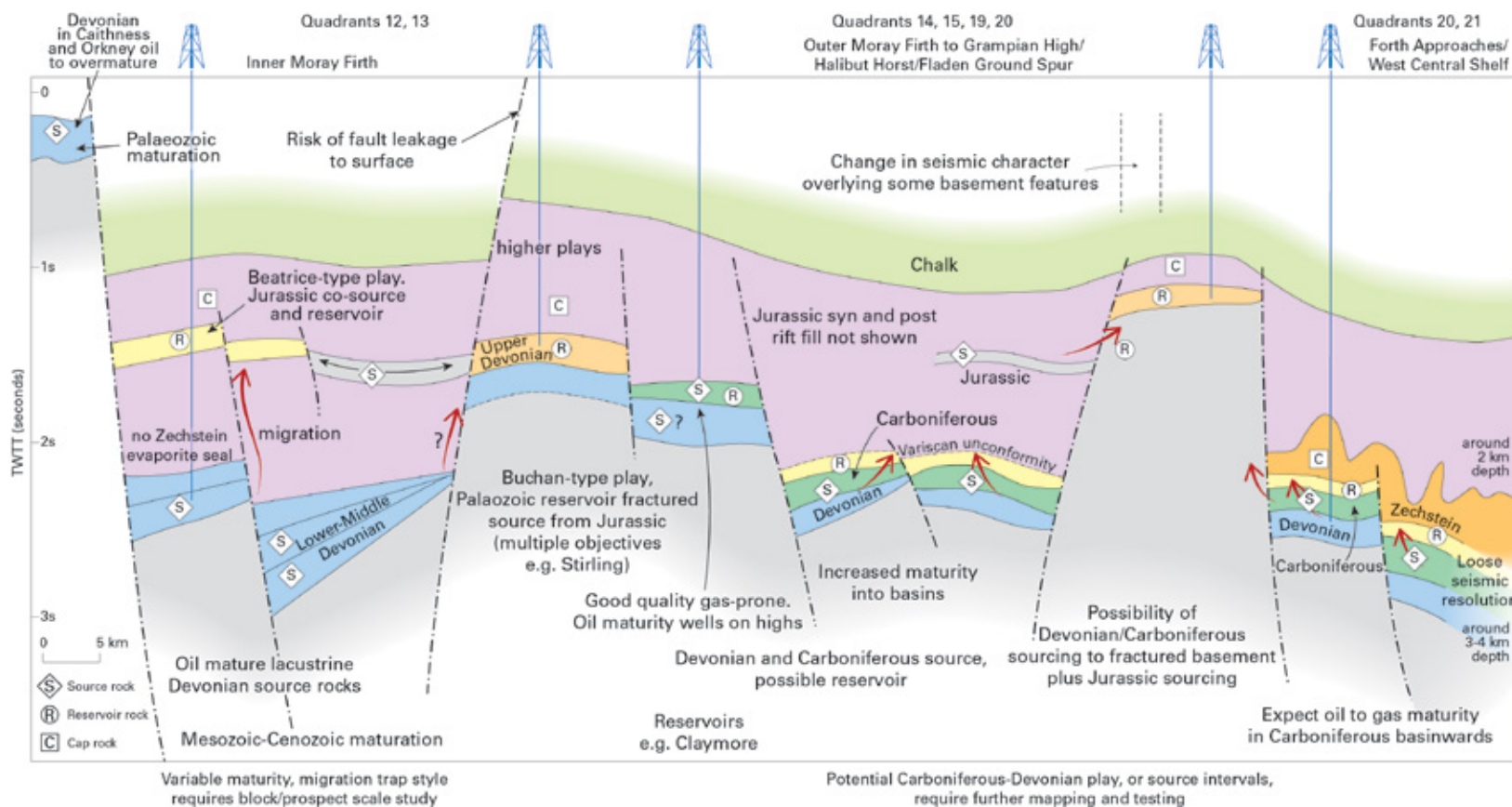
Twenty-first century roadmap project—21CXRM

Earlier this year we released a large petroleum systems dataset (25 peer-reviewed reports, GIS, gridded and spreadsheet datasets) that provides a wealth of new information about the Devonian and Carboniferous petroleum systems of the North Sea and greater Irish Sea, as well as correlations to onshore. This covers:

- geology, including well and seismic interpretation, basin configuration, stratigraphy, palaeogeography, tectonics
- geophysical interpretation, including gravity, magnetic, density
- petrophysics of reservoir and source-rock intervals, including spreadsheets of porosity, permeability and Rock-Eval well data
- source-rock geochemistry and maturity
- basin-modelling and petroleum systems analysis

The data comes from the 21CXRM Palaeozoic project, a £1.3 m joint industry–Government–BGS project to stimulate exploration of frontier areas of the UK Continental Shelf (UKCS). The project was led and undertaken by the BGS using a multidisciplinary team of over 30 staff who worked closely with the Department of Energy & Climate Change (DECC) (now part of the Department for Business, Energy & Industrial Strategy), the Oil and Gas Authority, Oil and Gas UK, and industry sponsors, ahead of the 29th Offshore Licensing Round. The project is part of the UK Government's endeavour to maximise the economic recovery of hydrocarbons from the UKCS, in response to the Wood Review. www.gov.uk/government/groups/wood-review-implementation-team

Some key findings of the project include:

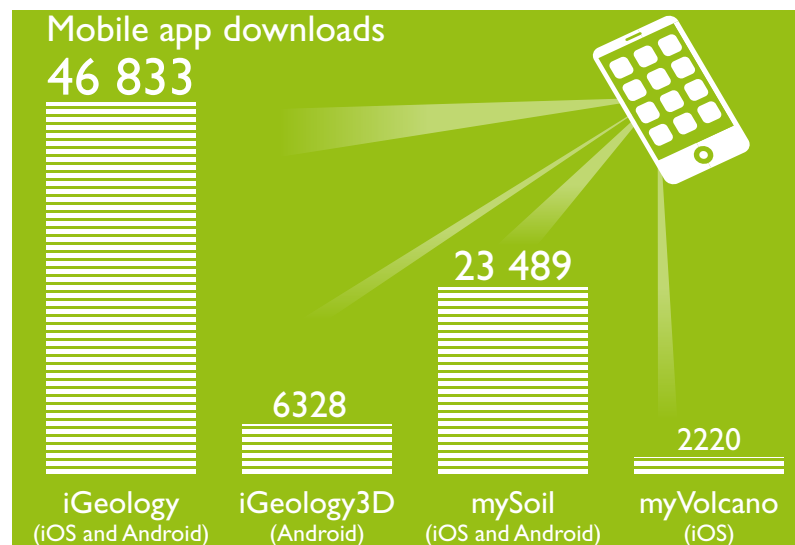


Cartoon summary of the Palaeozoic petroleum system elements and geometries observed across the the Inner to Outer Moray Firth and Forth Approaches, Quadrants 12 to 21 of the UKCS. Red arrows indicate potential migration pathways. Representative well locations and indicative scales are shown.

- widespread Carboniferous source-rock intervals and potentially prospective petroleum system elements east and south of the Mid North Sea High and in parts of the Outer Moray Firth and Forth Approaches
- recognition of the widespread possibility of Devonian and Carboniferous reservoir intervals hosting Jurassic-sourced oil, plus extensive mapping of Devonian source-rock intervals from the Inner to Outer Moray Firth
- detailed tectonostratigraphical development of Carboniferous source and reservoir intervals in the wider Irish Sea area with strong links to onshore knowledge

Did you know?

We monitor the Earth's magnetic field providing real-time data from our global observatory network.



England

To ensure a more effective regional delivery of services and expertise, the BGS has established a number of regional hubs throughout England. Based at our headquarters in Keyworth are the south and south-east England, Midlands (including East Anglia) and northern England regional geology hubs. In addition there is a south-west England regional geology hub that operates out of BGS Wales in Cardiff.

England – North

The Kilham catchment mapping and hydrogeology project

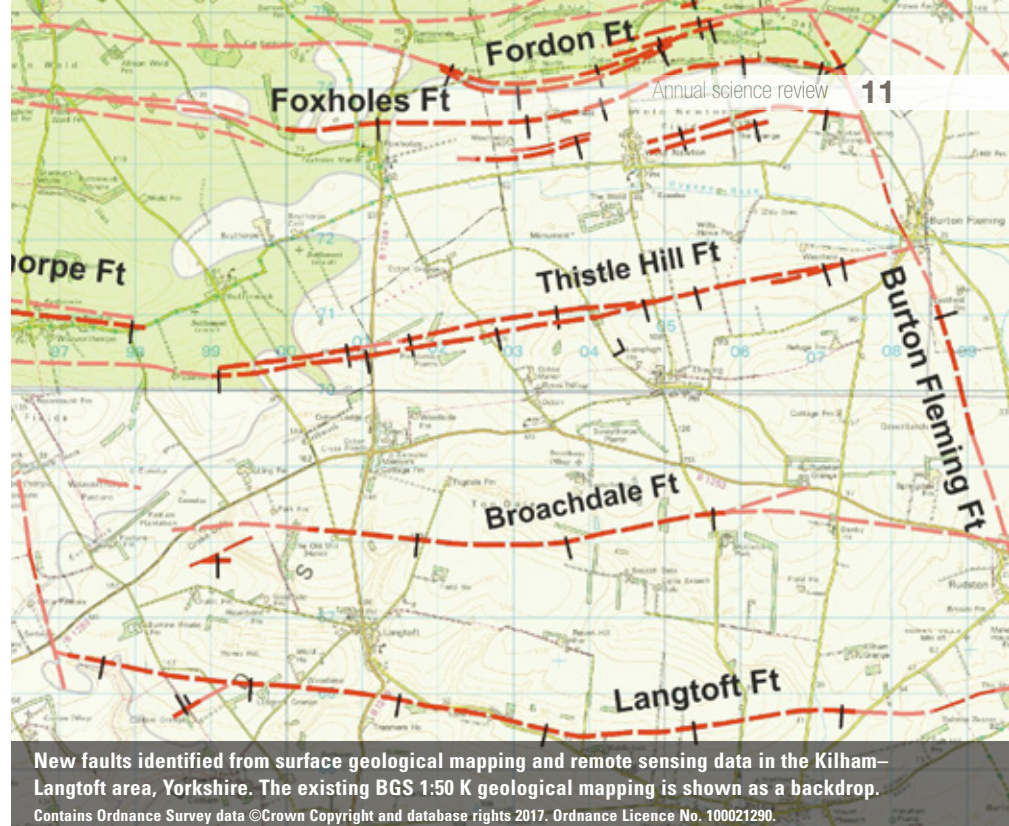
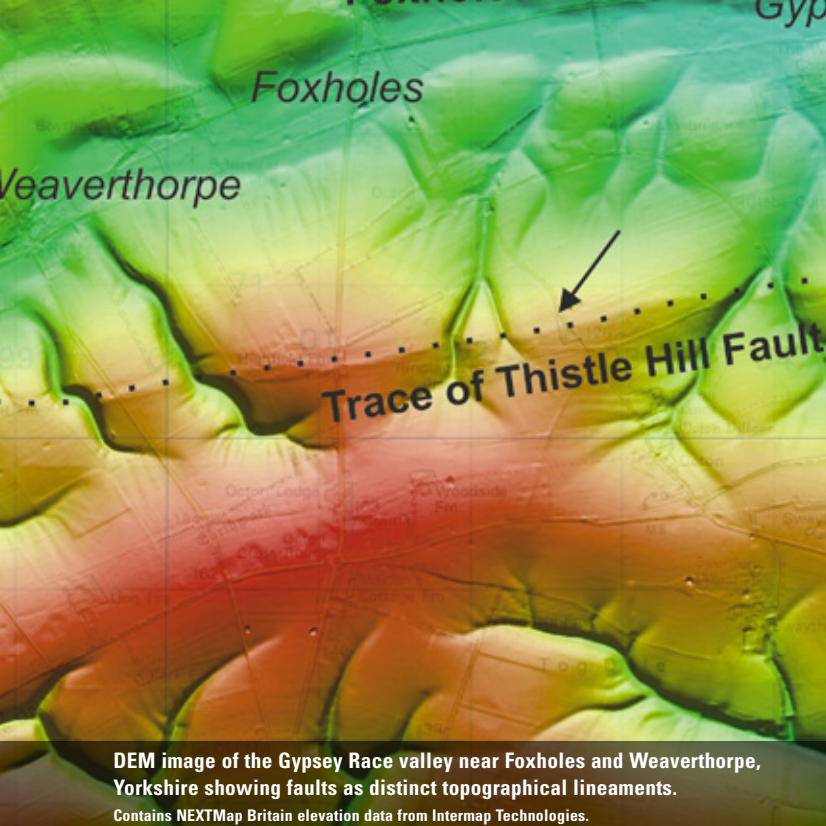
In 2016, the Environment Agency (EA) and Yorkshire Water approached the BGS for help in understanding groundwater flow in the Yorkshire Wolds. Several of the region's public water supply sources are at risk of contamination from nitrate, pesticides and other

contaminants. Treating water to reduce nitrate or blending it with other sources is very expensive. Instead, the water companies want to reduce nitrate inputs by changing land-use practice in the affected catchments.

Previous hydrological studies had failed to explain the unusual hydrogeology of the Kilham area near Driffield. We were tasked with providing a better conceptual geological understanding to assess whether groundwater flow is influenced by the geology. We did this by combining geological mapping, borehole log interpretation and geophysical surveys. Modern mapping proved that the region was cut by a series of major faults not shown on existing maps.

Did you know?

Our data and associated science have been used to establish groundwater quality standards for the UK to comply with EU regulations.



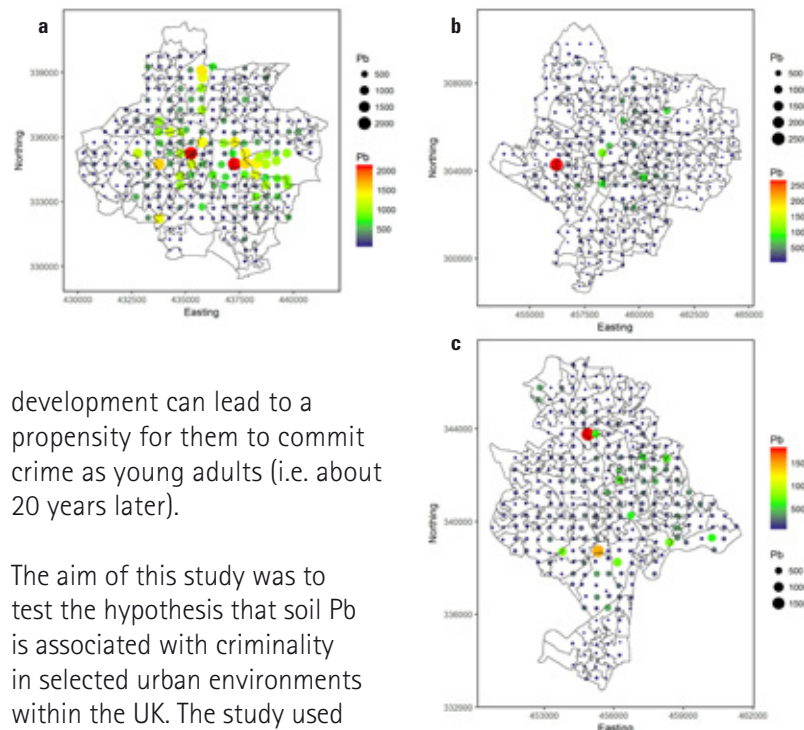
Seismic data had suggested that these faults terminated at the base of the Cretaceous but the mapping proved they extend to the surface.

The project demonstrated that geology has a strong influence on groundwater flow in the Chalk. Borehole flow logs indicate that water flow often occurs along discrete stratigraphical horizons and the influence of the faults can be seen in water table contours and pump test data in the region. This data is now being used to better define the catchment in conjunction with the EA, Yorkshire Water, Arup and Leeds University. This approach has been so successful it is now being used in other catchments in Yorkshire

England – Midlands and East Anglia

Lead in soil and crime deprivation

Lead (Pb) is toxic to humans, with some of its main detrimental effects being neurological, behavioural and developmental impairment in children. There is an increasing body of evidence that suggests that, if children are exposed to Pb at a young age, then the impairment of their neurological



development can lead to a propensity for them to commit crime as young adults (i.e. about 20 years later).

The aim of this study was to test the hypothesis that soil Pb is associated with criminality in selected urban environments within the UK. The study used geological and geochemical information and soil Pb data from

Did you know?

We have co-developed the UK Soils Observatory (UKSO) that improves mapping and monitoring of soils.

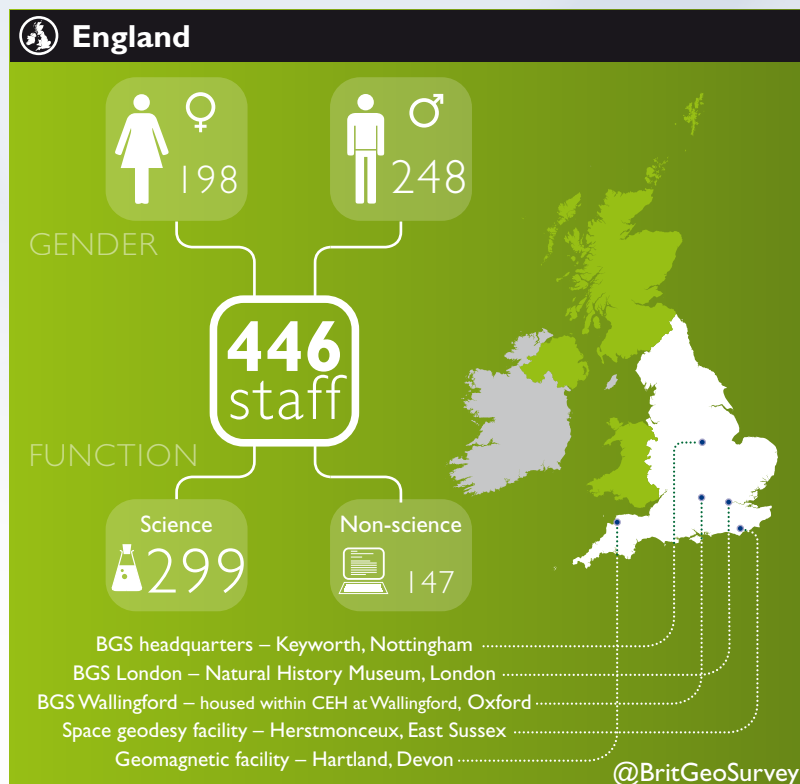
Concentration of lead in soils in a. Derby b. Leicester and c. Nottingham.

Derby, Leicester and Nottingham, collected as part of a geochemical survey of urban soils.

The data were modelled using crime deprivation as the dependant variable and Pb, selenium (Sn) and cerium (Ce) in soil as well as three socio-economic factors associated with personal deprivation, population density and environmental deprivation as predictor variables.

Modelling strategies showed that the socio-economic predictor variables and spatial associations were important in predicting crime deprivation. Lead and the two other soil chemistry parameters (Sn and Ce) were not important predictors of crime deprivation in Leicester and Nottingham. However, Pb and its interactions with spatial and socio-economic factors were shown to have a significant effect on crime deprivation in Derby. A machine learning (ML) model for Derby showed that there was an antagonistic interaction effect between Pb in soil and personal deprivation. The ML model produced 'dose-response' curves of the effect of Pb in soil on crime deprivation under different spatial and socio-economic conditions.

Did you know?
We produce and publish a monthly forecast of groundwater levels across the UK.



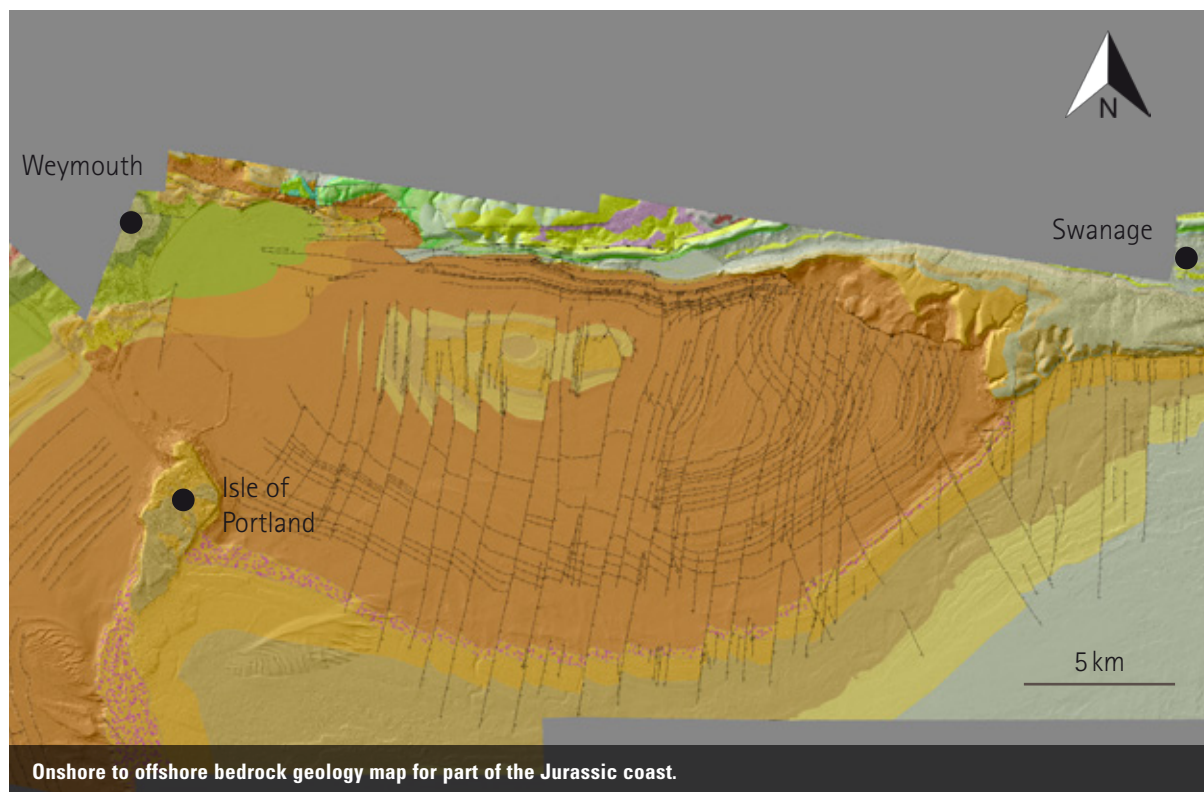
These findings may have implications for risk assessment methodologies that assume that the dose-response curves for contaminants are constant and independent of spatial and socio-economic factors, which this study suggests is not always the case.

England – South-west

Arsenic in Cornwall's groundwater

Between 2011 and 2013, the BGS worked with Public Health England (PHE), and latterly with the University of Manchester (UoM), on a two-phase sampling programme of private water

supplies (PWS) in Cornwall. Results were collected for around 500 households and showed that, in the case of arsenic (As) alone, six per cent of drinking-water samples exceeded the 10 µg/l prescribed concentration or value (PCV) as set out in the private drinking water supply regulations, 2009. Comparisons were made for other chemical substances to their respective PCVs, and a total of 35 per cent exceeded one or more of their corresponding PCVs (including As). These findings, in addition to the well-documented, high environmental arsenic concentrations in the region, warranted further



investigation into the potential uptake of this element by the local population.

Households that were previously involved in the PWS water sampling campaign were sent a letter inviting them to participate in a follow-up biomonitoring investigation. Households which had As levels above the PCV in their water were prioritised and requested to participate. In total 214 adults (aged 18 and over) from 129 households volunteered to take part in the biomonitoring study by completing a full lifestyle questionnaire and providing samples of urine, toenail and hair. These were used to assess the

relevance of various exposure routes, such as tap water, garden soil and household dust.

Results from the biomonitoring study have been communicated to both householders and stakeholders. In the case of householders, this will allow them to compare their results to the range of results found in the study population and the value for As in urine. Participants with As levels above the guidance value in their urine samples will be provided with tailored advice.

Project updates and results of the study are being circulated to all relevant stakeholders, including

Cornwall County Council; the NHS; Department of Health; the Drinking Water Inspectorate; the Environment Agency; the Department for Environment, Food and Rural Affairs; South West Water; Public Health England; and the National Poisons Information Service.

England—South and south-east

The bedrock of the Jurassic Coast

This year saw the online release of a new, 'seamless', onshore to offshore bedrock geology map for the eastern half of the Jurassic Coast in Dorset, a UNESCO World

Heritage Site and one of the most famous geological coastlines in the world, with highlights such as Lulworth Cove and Durdle Door.

This is part of a developing research programme within the BGS continental shelf geoscience team aimed at understanding the geological controls and processes across the whole coastal zone, from the onshore, through shallow coastal waters into the offshore area, and from the surface to subsurface. This will support wider understanding of coastal change and resilience.

The research was carried out as part of a joint project involving the BGS and the University of Southampton, as part of the Marine Environmental Mapping (MAREMAP) network. It used detailed aerial Lidar and seabed multibeam data collected through the National Network of Regional Coastal Monitoring Programmes, coordinated by the Channel Coastal Observatory, and as part of the Dorset Integrated Seabed Study (DORIS). By working with a wide range of partners, we are at the forefront of using such high-resolution data for modern, coastal zone, geoscientific research, using the varied coastlines of the UK as a test bed.

Did you know?

We were the first geological survey to produce a digital geological map.

Northern Ireland

The Geological Survey of Northern Ireland (GSNI) is based in Dundonald House in Belfast on the Stormont Estate. The GSNI is staffed by BGS scientists but is unique within the organisation in that it is an office of the Northern Ireland Department for the Economy (DfE). The GSNI's primary aim is to provide geoscience information and services to inform decision making and help develop the economy.

Groundwater monitoring at Portstewart Strand

The Northern Ireland Environment Agency (NIEA), as part of their active management of protected sites, commissioned the removal of invasive sea buckthorn on the Portstewart Strand on the north coast of Northern Ireland. They asked the GSNI to help inform both this and future management programmes by characterising and monitoring the effect of the removal on the shallow dune-sand aquifer beneath the strand.

The GSNI designed a new method for installing shallow piezometers by hand into the dune-sand aquifer to monitor groundwater levels and collect

samples. Removing sea buckthorn should lead to an increase in the height of the water table and reduce levels of nitrate, since sea buckthorn absorbs lots of water and fixes nitrogen from the air in its roots. A high water table and low nutrient levels in groundwater provide the ideal conditions for rare communities of flora to thrive in the slack areas between sand dunes.

Twenty-one piezometers were installed, groundwater samples

Did you know?

The GSNI works regularly with the NI Environment Agency to help monitor and protect NI's environment.



Groundwater monitoring on Portstewart Strand.



Portstewart strand sand dunes. © Bobbie Hamill, NIEA

were acquired and water level loggers were installed to establish baseline groundwater conditions prior to removal of the sea buckthorn. Initial results already show the damaging effect that the sea buckthorn has had on groundwater conditions.

Assessing ground motion from space

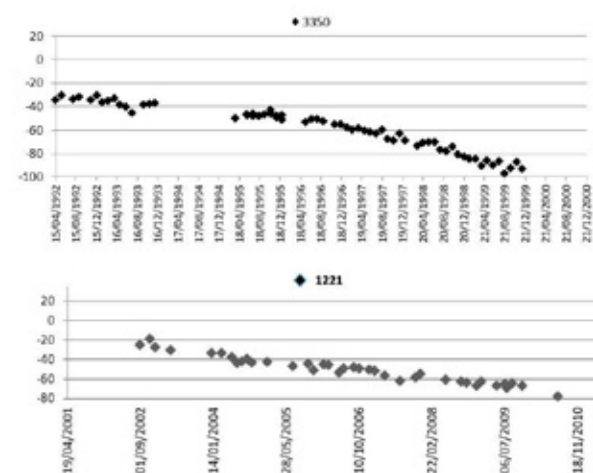
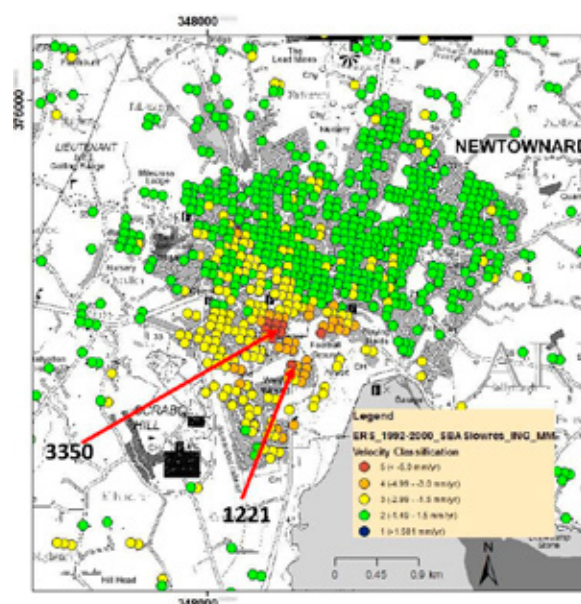
Both the BGS and the GSNI, together with Queen's University Belfast (QUB), have been working on a research study to analyse the benefits of using satellite radar interferometry (InSAR) techniques to remotely assess risk to infrastructure associated with ground movements in Northern Ireland.

InSAR techniques have the capability to remotely monitor

large areas, enabling a step change in techniques currently used by organisations to analyse risk to their infrastructure network.

Preliminary InSAR results display variable movements in many of the known landslide areas in Northern Ireland while also

highlighting motions associated with areas of historic mining activity. The initial results have also identified a number of areas



InSAR time series data for Newtownards showing abstraction related subsidence. © Crown Copyright and database rights MOU57.3



Launching *Uneathed*. Pictured are Mike Young (editor), Marie Cowan (Science Director, GSNi) and John Ludden (Executive Director, BGS).

Did you know?

The GSNi monitors over 2400 abandoned mine workings across Northern Ireland.

of interest displaying subsidence and surface heave, possibly as a result of water abstraction, soil compaction and shrink–swell processes.

The potential outcome will be an enhanced capability to monitor and assess hazards associated with ground motion across the infrastructure network. Stakeholders will be able to implement regional-scale hazard mapping using satellite technology to complement terrestrial monitoring. This could see huge benefits for the mapping and

understanding of geohazards, allowing better-informed engineering techniques to be considered and better targeting of sites, while reducing the risk to people living on unstable ground.

Uneathed: impacts of the Tellus surveys

This year saw the publication of *Uneathed: impacts of the Tellus surveys of the north of Ireland* by the Royal Irish Academy. It tells how an unparalleled combined land and air survey carried out between 2004 and 2013 has unearthed valuable natural resources, refined our understanding of the agri-environment and has identified naturally occurring hazards.

Uneathed draws together important findings of the largest

collaborative cross-border programme of geoscience surveys ever undertaken on the island of Ireland. Some £12 million of government and EU funding has been invested in high-resolution, airborne, geophysical and ground geochemical sampling surveys of Northern Ireland and the six northern counties of the Republic of Ireland.

In 30 peer-reviewed chapters, scientists from the BGS, the GSNi, the Geological Survey of Ireland and many universities, present the results of the Tellus and Tellus Border surveys. From the discovery of precious, industrial and critical metals to geothermal energy potential, and from naturally occurring heavy metals in soils to groundwater quality in various ecosystems, the results and benefits for the people of the area are extraordinary.

Permitted development rights policy review

Drilling exploration boreholes for oil and gas in Northern Ireland can, subject to certain conditions, be carried out under permitted development rights (PDR). This is in contrast to the situation in Great Britain where petroleum wells are excluded from PDR and planning permission is required. This inconsistency in the legislation covering PDR in different parts of the UK aroused controversy in Northern Ireland when a petroleum exploration well was drilled in County Antrim under PDR in May–June 2016.



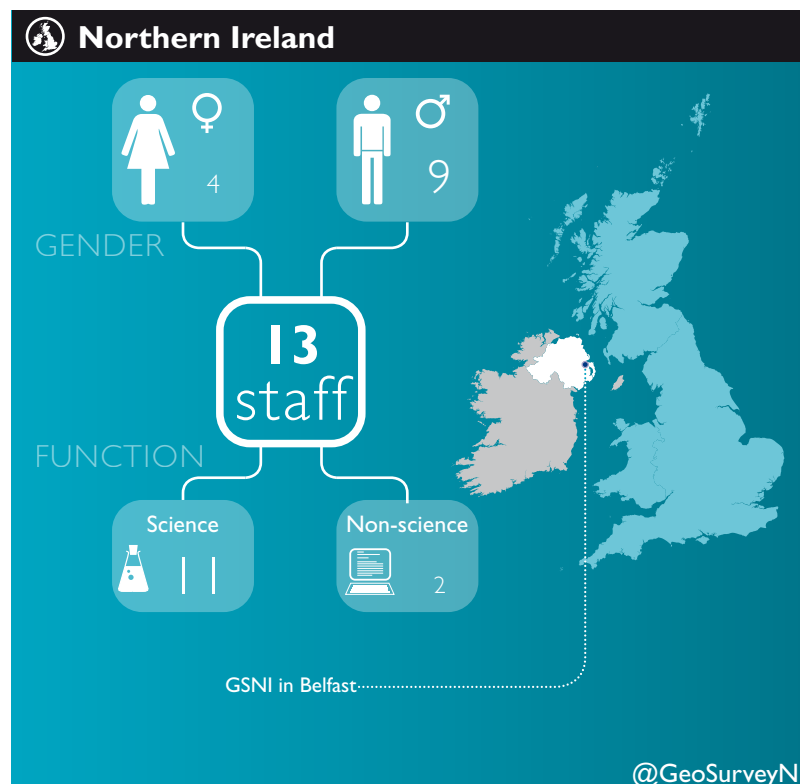
Borehole core forming part of the holdings in the GSNI core store.

As a result, the Department for Infrastructure (DfI) issued a Call for Evidence on permitted development rights and in June 2016 the Minister announced his intention to amend the legislation to exclude petroleum drilling from PDR. The GSNI compiled a detailed submission setting out the arguments for and against proposed changes to the legislation, based on staff

experience of previous exploration drilling, current regulatory regimes in NI and GB, and from feedback received previously from petroleum licensees. Following this, the GSNI have been able to support DfI in their policy review, which went out for consultation in December 2016. DfI and GSNI staff continue to provide clarification on technical issues relating to different options for PDR, particularly on the suitability of PDR for monitoring boreholes as opposed to petroleum exploration wells.

Did you know?

The GSNI is unique within the BGS as it operates on an agency basis within the NI Department for the Economy, whilst staffed by BGS scientists.



Scotland

BGS Scotland is based at the Lyell Centre which is shared with Heriot-Watt University. This joint research centre for geological, petroleum and marine sciences plays a key role in the science of energy supply, environmental impact, and global climate change. It provides geoscience solutions for Scotland's many environmental and social challenges through collaboration on issues such as the legacy of past industrial development, future land use, and resource and energy pressures.

Hydrocarbon hump

Recent research on the surface sediment chemistry of the upper River Clyde, its tributaries and tidal estuary has shown that Glasgow's urban tributaries have got the 'hump' – also known as the unresolvable complex mixture (UCM) – comprising thousands of hydrocarbon compounds, which are difficult to separate using standard analytical methods. The largest humps are usually found in soils and sediments that have accumulated weathered crude oils and/or refined oil products such as engine and industrial lubricants. These leak into soils and are washed into river sediments via road run-off.

Our scientists have found that nearly all the samples in and

Did you know?

About 200 staff at the Environment Agency rely on our data and models on a daily basis to help protect people and wildlife.

around Glasgow had the hump and it disappeared in sediments collected a few kilometres downstream of the city, only to return again in and around Greenock and Port Glasgow, which are situated toward the outer estuary. This suggests that these areas are either receiving modern-day, fugitive hydrocarbon pollution or that legacy hydrocarbon pollution is being remobilised – or both.



The rapidly developing cityscape of Oslo. Creative Commons 2.0 (CC BY 2.0) Konstantin Malanchev

Our research shows that the urban tributaries act as conduits, both receiving pollutants from the catchment and periodically delivering polluted sediment to the main river, and then out to sea. Additionally, it shows that

the impact of the anthropogenic pollution extends downstream but not upstream due to the flow of water and the presence of tidal barriers, which can impede sediment movement. All of this is important in helping us to

understand the concentration and possible health effects from persistent organic pollutants in Glasgow's soils.

COST SUB-URBAN

Over the last four years we have led a European Cooperation in Science and Technology (COST) action called 'SUB-URBAN'. This action has established a large, transdisciplinary network of practitioners and city partners involving over 31 countries, over 150 researchers (17 geological surveys and 22 research institutions) and 23 cities across Europe. The action is aimed at transforming the relationships between experts who develop urban subsurface geoscience knowledge and those who can most benefit from it, such as

urban decision makers, planners, practitioners (private consultants and contractors) and developers.

Key outputs from the action this year include specialist reviews that evaluate urban-geoscience research, knowledge and good practice in the subsurface across a range of topics such as:

- planning
- data management
- 3D/4D geological and geotechnical characterisation and visualisation

Did you know?

Our urban geology data is used to improve the resilience and liveability of UK cities.



Participants in the EU COST SUB-URBAN network. Photo courtesy of the COST-SUB-URBAN PROJECT.

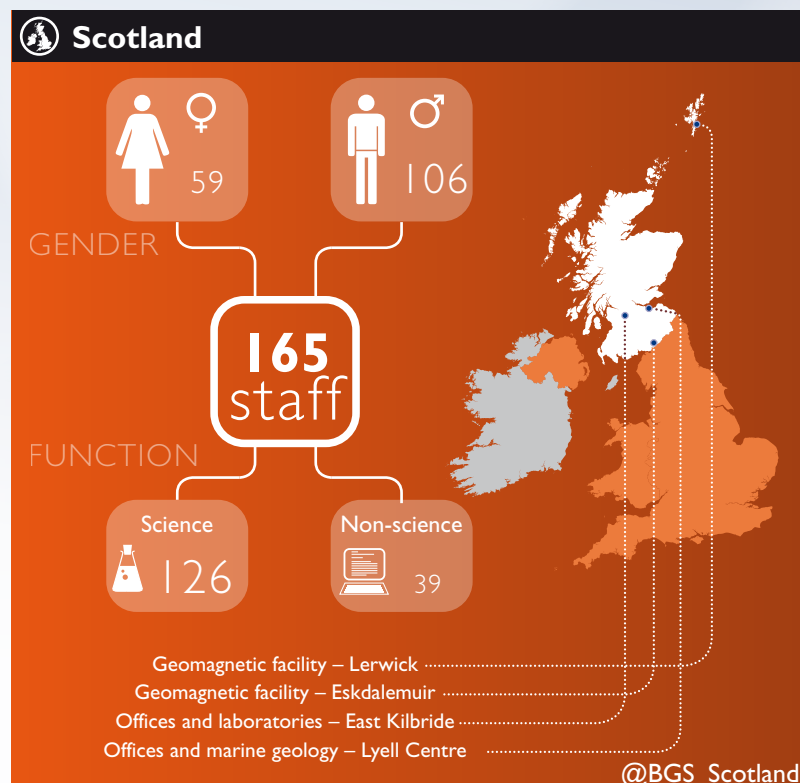
- groundwater and geothermal monitoring and modelling
- geochemistry
- cultural heritage

An online toolbox resource provides access to good practice, methodologies and guidance for practitioners, planners and policy makers. Within Scotland, we are leading work and new national collaboration with local government planning policy teams to establish how BGS data can have higher impact and utilisation in early-stage strategic decisions of city development processes and local development planning policy. The work, which is funded by a three-year NERC knowledge exchange fellowship, is the first to see a NERC (BGS) researcher embedded within local government (Glasgow City Council) over a significant time period, working with multiple service teams and levels of local government.

In addition, new national engagement mechanisms are being developed from this fellowship with all 32 local governments in Scotland. These form an important platform for us and other organisations to engage with local government in the longer term, and are a scalable and replicable approach for the UK and beyond.

TW:eed project

Fossils discovered in rocks from the Scottish Borders may be the earliest four-legged, backboned animals to have walked on land.



They fill a significant gap in our understanding of how, 360 million years ago, vertebrate animals moved from water to live on land for the first time. These fossils and the environment in which they lived have been investigated by a team from the universities of Cambridge, Leicester and Southampton, the National Museums of Scotland and the BGS, as part of the NERC-funded TW:eed project (Tetrapod World: early evolution and diversification) in order to understand how and why this momentous step in the evolution of life on Earth occurred.

Our team, alongside colleagues at the University of Leicester,

investigated the environments in which the animals lived and died. They discovered that the Scottish landscape at the time was a mosaic of forests, saline marshes, streams and lakes. The close juxtaposition of these diverse habitats and a strongly seasonal, tropical climate may have been conducive to exploitation of the terrestrial realm. The discoveries have been published in the journal *Nature Ecology & Evolution* and have received wide press coverage. The project exhibition at the National Museum of Scotland has attracted more than 60000 visitors.

HES-SIGMA

The BGS is continuing to work with Historic Environment

Did you know?

Our Building Stones group helps to protect and conserve the UK's historic stone buildings.

Scotland (HES) to develop an asset management tool capable of recording and reporting maintenance condition information for the historic properties in the care of Scottish Ministers. This tool is known as HES-SIGMA – a customisation of the BGS-SIGMA digital

data-capture platform. This year we completed Phase 2 of the project, which included the full release of HES-SIGMA across the HES Conservation Directorate. HES-SIGMA provides a fully integrated, digital data-capture system, replacing analogue reporting, which allows comprehensive data capture for surveying and monitoring the condition of a historic site. The system will ensure data consistency across sites, facilitate more effective planning for maintenance and repair programmes, and allow for condition monitoring over time.

It has been fully tested to ensure it meets the user's needs and all HES users have been fully trained by the BGS in the use of the system. HES-SIGMA has now been

adopted as the primary data-capture system for HES and forms the foundation for all future HES property condition monitoring and surveying.



Monument-condition surveying using HES-SIGMA at Tantallon Castle, East Lothian.



Artist's impression of the early Carboniferous landscape in Scotland. © Mark Witton and NMS.

Wales

BGS Wales is based in Cardiff and provides a full range of services and expertise. It collaborates widely to ensure that excellent scientific outputs contribute to the needs of local and central government, non-governmental organisations, and academia, and informs the wider community. By doing so, BGS Wales produces high-quality geoscience to address today's environmental and societal challenges.

Changes in topsoil acidity across England and Wales

For the first time, soil measurements using farmers' data have been used to measure changes in soil acidity, and other properties across the landscape. Our research shows that in Wales and north-west England, the acidity of grassland soils is increasing (pH values less than six). This is the value below which grassland productivity is considered to decline markedly.

Because less lime has been applied to agricultural soils over recent years, we increasingly see natural factors influencing the patterns of soil acidity across England and Wales. Agricultural soils farther to the north and west generally have

a smaller capacity to neutralise soil acidity because of the underlying geology, and the greater quantities of rainfall in these areas reduce that capacity further. This is less of a problem in the south and east.

Farmers need to be aware of these differences because acidic soil is less productive, and they need to apply more agricultural lime to their fields. With our partner institute, the Centre for Ecology & Hydrology, we

Did you know?

We work with other agencies to provide joined-up information systems on environmental issues.



Seasonal groundwater-controlled flooding in one of the largest ephemeral lakes in the UK.



are hoping to capture more farmers' data using a dedicated smartphone app.

A new lake for Wales

The BGS works across a range of wetland types, providing

hydrogeological advice and characterisation. We undertook a one-year study together with Natural Resources Wales, commissioned by key stakeholders, to characterise an unusual, unnamed, ephemeral

wetland nestled between the Roman town of Caerwent and the medieval Caldicot Castle.

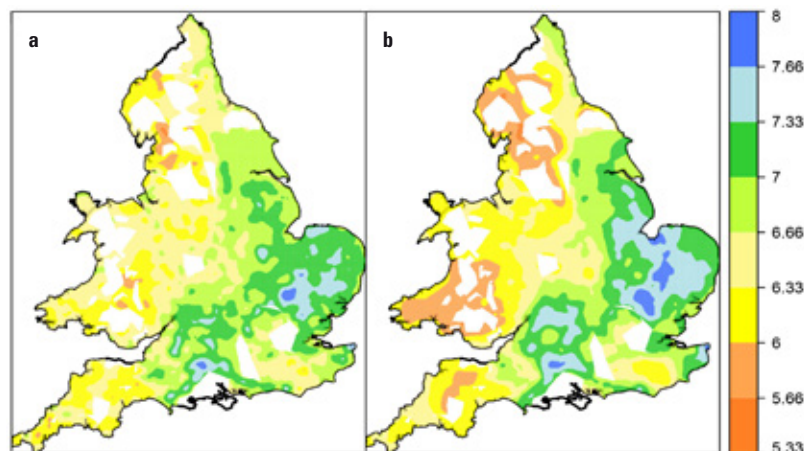
Situated in a broad, low-lying valley, a lake some 1.5 km in length forms each autumn before completely drying out during the following spring. It provides a popular feeding place for wading and overwintering migratory birds and as such is classified as a Site of Special Scientific Interest. Data collection from field survey and digital subsurface instrumentation has, for the first time, provided evidence for the mechanisms of flooding. These are controlled by the rising and falling groundwater surface within the underlying, dominantly karstic aquifer. This

Did you know?

We use soil geochemistry to look at potential impacts on, and the relationships with, human and animal health.

mechanism is similar to the well-known ephemeral lakes called 'turloughs' that occur across the Republic of Ireland, but are very rare in the UK.

Our data will support Natural Resources Wales to make evidence-based decisions about how to better manage or restore the wetland in the future.



Topsoil pH values a. 2004 to 2009 and b. 2010 to 2015.

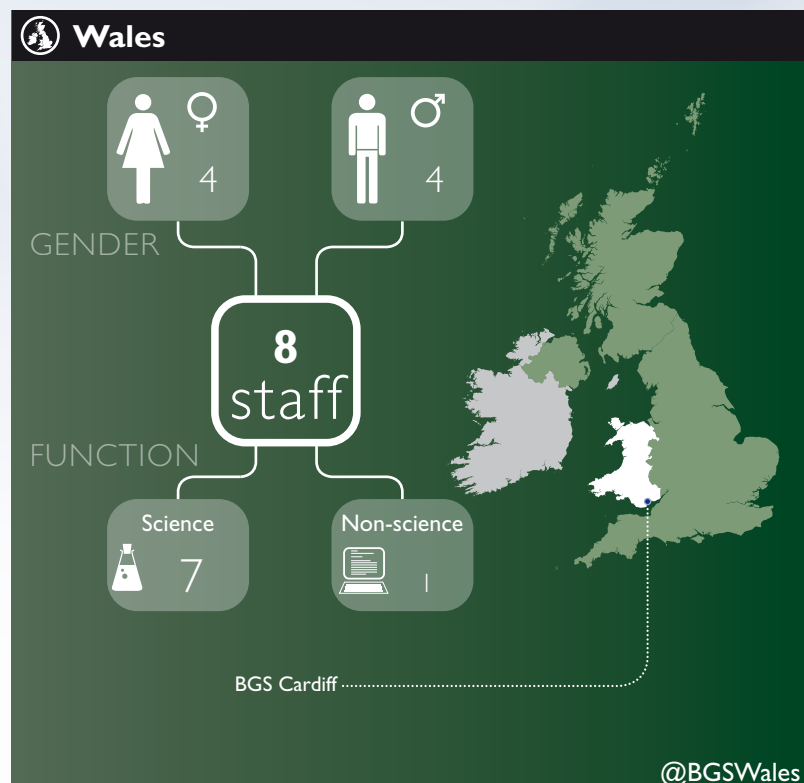
Fizzy streams

The babbling streams in upland landscapes contain more carbon dioxide (CO₂) than the air above them, so the CO₂ in the stream is released to the atmosphere. This is an important part of the global carbon cycle. This is the same process when you unscrew the cap from a fizzy drink; the bubbles of CO₂ are released into the air.

To estimate how quickly the CO₂ in streams in different parts of the landscape is transferred to the air, we need to estimate the turbulence of the stream, which depends on factors such as the steepness of the stream bed and the quantity of water flowing in the stream. We injected a gas tracer called SF₆ into a set of streams in parts of south Wales with different stream-bed slope angles. We then measured how much of this tracer was lost downstream and by doing so we could estimate the transfer rate of CO₂. We did these measurements when there was a small flow in the stream, and again after prolonged rainfall when there were much larger flows.

Did you know?

There is enough easily accessible heat in the rocks beneath our feet to heat all the homes in the UK for thousands of years.



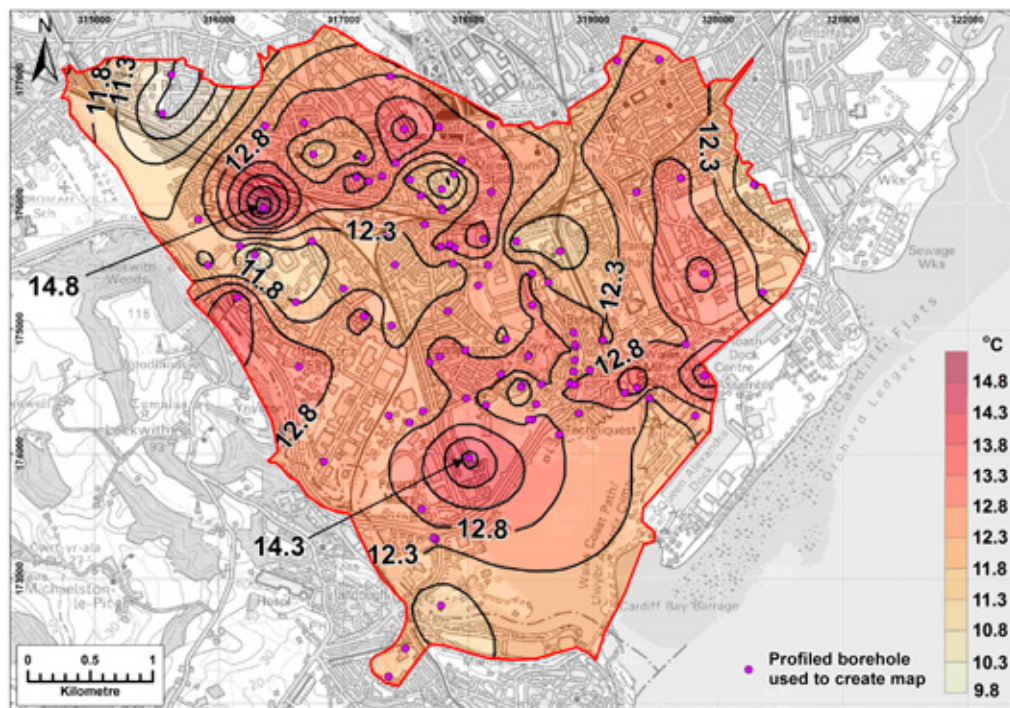
We found that gas transfer was much greater when the flows were large, and also when the bed slopes were steeper, although the effect of bed slope was smaller than for flow. We used our results to develop a model to predict CO₂ gas transfer based on bed-slope angle and the quantity of stream flow. The model will help other researchers estimate CO₂ transfer in different landscape settings.

Mapping in Anglesey

Multidisciplinary geological mapping of Anglesey has been completed recently. It commenced in 2008 and was designed to apply a wide range

of skills and knowledge and deliver new science in one of the UK's most complex regions of geology. The programme included a new, airborne, high-resolution geophysical survey as well as mapping of Quaternary superficial and bedrock geology.

The Quaternary study focused on investigating glacial processes, in particular the relationship between fast-streaming ice from the Irish Sea and the complex geological substrate. This work delivered a successful MSc project for one of the team members, as well as several peer-reviewed papers, web-delivered interpretive



Thermal resource map showing the distribution of groundwater temperatures beneath Cardiff.

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Folded metasediments of the South Stack Formation, South Stack cliffs, Anglesey.

information and a new DigMap 50 superficial dataset.

In parallel, a separate team of geologists examined the bedrock geology of the island, with a particular focus on key lithologies and geological relationships in the context of the evolution of the northern Appalachian orogenic belt and subsequent Atlantic opening.

This programme has developed international collaboration and numerous presentations at conferences, culminating in a recent 'Trans-Iapetus' field trip. The knowledge gained during this exercise underpins new research

both on Anglesey and in a wider context, for example in more modern accretionary settings.

Thermal resource map of Cardiff

This year the BGS has undertaken the UK's first high-resolution, city-scale, groundwater temperature survey to produce a thermal resource map showing the distribution of groundwater temperatures beneath the city of Cardiff. Groundwater temperatures were found to be up to 4°C warmer than predicted by the UK average geothermal gradient in over 90 per cent of sites, something we attribute to the subsurface urban heat-island effect.

Thermally enhanced, shallow groundwater can be used as an energy source through the use of ground-source heating systems. In partnership with Cardiff City Council and WDS Green Energy, we have installed a ground-source heat pump that has been heating a nursery school in the city since October 2015. We are monitoring the temperatures of the groundwater at the site and the surrounding area. This will determine the potential for long-term effects on the aquifer from operating the system, but so far the results look promising.

Global

The BGS is a leading global provider of applied geoscience services. For many years, we have had an extensive international programme of research, survey and monitoring, and data management and acquisition. Much of our work is directed towards development issues and includes major institutional strengthening programmes in the developing world.

Deep-ocean minerals

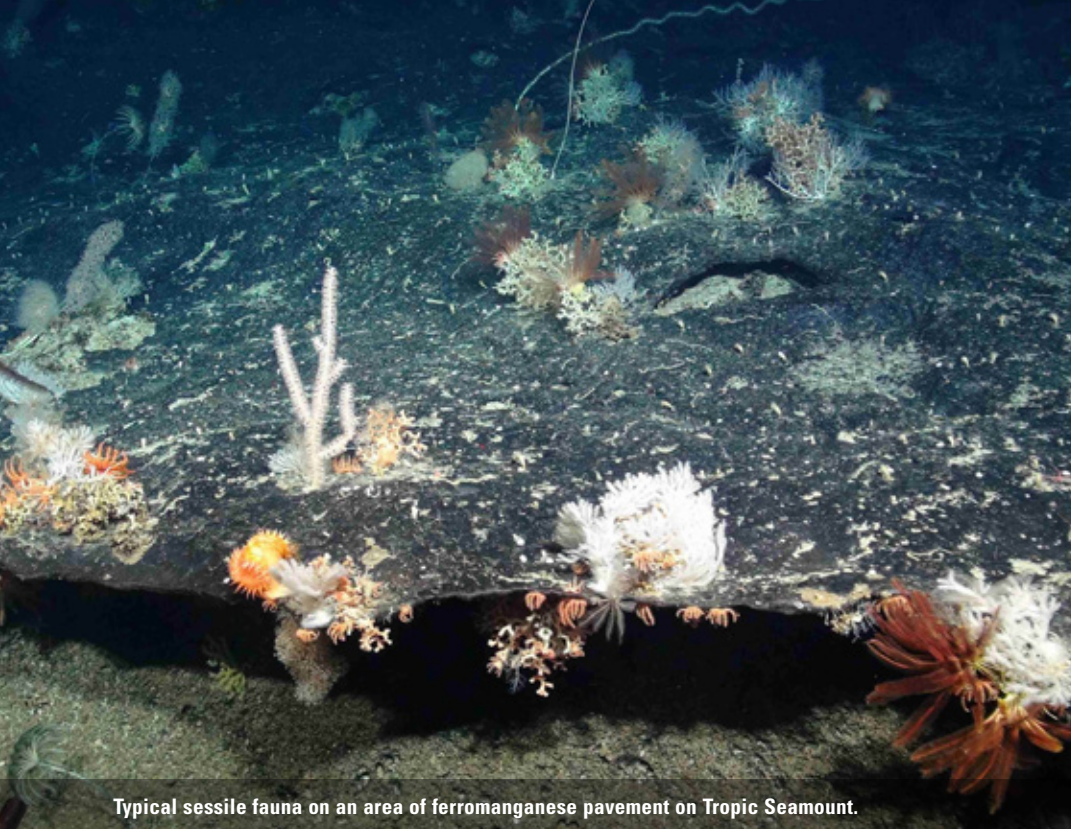
There is significant global interest in the mineral resource potential of the deep-ocean floor. However, our knowledge of this environment and the size of the mineral resources is generally poor. The BGS plays a major role in two deep-ocean, minerals-related research projects, which involved major expeditions to the Atlantic on the RRS *James Cook* during 2016.

The first cruise was to the Trans-Atlantic Geotraverse (TAG) hydrothermal field on the Mid Atlantic Ridge. It was part of the EC-funded Blue Mining project and was focused on mapping and sampling the extinct sea-floor massive sulphide deposits. This is technically challenging research,

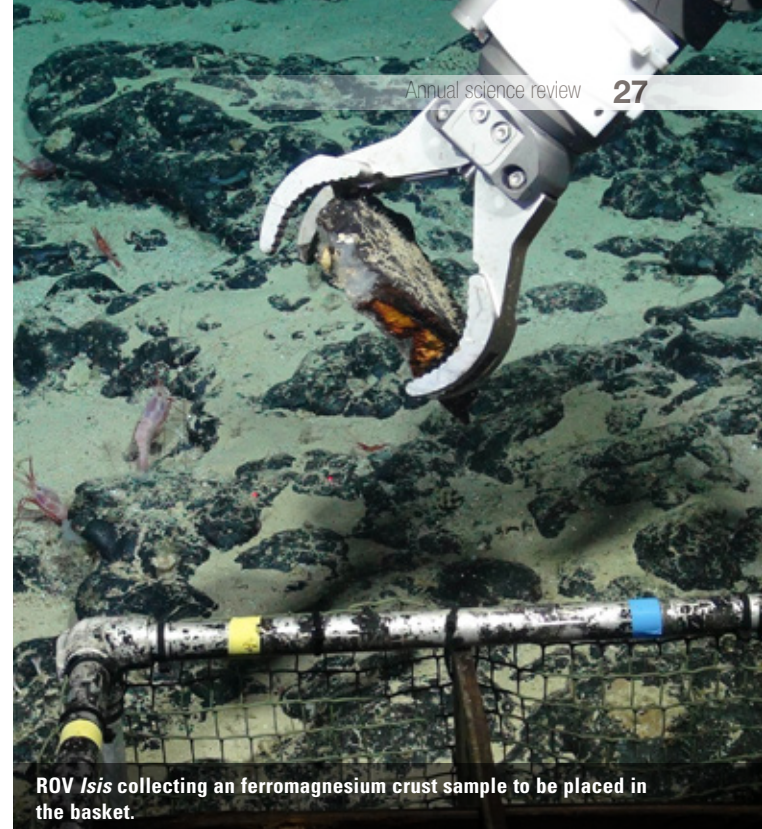
given the extreme water depths (about 3500 m), and used a range of novel geophysical exploration technologies and a robotic underwater vehicle. A highlight of the project was the deployment of our remotely operated subsea rockdrill (RD2) to obtain core material from deep inside the sulphide deposits and provide vital missing information on their 3D structure and composition. It represents the record for the deepest operation of a sea-

Did you know?

We are one of only two internationally important geological surveys that publish world mineral production statistics.



Typical sessile fauna on an area of ferromanganese pavement on Tropic Seamount.



ROV *Isis* collecting an ferromagnesium crust sample to be placed in the basket.

floor, lander-style drill rig and it acquired core from more than 12 m below the sea floor.

The second cruise was to Tropic Seamount, about 650 km south of the Canary Islands. It formed part of a NERC-funded grant (MarineE-tech) that aims to improve understanding of the processes concentrating 'e-tech' metals in sea-floor mineral deposits. These are the metals required for high-technology and green-energy applications. We spent six weeks exploring the distribution and thickness of the ferromanganese crust deposits, through a combination of high-resolution sea-floor imaging and rock sampling using the robotically remotely operated vehicle *Isis*. The new

samples form the basis for research that the BGS is leading, which aims to establish a litho-chemostratigraphy across the seamount, using high-spatial-resolution trace element and isotopic analysis.

Groundwater in sub-Saharan Africa

BGS scientists are working with WaterAid and universities in Ethiopia, Uganda and Malawi to help improve the sustainability of rural water supplies. For decades, boreholes equipped with hand pumps have been drilled to improve access to safe water for people living in rural Africa. However, until recently there has been little systematic study of their long-term sustainability. We are leading a large

interdisciplinary team of natural and social scientists to provide a new evidence base of current failure rates and to investigate

the complex reasons for failure. The first phase of the project, measuring current water-point functionality rates in Uganda,



Testing aquifer permeability in a poorly functioning borehole in Ethiopia.

Malawi and Ethiopia, finished in March 2017, and the results have been discussed with the national governments. Our research approach provides a much fuller description of the performance of each water point to complement national audits, which often only describe whether the water point is delivering any water or not.

The research has found that, in each of the countries, over 50 per cent of water points are not working to their design capacity, a much higher proportion than expected. There are no simple reasons for this, and the second phase of the project is now underway to dismantle and thoroughly test a subset of water points in each country. Alongside the physical research, the social scientists are trying to understand how each community manages and operates its water point.

The unfolding earthquake crisis in the central Apennines (Italy)
UK and Italian scientists are investigating the unfolding earthquake crisis in the central Apennines (Italy), aiming to determine the conditions under which large events and their catastrophic aftershocks nucleate. We have been on the ground together since last August, when the magnitude $M=6.0$ earthquake struck Amatrice village and caused extensive damage and loss of life along a 70 km zone. Since then, the BGS team has deployed

24 seismic instruments from the Geophysical Equipment Facility, supported by direct NERC emergency funds, to monitor the intense seismic activity. The largest event to date corresponds to the $M=6.5$ Norcia earthquake, devastating the historic San Benedetto basilica. It was followed in January by moderate magnitude activity near Campotosto dam.

Shortly after the disaster, the UK scientific team recognised the importance of developing preliminary earthquake models that shed light on the migration of aftershocks within the evolving sequence. In future, the dataset, which is unparalleled by European standards, will allow an international research team to image active faults with unprecedented precision

and formulate physical models describing earthquake occurrence. The team is led by Margarita Segou of the BGS and includes the University of Edinburgh, University of Stanford, US Geological Survey, Columbia University and the Istituto Geofisica e Vulcanologia.

LANDSLIP project

This year saw the start of LANDSLIP, a four-year project funded under the NERC–Department for International Development (DFID) Science for Humanitarian Emergencies and Resilience (SHEAR) programme. It pulls together physical scientists, engineers and social scientists in the UK, Italy and India to help protect lives, livelihoods and the local economy of vulnerable, landslide-prone communities of India.



BGS and INGV experts and a local fireman visiting the red zone of Amatrice village.

Did you know?

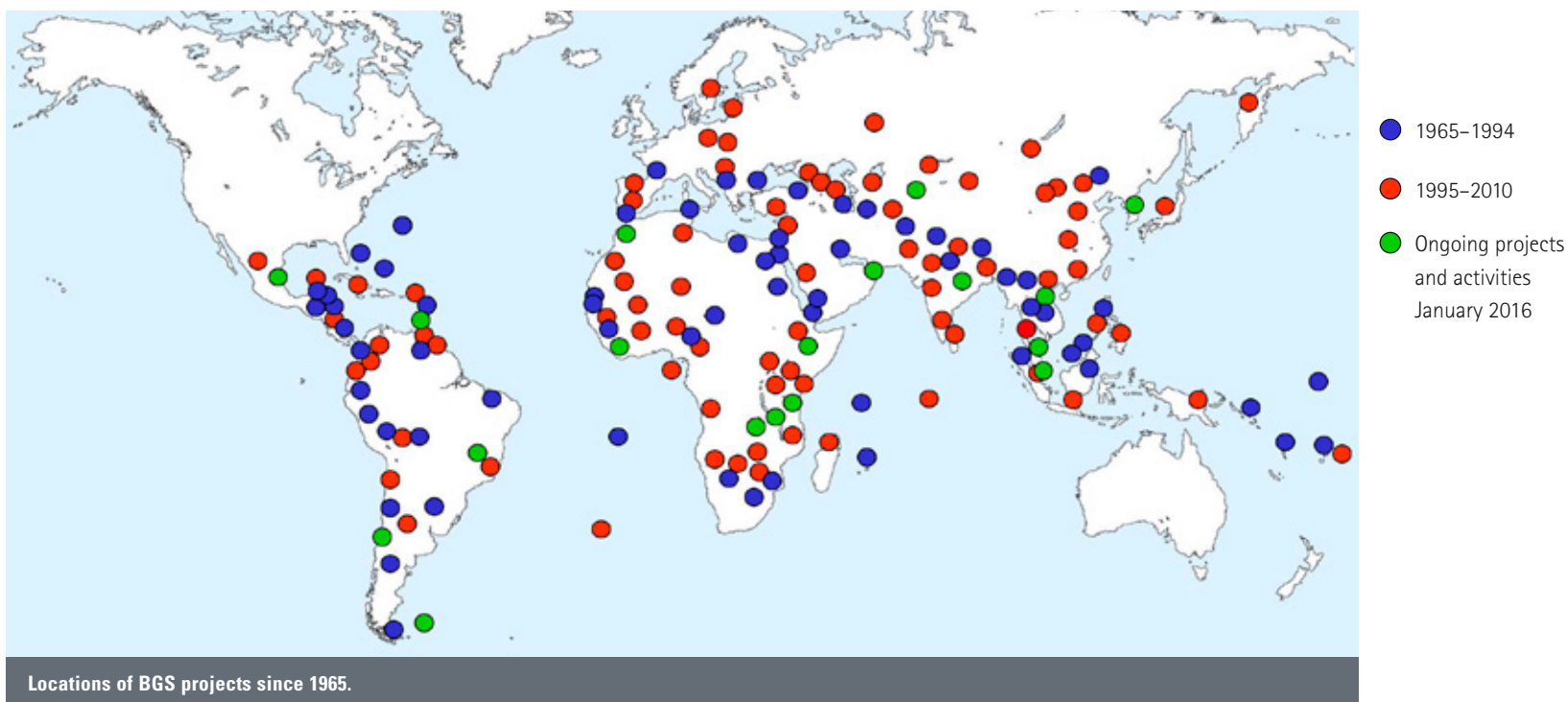
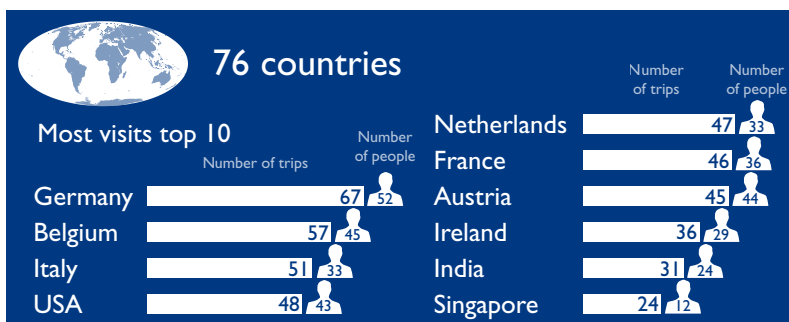
We operate a state-of-the-art earthquake monitoring network in the UK.

The team will work together to develop enhanced landslide risk assessment and monitoring methods using two study areas:

the Darjeeling and East Sikkim districts in the Eastern Himalayas in the states of West Bengal and Sikkim, as well as the Nilgiris District of the Western Ghats in the state of Tamil Nadu. LANDSLIP will help to develop landslide risk assessment and early warning systems, and the best means of disseminating this information to those that need it in India.



House at risk from toe erosion by a torrent stream causing a minor slide. Nilgiris, southern India.



Data

The BGS is a data-rich organisation with over 400 datasets in its care, including environmental monitoring data, digital databases, physical collections, records and archives. All of this underpins the public and national-good science that we deliver and is also depended upon by a wide range of users and communities. Our data is looked after by the National Geoscience Data Centre (NGDC).

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Coastal vulnerability dataset

The mainland of Wales and England is surrounded by over 12000 km of coastline. It is a very diverse coastline both in terms of geology and geomorphology, ranging from the high chalk cliffs of Sussex to the flat expanses of The Wash and Morecambe Bay. The coast has been shaped by the continual forces of erosion from the wind, waves and tide, and the characteristics and composition of the coastline dictate the degree of its vulnerability. The winter storms of 2013 to 2014 starkly demonstrated the vulnerability of the coastline of Wales and England to erosion and overtopping by waves and storm surges. However, when the BGS was asked to respond to media enquiries it became clear that a national picture of the sections of

coastline susceptible to erosion, based on geology, did not exist. Forecasts of an increase in the frequency and intensity of winter storms and associated erosion and coastal inundation have therefore prompted us to develop the coastal vulnerability dataset (CVD).

The CVD is a geographical information system (GIS)-based analysis that includes datasets displaying coastal erosion susceptibility; the spatial extent of beaches, tidal flats, salt

Did you know?

We have a huge amount of free data, images, apps, maps and models available through OpenGeoscience.



Cliff erosion at Happisburgh, Norfolk, after the December 2013 storm surge.

marshes and wave-cut platforms; cliff height, and coastal inundation potential for Wales and England.

The CVD will offer anyone with assets or an interest in the coastline around England and Wales, access to easy-to-use datasets linked to geohazard data. Version 1 of the CVD represents the natural geological coastline around the mainland of England and

Wales, as if no coastal defences or made ground are present. This will be of particular value in areas where coastal defences are no longer maintained. Scotland and the islands around Great Britain are not included in version 1. Both will be included in the version 2 release.

Groundhog Desktop

Groundhog Desktop has continued to evolve, providing easy access to BGS and external

baseline data ready for geological modelling and visualisation, as well as offering a growing set of interpretation tools. It is in regular, daily use by a range of BGS staff members.

Recent developments have responded to external feedback requesting improvements to the borehole log window and import of borehole information in AGS (Association of Geotechnical and Geo-environmental Specialists) format. These developments will significantly improve the user experience and make the tool more relevant to users in industry.

The Geological Survey of Finland (GTK) has recently awarded the modelling systems team a two-year contract to design and build

Did you know?

Our iGeology app provides free access to geology maps wherever you are in the UK.

new tools within Groundhog Desktop to visualise real-time, groundwater-level data inside a geological framework model.

Groundhog Desktop is available to all under the Open Government Licence, gaining 1400 downloads to date.

Global geoscience data web standard published

Earlier this year the Open Geospatial Consortium (OGC®) announced that GeoSciML was

GeoScenic - the BGS's online photo collection

73 340 different images viewed

approved and published with full documentation as an OGC standard. The OGC GeoSciML standard defines a model and the encoding for geological features commonly described and portrayed in geological maps, cross-sections, geological reports and databases. BGS staff led many parts of the development, testing and implementation of this standard through the OneGeology initiative, which we co-lead. We hosted the very first meeting to start work in 2003 at BGS Edinburgh.

GeoSciML provides a mechanism for storage and exchange of a broad range of geological data, enabling users to generate

geological depictions (such as maps) in a consistent and repeatable fashion.

The GeoSciML Standard includes a 'lite' model, used for simple, map-based applications; a basic model, for basic data exchange, and an extended model to address more complex scenarios. The standard also provides patterns, profiles (most notably of OGC observations and measurements and ISO 19156) and best practices to deal with common geoscience use cases.

The model was developed by the International Union of Geological Sciences (IUGS)'s Commission for

Did you know?
BGS Civils is a suite of maps that provides information on engineering characteristic, of the UK subsurface.

the Management and Application of Geoscience Information (CGI) and version 4.1 is the first version officially published as an OGC standard. This standard describes a logical model and GML/XML encoding rules for geological map data, geological timescales, boreholes, and metadata for laboratory analyses. It is used worldwide in the OneGeology initiative.

2171 GeoReports sold



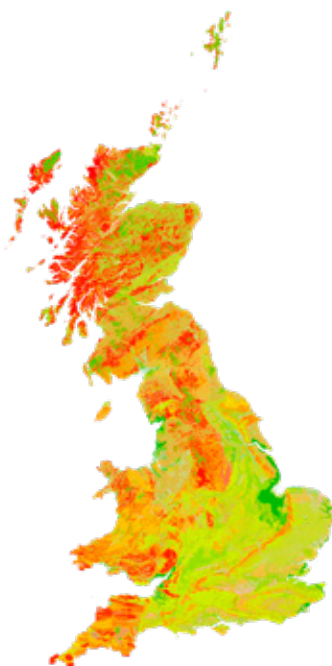
1432	Radon
209	Infiltration SuDS
147	Natural ground stability
105	Building stone assessment
96	Bespoke area assessment
69	Geological map extracts
59	Bespoke point prognosis
45	Ground-source heat pump
9	Other

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PropBase

In the BGS we collect little subsurface geological data ourselves; most is acquired and deposited by industry. Whilst this provides us with huge volumes of data, it also means that it is supplied in formats that suit depositors rather than meeting our needs. Projects that model subsurface properties therefore expend major effort identifying, collating and standardising the data needed so that datasets collected separately can be compared.

PropBase changes this by breaking down data silos and making information immediately available. Using innovative database technology, data is ingested, converted into a standard form



Map showing output from the BGS Civils database.

and then output through a single portal. This allows all equivalent data to be accessed and collated in minutes. Data collected at all depths – from the surface, from shallow site-investigation boreholes and from deep oil wells – can be immediately compared and used to analyse similarities or differences between rock properties in geological units across an area. New 3D geological models will no longer contain just the locations of geological units but also information on how consistent the lithologies are, which may affect their ability to, for example, trap migration of pollutants.

PropBase simplifies the process of collecting geological information, allowing time to be

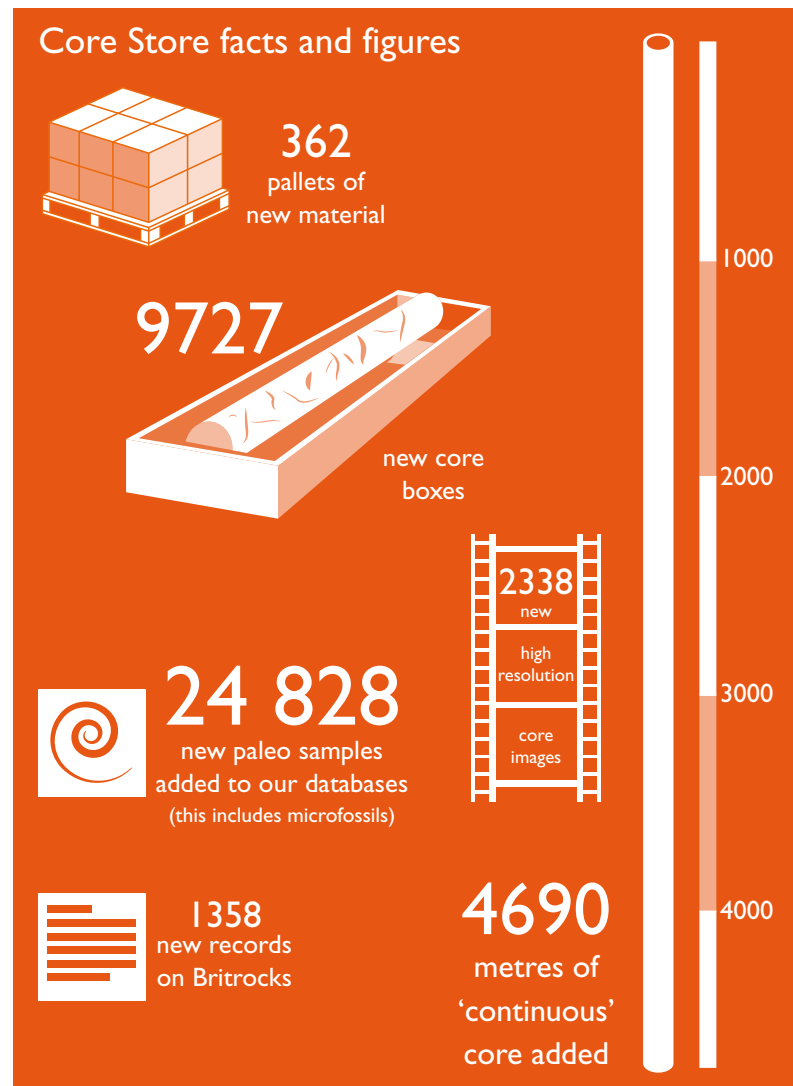
spent on interpreting data rather than searching for it.

BGS Civils

Our GeoAnalytics and Modelling directorate have developed and launched a series of new datasets for informing ground engineering design, called 'BGS Civils'. This is a suite of national maps of engineering properties based on geological data and the digital 1:50 000-scale geological map. The classification used in the dataset is based upon the British Standard 5930 code of practice for site investigation and is designed to slot directly into the desk-study phase of geotechnical assessments.

The package includes a suite of seven engineering properties for soils and rocks nationwide including strength, excavatability, discontinuities, engineered fill, sulfate/sulfide potential, bulking volumes and corrosivity. It has been developed to facilitate desk-study screening for ground engineering projects. Since this initial release, the BGS Civils project has continued to develop additional information and has added the 'BGS Civils foundation conditions' dataset to the bundle. Further developments are underway to create a new 'engineering rockhead' dataset, which should be available in the coming year.

Properties of rocks are important in all engineering projects and these new maps will, for the first



time, deliver this information efficiently to those undertaking geotechnical desk studies. The information will enable efficient planning of focused site design and will inform engineering geologists and ground engineers at the desk-study stage of investigation. This allows for more efficient planning and execution of ground investigations. They

are of great value to a range of uses, including, infrastructure route planning; pipe material selection; utility installation cost estimation, and preparing for works.

Inside the BGS

Finance

The financial year was a successful one: we brought in external funding of £20.7 m and managed the corporate finances to a near-balanced position (small surplus). During 2016/17 we received £22.48 m from NERC to fund the core strategic science programmes and as a contribution to infrastructure.

The NERC allocation, taken together with the competitively won NERC funding, accounted for approximately 57 per cent of non-capital funding. There has started to be a redirection of the funding from NERC towards major initiatives such as the UK Geoenergy Observatories project and Official Development Assistance (ODA).

We earned approximately 43 per cent (£20 m) of non-capital budget from external sources. Research commissioned by customers through externally funded projects accounted for £16.2 m. Externally won projects enhanced the science programme through funding, ideas, data and review, and made a vital contribution to infrastructure. In 2016/17, this income included revenue from various sources including £5.2 m from government departments, £9.3 m from foreign, public and private sectors, and £1.6 m from European funding. There was also £4.57 m from non-project sources, primarily royalties and licence fees (£3.1 m).

NERC also provided capital funding of £2.7 m, including £0.26 m towards the initial planning



costs for the UK Geoenergy Observatories. The Department for Business, Energy & Industrial Strategy (BEIS) funding for this project was agreed at the end of 2016/17. In addition, we received £1.08 m in contributions towards capital projects, giving an overall capital spend of £3.78 m.

Estates

The last year has been a busy one as we prepare for an exciting new

phase. The estates team continues to work with both the executive and senior management to ensure that the estate and infrastructure are well managed, energy efficient and, more importantly, remain fit for purpose in line with scientific advances.

The Lyell Centre was formally opened in 2016/17. It is now fully occupied and provides excellent collaboration facilities that are now being utilised by both Heriot-Watt University and the BGS. Both the Murchison House and Loanhead sites were sold in quarter one, which reduced the total number of sites managed by the BGS in line with Government policy.

Our office in Wales also relocated during the 2016/17 year. Moving from a business park on the outskirts of Cardiff to newly

refurbished accommodation on the main Cardiff University campus, the new site provides both greater visibility and opportunity.

Elsewhere, the estates team completed project works to the value of about £1 m. These include:

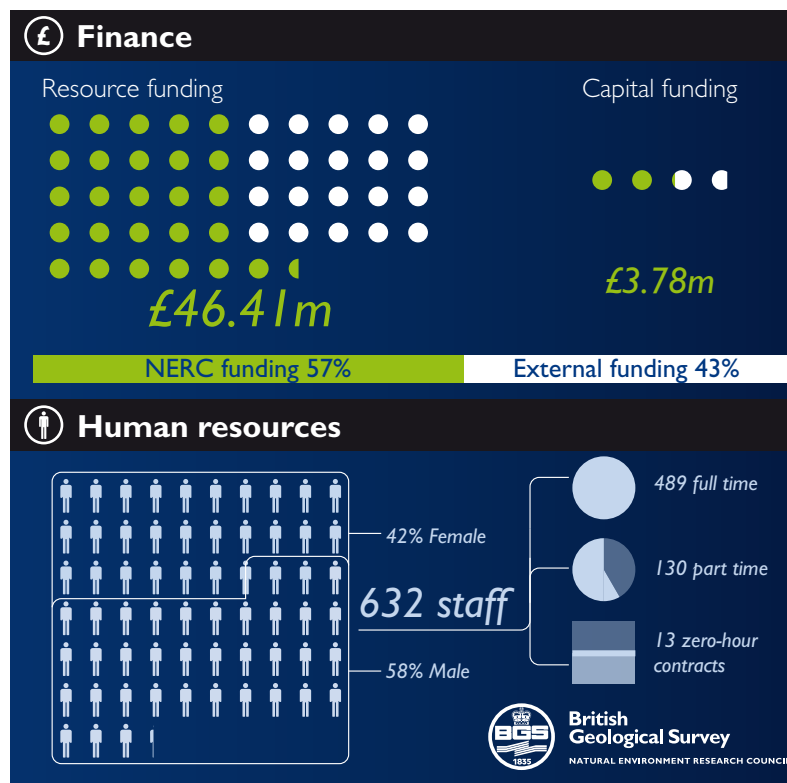
- extensive water-system upgrades at two observatory sites
- mains replacement at Keyworth
- full lift replacements at the Keyworth sites
- roof repairs
- a new gas boiler
- fire compartmentation works
- a new air conditioning system

Finally, the organisation completed an initial scoping exercise for new repository facilities for the storage of core samples and a purpose-built, flexible laboratory facility. The estates team very much looks forward to continuing to improve facilities during 2017/18 and working with the organisation to continue planning for the future.

Human resources

This year we have made further positive progress on the BGS People Strategy in a number of key areas:

- completion of the restructuring programme – a number of colleagues left the BGS, enabling specific areas to be reshaped and new employees to be recruited with different skills sets



- development of workforce plans to take account of staff resource requirements for the development of key strategic projects
- recruitment of a total of 42 new staff, some related to the reshaping of our workforce skills profile, others to directly replace leavers
- recruitment of five new apprentices
- review of the BGS science directorates, to allow a better match of resources to science priorities, as well as effective development and deployment of key skills across the organisation
- improvement of the 'staff review meetings' process, strengthening the focus on talent management
- management of the NERC 'growing future leaders' development programme – successful delivery of the first year of the programme for cohort 3

All this has been achieved through strong teamwork both within HR and with teams across the BGS. Our colleagues have demonstrated high levels of professionalism and commitment to BGS values and strategic aims.





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