Contents

WELCOME FROM THE CONVENORS

In 1815 William Smith published the first edition of his Geological Map of England and Wales. Smith's map made a seminal contribution to the understanding of the ground beneath our feet and, by showing the location of coal, iron ore, clays and other raw materials, helped fuel the industrial revolution. Two hundred years on, the demands for spatial knowledge about our geological environment and its resources and hazards have become ever more diverse and pressing. Nevertheless, many of the motivators, approaches and principles pioneered by William Smith survive in the geological maps, models and information systems of today.

The History of Geology Group and the British Geological Survey have worked together to convene two William Smith meetings at the Geological Society in 2015 to celebrate this landmark anniversary. The first, very successful meeting in April 2015, convened by HOGG, chronicled the history and development of the geological map from its earliest beginnings to the digital maps of today. This second meeting, convened by the BGS, looks to the future of geological mapping, and to the grand challenges for geoscience that will motivate the 'William Smiths' of tomorrow. It showcases the new science, technologies and information systems that are changing and broadening the whole concept, purpose and impact of geological mapping. A concluding panel discussion will focus on the skills and roles of the field geologists of the future. The meeting will be followed by a drinks reception and an evening lecture that takes geological mapping to the next frontier – planetary geology.

The Society should like to congratulate Amy Elson and Charlotte Jackson, winners of a William Smith travel grant to attend our meeting and present posters on the outcome of their geological mapping dissertations.

We should like to thank:

The William Smith Bicentenary programme sponsors who have supported the William Smith travel grant for this meeting.

The Geological Society Conference Office for their help in convening the conference, with special mentions for Jess Aries who helped considerably with abstracts, budgets and logistics while working at the office until September 2015, and for Ruth Houlsby who dealt with all the last minute troubleshooting to land the meeting on the day.

John Henry and HOGG for working with us to develop the overall concept, programme and approvals for the two William Smith meetings in 2015.

We hope you enjoy the day!

The BGS convening team:

Andy Howard
Leanne Hughes
Jim Riding
Sam Roberson
Wayne Shelley
Jackie Swift

Programme

The Geological Society

Morning

09.00	**Registration, Tea and Coffee**
09.20	**Welcome:** Andy Howard (BGS)
Session 1: Future demands for geological spatial information **Chair: Jim Riding (BGS)**	
09.30	**KEYNOTE:** **Future demands for geological spatial information** Mike Stephenson (BGS)
10:00	**Mapping the unusual - site to regional scale investigation of basin inversion faulting in London** Jackie Skipper (Geotechnical Consulting Group)
10.15	**Bridging the gap between the supply and demand for geo-mapping data in emerging economies** Gareth Hearn (Pettifer and Hart)
10.30	Tea and Coffee Break

Session 2: Meeting the demands: Geological models for a digital world **Chair: Jackie Skipper (Geotechnical Consulting Group)**	
11.00	**KEYNOTE:** **From Geological Maps to Models in GSOs worldwide** Gerold Diepolder (Bavarian Environment Agency)
11:30	**BGS TAG TEAM: The Development of digital mapping at the BGS** Nikki Smith (BGS)
11.40	**BGS TAG TEAM: Field geology, collecting data in a digital environment.** Leanne Hughes (BGS)
11.50	**BGS TAG TEAM: Mapping in 3D space: Linking the subsurface to the surface, a chalky perspective** Andrew Farrant (BGS)
12.00	**BGS TAG TEAM: Mapping change in our dynamic earth** Katie Whitbread (BGS)
12.10	**BGS TAG TEAM: Taking our understanding of river valley deposits beyond William Smith and its practical importance for Britains chalkland streams** Andrew Newell (BGS)
12.20	**BGS TAG TEAM: Enhancing Geological Mapping in South West England** Christopher Yeomans (BGS)
12.30	**BGS TAG TEAM: Maps to Apps, dissemination of geological data** Patrick Bell (BGS)
12.40	Lunch and Poster Session

Afternoon

13.30	**KEYNOTE:** **Future demands for geological spatial information** Iain Stewart (Plymouth University)
Session 3: New methods and technologies for multi-scale mapping **Chair: Mark Rattenbury (GNS Science, New Zealand)**	
14.00	**KEYNOTE:** **Earth geography through time: how magnetic grains take geological maps into the 4th dimension** Conall Mac Niocaill (University of Oxford)
14.30	**Geological mapping in ways never imagined by William Smith: How 2D, 3D & 4D digital rock analysis is driving a revolution in the understanding of mappable lithologies** Alan Butcher (FEI)
14.45	**Geological mapping using airborne thermal hyperspectral data in Antarctica** Teal Riley (British Antarctic Survey)
15.00	**Sediment-filled hollows in the Peak District: Mapping the Miocene Brassington Formation of the UK** Matthew Pound (Northumbria University)
15.15	Tea and Coffee Break

Session 4: Building skills and capacity for future needs **Chair: Conall Mac Niocaill (University of Oxford)**	
16.00	**KEYNOTE:** **Mapping surficial geology and geomorphology in landscapes undergoing rapid deglaciation: lessons for understanding Quaternary geology** David Evans (Durham University)
16.30	**Digital Field Mapping in the 21st Century: Making the change from paper to touchscreen technology** Roddy Muir (Midland Valley)
16.45	**Teaching Basic Geological Mapping Skills in a Virtual World** Jacqueline Houghton (University of Leeds)
17.00	**A new generation of marine geological maps** Dayton Dove (BGS Marine Geoscience)
17.15	**Panel Discussion: Geological maps and mapping, the vision for the future** Chair: Andy Howard Panellists: Jacqueline Houghton, Leanne Hughes, Mike Stephenson, Iain Stewart
18.00	**Closing Remarks**
18.10	Drinks Reception
19.00	Introduction and Welcome
19.05	**EVENING KEYNOTE**: William Smith in Space: Geological maps of other planetary bodies David Rothery (Open University)
20.00	Conference End

Speaker Abstracts

Future demands for geological spatial information

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The world's subsurface space, including Britain's, is already used in a variety of ways, ranging from human occupancy to disposal and the bulk storage of materials and fuels. In the future it is likely that it will be put to further use in response to trends in technology, resource supply and demand, socioeconomics and geopolitics. Geological spatial information in the form of 3D geological maps will be vital in managing that usage, for example in allowing the subsurface resource to be assessed and delineated, for underground space and processes to be regulated, for questions of liability and insurance, and for planning and public reassurance.

An example of a future use of geological spatial information is in carbon capture and storage, one of the chief methods that governments across the world may adopt to reduce CO2 emissions to the atmosphere. New kinds of 3D geological maps will have to be developed for this kind of storage making possible estimates of CO2 capacity, injection rates and fluid pathways. Perhaps more important for possible CO2 operators in Europe (for example), is the EU CCS Directive which requires that such a 3D model must be deemed 'fit for purpose' in order to gain a storage permit, and that after 50 years following the end of injection the rock 'store' must be behaving as the 'model predicted'. Only then can the store be closed and future liability handed over to the relevant authority (usually the government).

It is likely that further advances in sensor technology, and big data storage and processing will particularly impact on geological spatial information. Sensors are already used to monitor surface systems like the atmosphere, rivers and coasts, and allow planning and useful prediction, but comprehensive subsurface monitoring is in its infancy. Adding high resolution data on flow and geodynamic change from sensors will convert 3D to 4D and allow us to use our geological maps to monitor and predict geological processes at timescales that matter to lives and livelihoods.

Mapping the unusual - site to regional scale investigation of basin inversion faulting in London

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Improvements in engineering site investigation techniques over the past 20 years, a dramatic increase in large scale construction projects and improved understanding of the ground in London are leading to a change in the geological paradigm for London.

Formerly thought of as mostly simple, layer-cake strata, certain areas of London are now emerging as far more complex, with many local occurrences emerging of low angle, strike slip or reverse faulting (Figure 1) - and evidence of ground movement during Palaeocene, Eocene and Pleistocene to Holocene epochs, despite London's presence in a 'low-seismicity' area.

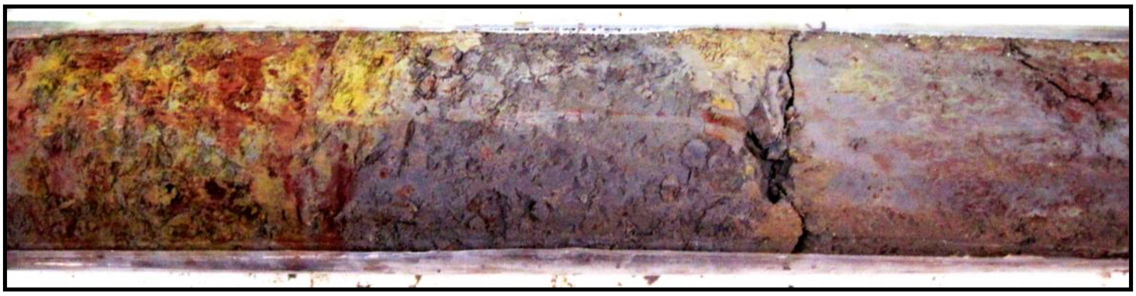

Figure 1 Rotary cored borehole from the Mayfair area showing interfaulting of Lambeth Group Reading (mottled) and Woolwich Formation (grey) sediments.

Part of the improvement in geological data for mapping and interpretation purposes has required a rethink about how the ground is interpreted from the very beginning - from how we teach stratigraphical training to loggers to an instilling of a more open approach when looking at historic borehole data.

This presentation will show recent examples of these more complex structural areas at a variety of different scales in central London. We will give examples ranging from 2D to 3D interpretations of individual sites (Figure 2), to current regional modelling using London PSInSAR (Persistent Scatterer Interferometric Synthetic Aperture Radar, Figure 3). The integration of these data from different scales suggests that these areas of high complexity may be the result of fault-controlled intraplate movements, indicating basin inversion, which may be persisting into the present day.

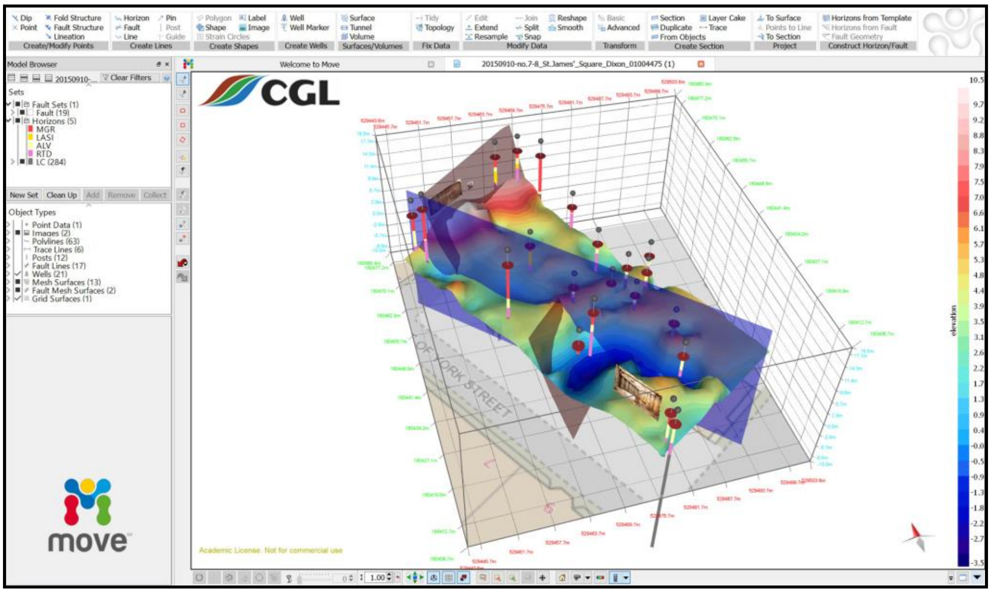

Figure 2. 3D model of a site near Piccadilly, London, showing deformed and scoured surface of the London Clay (colour by elevation). Detailed analysis of site data provided evidence for a normal fault (brown) displaced by a sinistral strike-slip fault (blue) cutting across the site. The 6m deep fault-bounded hollow in the clay surface was filled with gravels, consistent with formation by scour from a fault-controlled braided river channel at the end of the last ice age.

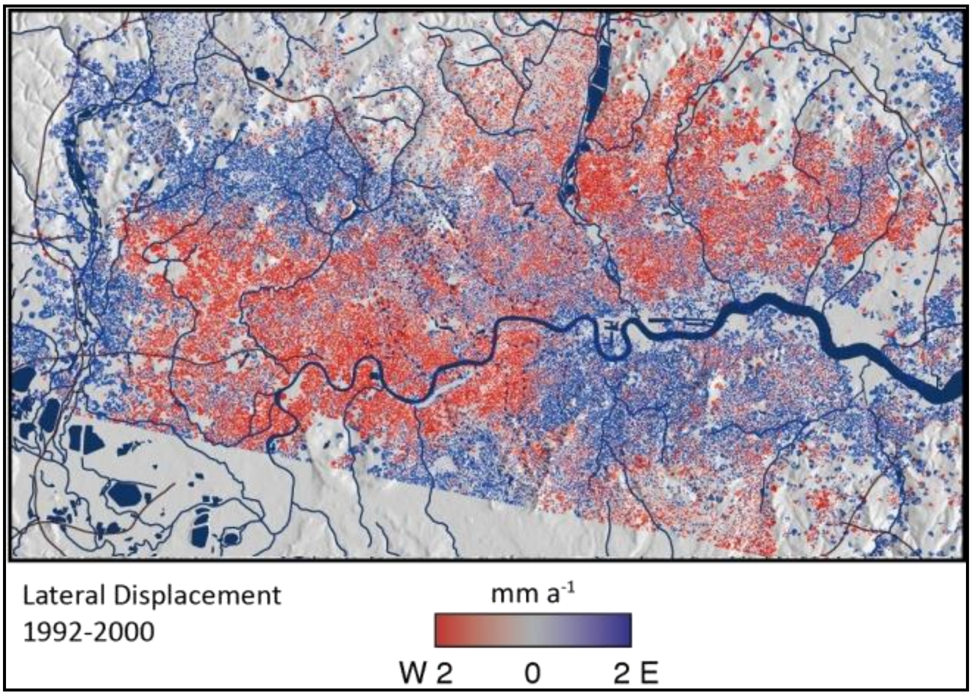

Figure 3 PSI lateral data - ascending and descending mode ERS data combined to isolate the east-west component of displacement. Two large west-moving blocks are identified in the west and NE, and two east-moving blocks in the NW and SE.

Bridging the gap between the supply and demand for geo-mapping data in emerging economies

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Some of the highest levels of investment in infrastructure are taking place in countries with emerging economies. The plan for the future in many of these countries is to continue and accelerate these rates of expansion to satisfy demands for regional development, resource exploitation, increased mobility and livelihood improvement. Infrastructure development projects place a high demand on geological data, especially in areas of complex ground and especially where the location and design of structures require detailed and reliable interpretations of the sub-surface. Much of this development is also taking place in areas of steep and mountainous terrain, or in areas of otherwise marginal ground, where geological and geotechnical hazards such as landslides, subsidence and problematic soils pose a significant threat to the performance of the works.

Unfortunately, many countries in Africa and Asia especially do not have the required levels of geo-mapping data to satisfy these demands and many development projects are ill-equipped to provide it, either through lack of awareness or lack of funds. 1:50,000 scale outcrop mapping is frequently the only source of data available and, unless intensive mapping is undertaken on a project by project basis, critical path decision making and design can be significantly compromised. Drift maps, at any scale, are a rarity, and important information on landforms and geomorphological processes is usually lacking.

The development of geo-models, based on remote sensing, rapid field reconnaissance survey and geological desk study provide a potential solution to the problem. Ground conditions at any site are a product of the lithology, stratigraphy, structure, hydrology and the past and present climatic conditions and geomorphological processes, i.e. the ‘total geological history’. The development of the geo-model involves the 3-D modelling of these components and the derivation of mapping outputs at increasing scales as route selection, design, construction and operation require increasing scales of information. Traditional methods of remote sensing, field observation, testing and mapping will continue to be the basic components of geo-modelling but will increasingly need to be integrated with new automated digital procedures for collecting geospatial data, including the integrated use of satellite and satellite remote sensing. Examples from parts of Africa and Asia, illustrate the manner in which these geo-models are developed to satisfy planning and engineering demands.

Representing epistemic uncertainties in geological mapping for hazard assessments and other applications

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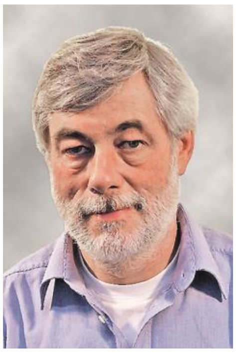
Geology-based assessments of natural hazards are one of many applications of geological mapping for which legislation or commercial requirements currently require evaluations of uncertainties in the assessments. These uncertainties are commonly classified as aleatory, related to variations in hazard occurrence and intensity that can be represented as statistical distributions, and epistemic, related to deficiencies in the data and interpretations used to construct the assessments. A key problem for geologists is that of representing epistemic uncertainties in ways that are comprehensible to statisticians and amenable to statistical analysis. Furthermore, the time-consuming nature of classical geological mapping and the mapping of inaccessible regions such as the ocean floor and the surfaces of other planets, mean that many geological maps are now constructed with highly incomplete data that create epistemic uncertainties. Absolute geochronological data on incomplete subsets of mapped units are critical to the use of geological maps in hazard assessments, but also create epistemic uncertainties.

Standard geological maps and their keys, stratigraphic columns and relative chronologies represent epistemic uncertainties – or rather, do not represent them – in ways that have changed little since the time of William Smith. Smith's methods were developed during thorough mapping of a region where near "layer cake" sediment stratigraphy and the availability of fossil biostratigraphy means that epistemic uncertainties in his work are small. However, this does not apply to most geological maps especially those of igneous, metamorphic and structurally complex areas, where it may be inherently impossible to obtain complete relative chronologies by mapping; nor to maps based upon incomplete data sets. In such situations, mappers have applied a variety of indirect approaches to constructing relative chronologies, some of which are more valid whilst others are critically model-dependent interpretations. Such desperate measures may result from the lack of a satisfactory method of representing incomplete chronologies.

An alternative approach, that I have used both in geological mapping research and teaching, is that of representing both spatial and time relationships between map units in a topological net diagram that shows both what is known and not known about the relative ages of the units. Examples of such diagrams for maps dominated by volcanic and intrusive rocks are presented along with an explanation of how they can be used to optimize selection of samples for absolute dating, investigate the presence or otherwise of trends in styles of activity through time, and applied to hazard assessment.

From Geological Maps to Models in GSOs worldwide



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Over the past 25 years Geological Survey Organisations (GSOs) worldwide have begun the transition from the production of digital geological maps to 3D geological models attributed with geological and environmental parameters, as the core output of their national geological understanding. These models are a prerequisite for any future subsurface or environmental investigation. This progression from 2D to 3D data represents a paradigm shift in the delivery of geospatial after 200 years of geological map production starting with William Smith's first ever national geological map in 1815 and the subsequent establishment of GSOs worldwide.

This change has been facilitated by the rapid development of IT hardware and software for model construction, visualisation and delivery. This presentation will review the progress in leading GSOs in the field of geological modelling and model delivery. We also discuss, the problems encountered and those that remain unresolved; the softwares used; the tools for delivering the model data; and most importantly, examples of how the enhanced 3D geological understanding has led to direct benefit for society. Today, we are finally communicating our full 3D understanding to our users and stakeholders, by capturing *the geologist's vision*! We will conclude with some speculation on what the future may hold in this rapidly evolving technological field.

BGS TAG TEAM: From Maps to Models to Apps: Geological Mapping in a Digital World

The Development of digital mapping at the British Geological Survey

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Geological mapping methods have evolved significantly since the days of William Smith and most recently this has included the transition to digital field data capture. BGS has been developing methodologies and technologies for this since 2001, and has now reached a stage where our custom built data capture and map compilation system (BGS·SIGMAv2015) is the default toolkit, within BGS, for bedrock and superficial mapping, along with other data acquisition projects across the UK and overseas.

BGS·SIGMAv2015 is an integrated toolkit which enables assembly, interrogation and visualisation of existing geological information; capture of, and integration with, new data and geological interpretations; and delivery of digital products and services. From its early days as a system which used PocketGIS run on Husky Fex21 hardware, to the present day system, developed using ESRI's ArcGIS 10.1, which runs on ruggedized tablet PCs with integrated GPS units, the system has evolved into a complete digital mapping and compilation system.

The benefits, for BGS, of digital data capture are huge. Not only are the data being gathered in a standardized format but project teams can start building their digital geological map in the field by merging data collected by colleagues, building linework and polygons, and subsequently identifying areas for further investigation. This digital data can then be easily incorporated into corporate databases and used in 3D visualisation software once back in the office.

BGS is now at a stage where the free external release of our digital mapping system is in demand across the world and is successfully being used by other geological surveys, universities and exploration companies. However, we recognise that in some areas usage is restricted due to access to the software platform the system uses. To combat this, and to try and facilitate access to the system for all, BGS now aims to develop a SIGMA companion app. This will be developed for smart phones and tablets, and as well as enabling developing counties access to the system it will also facilitate rapid point based mapping, something BGS geologists are increasingly required to carry out.

Looking further to the future BGS is developing a set of modular, re-usable tools for data capture, storage, manipulation and delivery that will help organisations, which are just starting their journey into the digital world, to learn from our experiences and implement a system that is already fully integrated and can be customised for specific user requirements.

Field geology, collecting data in a digital environment

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200 years ago William Smith observed landscape changes by colouring in selected sections of his map to represent the different rocks. Today geologists at the British Geological Survey continue to collect field data to develop the next generation of geological output, from 3D to properties to hazards the information we communicate has evolved as much as the mapping methodologies we use. To collect the data preliminary interpretations from a desktop pre-survey are imported into the BGS digital mapping system 'SIGMA'. This uses a typical tablet PC with integral GPS, camera and long-life battery, running purpose-built software applications designed by BGS. SIGMA holds data such as aerial photographs, historic maps and 3D terrain models that provide data on the landscape, and boreholes, reports and geological cross sections that provide data on the ground beneath. Field geologists are no longer isolated from such data while in the field and can make new interpretations in the context of all the information available. By integrating all this data, a geologist can build up an interpretation of the subsurface, and use a range of data input tools in SIGMA to capture a map and 3D model of the geology while still working efficiently in the field. But SIGMA has evolved way beyond its original brief as a geological mapping tool, and now has versions that enable scientists and international disaster relief teams to record vital information on the aftermath of natural hazards such as landslides, earthquakes and tsunamis.

The data collected in the field can then be easily converted into whichever format is needed. Often this format will now be a digital, 3D, geological model.

Mapping in 3D space: Linking the surface to the subsurface - a Chalky perspective.

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The need to understand the geology of the UK has never been greater. Mounting pressure on both surface and subsurface environments means 2D, and increasingly, 3D geological data is critical for many applications. Technological advances in computer modelling and remote sensing have made a huge impact in visualising the subsurface geology, and enabled the construction of ever more sophisticated mathematical models for simulating geological and hydrogeological processes. However, such models require geological information to constrain them, and in future, are likely to be increasingly limited not by computing power but by the lack of adequate baseline data. Geological mapping has a key role to play in providing the data needed to constrain and validate these models, particularly in areas where other datasets are lacking.

This presentation will showcase our vision for the future of geological mapping using examples of recent work from the Upper Cretaceous Chalk. A good understanding of the Chalk is essential as it is a major aquifer and host to many civil engineering projects. By applying a detailed Chalk lithostratigraphy, we are able to create high resolution geological maps of the Chalk outcrop. Technological advances means we can now extend this into 3D space by combining mapping, section logging, borehole data, remote sensing and other information into high quality 3D geological models at a variety of scales. Insights from the 3D modelling are then iteratively applied to update and improve the 2D field maps.

By bringing together many technological advances in data visualisation, interpretation and presentation we are transforming our understanding of the Chalk, its structure, facies and thickness changes. These models, and the maps derived from them, provide essential baseline data for a wide variety of end users including engineers and hydrogeologists. Increasingly these models will be used to visualise spatial variations in physical properties, and to constrain mathematical models of geological processes. William Smith’s legacy lives on.

Mapping change in our dynamic Earth

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Geological maps give us a three-dimensional representation of the materials that make up the Earth's surface - now. But, what about yesterday or tomorrow? Our rocks and sediments are subject to change, and not all geological change requires millions, or even thousands, of years.

Erosion of rock and sediment can dramatically alter the form of the land and the distribution of surface materials over timescales from seconds to decades. The transport and deposition of sediments on hillslopes, along rivers, glaciers and coasts, and across deserts, continually modifies the earth's surface. Humankind can level mountains and construct islands in the ocean, short circuiting millions of years of natural processes. Geological time has not stopped - if anything, anthropogenic activity and climatic change may accelerate the natural pace of change.

A challenge of modern geology is to understand the dynamic interactions occurring in our surface and subsurface environments. Such knowledge underpins the sustainable use of our earth's resources and effective management of our urban, rural and natural landscapes. So, how do we map geological change?

One approach is to investigate geomorphological processes and their relationships to geological properties and changing land-use patterns at catchment scales. Catchments provide natural boundaries within which pathways of sediment flux from hillslope source areas, through rivers, to coastal sinks may be characterised. Using a multidisciplinary approach, we integrate process modelling with time-series data and geological knowledge to assess the interrelationships between soil and sediment stability, river morphology, and coastal change in three rural and urbanised catchments in southern Scotland. In partnership with Local Government, regulators, environmental organisations and the farming community, we are developing methods to map connectivity in sediment processes and landscape sensitivity to land use and climatic change, to provide information and tools to help us better use, protect and manage our dynamic Earth.

Taking our understanding of river-valley deposits beyond William Smith and its practical importance for Britain's chalkland streams

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The representation of Quaternary river-valley fills on geological maps has changed little in the 200 years since William Smith's mapping. However, the simple swath of alluvium that is shown on the earliest geological maps, and on most modern maps, conceals a complex buried fluvial stratigraphy which developed as Britain emerged from the Pleistocene ice-age into the temperate conditions of the Holocene. Moreover in the second half of the Holocene, rivers in Britain and across northwest Europe came under increasing interference from man who started to leave a mark in the stratigraphic record. This talk will show how combining traditional geological mapping with geophysics, geochemistry and radiocarbon geochronology in cutting edge 3D visualisation software unlocks the 15,000 year story concealed beneath the deceptively simple strips of alluvium on geological maps. It considers how an understanding of these deposits is of great importance in chalkland settings where Late Quaternary valley-fill sediments influence the exchange of water between Chalk aquifers and modern clear-water streams: one of Britain's most highly-valued natural environments. A range of geothermal, geochemical and botanical methods can be used to locate areas of groundwater-surface water interaction and demonstrate that our understanding of river-valley deposits must be taken beyond William Smith's 2D mapping to understand the behaviour of streams and wetlands on Britain's chalklands.

Enhancing Geological Mapping in South West England

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The Lizard, Bodmin and Ivybridge geological districts in South West England have not been surveyed for over 100 years. South West England has historically, and continues to be, a region of national importance in terms of the contribution of mineral extraction to the economy. Its long history of metalliferous mining ended in 1998 with the closure of South Crofty Mine. However, it has since become an important target for 'critical raw materials', specifically tungsten, and extraction of these materials could contribute to European security of supply. This is demonstrated by the development of the Drakelands Tungsten Mine near Plymouth.

Renewed economic interest in the South West is a major incentive for current initiatives, aimed at improving geological understanding of the region. For example, the Drakelands deposit falls in the Ivybridge district and tin exploration is taking place in the Bodmin district. In the last two years, significant amounts of new data has been collected over South West England and the development of novel data analysis methods may revolutionise geological mapping.

In 2012, the Tiverton sheet was revised based upon a range of remote sensed data. Superficial deposits and a shaded DTM helped define bedrock relationships between the Crackington and Bude formations in an area of minimal surface outcrop. A recent gravity survey was also used to define basement structures beneath the Permo-Triassic succession.

Current research into new mapping techniques involves the integration of new airborne radiometric, magnetic and LiDAR datasets from the Tellus South West survey with stream-sediment and soil geochemical data from G-BASE (Geochemical BAseline Survey of the Environment). Furthermore, multi- and hyperspectral imagery, legacy mineral exploration data and more recent geological mapping data will help to establish an enhanced geological framework for South West England.

Initial research classifies the radiometric signature (concentrations of potassium, uranium and thorium) of the granite facies and correlates this with G-BASE data. Facies discrimination will then be enhanced through the integration of multi- and hyperspectral imagery by identifying hydrous clay minerals and also iron oxides and hydroxides. A high resolution DTM will be incorporated into the lithostratigraphic mapping and be used to define structural lineaments to develop knowledge of the complex structural evolution of the region. The datasets derived from this research will be used to create new geological maps for Britain's largest mining region, which will inform future mineral exploration targeting.

Maps to Apps, dissemination of geological data

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The information world is on the move. Rapidly developing web and communications technologies are making geospatial data much more accessible to a new generation of environmentally-aware users. Smartphones, tablets and innovative web services are combining to enable providers of geospatial data, like the British Geological Survey (BGS), to deliver user-centric, relevant and current data wherever and whenever users need them.

BGS OpenGeoscience (www.bgs.ac.uk/opengeoscience) offers free online access to a portfolio of BGS apps, maps, web services for research, education and business use.

Available resources include digital geological mapping for the whole of Great Britain, over one million scanned borehole records, images from its extensive collection of photographs and 3D geological models

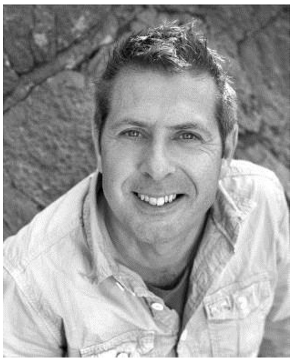
Information is made available in many formats including data downloads in GIS formats and KML files for visualisation in GeoBrowsers such as Google Earth. Interactive online map visualisation tools are provided, as well as mobile apps such as iGeology which enable over 250,000 people to carry the UK geology at street-level scale in their back pocket. New audiences are being engaged by making geological maps available within the world of Minecraft.

Underpinning these visualisation and download tools are freely accessible web services following a range of open standards and formats. Such flexible and interoperable formats enable users to combine the data in their own systems with their own information. Developing these ‘mashups’ helps to free BGS’ data, making vast data assets available, usable and relevant to a whole new audience.

These data services are being incorporated in to innovative visualisation software. Our iGeology 3D augmented reality mobile app superimposes geology maps on to the camera view. The app also allows users to fly around the landscape, exploring the geology in three dimensions above and below the surface.

The use of such everyday consumer technology also promotes citizen science, empowering users to get involved by sending photographs and measurements to gather vital new information on geological science. For example, the mySoil mobile app has gathered over 3,000 soil property records from users, creating a valuable data bank in different localities. As the crowdsourced data provided by users builds up, it can be used to feed into the underlying soil databases and improve their quality. It can also be used by the community to create new information products. We are very much at the start of a new era of two-way sharing of information with an increasingly environmentally aware user community.

Future demands for geological spatial information



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Biography

Iain Stewart is an Earth scientist with research expertise in geohazards and recent geological change and a long-standing interest in promoting geoscience to the public. As professor of geoscience communication at Plymouth University, he works closely with BBC Science to make documentaries on the nature, history and state of the planet, most notably *Earth: The Power of the Planet; Earth: The Climate Wars; How Earth Made Us, How To Grow A Planet; Volcano Live; Rise of the Continents,* and *Planet Oil.* He is currently President of the Royal Scottish Geographical Society, and a Patron of the Scottish Geodiversity Forum and of the English Riviera GeoPark. As well as receiving an MBE for services to UK geoscience in the 2013 Birthday Honours list, he has received awards for geoscience communication award from The Geographical Association, The Royal Geographical Society, the American Geophysical Union, and the American Association of Petroleum Geologists.

Earth geography through time: how magnetic grains take geological maps into the 4th dimension

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When William Smith produced his geological map of Britain in 1815 he probably little realised that he was sowing a seed for a revolution in our understanding of how the Earth works that did not come to full fruition for another 150 years. Smith's map was based on his realisation that geological strata and fauna were arranged in a predictable pattern, and that he could delineate the lateral extent of the strata by tracing the boundaries of the rock outcrops. These same simple principles of geological and faunal correlation later informed Alfred Wegener's proposal, nearly 100 years later, that all the continents had once formed part of a single supercontinent, and had since rifted apart.

The confirmation of continental drift in the 1950's and '60' was to rely again on the long distance correlation of geological time-horizons, but this time the geological markers were the record of reversals of the Earth's magnetic field encoded in the tiny grains of magnetic minerals that are present in nearly all geological strata. The recognition of this pattern of reversals, coupled with the observation that the Earth's magnetic field represents, on average, a dipole aligned with the Earth's rotation axis meant that we could start to roll Smith's geology map back in time, and look at how the world looked when each of the geological successions was being laid down.

Modern-day plate reconstructions now go back to the Early Palaeozoic with reasonable accuracy (and data coverage!), while reconstructions for older time periods are more speculative, with patchier data coverage. While earlier reconstructions typically depicted only continental outlines separated by rather barren-looking oceans, more recent reconstructions are much more tightly integrated with other geological and geophysical datasets, and depict volcanic arcs and intra-oceanic islands. As a result the reconstructions look much more like modern tectonic maps, but also have some predictive power in stratigraphic correlation, and serve as inputs into reconstructions of palaeoclimate. In this talk I outline what we have learned from Phanerozoic plate reconstructions about the distribution of rocks depicted in William Smith's iconic map, and will look at current controversies and future directions in plate reconstructions, particularly with regard to constraining the absolute longitude of plates.

Geological Mapping in ways never imagined by William Smith: How 2D, 3D & 4D digital rock analysis is driving a revolution in the understanding of mappable lithologies

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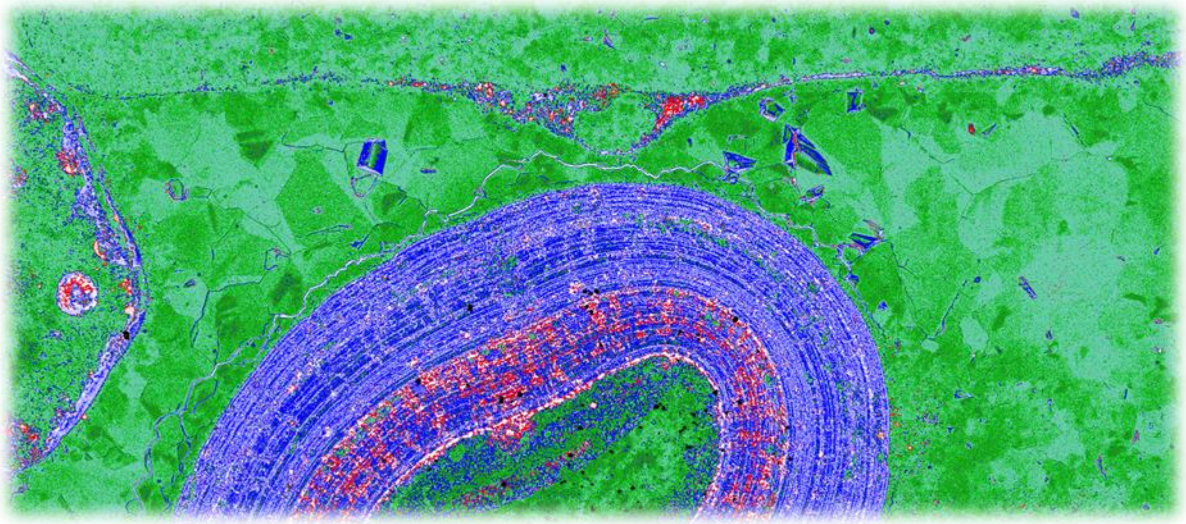
The geological mapping carried out by William Smith, which resulted in his famous 1815 map, was remarkable in many respects, not least because it relied on him being able to make consistent and accurate observations on the rocks he encountered during his fieldwork. For example, he was clearly able to confidently distinguish one type of oolitic limestone from another, based merely on what he could observe in hand specimen. This ability, gained from his many years studying rocks, allowed him to observe features in rocks that others could not, with his own eyes, or at the very least, with the aid of a magnifying device. With the invention of rock thin sections, combined with the application of optical microscopy in the 19th Century, field mapping further benefited because mineral and texture discrimination was possible at extended scales, resulting in improved rock identification and classification. The present paper covers new and novel digital rock analysis techniques which take geological mapping to new and previously unimaginable levels, in terms of visualization (2D-3D-4D), resolution (m-cm-mm-nm), and quantification (objective, repeatable). Samples collected from Smith’s classic field areas around the City of Bath in Somerset, are used to demonstrate how spatial mineralogy maps, in combination with 3D & 4D visualization techniques, are being incorporated into the modern age of digital mapping. The new information can be used for applications such as quantifying mappable units, leading to stratigraphic refinement and even geomodelling. When available contextually and interactively, on mobile (field deployable) devices, this information can be used to continuously build and improve on existing databases, but also to bridge the many scales of geological observation, from outcrop-scale down to the scale of individual mineral grains and their inter-grain boundaries.



Oolitic limestone, of the type mapped by William Smith around Bath , and which he recorded on his 1815 map as Great Oolyt, or Bath Freestone. Sample from Iford Estate, close to his former home in Tucking Mill, Midford, Somerset, UK. Mapped using digital 2D, spatially-resolved, mineral and texture mapping. Ooids and bioclasts (blue, red and purple) are cemented by sparry calcite (greens).

Geological mapping using airborne thermal hyperspectral data in Antarctica

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Despite more than 50 years of mapping of the geology of the Antarctic Peninsula there are still significant gaps in the coverage, with large areas (100s km^2) where mapping is absent or based upon limited or inferred field observations. As a result there is an uneven distribution of geological information that causes inevitable problems in establishing the detailed geological structure and history of the Peninsula. Some of the outstanding questions include the compositional diversity of the Antarctic Peninsula batholith and the extent of the metamorphic basement of the Peninsula.

Spectral remote sensing offers the potential for improving our understanding of the geology of the Antarctic Peninsula by undertaking lithological mapping of unmapped rock exposures and providing information to validate less certain and/or inferred field mapping. Remotely sensed spectral images acquired at discrete wavelengths in the solar reflected (0.4 – 2.5 µm) and thermal emitted wavelength regions (8-11 µm) can be used for lithological mapping by discrimination and identification of the different spectral properties of rocks, which are a function of the absorption and emission features of their mineral constituents.

The thermal infrared region has been shown to hold the most potential for quantitative lithological and mineral mapping using remote sensing. Spectral variations in the thermal infrared typically relate to differences in Si-O bonding that can be used to discriminate rocks based upon silicate mineralogy, which is an important criterion in classification schemes for igneous and sedimentary rocks.

The British Antarctic Survey collected the first known airborne hyperspectral dataset in the Antarctic in February 2011. Multiple spectrometers were simultaneously deployed imaging the visible, shortwave and thermal infrared regions of the electromagnetic spectrum. Additional data was generated during a field campaign in January 2014, with the deployment of multiple ground spectrometers collecting data in coincident visible, shortwave and thermal infrared regions.
In arid areas, such as polar or desert regions, sparsely developed vegetation cover can allow for detailed spatial mapping of mineral outcrops using a three step processing chain; (1) determine the number of endmembers in the image, (2) extract the endmembers and (3) determine the fractional abundance of the endmembers using spectral mixture analysis produce abundance maps. Here we present preliminary results of this processing chain applied to a target area to discriminate local igneous rocks (e.g. granite, granodiorite, dolerite) using hyperspectral thermal infrared data.

Sediment-filled hollows in the Peak District: mapping the Miocene Brassington Formation of the UK

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The Brassington Formation of Derbyshire and Staffordshire is the most extensive Miocene sedimentary succession in the UK. It predominantly a succession of sands, gravels and clays found in ca. 60 karstic cavities distributed in three distinct clusters in the southern part of the Lower Carboniferous Peak Limestone Group outcrop of the Peak District. The formation is considered to have formed from a continuous, extensive sheet of alluvial/fluvial/lacustrine sediment which blanketed the White Peak area during the Miocene. The underlying limestone has been dolomitised, fractured, mineralised and subjected to deep karstification. This has created a highly variable sub-surface bedrock topography, but has protected the Brassington Formation, through subsidence, from Quaternary erosional processes.

To add to the complexity of the pre-Quaternary geology the subsidence process that preserved the Brassington Formation has also structurally deformed the sediments. Add to this, the Peak District has seen the larger cavities extensively quarried for silica sand brick making and exploitation of lead-zinc mineral veins. This has created a unique Anthropogenic landscape in the UK: terrestrial Miocene deposits, with the potential to yield important information on a climate warmer than present; the potential for geohazards and difficulties in construction; with the complexities of mapping in a heavily exploited environment. To document, map and understand these incomplete complex deposits we have combined traditional field techniques (logging and mapping of temporary exposures) with GPS, terrestrial laser scanning, GIS, passive seismic surveys, palynology, structure from motion photogrammetry, archival research and subsurface records. This multi-disciplinary 21st century mapping approach is providing an unprecedented view of this landscape and the processes that have formed it.

Mapping surficial geology and geomorphology in landscapes undergoing rapid deglaciation: lessons for understanding Quaternary geology

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In order to ensure the integrity of maps of Quaternary geology in glaciated terrains and from them attempt to progress our palaeoglaciological reconstructions of former glaciation styles and dynamics, it is imperative that we understand fully the process-form regimes of modern glacierized basins. In glacial geomorphology this often involves the process of ergodic reasoning, or substituting space for time, a procedure that demands high resolution charting of spatial and temporal patterns. The employment of glacial landsystems is increasingly helping us to secure this level of data compilation, from which we can appreciate not only the relationships between sediments, stratigraphy and landforms in ancient glacial settings but also erect conceptual models or exemplars of sediment-landform associations from specific glaciation styles as dictated by topography, climate and ice dynamics. A range of glacial landsystem exemplars are presented from modern glacierized terrains, depicted in maps at a range of scales compiled from aerial photography and satellite imagery. Temporal evolution of some of these exemplars can be demonstrated where map series have been derived from historical photography and survey. Applications of these modern exemplars are then presented, using ancient glaciated terrain in North America and the British Isles, and then related to modern approaches to Quaternary geology mapping that are increasingly informed by our improving knowledge of glacial process-form relationships.

Digital Field Mapping in the 21st Century: Making the change from paper to touchscreen technology

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Current desktop technology is largely mouse-driven, but many analysts predict that in less than five years we will have a professional workforce that have only experienced learning in a touchscreen environment. These new workers will expect to start their professional careers using touchscreen devices and we have to be ready for this change. At Midland Valley we have been actively exploring how our geological modelling software Move will be used in the future. Beginning with our digital compass clinometer app for smartphones (FieldMove Clino), we have now built a new generation of digital mapping tool (FieldMove) that will enable geoscientists to collect and interpret their data in the field in a single application.

FieldMove Clino is a free digital compass clinometer for Apple and Android smartphones. The app allows you to use your phone as a traditional hand-held bearing compass, as well as a digital compass-clinometer for measuring and recording the orientation of planar and linear features in the field. You can also capture and store georeferenced text notes and photographs within the app, plot data on a stereonet and in the iOS version you can draw on your basemap in the field.

The new FieldMove application contains all of the functionality in the Clino app, but this has been presented in a map-centric format for use on larger touchscreen tablets (running iOS, Android and Windows). The drawing tools in FieldMove include a virtual mouse for precision work, enabling the user to create realistic geological boundaries, fault traces, outcrop polygons and other georeferenced linework. The ability to capture all of your data in a single application significantly reduces the amount of field equipment that the geologist needs to carry. Errors are no longer introduced during the “inking-in” of field slips or when a paper map is being digitised and more time can be spent thinking about the geology in the field and testing alternative scenarios.

Many of the frequently asked questions about digital mapping tend to be hardware related, with concerns over the accuracy of the sensors in the device (the magnetometer, gyroscope and accelerometer), or battery life, but none of these should be seen as show stoppers for adopting this technology. The benefits of using touchscreen devices in the field are considerable and there is a compelling case for making the switch from paper to digital technology to help solve a wide variety of geological problems.

Teaching Basic Geological Mapping Skills in a Virtual World

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Geological mapping is more than just the recording of the spatial distribution of different lithologies across an area. One of its key objectives is to understand the three-dimensional inter-relationships between the various geological elements to determine and understand the geological evolution. As such learning and developing map skills is a fundamental part of geological training.

Basic mapping skills, such as plotting data on to field slips, are traditionally introduced in the field. However, with its unpredictable weather and myriad distractions, including increasing student numbers, this is not always the ideal learning environment to teach and reinforce these skills. Video game technology is now more readily accessible and is increasingly being used in teaching as it allows students to actively participate in learning. We have created a virtual training environment (http://www.see.leeds.ac.uk/virtual_worlds/demo/) that provides a virtual space between the class room and the field in which basic mapping skills can be introduced, learned and practiced in the comfort and control of a class room environment.

Built in collaboration with Leeds College of Art using the *Unity*^{TM} software, the virtual landscape is populated by rock outcrops with associated notebook entries. Students are expected to evaluate the virtual notebook, record relevant information in their own real notebooks and plot the lithological and orientation data provided on to real field map slips. They then use this information to decide in which direction to proceed for the next appropriate outcrop, where the process is repeated.

The virtual environment is *not a replacement for field training.* It is not possible to measure features within it; nor can it replicate the natural variability within and between lithologies or fully represent the interactions between landscape and geology. The virtual approach therefore will not meet the learning outcomes expected from a geosciences degree. However, it does allow students to become confident with basic mapping skills and also saves valuable teaching time in the field. In addition, for students whose mobility issues prevent them from attending field mapping classes, a more detailed version incorporating hand specimens, thin sections and field photographs has been produced. We are also creating a simplified version for schools to show how geological maps are made.

A new generation of marine geological maps

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Detailed and accurate mapping of the seabed and shallow sub-seabed geology is important for a number of user-groups (commercial, academic, conservation and policy). For example, the ever increasing activity in the offshore renewables industry, in particular wind-energy, has demonstrated a critical need for improved characterization of shallow geology for appropriate site selection and foundation design; the designation of marine protected areas (MPAs) requires the identification and mapping of benthic habitats, which are underpinned and strongly influenced by the geological substrate; and to understand the environmental processes which formed and actively govern the marine environment, researchers require more accurate, up-to-date geological interpretations at finer scales. New, extensive high-resolution datasets are enabling significant new insights into the geology of the seabed and shallow sub-seabed. Perhaps in contrast to terrestrial settings, the increasing availability of high-resolution data in the marine environment is leading to many features being revealed and described for the first time. This calls for a fundamental and observational mapping approach which may have originally been applied on land over a century ago. For example, swath-bathymetry datasets (~1-10 m resolution) not only permit scientists to better distinguish the genetic origin of seabed features, but also cover sufficiently extensive areas that feature assemblages may be placed into the broader context of environmental systems. Such seabed characterizations combined with ground-truthing and shallow seismic data yield considerably improved geological map outputs, as well as predictions of associated geotechnical properties. New high-resolution and extensive datasets also result in large, and exponentially increasing data volumes. This requires that BGS, together with academics and industry-based scientists supplement classical mapping with improved methodologies. The BGS has adapted to this challenge and continues to be active in innovating data acquisition, processing, and interpretation techniques, including: image analysis, statistical, and automated-feature-detection protocols.

Geological Surveys fall at a natural junction between commercial, policy, and academic interests. The BGS endeavours to utilise its unique assets and expertise to provide information and products that serve these communities. This includes translating new and legacy data into a new generation of map-based digital products which enable improved science, application, and spatial planning within the marine environment.

William Smith in Space – geological maps of other planetary bodies

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William Smith relied upon the law of superposition to formulate his principle of faunal succession that proved so valuable in compiling his geological map of England and Wales. Although Solar System geologists have no faunal succession to guide them, they are hampered by neither vegetation nor (usually) drift, with the result that outcrop patterns are more apparent at the surface than in the terrains where Smith worked.

The near-surface stratigraphy of the Moon was mapped in the mid-late 1960s using principles that would have made perfect sense to Smith, using observations by telescope and images sent back the Lunar Orbiter probes. As Don Wilhelms and John McCauley put it in the notes to accompany their 1:5 million scale Geologic Map of the Near Side of the Moon (1971) “The goal is to portray units that are … three-dimensional bodies of finite horizontal and vertical extent which are in effect the building blocks of the visible part of the crust. In most instances the units can be treated conceptually as rock-stratigraphic units.” and “Each material unit is placed in order of age relative to its neighbouring units on the basis of superposition and transection relations.”

Even today, systematic study of any solid body in the Solar System benefits from local geological maps because these can contextualise the relationships between units of different age or different emplacement mechanism. Wilhelms and McCauley-style maps therefore continue to be made of whole globes, quadrangles, and special interest areas. Mostly this is done on the basis of remotely sensed data, but on Mars we now have rovers that are in the course of field excursions measuring tens of km in length, sending back pictures that any field geologist would recognise of features such as fluvial and aeolian cross-stratification, unconformities, cross-cutting veins and joints, and weathering profiles.

Even though GIS now enables multiple layers of information to be co-registered and interrogated, the basic geological map retains its appeal and utility. A simple and preliminary photogeologic map of one hemisphere of Pluto appeared on the internet on 15 July within hours of the close-up image being released, and triggered more Twitter interest than the whole discussion article in which it had been embedded.

Poster Abstracts

Exploring Geological Map Outcrop Patterns in a Virtual World

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We have created a series of video game-style worlds, where students explore virtual terrains to understand three-dimensional interaction of geology with topography on two-dimensional maps. Worlds are built using *Unity* game engine software.

Visualisation of outcrop patterns has traditionally involved use of block diagrams. However, 3D visualisation and 3D/2D relationships are ‘threshold concepts’, which many students struggle with and only fully appreciate with (significant) field experience. The virtual approach offers immersive and realistic appreciation of 3D landscapes and relationships to geology, benefitting learning experience and outcomes of actual field training as more students pass the threshold into 3D thinking.

Each world has two versions: 1. *natural landscape* - geology indicated by variations in vegetation with clickable outcrops; 2. *geological landscape* – geology draped over topography. Clickable outcrops give additional information on geology (rock type, bedding readings, field sketch, etc.) as a ‘pop up notebook’. The same surface relief (two hills, central valley and coastline) is used for each world. The topographic map has its own world, allowing 3D observation of topography and landscape.

Geology is deliberately simple, with two/three rock types (sandstone, limestone, shale/siltstone) per map. Different lithologies are indicated by ‘painting’ the landscape with different vegetation (sandstone - green with gorse bushes; limestone - pale green with karst features; shale/siltstone - dark green with sedge).

Each world is designed as an in-class exercise where students map the natural landscape on to field slips to understand how outcrop patterns from the 3D world translate on to 2D maps. They then explore the 3D geological map.

Currently, we have four worlds: horizontal bedding; V-ing in valleys; and horizontal unconformity above steeply dipping beds. Future plans include: vertical bedding, folding and faulting; impact of strike on outcrop pattern; etc.

Outcrop pattern virtual worlds are distinct from, but complementary to, the main Geological Mapping Virtual Training Environment (see talk abstract) in their focus, as it is impractical to have all potential outcrop patterns within one virtual world.

Enhancing Geological Mapping in South West England: Granites

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The Lizard, Bodmin and Ivybridge geological districts in South West England have not been surveyed for over 100 years. South West England has historically, and continues to be, a region of national importance in terms of the contribution of mineral extraction to the economy. Its long history of metalliferous mining ended in 1998 with the closure of South Crofty Mine. However, it has since become an important target for ‘critical raw materials’, specifically tungsten, and extraction of these materials could contribute to European security of supply. This is demonstrated by the development of the Drakelands Tungsten Mine near Plymouth.

Renewed economic interest in the South West is a major incentive for current initiatives, aimed at improving geological understanding of the region. For example, the Drakelands deposit falls in the Ivybridge district and tin exploration is taking place in the Bodmin district. In the last two years, significant amounts of new data has been collected over South West England and the development of novel data analysis methods may revolutionise geological mapping.
In 2012, the Tiverton sheet was revised based upon a range of remote sensed data. Superficial deposits and a shaded DTM helped define bedrock relationships between the Crackington and Bude formations in an area of minimal surface outcrop. A recent gravity survey was also used to define basement structures beneath the Permo-Triassic succession.

Current research into new mapping techniques involves the integration of new airborne radiometric, magnetic and LiDAR datasets from the Tellus South West survey with stream-sediment and soil geochemical data from G-BASE (Geochemical BAseline Survey of the Environment). Furthermore, multi- and hyperspectral imagery, legacy mineral exploration data and more recent geological mapping data will help to establish an enhanced geological framework for South West England.

Initial research classifies the radiometric signature (concentrations of potassium, uranium and thorium) of the granite facies and correlates this with G-BASE data. Facies discrimination will then be enhanced through the integration of multi- and hyperspectral imagery by identifying hydrous clay minerals and also iron oxides and hydroxides. A high resolution DTM will be incorporated into the lithostratigraphic mapping and be used to define structural lineaments to develop knowledge of the complex structural evolution of the region. The datasets derived from this research will be used to create new geological maps for Britain’s largest mining region, which will inform future mineral exploration targeting.

New tools to map and visualise the geology of Mars

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On Earth, sediments and sedimentary rocks, particularly those formed by or in water, are where we find fossil life and other preserved biosignatures. One of the prime goals of NASA's Mars Exploration Rovers (MER) and Mars Science Laboratory Curiosity Rover (MSL), and ESA's 2018 ExoMars Rover is to analyse outcrops of sedimentary rocks and assess their potential for habitability and preservation of ancient microbial life. Thus techniques and tools for analysing sedimentary rock outcrops are crucial to developing efficient exploration strategies.
Panoramic digital cameras (PanCam on MER and MastCam on MSL) serve as the 'eyes' of the rovers, and are used for identifying suitable rock outcrops and characterising features that provide clues as to how the rocks were originally deposited as sediments. These clues are preserved in layer geometries, internal features within layers and the size and texture of constituent grains. On Earth these features are understood through 3D measurements and analyses of geological features in rock outcrops. The panoramic camera systems can take stereo images which are used to create 3D reconstructions of rock outcrops which can be analysed much like geologists might do on Earth.

The EU-FP7-PRoViDE project has compiled all the vision data from the rover missions within a database accessible through a web-GIS (PRoGIS) and 3D viewer (PRo3D). Stereo-imagery selected in PRoGIS can be rendered in PRo3D, thus enabling the user to zoom, rotate and translate the 3D model. Interpretations can be digitised directly onto the 3D surface, and simple measurements can be taken of the dimensions of the outcrop and sedimentary features within it. Dip and strike is calculated within PRo3D from mapped bedding contacts and fracture traces. Results from multiple outcrops can be integrated within PRoGIS to gain a detailed understanding of the geological features within an area.

These tools have been tested using three case studies; Victoria Crater, Yellowknife Bay and Shaler. Victoria Crater, in the Meridiani Planum region of Mars, was visited by the MER-B Opportunity Rover. Erosional widening of the crater produced <15 m high outcrops which are ideal for analysis of the geometries of aeolian bedforms on Mars. Yellowknife Bay and Shaler were visited in the early stages of the MSL mission, and provide excellent opportunities to characterise Martian fluvio-lacustrine sedimentary features in 3D. Development of these tools is crucial to full exploitation of similar data from future missions, particularly the 2018 ExoMars Rover PanCam.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312377 PRoViDE.

Aeromagnetics – the modern geologist's special mapping tool

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High quality aeromagnetic data covers most of the earth's prime on-shore resource areas, but its integration with local geology has, in the past, been superficial. Robust integration requires careful observations from both accessible geology and the core aeromagnetic data, and the commitment to reconcile the two. The patterns observed in aeromagnetic imagery directly reflect the 3-D distribution of magnetic minerals, so in essence, both sets of observations stem from the same general source - the 'real' geology. The process of aeromagnetic integration is a simple extension of conventional mapping methodology and has very strong parallels with aerial photo interpretation. The keys to successful integration are geological thinking at the observation stage and (wherever possible) field-based substantiation of interpretations. Leaving these tasks to specialist geophysicists is unlikely to deliver the optimum outcome.

We present two examples of integrated interpretation: one in a well-exposed and well-mapped area, and another in a poorly exposed area- the more 'traditional' domain for the application of aeromagnetics.

The Golden Dyke area lies within the early to mid Proterozoic Pine Creek inlier in Australia's Northern Territory. The prospect area comprises low grade and largely fine grained metasediments intruded by thin dolerite sills and younger granites. The enhancement of the near surface geological interpretation caused by the introduction of a small amount of modest quality aeromagnetics is remarkable. Astute observations on the aeromagnetic imagery lead to a wide range of structural and some stratigraphic inferences, many of which can and have been validated in the field. Where the surface mapping yielded an incomplete and uncertain picture of the local structure, the integrated interpretation map provides a clear and coherent structural framework. In the exploration context, this delivers a much sharper targeting focus.

The Comet Vale area, in Western Australia's Archaean goldfields, is dominated by thin (<50m) tertiary cover, beneath which is a 'greenstone' sequence intruded by syn and early post tectonic granites. Both granites and greenstones are rich in magnetic minerals, such that the aeromagnetic patterns drive the geological mapping. Once again the structural picture derived principally from the aeromagnetics is outstanding, but the data also delivers key inferences on stratigraphy and alteration effects.

The proven value of aeromagnetic data in 'hard rock' domains is now extending into mapping and exploration in sedimentary basins and the prominent role of this data in future geoscience seems assured.

Geological mapping by clustering of high resolution soil geochemistry modelled by remote sensing based random forest regression

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Geological mapping, the classification of bedrock into distinct identifiable units, has traditionally been conducted at the discretion of the field geologist on the basis of human-observable properties such as those of mineralogical composition and texture. In recent years technological developments have allowed the collection and analysis of ever more advanced quantitative geoscientific datasets. We are now approaching a point where migration of traditional mapping procedures to the digital domain is a feasible reality, with such benefits as consistency, transferability and transparency. One issue that we encounter is that the most geologically informative measurements, such as those of chemical composition, tend to have their sampling density limited by their high cost. Meanwhile, remote sensed data will tend towards extremely high sampling density, but may lack stand-alone geological significance. Nonparametric regression techniques have the potential to negate this issue by modelling the most geologically informative measurements as complex interactions of multiple remote sensed covariates. In this poster we present the use of random forest regression to model soil geochemistry in south west England using remote sensed data, and demonstrate how clustering of the predicted high resolution soil geochemistry is able to differentiate geological units – a process that can be trained to match pre-existing rock classification systems.

We find that random forest regression based on remote sensed data is capable of predicting element concentrations in soils with superior accuracy to that of ordinary kriging of sparsely sampled point data. Crucially the random forest predictions incorporate the high resolution structure of the remote sensed covariates. This allows geological units, in this case defined purely on the basis of the geochemical composition of their soils, to be mapped with sharp boundaries limited only by the resolution of the remote sensed covariates. It seems likely that such techniques could take centre stage in the future of geological mapping: improving not only on the consistency of classified maps based on human observations, but also allowing the continuous mapping of any geologically constrained variables, such as radon potential, to the best resolution and accuracy that our covariate datasets can support.

Long term curation of geological maps: hardcopy, digital 2D and now 3D models

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Geological surveys traditionally have a curatorial mandate for geological information and manage collections of historic geological maps of their jurisdictions. The New Zealand Geological Survey, now part of GNS Science, has a repository of geological maps that extends back more than century. Unpublished maps and compilations in the Geological Map of New Zealand collection can contain unique information and it is this information that is particularly valued by research and exploration geologists. Digital scans of these geological maps can now be searched for using a metadata catalogue, viewed online and downloaded.

Hardcopy geological maps have their own issues in terms of durability and storage space needs but if well archived, are resilient to technological change. The information in them, for the most part, remains readable and understandable for many decades and therefore is available for re-use and building upon.

Geographic Information Systems (GIS) software is now mainstream technology for storing and managing geological map information. Using GIS has opened up many versatile ways to deliver our geological information but has also challenged us on how to ensure that information remains readable and understandable with different software applications and over time. Even greater challenges lie ahead in preserving 3D geology model information for the long term but the underlying premise is that they contain information and insight that is worth preserving. Open exchange file formats and international data models are part of a solution but their longevity is not yet established either.

Three dimensional geology models are increasingly part of New Zealand’s geological map product suite. GNS Science has just published a geological map product of the Christchurch area containing 3D geology models built using Leapfrog Geo software. Aside from providing the models in their native software file formats, we have included Gocad T-surface and ArcGIS shapefile contour and grid format representations of base and top surfaces of modelled volumes, as well as their thickness. Delivering in these formats is an attempt to future-proof the 3D geology models. By breaking 3D geology models into their components, the expectation is that these components can be rebuilt later with updated or alternate vendor software and retain information as long as possible in a comprehensible form.

Digital mapping at the Geological Survey of Norway: Experiences from the Sveconorwegian and Caledonian orogens

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The Geological Survey of Norway is implementing a digital workflow for geological bedrock mapping in Norway, from fieldwork to final product. Whereas various approaches relying on different hardware and software solutions are still being tested, we report here results and impressions derived from two mapping projects in populated areas, one in the Kongsberg domain of the Sveconorwegian orogen, and the other in the greater Trondheim area (Orkanger) in the Caledonian belt. Field work was carried out on different hardware platforms by using the Sigma Mobile software package developed by the British Geological Survey. Maps are now in the final compilation and production phase. These projects were successful in: (1) collecting new systematic geological data, that allow a substantial improvement of the local tectonostratigraphy and a significant refinement of the understanding of the geological and tectonic evolution of the mapped areas, beyond the reach of university-based academic researchers, (2) generating greatly improved map products useful for society, research and education, and (3) training young researchers and students to the importance of a full digital approach. The mapping projects combine collection of high-resolution geophysical data, digital acquisition of field data, and collection of geochronological, geochemical and petrological data. Field information includes lithological description, structural data, photographs and sketches in their geo-referenced framework. During the Kongsberg project, some 25000 field observation points were collected by eight geologists. For the Orkanger project, some 2100 field observation points were collected so far by three geologists. In this contribution, we will discuss the workflow and the database architecture, and show preliminary map products. We will analyze the philosophy of a fully digital future in geology, in addition to present how we have perceived the many benefits and unavoidable disadvantages of the newly implemented workflow.

Geochronological mapping of the Himalaya

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Since the first major mapping of the Himalaya by Heim and Gansser, 1939, there has been an explosion of geological studies of this orogen. Recent works have focused on combining multiple datasets to understand the four dimensional (pressure-temperature-time-deformation) evolution of this archetypal collisional zone. There is now a wealth of geochronological, geochemical, geophysical, modelling, and structural data published from across the mountain belt. The challenge becomes how to present this mass of data in order to find spatial and temporal trends, and thus develop understanding of large-scale deformation processes.

In collaboration with around twenty other Himalayan geologists, this study uses titanite geochronology to date rocks from over 2000 km along-strike distance along the Himalayan mountain belt, from Pakistan to central Bhutan. This is the first large-scale campaign-style study of its type in the Himalaya, utilising both the geochronology (age) and geochemistry (fingerprints of geological processes imprinted in the mineral) from a single mineral system to understand both the temperature and timing of deep-earth processes. Here, combined U-Pb laser ablation split-stream analysis was used to date and characterise the geochemical signature of titanite from over fifty calc-silicate samples. The results are combined with the large database of previously published geochronological data from the Himalaya to reveal a large-scale map of the temporal evolution of the mountain range.

This study highlights the importance of using micron-scale geochronological information to understand mountain belt-scale deformational processes. By collating and presenting enormous multi-faceted datasets in spatial form, it is possible to go beyond the information conveyed in a traditional geological map, to reconstruct a history of rock deformation in collisional mountain belts through time.

References:

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Thrust Mapping in the Ord Window, Isle of Skye

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I mapped an area of approximately 12 km2 in the Sleat Peninsula, Isle of Skye. The main focus was the structure in the Cambro-Ordovician succession within the Kishorn Thrust Sheet.

The Cambro-Ordovician shallow marine succession is surrounded by considerably older immature fluvial sediments - the Torridonian group - and it is referred to as the “Ord window”. West of the tectonic window structure, the same succession is repeated in the form of a syncline, cut by the Ord thrust. On a regional scale this area is dominated by a series of nappes, driven by the Moine, the Kishorn and the Ord thrust.

The field data strongly indicates a series of at least 2 stacks of imbricates in the Durness dolostone and Salterella grit beds. The Fucoid bed is used as a detachment ramp and accommodates the floor thrust, as it is mechanically susceptible for this role. The imbricates represent the first brittle response to compression, and together with the underlying formations are overturned in a large anticline structure. The anticline is the most obvious in the quartzite ridge. A second ridge is formed by repeated thrusting of previously overturned pipe and basal quartzite on top of the imbricate stack. The two ridges have different strikes and younging directions, which suggests that they were formed through different events and are connected by an intense brecciation zone. I interpreted this as a transfer zone with left-lateral strike slips. The imbricates and the second quartzite ridge show strong and clear evidence for left-lateral strike slip. All the thrusts are striking NE-SW with perpendicular strike slips.Thus, the general structure is inferred as fault migration in the thrusted sediments with a left lateral sense of shear.

The outcome is particularly rewarding as the area is not yet fully understood in all its complex dimensions.

William Smith Grant 2015 - Winner

A Structural Interpretation of the Strike- Slip Fault Zone and its associated sinistral wrenching of a basal thrust, in the San Emiliano area, N. Spain

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Geological mapping was undertaken to the north of San Emiliano, N. Spain. The purpose of this project was to lithostratigraphically map the area from Los Colladones to the northern most point of the El Reboflallon ridge, with a specific emphasis on the structural geology of the strike slip fault zone and its shear lenses.

Major structural deformation is present throughout the area, in the form of older thrust tectonics associated with the Variscan Orogeny (and to some extent, the Alpine). Along with the compressional tectonics, the area is heavily deformed by a younger sinistral strike slip fault zone with shear lenses bounded by faults, along with R, R' and P shears.

Interaction between the basal thrust and a strike slip fault created some structurally complex features, chiefly, the La Campana shear fault lens. In this instance, the geometry of the syncline axis to the fault axis supports pre fault folding of the Láncara Formation up to the basal thrust. As the strike slip fault began to wrench the basal thrust back, this lens was further deformed and as a result of the extensional nature of a sinistral fault curving leftwards, the lens migrated to its current position today.

The remainder of the thrust fault was displaced nearly 2.5 km westwards, causing steepening of the dip of beds within this, to the point where some beds were marginally overturned. Shear lenses between the basal thrust sections had a strike generally perpendicular to the strike of the thrust fault.

Termination of the fault occurs towards the west, in a horsetail splay that curves towards the north; this results in contractional forces that fold the beds within Puertos de Triana. Measurements of these folds show that they are perpendicular to the expected stress for a contractional sinistral fault bend; this combined with the theory that shear lenses aren't typically deformed within the lens under usual circumstances leads to a conclusion that this fault terminates to the west of the mapping area.

Strike slip faulting of the area occurred after the thrust faulting, during the formation of the Cantabrian Arc, with the basal thrust in the local area undergoing ductile compression and curvature up to maximum stress, before strike slip faulting occurred, wrenching the basal thrust westwards and taking up residual stress.

William Smith Grant 2015 - Winner

A basalt pillow and a soft bed of sediments: Montgenèvre, where the Ligurian Ocean came to rest

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The Chenaillet Ophiolite is situated upon the Lago-Nero Replatte Ophiolite in the Franco-Italian Alps. The former is oceanic crust formed by a slow-spreading ridge and the latter pelagic sediments deposited in the Ligurian Ocean. Detailed mapping of the area showed that the Chenaillet Ophiolite is an analogue of a slow spreading ridge and consists of a serpentinised peridotite basement with multiple gabbroic intrusions and a cap of pillow basalts and lava tubes. A study into the variation of crystal size in the Gabbro indicated that there is no general trend, with R^2 correlation coefficients as low as 0.37, instead the range in crystal size is attributed to the fact that the large body of Gabbro is made up of multiple smaller bodies. The Lago Nero-Replatte thrust sheet has three interbedded units, a primary bedded limestone and Radiolarite, a meta-chert.

It is heavily structurally deformed, more so than the Chenaillet Ophiolite. There is extensive folding on a small scale in the Calcareous shale and a larger scale, particularly at the Sommet des Anges. A general trend was discovered in the folding of the calcareous shale. The fold axial traces tend to dip shallowly and trend in an east-west direction, implying the original principal stress direction to also be roughly east-west. The rocks in both thrust sheets show evidence of metamorphism, 83% of the igneous units contained a full or part greenschist grade metamorphic assemblage. Mapping this area highlighted the widespread faulting and fracturing, many planar surfaces are visible in the pillow basalts and the dolomite.

Burlington House
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Alarm Bells are situated throughout the building and will ring continuously for an evacuation. Do not stop to collect your personal belongings.

Leave the building via the nearest and safest exit or the exit that you are advised to by the Fire Marshall on that floor.

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Lower Library:
Exit via main reception onto Piccadilly, or via staff entrance onto the courtyard.

Lecture Theatre:
Exit at front of theatre (by screen) onto Courtyard or via side door out to Piccadilly entrance or via the doors that link to the Lower Library and to the staff entrance.

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The Gents toilets are situated on the ground floor in the corridor leading to the Arthur Holmes Room.

The cloakroom is located along the corridor to the Arthur Holmes Room.

Ground Floor Plan of the Geological Society, Burlington House, Piccadilly