Mobile patial mapping and augmented reality applications for environmental geoscience

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Abstract— **Modern communication technologies are changing the way we think about spatial mapping information and how we deliver it into the hands of end-users. For geoscience, the challenges are particularly interesting because of the strong three-dimensional nature and sheer richness of the underlying geological information. For several hundreds of years, the favoured method for delivering this information has been the paper map. However, as in the topographical sector, the geosciences have moved rapidly over recent years to digital platforms for effective delivery of spatial information. What we are delivering is still a map, but what it looks like and how it is carried will have changed beyond recognition for earlier surveyors. In particular, new generations of mobile tablet computers and smartphones, which can self-locate using GPS technology, and stream in spatial mapping live to the user, have all but rendered the paper map redundant in many parts of the UK and beyond. Furthermore, the interactive nature of these technologies allows two-way sharing of information, through twinned display of digital maps and live 'crowdsourced' collection of point observations. But perhaps the greatest opportunities lie in the use of augmented reality techniques to transform complex three-dimensional information into an easily digestible form for the user. The paper map made an admirable attempt to do this in the geosciences but mobile technologies and software offer the chance to at last display the information in the way it has always existed within the mind of the geological surveyor. This paper describes the informatics research and development work lead by the British Geological Survey (Natural Environment Research Council) which is taking on these challenges and opportunities, and is already beginning to deliver a new and very different generation of the geological map.**

Keywords- 3D, spatial data, smartphone apps, geology, geoscience, map, augmented reality, digital mapping

I. INTRODUCTION

In the urban or rural setting, knowing what lies beneath the ground is important for safe and effective land-use but is also interesting to the researcher and to anyone fascinated by their environment. The science of geology strives to understand this third-dimension beneath our feet and make it understandable to us at the surface. Typically, this has been done by adding geological detail to the 2D paper map but advances in communication technology are opening up new ways to collect and convey geological maps through multiple media and dimensions.

Stimulated by the resource and transport needs of the industrial revolution, the first map of the bedrock geology of Britain was produced by William Smith in 1815 [1]. Surveying in ever greater detail, subsequent generations of geologists have added flesh to the bones such that today, the geological map forms just part of a whole-Earth approach to describing the nature of the geological environment how it may affect us. Modern geology underpins economic development and is fundamental to industries interested in the subsurface space and resource whether for construction, oil, minerals, water or storage.

This paper describes how we are moving from depiction of geology on two-dimensional paper to its representation in a multi-dimensional, digital space, and how this is opening up a bright new future for the geological map.

II. WHERE DO PEOPLE 'MEET' MAPS?

If you asked someone 10 years ago to show you a map, they would probably have reached for a paper road atlas from their car, a topographical map from their shelf, a sea chart, star map or perhaps a geological map. Now in the 'age of the screen' if you asked someone to show you a map, they are just as likely to reach for their mobile smart phone and click on Google Earth or a multitude of other map 'Apps' (Applications).

Indeed, it has not taken long for these new digital maps to overtake the paper map. For example, sales of British Geological Survey (BGS) paper maps have declined from the 10,000's per year in 1999 to 1,000's per year in 2010, in parallel with trends across the mapping sector. In contrast, the number of downloads of the recently released BGS iGeology [2] App (Fig. 1), which shows the same type of geology as the paper maps, have reached 70,000 in just one year.

This trend may largely be due to the ease of use of such mapping applications on mobile tablets and smart phones, including their inbuilt Global Position System (GPS) technology which allows the map to be centred automatically on where you are standing - something which would have astounded past map makers and has fundamentally changed our view of the world. Such interactive geospatial applications have come to dominate our everyday lives and overtake the traditional world of printed maps and cartography [3].

Figure 1: the BGS iGeology App for smartphone and tablet computer in use in the urban environment

The interaction between people and place has also changed, with many digital maps dynamically engaging with the user. This might be a commercial intent such as spatial advertising or a societal driven intent such as citizen science. In June 2012, the BGS and the Centre for Ecology and Hydrology (CEH), both research centres at the Natural Environment Research Council (NERC), jointly released another app called mySoil which combines soil data from both organisations. As well as giving the user access to a map of soil properties of Britain, mySoil also allows the user to upload information about the soil where they live. This 'citizen science' helps to improve our knowledge about the properties of soils and the vegetation habitats that they provide. Smartphones provide the perfect platform to reach out to citizen scientists as they have inbuilt hardware (e.g. GPS and camera) which can be used to facilitate record collection. Since its recent launch hundreds of records have been uploaded and are made freely available via the app (see Fig. 2).

Another powerful feature of digital mapping applications is their ability to make huge amounts of data available to an individual user, through 'as you need it' streaming of data - iGeology, for example, is the equivalent of carrying 500 paper maps covering the UK around in your back pocket. Not only this, but you can tap and interrogate the map to receive additional descriptions of the geology beneath you to help inform decisions relating to your use of the local environment, for example, when buying property or developing land.

Mobile mapping applications are also extremely useful to the mapping agencies serving them out, as they enable a much better understanding of how many people are using the maps, and where. Feedback from users is also much more immediate and meaningful through the online comments and discussions surrounding the applications.

Figure 2: distribution of user-recorded (citizen science) observations in the BGS-CEH mySoil App for smartphone

The results can be quite startling. Since its launch in late 2010, BGS iGeology has been downloaded nearly 100,000 times from 56 countries around the world. The map in Fig. 3 shows where iGeology is being used in the UK. This map has been generated by knowing which areas of data are being downloaded by the user, and is the first time it has been possible to clearly see where BGS geological maps are being most used. The implications of this are very considerable, not least in planning where surveying work and research can be targeted for the greatest benefit to the user community.

From the map in Fig. 3 it is evident that most of the usage of geological maps is within urban areas and that there is a direct correlation between population density and usage. The most likely explanation for this is that our users are interested in the geology around where they live and work, or where they are considering using or developing land, which is often in the urban setting. However, there are some areas that do not follow this trend, for example the south coast of England and the Isle of Skye. We believe this is attributed to areas with interesting geological formations, where educational field trips take place or where the public is simply fascinated by the geology before their eyes and beneath their feet.

All of this is changing the way we as mapping agencies, and our customers, think about and interact with maps and, indeed, is leading us to question, what is a 'map'? The map is transforming from a physical organic 2D object that connects us to our physical world, to a digital construct which shares information on our environment with us as we move through it.

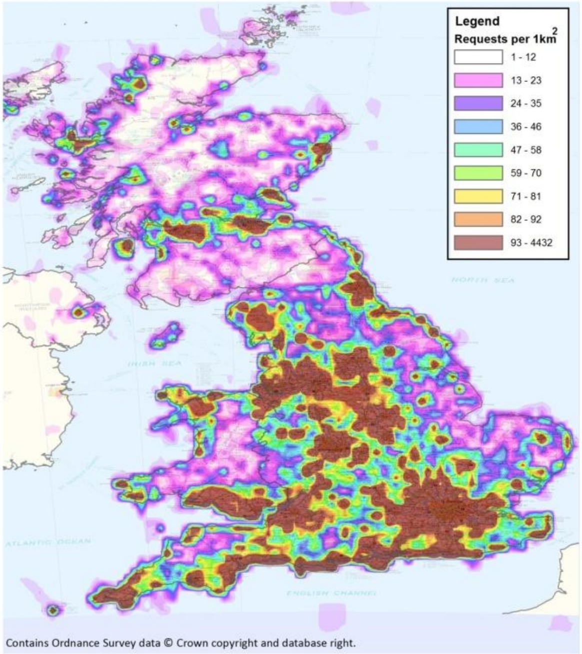

Figure 3: Distribution map showing where the iGeology map has been interrogated by people using their smartphones and mobile tablets (September 2010 to November 2011)

III. EXPANDING DIMENSIONS (3D GOING UNDERGROUND)

Although these new style of digital applications are increasingly sophisticated and interactive, they still essentially ‘trap’ us in the two-dimensions of our phone or computer screens. This will always be extremely useful of course because the part of the world in which we live is in a sense a two-dimensional surface. An encounter with the third dimension is for most of us restricted to climbing a hill or descending into a valley, which on a paper topographical map may be represented by contours or artificial shadowing to give a ‘two-and-a-half’ dimensional impression.

However, when trying to convey the 3D complexity of the geological underworld, 2D representation is always going to be limited. It is this largely invisible third dimension which is more difficult to imagine, so we have up to this point relied on the skill of the geologist to ‘read’ the landscape and extrapolate to depth (a skill know as 3D acuity) and project it to us via the 2D map [4].

So the emergence of 3D communication technologies for the collection and visualization of information has great potential in the science of geology. The following sections describe some progress in this field including the exciting possibilities of a virtual reality world.

IV. A NEW WAY OF MAP MAKING

As this progress has been made in mobile display of mapping, significant advances have also been made ‘behind the scenes’ in the use of new technology by geologists to collect and analyse information on the third dimension.

Leading this, as part of a digital geological workflow, the BGS GeoVisionary project (a collaboration with Virtalis Ltd, a British-based virtual reality company [5]) has revolutionised geological visualisation with software that allows seamless streaming of terabytes of data, merging digital geological maps, aerial photography, satellite imagery, field-slips, historical topographic maps, and subsurface 3D geological models, cross-sections and boreholes.

The system allows teams of geologists to carry out a ‘virtual survey’ of an area before commencing fieldwork, building an understanding of the terrain and the geology beneath the ground (Fig. 4). This initial assessment allows surveyors to effectively target fieldwork in areas where surveying is most required. On completion of fieldwork, surveyors can check their field interpretation in the virtual landscape. This team approach allows colleagues to collaborate, better enabling communication and scientific understanding. Another powerful aspect of GeoVisionary is to demonstrate the three-dimensional geology to collaborators and other observers with the added context of their own spatial data, including 3D designs for buried assets or other infrastructure.

Following this approach, the geological interpretation can be ‘interrogated’ to provide decision support for a range of stakeholders including the environmental, engineering and energy sectors. These diverse applications call for 3D geological information at a variety of scales and depths, ranging from individual sites with a focus on the immediate subsurface to models of entire river-catchments reaching depths of several kilometers.

This multi-scaled approach has been successfully employed in London and the Thames basin where a combination of GeoVisionary and 3D geological modelling has allowed the knowledge of experienced geologists and the wealth of existing spatial data (including in excess of 8000 borehole logs and geological maps spanning over 100 years) to be assimilated into a single, consistent, geological ‘framework’. At shallow levels, this has contributed to effective ground investigations for railway and underground construction [6]. At deeper levels, the model has been used to inform the management of groundwater beneath London [7].

GeoVisionary encourages the exploration of these models and their underpinning data, allowing scientific discovery and the refinement of previous interpretations [8]. 3D acuity applied to subsurface analysis is providing a unique insight into the geometry of the Earth, allowing the interpretation of structural elements such as faults, folds, and the reconstruction of past environments.

These changes in surveying techniques can be likened to geologists moving from making a jigsaw (the traditional 2D map) to building a Rubik’s cube (the 3D geological model) of surfaces and volumes and in the process has opened up new opportunities and ways to deliver knowledge on our environment. ‘Surveying’ is still as important as ever but is now increasingly carried out in 3D digital environment – the map is still with us but has expanded in all dimensions.

Resulting from this new approach to mapping, today's 3D geological models show a huge variety of information, from the basic rock type (e.g. Chalk or Clay), to their chemical and physical properties and how fluids (such as water) or gases (such as CO_2) move through the various layers of geology, introducing the 4^{th} dimension of time. How certain we are of the presence of a particular rock type or structure can now be analysed and presented as a statistical probability thus adding deeper meaning to the modern map. In the future we will be able to dice and slice a geological model to deliver not just a map of the surface geology but from any specified depth from metres to kilometres, tailored to the user requirement.

V. DELIVERING 3D ENVIRONMENTAL INFORMATION TO THE MASS MARKET

Despite these advances in visualisation and surveying, there is still some distance to go in terms the widespread delivery and understanding of 3D information. As a community of modern geological map makers one of our key challenges is to bring the 3D presentation of geological models 'out of the lab' and to the mass market in the way we have done for 2D mapping with the first release of iGeology.

Figure 4. Three-dimensional surveying using the BGS GeoVisionary system

Some significant advances have already been made in the wider market place in display of 3D images via personal computer, for example, using software applications which allow 3D projections to be spun around by the user (e.g. Smithsonian National Museum of Natural History online 3D collection [9]). These techniques have a bright future (particularly as 3D screen technologies improve) but it is perhaps technological advances in the mobile and augmented reality computing field which have the greatest potential for aiding 3D visualization in the field of geology. Such technology is already in use in the astronomy field, with smart phone Apps such as SkyView (e.g. available via Apple's App Store) and our aim is to bring it to the field of geology.

In July 2012, the BGS released "iGeology 3D", an augmented reality application for mobile phones which overlays geological information on the landscape around you (Fig 5). The aim is to dissolve the separation between the landscape and the information about that landscape locked up in a 2D map by painting the map onto your view of the landscape. This empowers the map by linking it immediately to the landscape you are observing, without requiring specialist skills in reading a 2D geological map.

Figure 5: BGS iGeology 3D 'augmented reality' Smartphone app for displaying the geological map over the landscape

Touching a place in the iGeology 3D on-screen landscape pops up an information box describing the geology at that position in the actual landscape. The App currently available (free) for Android devices. In the two months since first release in July 2012 it had been downloaded over 3000 times.

iGeology 3D's augmented reality is made possible by bringing together server technologies developed for web map applications and the mobile technologies built into most smart phones (Fig. 6).

A 3D model of the local landscape is constructed within the smart phone from terrain elevation data and an image of the corresponding area of the geological map is draped over the surface. The geological map is delivered from the server as PNG image format tiles following Google map tiling conventions. Elevation data is also delivered as tiles following the same spatial tiling system but these are files of gridded land surface elevation values.

The smart phone's OpenGL renderer is used to display the 3D model in realistic perspective as if seen from the user's actual position in the landscape. Finally, the scene from the phone's camera is superimposed on the display.

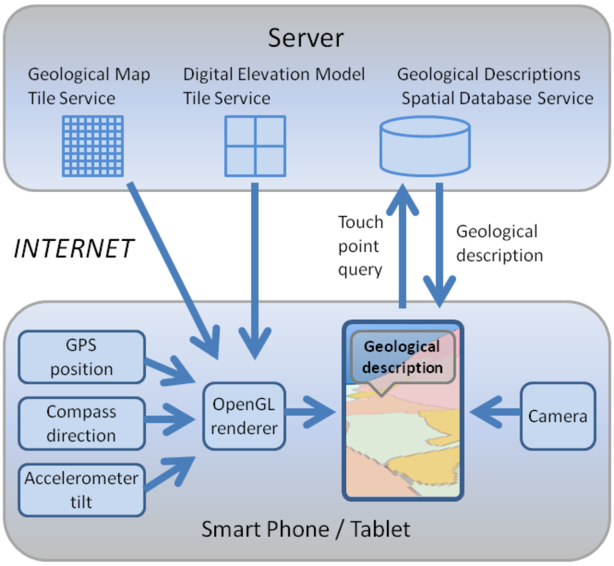

Figure 6: iGeology 3D data and device services.

To achieve convincingly real augmented reality the displayed digital landscape has to adjust quickly to match the actual camera view as the user turns and tilts the phone to look around and walks over the landscape. Devices built into most smart phones and tablets make this possible. GPS provides a stream of location information; an electronic compass provides real time direction and accelerometers track the tilt.

Implementing geological augmented reality on a smart phone presented some challenges including:

- Handling map and elevation data volumes for an extensive landscape model in a small device.
- Delivering elevation data quickly at a useful resolution.
- Pre-loading data for use where there is no phone signal for an Internet connection.
- Providing fast and smooth viewpoint transitions from noisy GPS, compass and accelerometer data.

These have been resolved to produce a practical and easy to use app and will no doubt be refined in the light of user feedback.

Smart phone GPS seem to achieve a horizontal position accuracy of 5 to 10 metres, which is sufficient for this app. The vertical position is much less reliable so iGeology 3D derives this from the elevation model at the GPS horizontal location.

The electronic compasses need regular recalibration but this is easy to do and instructions are provided in the app. Once calibrated the compass data are noisy but respond well to simple filtering.

The smart phone accelerometers are naturally sensitive to motion as well as gravity and even a light tap on the screen to query the geology creates a data spike causing the apparent orientation to tilt sharply. Again, applying a simple filter stabilized the display.

For future development the augmented reality technique is also applicable to sub-surface information. An imaginary quarry could be cut anywhere in the landscape to show vertical sections through the geology. Subsurface structures such as laser scanned caves could also be added (Fig. 7).

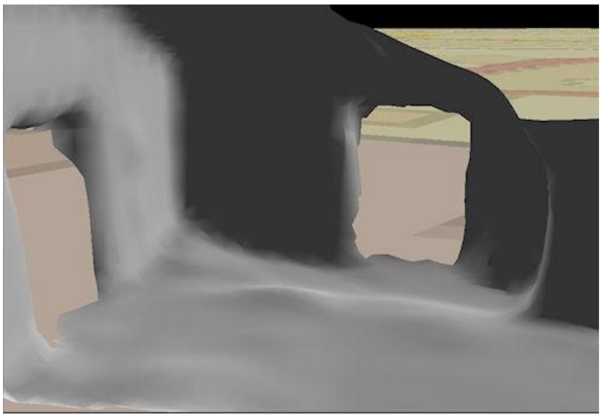

Figure 7: An experimental iGeology 3D prototype showing part of a Nottingham cave.

BGS are working with Leeds University to assess the potential for using augmented reality for teaching geology in the field. Feedback from students will help us use these technologies to really bring our geological maps to life.

VI. CONCLUSIONS

In this paper we have shown how modern communication technologies are opening up a new world of opportunities for the geological map. Rather than represent its demise, the move from use of paper to digital display through mobile devices has been shown to increase interest in the map by orders of magnitude.

The GPS and recording capabilities within modern mobile devices are becoming practical sources for citizen science data. This moves us towards a new era when the boundary between the scientific map maker and user will become increasingly blurred and dynamic.

New 3D information technologies are driving significant advances in the collection and interpretation of complex sub-surface geoscientific information. This translates into much more effective decision support systems for end users, in particular, in complex urban environments where buried infrastructure interacts directly with the geology.

Using the orientation and display capabilities in the modern mobile phone or tablet computer to their full extent is also opening up exciting possibilities for delivering the third geological dimension to the general public in an easily understandable way. This will enable non-expert users to begin to interact with a complex science in an expert way which was not possible for previous generations.

This work gives us a glimpse into the future for the geological map and spatial information in general, which breaks away from the restrictions of two-dimensions to encompass the whole space around us.

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