

## The use of NEXTMap Britain for geological surveying in the Vale of York

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Abbreviated title: NEXTMap Britain for geological surveying.

### Abstract

The NEXTMap Britain Digital Elevation Model (DEM) has opened many new opportunities that considerably help and enhance the way we undertake our geological mapping of bedrock, structure, superficial and artificial deposits. The dataset has been successfully integrated into the digital and conventional mapping workflows of the Vale of York mapping team.

A variety of visualisation and analysis techniques have been applied throughout the mapping process. These techniques include an initial appraisal of NEXTMap with a comparison to existing geological mapping to define the field mapping strategy and site specific manipulation using Tablet PCs.

NEXTMap interpretation has made an important contribution to the understanding of the extensive glacial and pro-glacial deposits found in the Vale of York, such as sand bodies resting on lake deposits and identifying details within morainic and alluvial complexes. For bedrock mapping, NEXTMap has been used to identify landform

features that relate to the underlying geology such as breaks in slope, the extent of escarpments, hillcrests and dip slopes, provide an overview of the landscape and save time mapping out features in the field. Techniques have also been developed to automatically generate these landform features.

The dataset has also been used to identify areas where landsliding has occurred, for accurate mapping of artificial ground and as a key surface for 3D geological models.

(End of Abstract)

The York district (Sheet 63), originally surveyed in the 1880's is currently being resurveyed as part of a national targeted revision program; the Selby district (Sheet 71) has just been completed (Figures 2 and 3). Modern geological mapping has involved bringing together a range of digital datasets and the move towards a digital mapping workflow. The multidisciplinary work is integrating existing British Geological Survey map data holdings, geochemical information (G-Base), borehole records, seismic data, digital elevation models, aerial photography interpretations and 3D modelling techniques with traditional field based geological surveying. The NEXTMap elevation model is a key dataset used extensively throughout the mapping workflow.

This paper focuses on the contribution that NEXTMap has made to the digital mapping workflow, including the processing techniques used for enhancing the dataset for geological feature collection. It also briefly covers its use within the digital field data capture system and for the production of three dimensional geological models.

## **Study area**

The Vale of York is a broad area of low lying and generally gently undulating land in the north east of England constrained between the Yorkshire Wolds and Howardian Hills to the east and the Pennines to the west (Figure 1). The bedrock geology in the Vale consists of Triassic sandstones and mudstones bounded by Jurassic and Cretaceous rocks to the east with Permian and Carboniferous rocks to the west (Figure 2). Overlying the bedrock geology there is a varied cover of superficial deposits consisting of glacial till, outwash sands and gravels, glaciolacustrine clay, peat and alluvium (Figure 3). Their distribution is strongly influenced by the advance and retreat of ice during the Devensian glaciation. Detailed descriptions of the geology of the Vale of York and surrounding areas can be found in Fox-Strangways (1884), Gaunt (1981, 1994), Powell *et al.* (1992), Cooper and Burgess (1993) and Cooper and Gibson (2003).

## **Terrain Modeling for Geological Applications**

In temperate environments such as the United Kingdom, extensive vegetation cover and soil development results in little exposure of the underlying geology. Geological mapping relies on using the interpretation of landform features to tie together information obtained from exposures, field brush and auger holes. Traditionally these features are identified in the field or from hardcopy air photos using a stereoscope.

However, both these methods can be time consuming and the interpretation of air photos can be difficult due to inherent distortions and scale variations present within the imagery. Modern methods such as digital stereo air photo interpretation and the use of a Digital Elevation Model (DEM) are the two main remote sensing techniques that can enhance the efficiency and accuracy of the landform feature capture process.

Elevation models have been used for some time as a useful tool for regional and local geological applications (Onorati *et al.* 1992; Pike, 1992; Bonham-Carter, 1994) and landform mapping (Smith and Clark, 2005). Focused studies have made use of aerial photography or LiDAR derived models, but at a relatively high cost, with contour derived models being applied for regional applications. With the availability of NEXTMap, elevation models have become routinely used for geological applications within the British Geological Survey (Hall *et al.* 2004; Bradwell *et al.* 2007) and more widely (Smith *et al.* 2006). The combination of high resolution and national coverage is ideally suited to geological mapping and modelling applications.

The NEXTMap dataset for England and Wales was collected by InterMap technologies between 2002 and 2003 using Interferometric Synthetic Aperture Radar (INSAR), producing a 5m post spacing DEM having a quoted vertical accuracy of 1.0m Root Mean Square Error (RMSE) for Type 2 data (Intermap Technologies, 2007). Two main elevation models make up the dataset, these are the Digital Surface Model (DSM) and the Digital Terrain Model (DTM). The DSM represents the unedited model. The DTM has undergone editing to remove cultural features and smaller areas of trees, embankments have been enhanced and the model has been modified to make it hydrologically correct for drainage.

### **Quaternary Evolution of the Vale of York**

The geological evolution of the Vale of York during the Quaternary produced a distinctive range of sediments and landforms that characterise the present day area (Cooper and Burgess, 1993; Gaunt, 1994). The superficial deposits present in the Vale of York are largely a result of the last Devensian glaciation between about 115 000 and 10 000 years ago, when ice covered most of northern Britain (Cooper and Gibson, 2003). The advance of Vale of York ice and its subsequent retreat created an assemblage of ice contact, ice-marginal and pro-glacial deposits. The main morphological features can be seen in the NEXTMap DTM (Figure 4).

The Pennines valleys were glaciated as far south as Leeds and a tongue of ice occupied the Vale of York advancing as far south as the Escrick Moraine (Figure 5a). At the same time, the North Sea ice advanced to Norfolk blocking the drainage out through the Humber gap. In front of the ice, fluvio-glacial outwash deposits and pro-glacial lake deposits were formed in the dammed pre-glacial valley system.

As the ice advanced to the Devensian maximum, forming the Escrick Moraine, it overrode many of the pro-glacial deposits. The ice front then retreated progressively northwards with intervening still-stands depositing the Crockey Hill Esker (Figure 5a), the York Moraine (Figure 5b) and the Flaxby-Tollerton Moraine (Figure 5c) (Cooper and Burgess, 1993). The York and Flaxby-Tollerton moraines represent still-stands in the ice margin where the supply of sediment-laden ice was in equilibrium with the degree of melting or wasting.

The vast amounts of meltwater draining from the ice-sheet formed sub-glacial drainage systems that commonly became choked with sand and gravel. Upon melting of this ice-sheet, these choked drainage systems were left as ridges (eskers) of partially disturbed deposits. Where the drainage emerged from the ice-sheet (at the sides or in front) it commonly deposited terraces or fans of sand and gravel. Where the drainage disgorged into glacial lakes, fans of sand and gravel formed; these have an upper surface approximating to the glacial lake water level. Some of these fans were subsequently buried by glacio-lacustrine deposits including laminated clay. Three separate glacial lakes were formed, the largest pro-glacial lake (Humber pro-glacial lake) being in front of the Escrick Moraine, another between the York and Escrick moraines and another to the north of the York moraine; the deposits formed in these lakes are, from south to north, the Hemingbrough, Elvington and Alne glaciolacustrine formations (Figure 6).

After the Devensian glaciation, the ice retreated from the Humber Gap and the pro-glacial lake of the Vale of York drained eastwards into the North Sea. Extensive sand deposits were washed out across the floor of the recently drained lake and spreads of sand with a little gravel were formed. As these deposits dried and the drainage became established, exposed sand deposits were blown around the newly emerged lake bed forming subdued dunes of blown sand. Much of the drainage followed its previous course into the Vale such as around the front of the Escrick Moraine cutting into the glacial till, the glaciofluvial outwash terraces and the associated glacial lake deposits (Figure 6) (Cooper and Gibson, 2003).

### **NEXTMap and Superficial Mapping**

The glacial deposits within the vale of York are extensive and NEXTMap has made an import contribution to the understanding of lake-bottom elevations, the recognition of sand bodies resting on lake deposits and identifying details within morainic and alluvial complexes.

The BGS produces geological linework of Great Britain at a number of scales in digital and hardcopy format and in Superficial and Bedrock versions. Geological mapping typically takes place at 1:10k or 1:20k and this linework is then produced in 1:50000, 1:250000 and 1:625000 versions with the appropriate generalisations. These datasets are named DiGMap GB-50, 250 and 625, with DiGMap GB50 being the standard scale of the national sheet based printed maps.

To allow comparison with the current DiGMap GB-50 scale geological line work, the NEXTMap data is processed to enhance the topographic information held within the dataset. A number of steps are involved with this enhancement process, which is undertaken in the ArcMap environment. Firstly the terrain model is artificially lit using the Spatial Analyst extension. This artificial lighting effect, or shaded relief, gives the appearance of sunlight illuminating the model, creating shadows and highlights. The sun azimuth and elevation can be modified to enhance landform features with a particular orientation. A second semi-transparent copy of the NEXTMap dataset is superimposed above the shaded relief and colour ramped according to elevation, producing a combined shaded and colour ramped image. The pre-revision linework can then be checked against the landforms displayed in the hill-

shaded and colour ramped image. The features are typically subtle and individual colour ramp intervals of 10-15cm were found to be most effective in identifying features. Fieldwork was then targeted in areas where there was found to be a discrepancy between the landform features and the existing linework. It was established that the DSM model was more useful than the DTM as the algorithm used to remove trees and culture features from the DSM to produce the DTM was found to also remove subtle landform features.

The correspondence between the existing geological line work and the NEXTMap DSM model is shown in Figures 7 and 8; numerous features are clearly identifiable. The Crockey Hill Esker is visible as an elongated ridge aligned north-south; sand and gravel deposits form several raised areas and the Escrick Moraine in the southern part of the image is striking (Figure 7). Localised ponding caused by the moraine restricting draining in this part of the Vale has resulted in an area of alluvium in the low lying areas behind the ridge. Figure 8 shows the area of high ground formed by the central part of the Escrick moraine. A relict drainage channel can be identified, which is thought to represent drainage through the moraine prior to the break through by the River Derwent. The Derwent, with its associated floodplain deposits, can be seen in the centre of the image. Some areas show a clear discrepancy between the landform features present on the NEXTMap DSM and the existing mapping for the northern extent of the Escrick Moraine. In Figure 9, a possible river terrace, not present on existing mapping, can be identified on the Western bank of the Derwent; there are also areas where the morainic till and the glaciofluvial deposits could be extended.

The NEXTMap dataset has considerable advantages over contour derived models in the low relief areas of the Vale of York. The wide spacing of contours was found to result in interpolation artefacts and the smoothing of subtle features. As the NEXTMap model is based on a radar signal collected at regular intervals along the ground surface, the model is particularly useful for the interpretation of superficial deposits in river floodplains and other low relief areas.

### **NEXTMap and Bedrock Mapping**

An extensive outcrop of Jurassic and Cretaceous strata forms the eastern limit to the Vale of York and the prominent topographic feature of the Yorkshire Wolds. This area of higher ground is relatively well featured compared to the superficial deposit covered lower ground. The NEXTMap dataset was used for a number of aspects of bedrock mapping. Prior to fieldwork, a study of the DSM allowed breaks in slope to be recognised and interpreted in the context of the local geological succession. Discrepancies between existing geological mapping and the NEXTMap interpretation were targeted and prioritised for subsequent fieldwork, resulting in a more effective use of field resources.

In order to provide a rapid initial appraisal of the existing linework techniques were developed to automatically extract the main landscape features, as described by Ford (2007). This 'synthetic feature mapping' process was carried out with ArcMap using the Spatial Analyst extension; the method is outlined in Figure 10. Firstly the DSM was classified by slope angle (Figure 10a). The slope angle map was then classified; this produced the second derivative of the DSM and highlights areas of dissimilar

slope angle, effectively showing breaks of slope (Figure 10b). Symmetrical crest and valley features were defined by an appraisal of slope facing direction. By combining these derived maps and overlaying existing geological linework, it is possible to identify discrepancies between landscape features shown on the DSM and existing mapping (Figure 10c). Figure 10c shows the Penarth group following closely the relatively steeper sloping ground illustrated by the darker shading. However, as the unit follows the hillside northwards the unit is shown to be no longer constrained by the steeper ground (as shown by white arrow) and moves up the slope to the flatter ground at the top of the hill. This appears to be wrong and it is more likely that this unit would remain on the steeper ground. Detailed contour and elevation information were not available at the time of the original survey and would make a contribution to the inaccuracies identified. Positioning geological boundaries would be difficult in areas where there was little outcrop and subtle landform features. Cultural and vegetation features are also brought out by synthetic feature mapping approach, as the DSM was used, but it was found to be relatively straightforward to separate these from the landscape features by consulting topographic maps and aerial photography. Results using the DTM, were not as favourable as using the DSM as filtering approach used to generate the DSM from the DTM appears to “erode” some of the subtle topographic features.

Landslides exist on a number of the steeper slopes formed by the Penarth Group, Redcar Mudstone Formation, Amphill and Oxford clay formations and the Cretaceous chalks. The existing geological map for York does not show the location or extent of these landslides because they were not mapped during the 1880’s survey, being noted with a comment only on the field maps. With an increasing awareness of geological hazards, the accurate mapping and understand of mass movement deposits has become increasingly important. The NEXTMap DSM displayed a marked contrast in surface texture between bedrock areas subject to landslide activity and areas with more stable slopes. The most effective processing techniques were the generation of shaded relief and slope images. An example of the undulating texture caused by landsliding can be seen in the shaded relief image in Figure 11. The resolution of NEXTMap is high enough to identify individual rotated blocks within the landslide complex (Figures 11 and 12). In this way it is possible to not only identify areas of possible landsliding, but to begin to understand the failure mechanisms responsible for the movement.

### **NEXTMap manipulation in the field and 3D modelling using NEXTMap**

A digital data capture system is currently being introduced within the British Geological Survey as a replacement for paper fieldslips and notebook as a component part of the move towards a complete digital mapping workflow (Jordan *et al.*, 2005). The system is based on a customised version of ArcMap running on a ruggedised tablet PC with an integrated GPS, allowing the capture of text, polygons and lines and form based data (Figure 13). One significant benefit of the system is the ability to manipulate NEXTMap data on a site specific basis, such as adjusting artificial shading and colour ramping parameters, according to local topographic variations. The system also includes a ‘structure contour tool’ for calculating where a geological bed will outcrop based on structural measurements. Given the location of an observation point where the angle and direction of dip of the bed are known, and assuming the dip is uniform, the tool can calculate an equation for the plane of the

bed. Where this plan intersects with the ground surface it can be predicted where the bed will outcrop. The NEXTMap DTM is used by the tool to provide elevation data for the calculation and allows the calculation to be completed in the field.

The British Geological Survey is increasingly producing three dimensional geological models for geological analysis and for external customers as described by Kessler and Mathers (2004) and Kessler *et al.* (2005). The terrain surface is a key input to a 3D geological model, providing the top surface of the geological sequence and an elevation from which to hang boreholes. To assist in the geological mapping of the York sheet a geological model was constructed to investigate the superficial deposits in York city centre, allowing an appraisal of a large number of boreholes. NEXTMap data provided the surface constraint for the constructed units. The resultant model is shown in Figure 14, with the individual units vertically separated.

## **Conclusions**

The NEXTMap Britain elevation model has provided many opportunities to enhance the geological mapping of bedrock, structure, superficial and artificial deposits and has been successfully integrated into the digital and conventional mapping workflows of the Vale of York mapping team.

A variety of techniques have been applied throughout the mapping process and NEXTMap interpretation has made an important contribution to the understanding of the extensive glacial and pro-glacial deposits found in the Vale of York.

NEXTMap has been used to identify landform features that relate to the underlying geology, providing an overview of the landscape and reducing the time needed to map out features in the field. Techniques have also been developed to automatically generate these landform features in areas of well featured bedrock.

The dataset has also been used to identify areas where landsliding has occurred, for accurate mapping of artificial ground and as a key surface for input into 3D geological models.

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## Figures

Figure 1. Location map of the Vale of York and surrounding areas shown in Figures 2 and 3

Figure 2. Simplified bedrock geology of the Vale of York and surrounding area extracted from the British Geological Survey 1: 625,000 scale digital bedrock geology dataset. The Jurassic stratigraphy shown in the key is that for Yorkshire and for clarity a few of the thinner Jurassic and Triassic units are un-named or not shown.

Figure 3. Simplified diagram of Devensian and Pre-Devensian deposits in the Vale of York and surrounding areas extracted from the British Geological Survey 1:625,000 scale digital superficial geology dataset. Devensian limit in the Vale of York based on borehole data and recent surveying.

Figure 4. The main morphological features of the Vale of York NEXTMap DTM, shaded and colour coded according to elevation. Light green colours represent low elevation, rising through yellow and brown to white representing high elevation. Elevation data from Intermap Technologies.

Figure 5. Glacial landforms in the Vale of York and their relationships to stages of ice advance and retreat during the Devensian. (a) Ice position during Devensian Maximum, forming Escrick Moraine. (b) Ice retreat and formation of York Moraine during stillstand. (c) Ice retreat and formation of Flaxby-Tollerton Moraine. Elevation data from Intermap Technologies.

Figure 6 Cross Section through superficial deposits in the Vale of York, illustrating the relationship between the units.

Figure 7. Crockey Hill Esker, NEXTMap shaded and colour ramped DSM. Blue 5m, yellow 10m, white 30m elevation. Existing DiGMap 1:50000 scale superficial

geology linework shown in right hand panel in semitransparent format with underlying colour ramped and shaded NEXTMap DSM. Elevation data from Intermap Technologies.

Figure 8. Escrick Moraine centre. NEXTMap shaded and colour ramped DSM Blue 5m, yellow 10m, white 30m elevation. Existing DiGMap 1:50000 scale superficial geology linework shown in right hand panel in semitransparent format with underlying colour ramped and shaded NEXTMap DSM. Elevation data from Intermap Technologies.

Figure 9. Escrick Moraine North. NEXTMap shaded and colour ramped DSM Blue 5m, yellow 10m, white 30m elevation. Existing DiGMap 1:50000 scale superficial geology linework shown in right hand panel in semitransparent format with underlying colour ramped and shaded NEXTMap DSM. Elevation data from Intermap Technologies.

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Figure 11. Area of landslides near Oxpasture Wood, shown by the textural variation within NEXTMap shaded relief DSM. Black line illustrates probable extent of mass movement, arrow shows location of rotated block. Elevation data from Intermap Technologies.

Figure 12. Landslides near Oxpasture Wood, the large landslip block on the left is the one arrowed in Figure 11.

Figure 13. NEXTMap manipulation in the field using a ruggedised tablet PC with integrated GPS, running customised ArcMap Software. Elevation data from Intermap Technologies.

Figure 14. 3D ‘exploded’ geological model of the superficial deposits around York, with surface elevation information from NEXTMap DTM. Elevation data from Intermap Technologies.

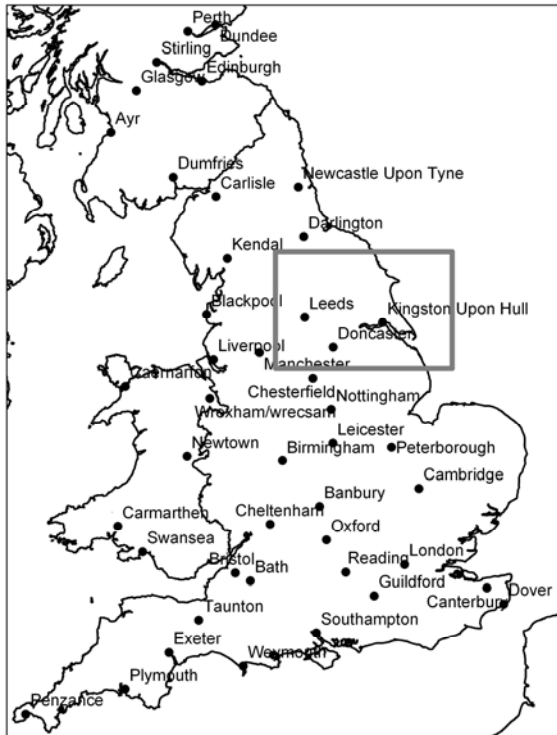


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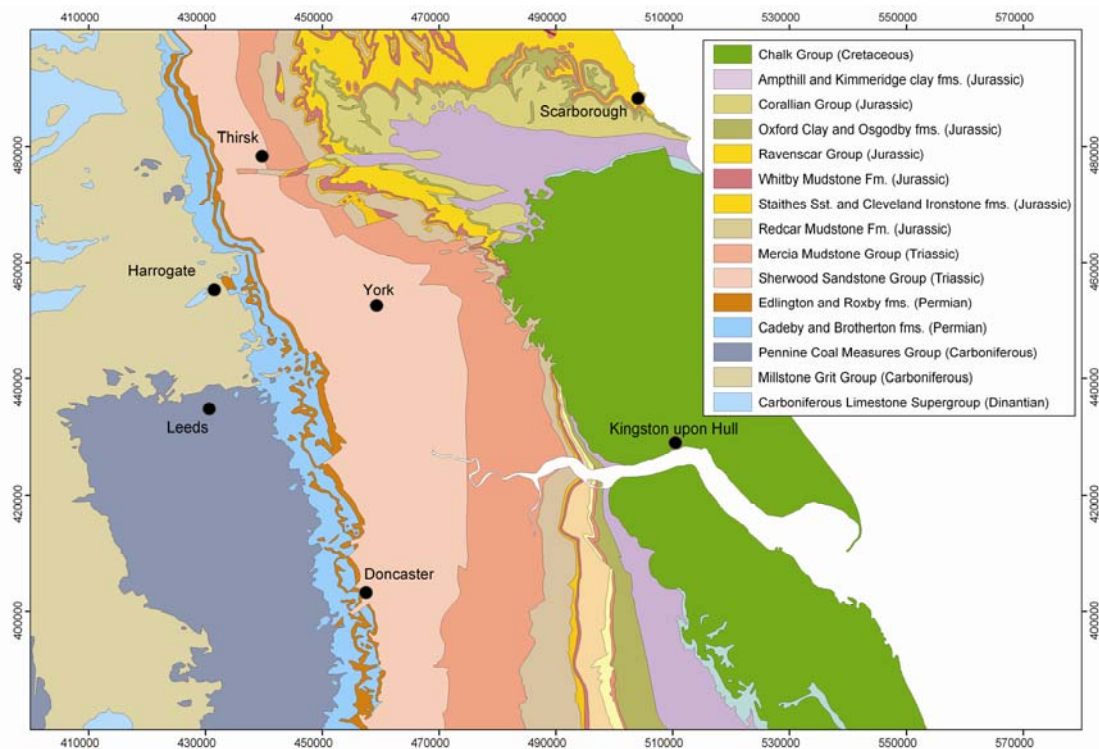


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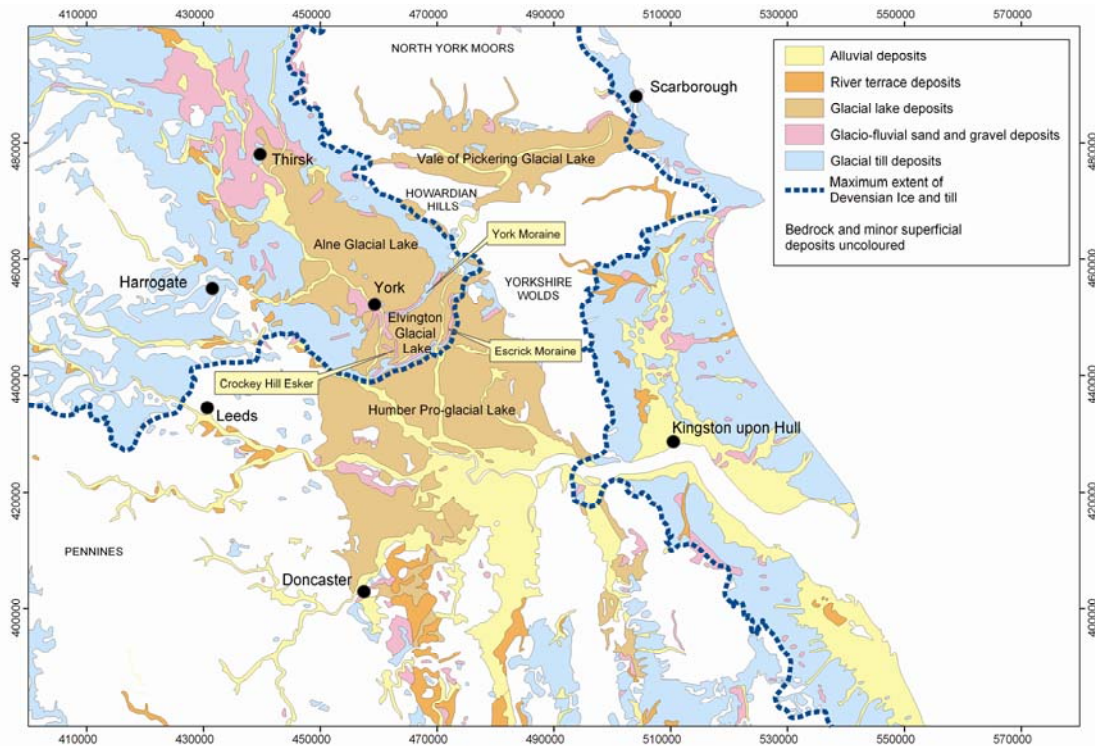


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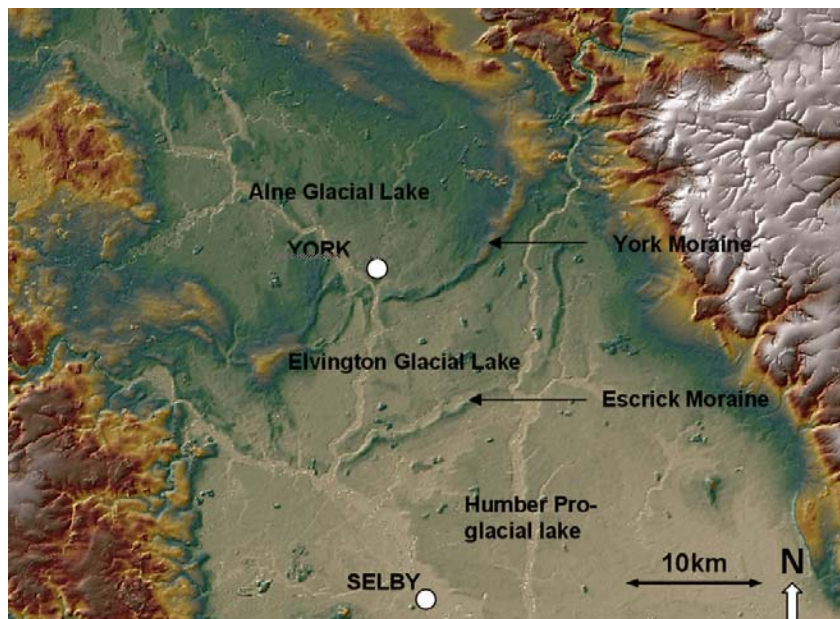


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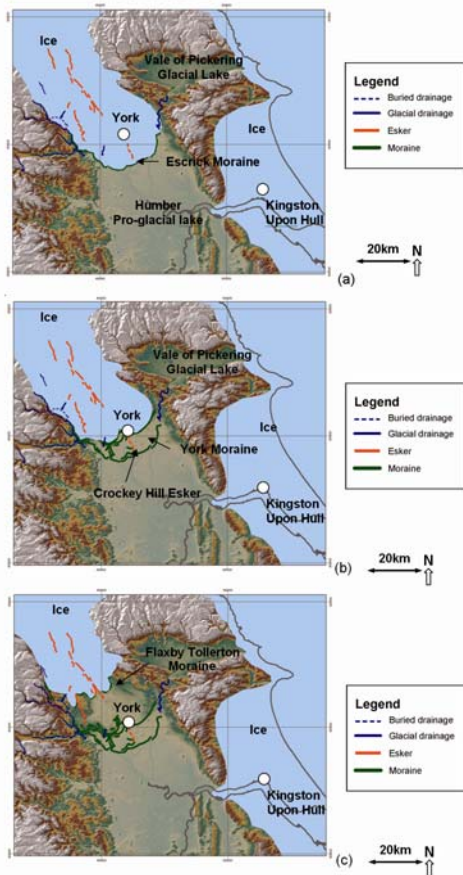


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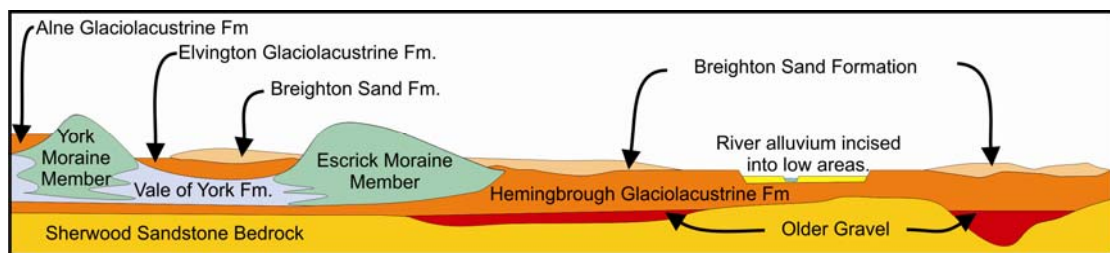


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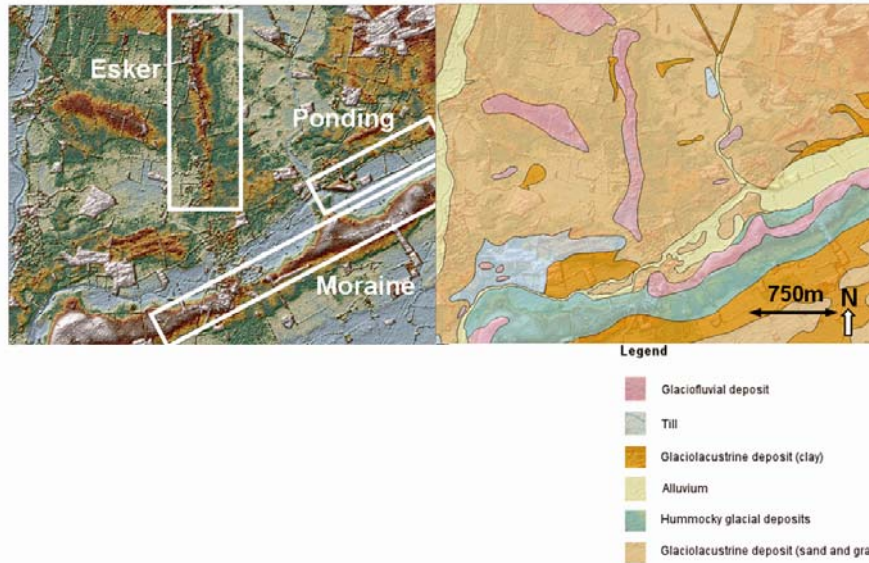


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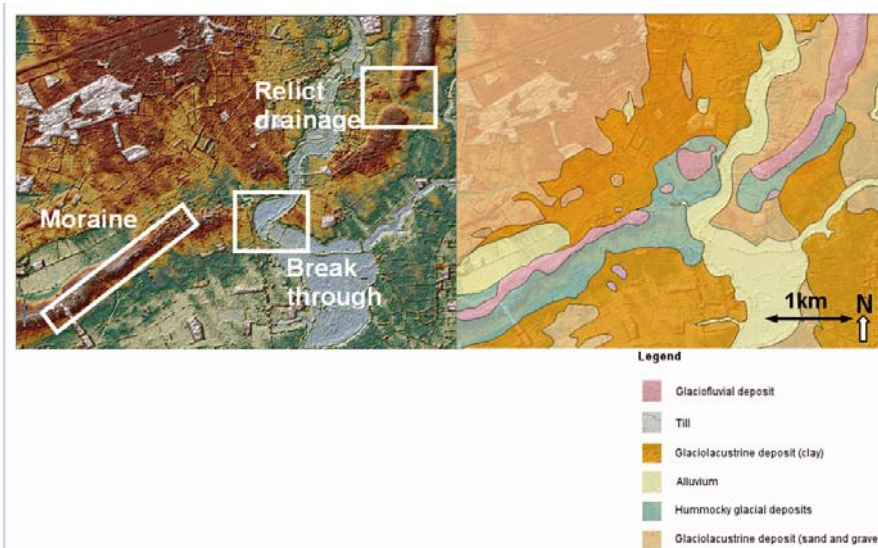


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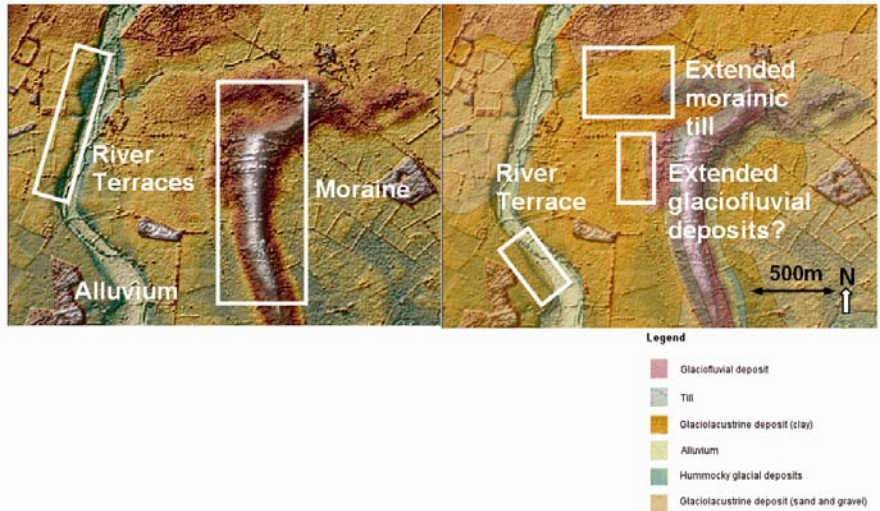


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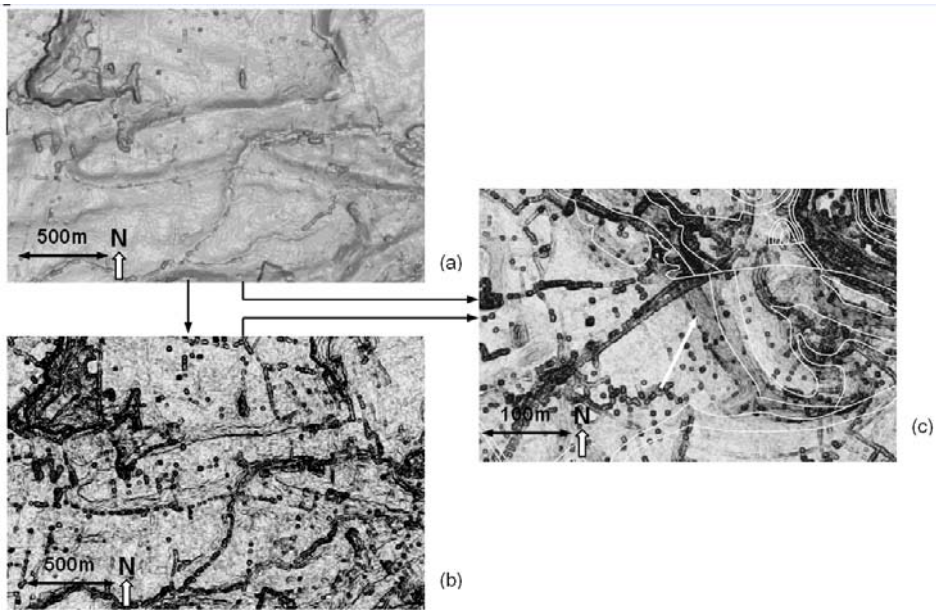


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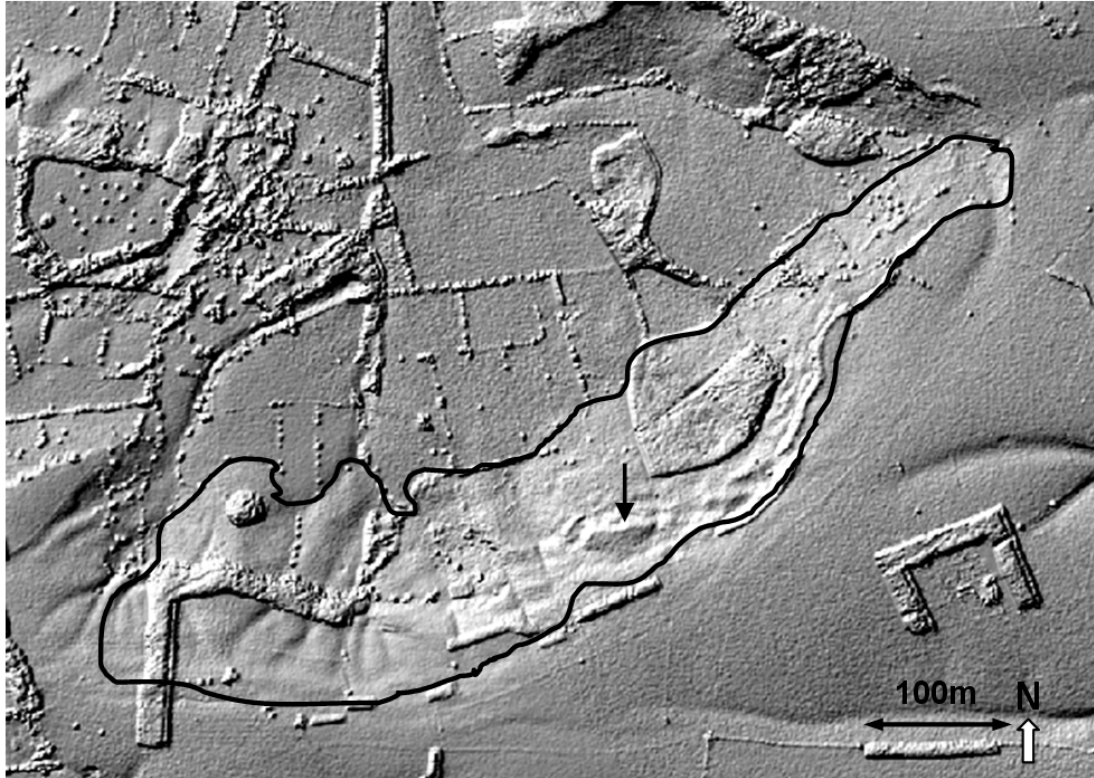


Figure 11. Area of landslides near Oxpasture Wood, shown by the textural variation within NEXTMap shaded relief DSM. Black line illustrates probable extent of mass movement, arrow shows location of rotated block. Elevation data from Intermap Technologies.



Figure 12. Landslides near Oxpasture Wood, the large landslip block on the left is the one arrowed in





Figure 13. NEXTMap manipulation in the field using a ruggedised tablet PC with integrated GPS, running customised ArcMap Software. Elevation data from Intermap Technologies.

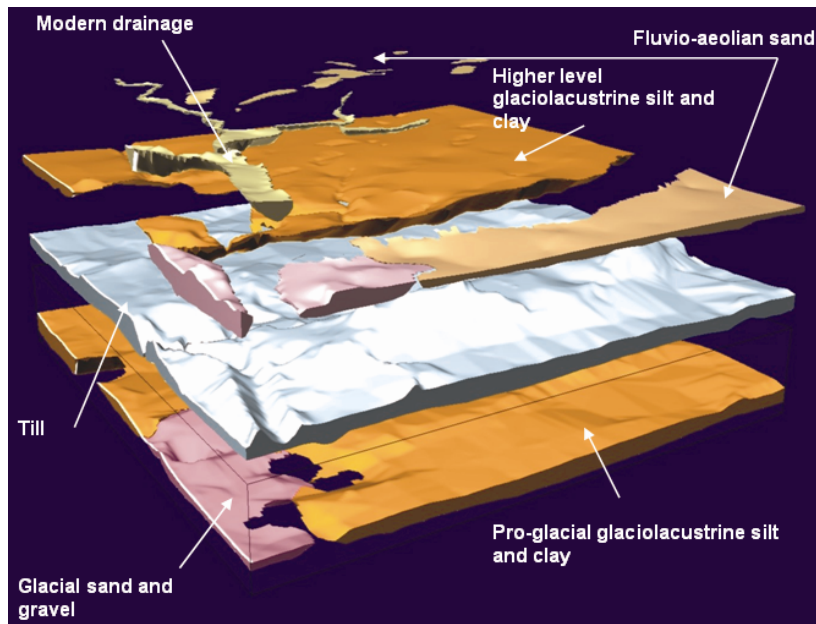


Figure 14. 3D ‘exploded’ geological model of the superficial deposits around York, with surface elevation information from NEXTMap DTM. Elevation data from Intermap Technologies.