How accurate is your model between boreholes? Using shallow geophysics to test the best method to model buried tunnel valleys in Scotland, UK

Tim Kearsey[a*], Katie Whitbread[a], Sarah Arkley[a], David Morgan[b], David Boon[b] & Mike Raines[b]
[a]British Geological Survey, The Lyell Centre, Research Avenue South, Edinburgh EH14 4AP, UK
[b]British Geological Survey, Nicker Hill, Keyworth, NG12 5GG, UK
*corresponding author:timk1@bgs.ac.uk

Abstract

3D geological models are fast supplanting 2D maps as the primary way for geological surveys to deliver subsurface understanding. In parallel, there is an increasing interest in the accuracy and uncertainty of geological models as more and more end users rely on them for subsurface prediction. This is putting geological reasoning under a degree of scrutiny that it has previously not been subjected too (Bond 2015). The problem is enhanced when the feature of interest has no surface expression. Since 2001 the British Geological Survey has published a National Superficial Deposit Thickness Model (SDTM) derived by interpolation of borehole data (Figure 1). This shows variation in thickness of unconsolidated deposits, less than 2.6 million years old (Quaternary System). It includes all deposits of fluvial, glacial, marine, residual, aeolian or anthropogenic in origin (Lawley & Garcia-Bajo 2010). The borehole data used in the derivation of SDTM comes largely from 3rd party sources, stored in the BGS digital borehole archive. The characterisation of superficial thickness is thus affected by the irregular distribution of the borehole data, with potential implications for the accuracy of the SDTM model particularly in relation to complex features such as buried tunnel valleys and overfilled bedrock depressions (Figure 1). Here we explore the characterisation of these features using an example from central Scotland, and test whether alternative modelling methodologies enhance our ability to predict the geometry of these features.

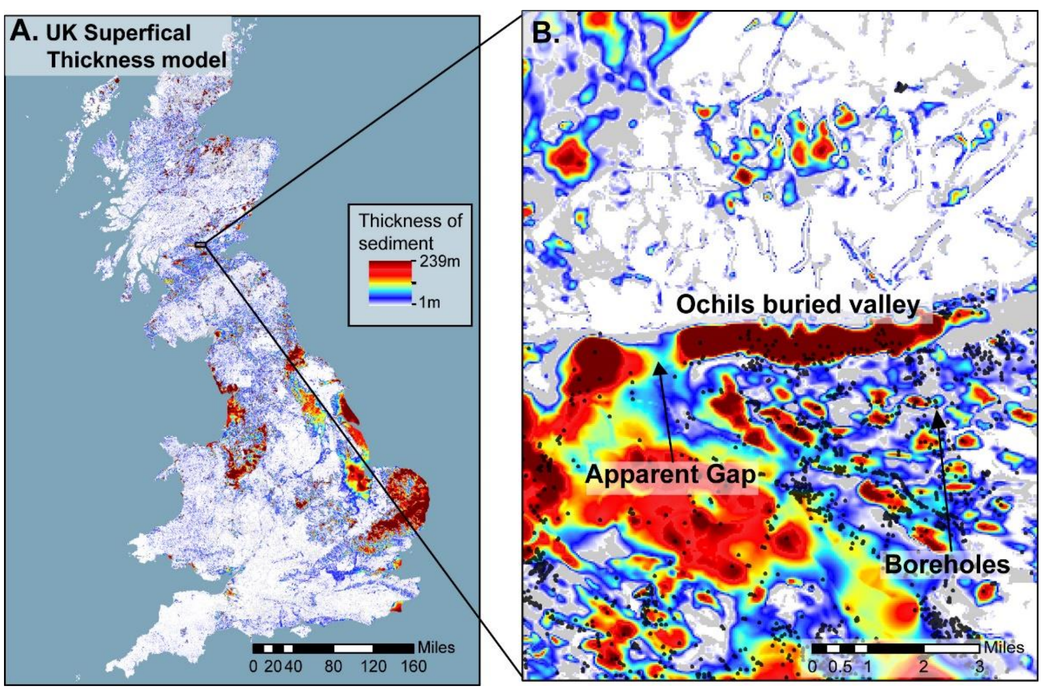

Fig. 1. A) SDTM the BGS national superficial thickness model. B) The Ochils buried tunnel valley as shown in SDTM. Black dots mark the positions of boreholes. The apparent gap may be caused by the interpolation method.

Work on uncertainty in 3D geological models has focused on the clustering of input data (MacCormack & Eyles 2012); the role of geologists experience in the model accuracy (Lark et al. 2014); whether a regional approach improves accuracy (MacCormack et al. 2017); and the role of information entropy (Wellman and Regenauer-Lieb 2012). However, there has been less research in to the role that the relief of buried surfaces has on the accuracy of 3D geological models.

In this study we focus on the Ochil's buried tunnel valley, east of Stirling in central Scotland (Figure 1B). This feature has a maximum depth of 113 m proved in boreholes and is the second deepest buried bedrock trough known in Scotland. In the UK Superficial Thickness model, the Ochil's trough is not completely resolved; there are apparent gaps in the longitudinal continuity in an areas with no borehole data (Figure 1B), and the cross-sectional geometry is variable along the length of the feature. These apparent characteristics of the feature may arise, at least in part, due to the way the SDTM was constructed. The model utilises all the boreholes which intersect the top of bedrock and the depth to bedrock is extrapolated on a grid using a Natural Neighbourhood interpolation and area weighting of the Voronoi neighbourhood of each data point (Lawley & Garcia-Bajo 2010).

To examine the degree to which the method of interpolation has affected the surface morphology, two additional interpolation methods were applied to the SDTM borehole dataset. The first was using direct triangulation using Delaunay-triangulation (Kessler et al. 2009) and the Paradigm SKUA Geological Grid (Oil-Gas 2008) which creates implicit surfaces using a 3D grid, which is parallel to original depositional normals (Mallet 2004).

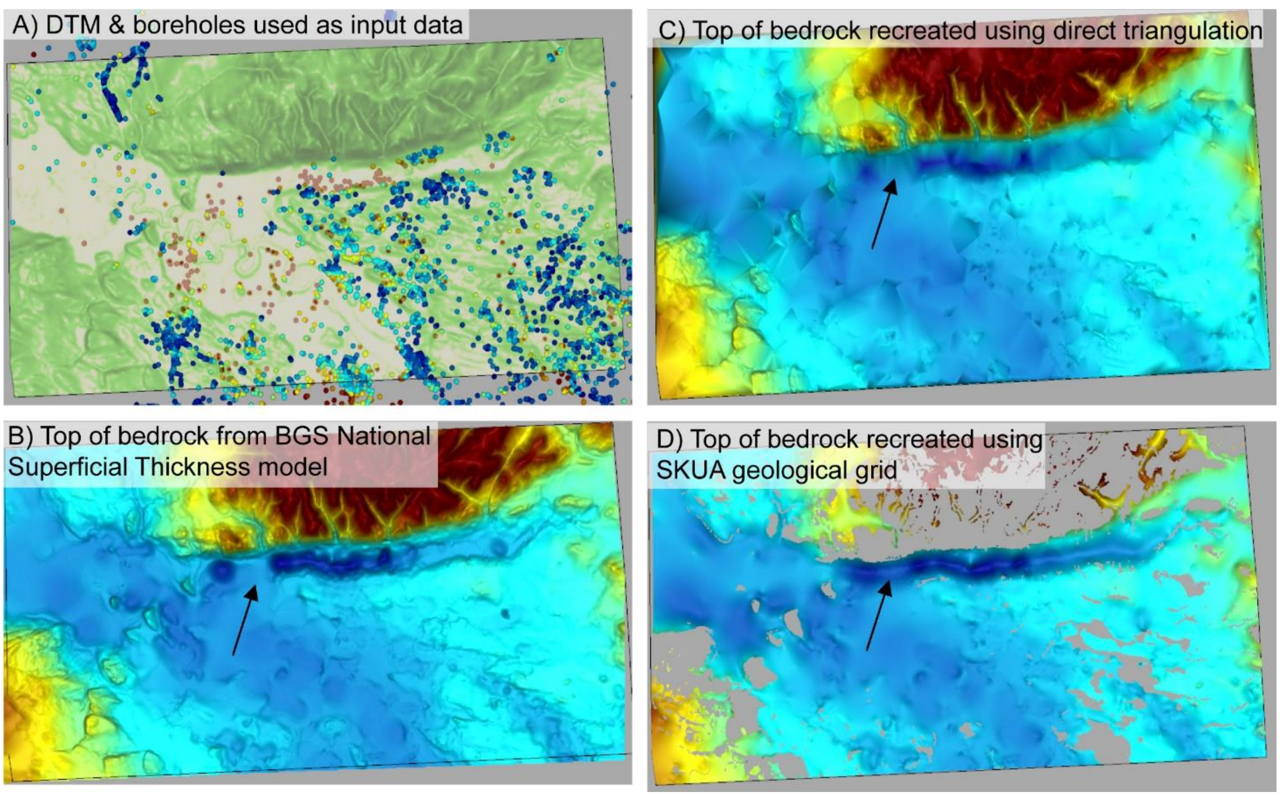

Fig. 2. A) Distribution of borehole input data used in the test. B) Is the top bedrock surfaces from the current BGS superficial thickness model (SDTM). C) & D) show the recreated surfaces using different methods. Note that only method D) does not contain the apparent (arrowed) gap in the buried valley.

The direct triangulation method (Figure 2C) creates a surface that differs from SDTM by an average of 2 m (max 100 m above; min 99 m below). The SKUA Geological Grid bedrock surface (Figure

2D) differs from SDTM by an average of 3 m (max 63 m above; min 36 m below). However, this method SKUA geological grid appears to resolve the Ochils buried valley as a continuous feature rather than creating the apparent gap and reduces the localised deepenings ('bull's eyes') . All methods are using exactly the same input data so all the differences between the surfaces are a product of the algorithms that were used.

To test the accuracy of the different interpolation methods, we used try and resolve which of these methods provided the most accurate prediction we needed to collect more data. Drilling new boreholes was too expensive given the >90 m thickness of Quaternary sediments in the Ochils buried valley. Instead we used a TROMINO® passive seismic instrument to provide geophysical constraint on the bedrock surface. Two separate survey lines were selected: line 1 was targeted on an area of the Ochils buried valley with good borehole control; the second targeted on a section of the feature with no boreholes and that some methods interpret as a high (Figure 3). Each survey line consisted of an individual measurement of depth to bedrock every 100 m along the survey line.

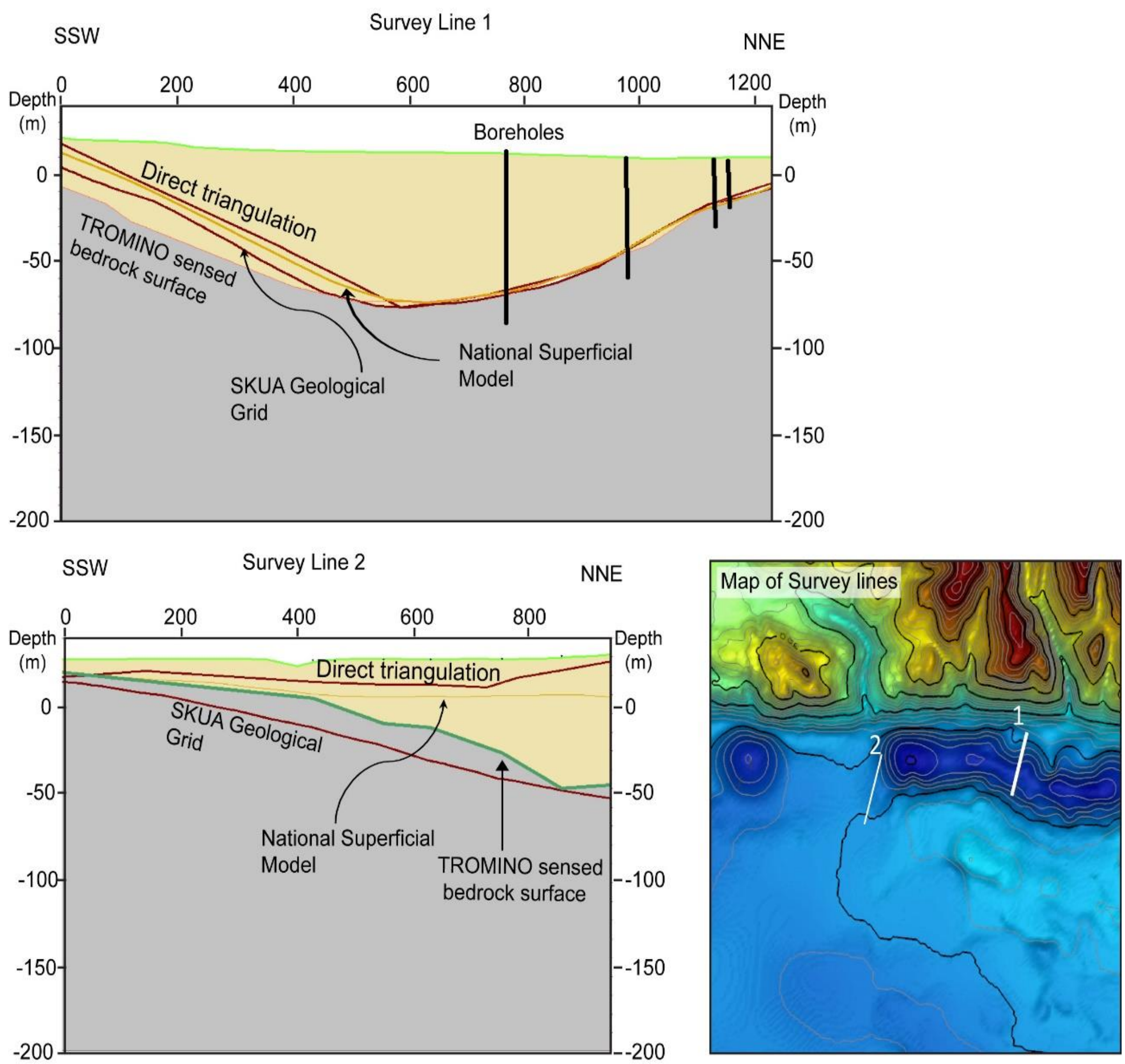

Fig. 3. The results from the two passive seismic lines comparted to the surfaces created by the different methods described in figure 2. Survey line 2 shows that the apparent gap in the valley predicted by SDTM and the direct triangulation method is likely to be an artefact the interpolation

The results reveal that along Survey line 1, in an area of good borehole control, all the methods proved to be accurate within a distance of 200 m of boreholes (Figure 3). Away from the boreholes all methods underestimated the thickness of superficial deposits, with direct triangulation being the worst performing, followed by the SDTM model and then the SKUA Geological Grid. Survey line 2 focused on an area that SDTM and the direct triangulation method suggested may be a bedrock high. The results showed that this is actually an artefact of the interpolation and that these two methods underestimated the thickness of superficial deposits by between 50-60 m (Figure 3). The SKUA Geological Grid, on the other hand, overestimated the thickness of superficial deposits by up to 16 m.

The results suggest that for modelling buried valleys using scattered data points the SKUA Geological Grid model produces the most predictive result. Furthermore, using Natural Neighbourhood interpolation or direct triangulation can lead to a substantial underestimation of the geometry and thickness in linear features such as buried valleys. It also suggests that when modelling buried geological surfaces with a substantial degree of relief the method used to interpolate between data points can have a significant impact on how predictive that surface is. It also highlights the utility of targeted shallow geophysical methods in improving the accuracy of 3D geological models.

References

Bond, C.E., 2015. Uncertainty in structural interpretation: Lessons to be learnt. *Journal of Structural Geology*, *74*, pp.185-200.

Kessler, H., Mathers, S. and H.G. Sobisch. 2009. The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology. Computers & geosciences, 35(6), 1311-1321.

Lark, R.M.; Thorpe, S.; Kessler, H.; and S.J. Mathers. 2014 Interpretative modelling of a geological cross section from boreholes: sources of uncertainty and their quantification. *Solid Earth*, 5. 1189-1203.

Lawley R., and M.Garcia-Bajo, 2010. The National Superficial Deposit Thickness Model (version 5). *British Geological Survey Internal Report*, OR/09/049. 18pp.

MacCormack, K., Arnaud, E. and B.L. Parker. 2017. Using a multiple variogram approach to improve the accuracy of subsurface geological models. Canadian Journal of Earth Sciences, (999), pp.1-16.

MacCormack, K.E. and C.H. Eyles. 2012. Assessing the impact of program selection on the accuracy of 3D geologic models. Geosphere 8, 534-543.

Mallet, J.L., 2004. Space–time mathematical framework for sedimentary geology. Mathematical geology, 36, 1-32.

Oil-Gas. 2008 .S.K.U.A. "A Step Change in Modeling, 3D Modeling." Scandinavian Oil-Gas Magazine 9/10.

Wellmann, J.F. and K. Regenauer-Lieb. 2012. Uncertainties have a meaning: Information entropy as a quality measure for 3-D geological models. Tectonophysics, 526, 207-216.