Lithostratigraphy does not always equal lithology

Lessons learned in communicating uncertainty from stochastic modelling glacial and post glacial deposits in Glasgow U.K.

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1. Introduction

Glasgow is the largest city in Scotland and has a long history of heavy industry, much of which has now been closed down. As such the city is undergoing urban regeneration and has problems with remediation of contaminated land. However, the city of Glasgow us built on up to 80 m of complex glacial sediments

Our motivation is to test whether a facies-based stochastic modelling approach can produce a geologically valid representation of subsurface lithological variation in a complex depositional environment affected by glaciation – typical of the Quaternary geology under many cities in North America and Northern Europe.

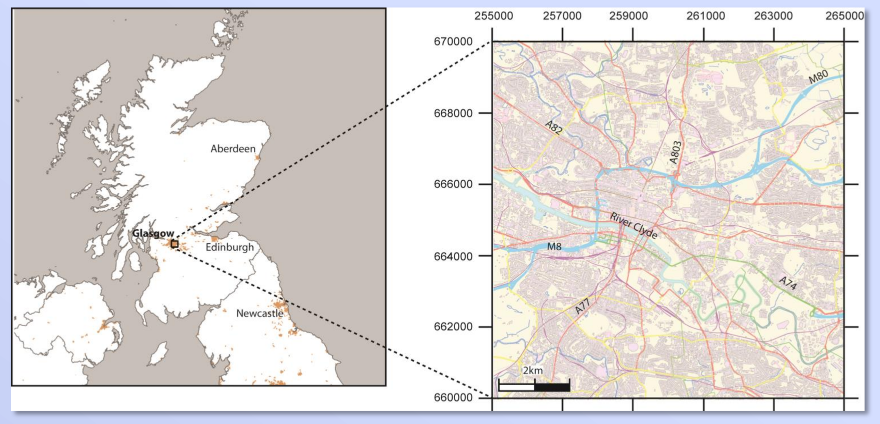
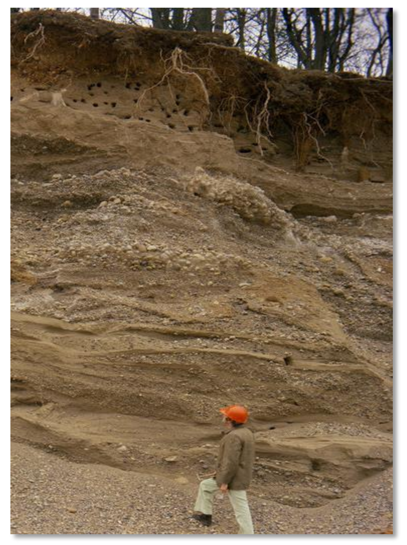


Figure 1.1 Area of this study a 10x10 km area in the centre of Glasgow, Scotland

2. Lithologies in glacial and fluvial deposits

Predicting lithology in sediments formed by glacial and fluvial processes is notoriously difficult. The lithostratigraphic units shown on maps and 3D models of glacial and post glacial deposits in Glasgow are substantially defined by the method of the formation and age of the unit rather than its lithological composition.

Figure 2.1 Glacial fluvial deposits in the Glasgow area



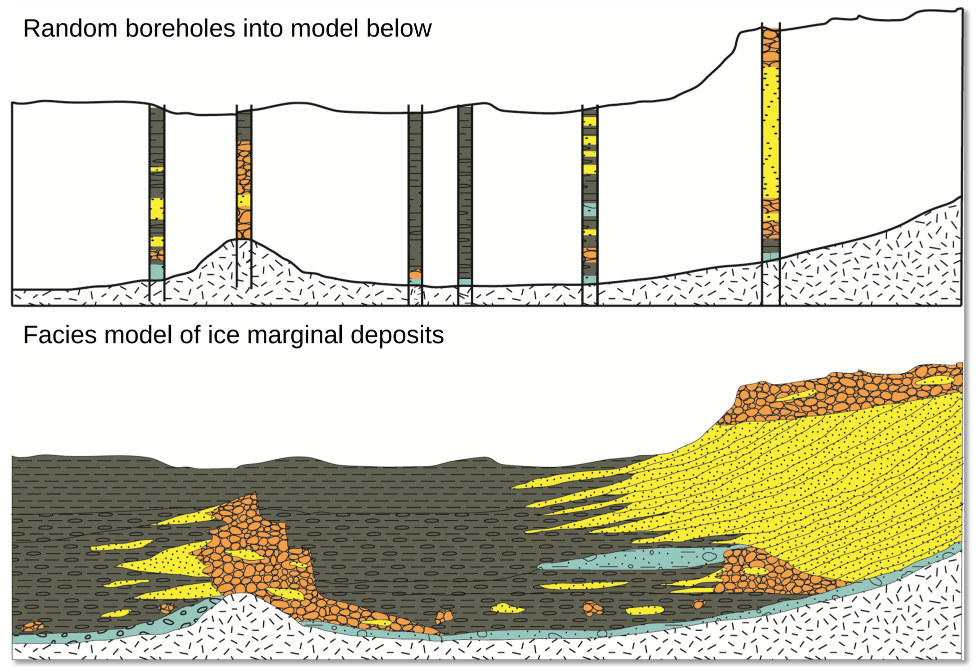


Figure 2.2 Given the variability of Glacial Fluvial deposits it can be hard to manually correlated boreholes (facies diagram adapted from Powell 1981)

3. Lithostratigraphy does not equal lithology

In Glasgow the BGS, in partnership with Glasgow City Council and other local authorities, have used extensive borehole datasets to develop and successfully apply a suite of 3D Quaternary lithostratigraphic models (Merritt et al., 2007; Campbell et al., 2010). A key strength of lithostratigraphic modelling is that it brings together the expertise of geologists and known geological relationships, enabling a geologically realistic representation, even where subsurface data are lacking. However, owing to the complex and heterogeneous nature of glacial deposits, lithostratigraphic modelling may not always represent the full subsurface variability that is of direct relevance to end-users, such as ground engineers or groundwater modellers.

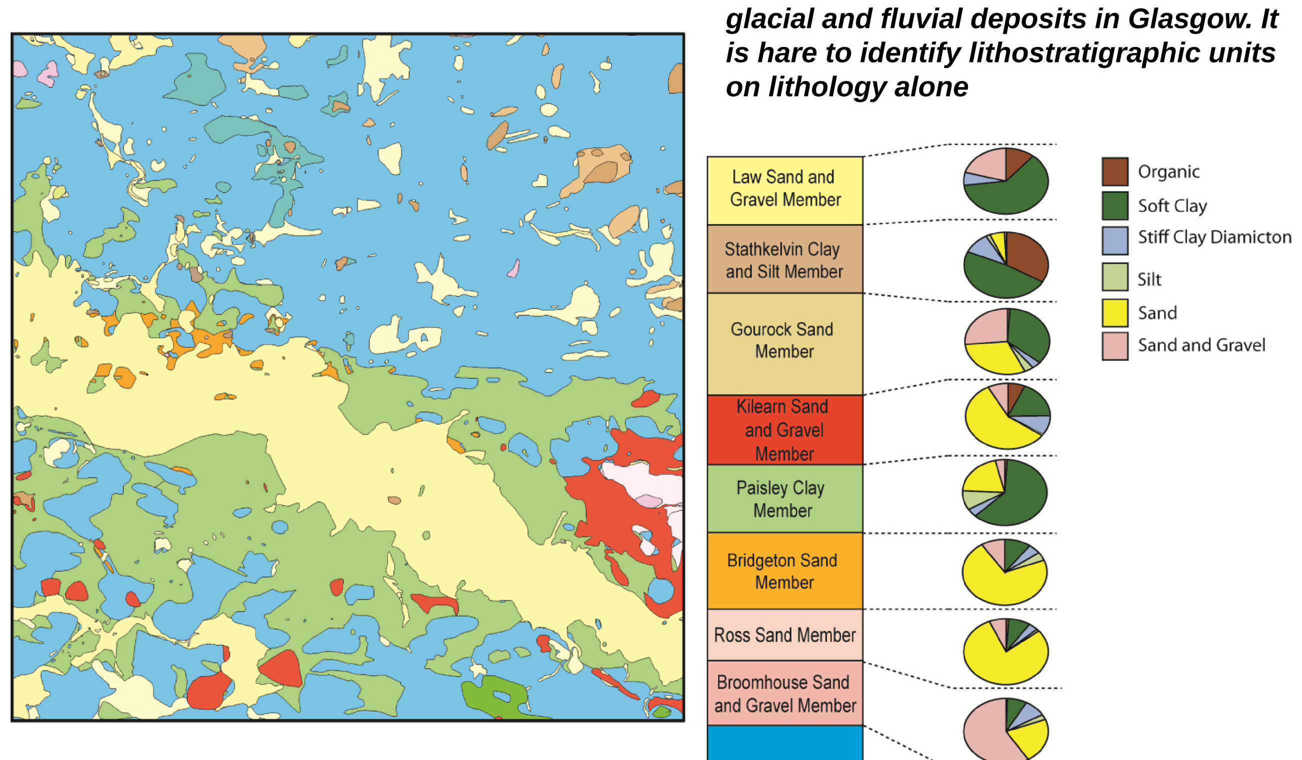


Figure 3.1 The lithological variability in glacial and fluvial deposits in Glasgow. It is hare to identify lithostratigraphic units based on lithology alone

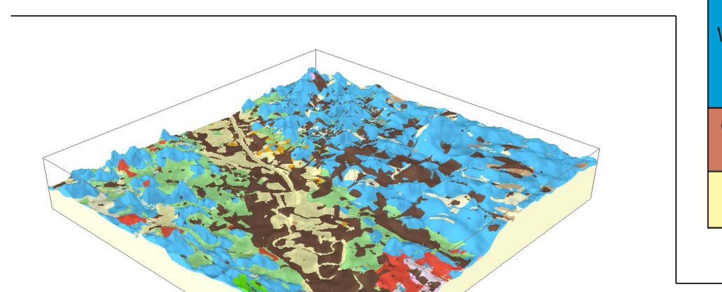


Figure 3.2 Lithostraigraphic 3D model. If a single lithology is assumed for each litostratigraphic unit based on the major component in the published lithostratigraphic description there is only a 54% match when compared against the borehole data used in this study.

4. Stochastic model input data

The dataset includes the logs of 4391 geotechnical boreholes and trial pits. These data were collected over a few decades for a variety of purposes by different contractors. 185 different lithological codes have been used to describe the Quaternary deposits seen in these boreholes – too many to include in a modelling exercise. These were reduced to 6 through a combination of analysis of the lithological description and consistency and particle distribution analysis.

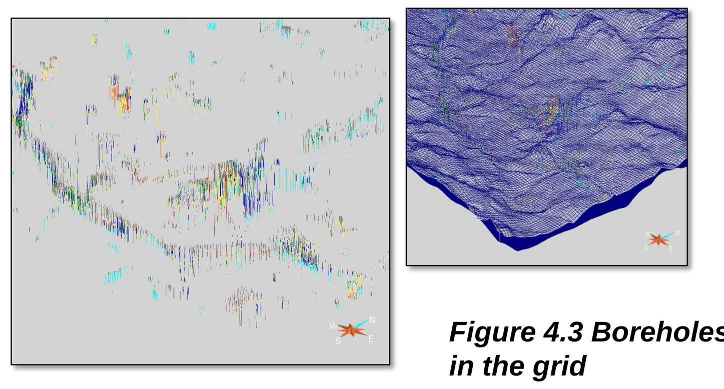


Figure 4.3 Boreholes in the grid

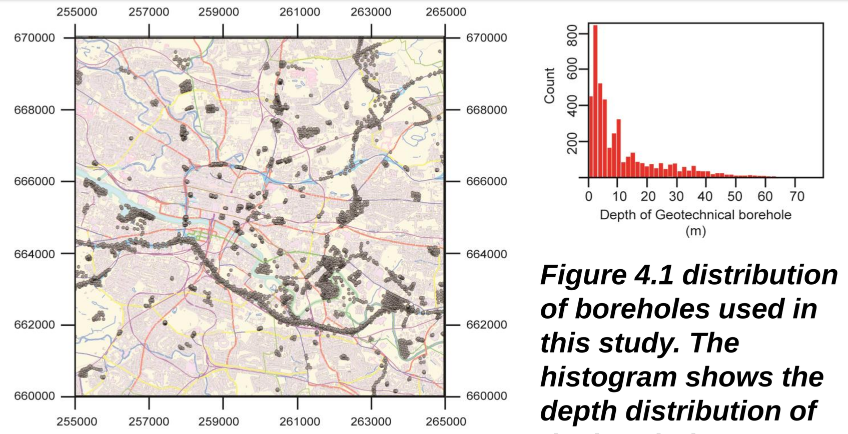


Figure 4.1 distribution of boreholes used in this study. The histogram shows the depth distribution of the boreholes

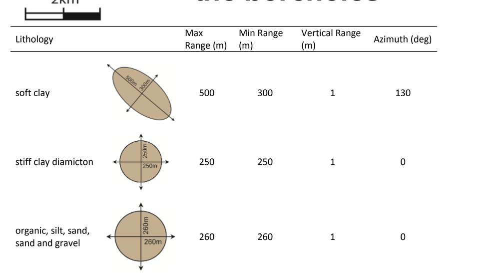


Figure 4.2 variograms used to control stochastic model

5. Investigating uncertainty in a stochastic model

There are different ways of stochastically modelling lithology. We test two different algorithms using the same input data; Indicator Kriging and Sequential Indicator Simulation.

The predictive ability of both the IK and SIS models was investigated by testing them against BGS boreholes that contributed to defining the published lithostratigraphy of the area (Figure 4.1).

The stochastic models were tested by excluding 50% of the input boreholes from the conditioning data, re-running the simulation and then comparing the result to the 50% boreholes that were removed. Using the 50% deletion test there was 0.23% difference between the two algorithms.

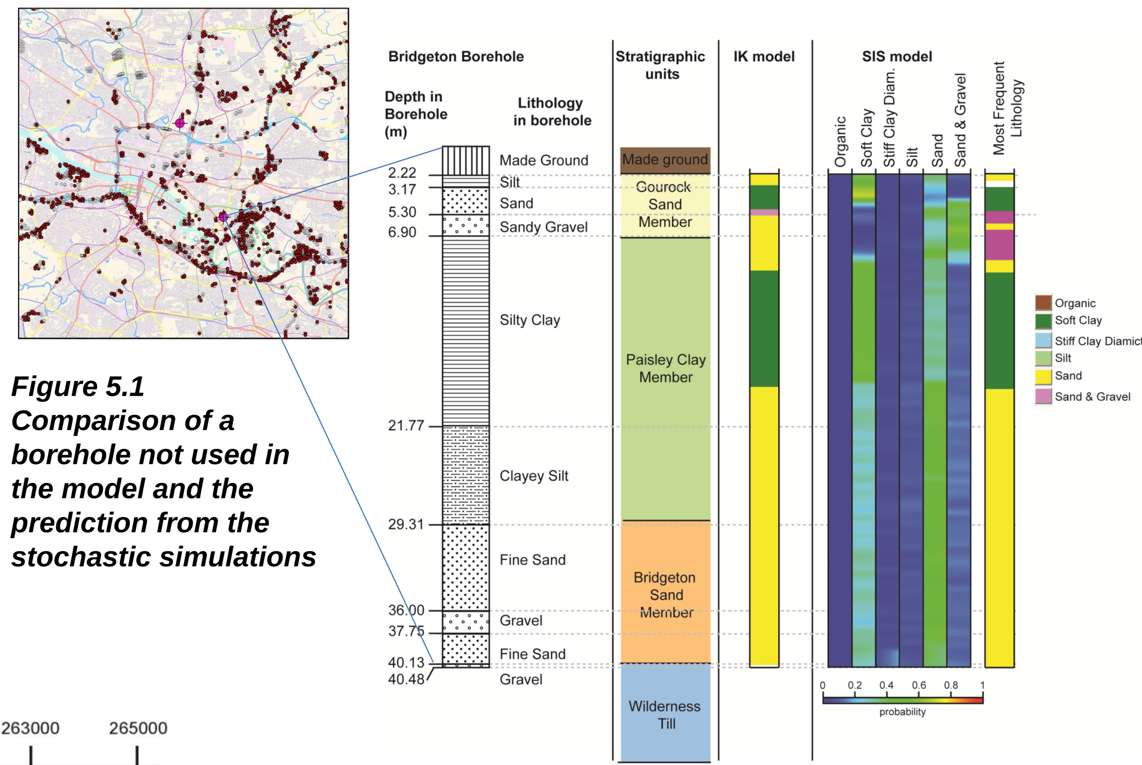
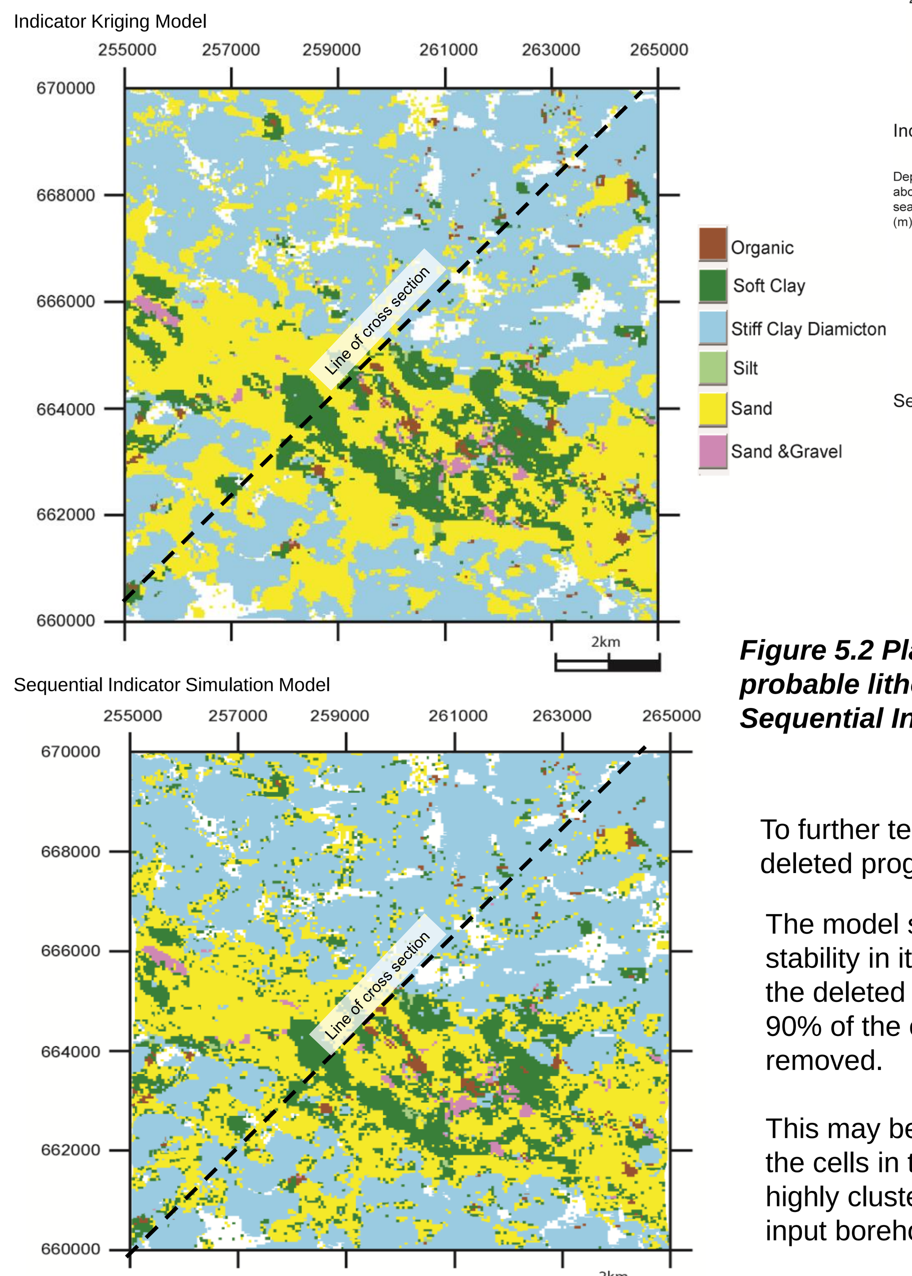


Figure 5.1 Comparison of a borehole not used in the model and the prediction from the stochastic simulations



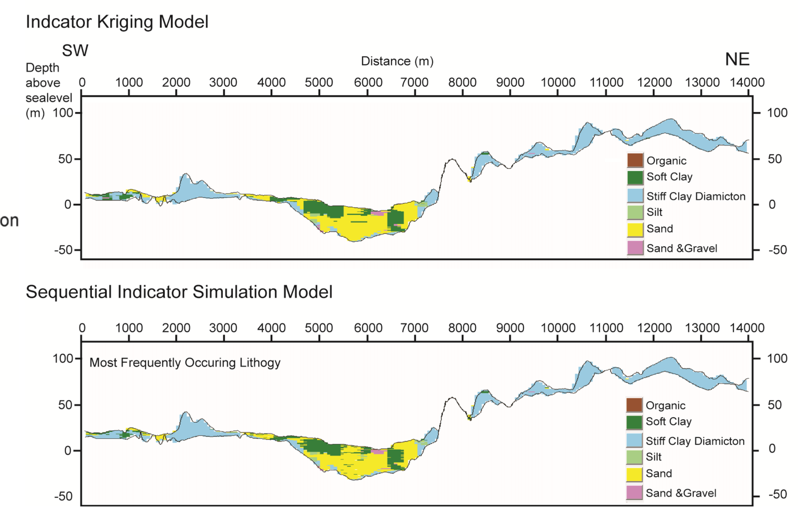
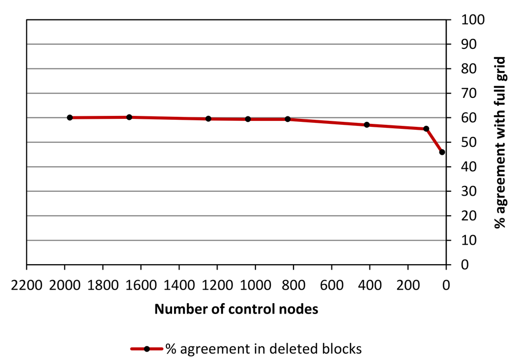


Figure 5.2 Plan and cross section views of the most probable lithology from the Indicator Kriging and Sequential Indicator Simulation models.

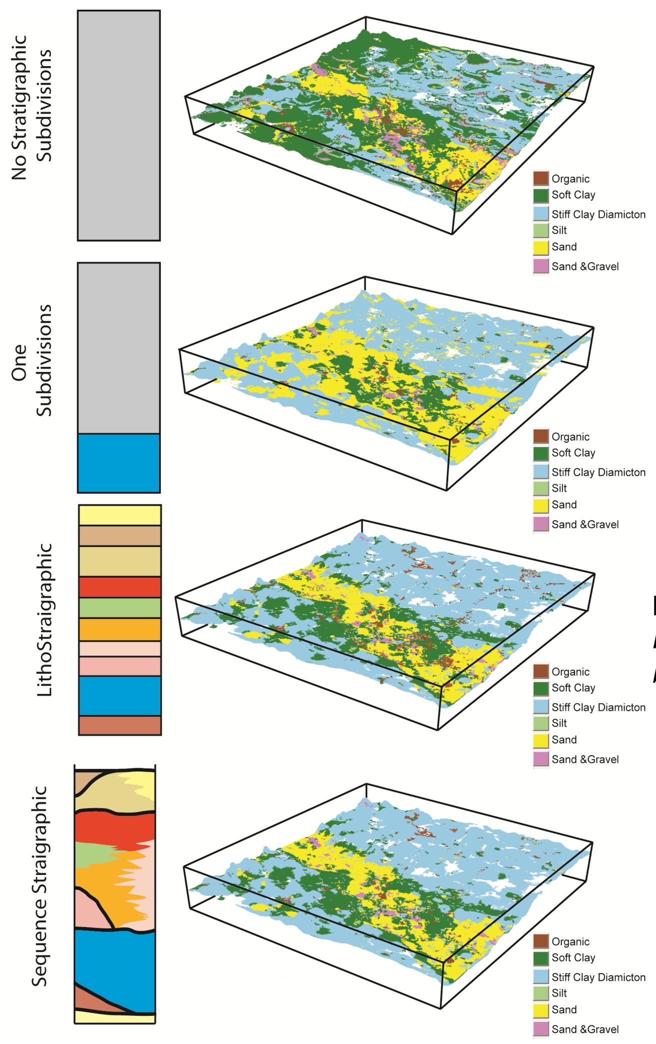
To further test the uncertainty of the stochastic model we deleted progressively more data from the model.

The model shows remarkable stability in its ability to predict the deleted data until over 90% of the control data was removed.

This may be due to the size of the cells in the grid and the highly clustered nature of the input boreholes.



6. How many stratigraphic surfaces do you need?



50% deletion test results

No lithological division
Percentage of correct results from the removed boreholes: ***56-57%***

Glacial and post glacial division (1 surface)
Percentage of correct results from the removed boreholes: ***59%***

Full lithostratigraphic division (10 surfaces)
Percentage of correct results from the removed boreholes: ***61%***

Sequence stratigraphic division (5 surfaces)
Percentage of correct results from the removed boreholes: ***61%***

Stratigraphic surfaces can be used to subdivide the stochastic grid and stop the lithologies from one part of the model communicating with those from other parts of the model.

We tested 4 different scenarios. Of the tests we undertook modelling the unconformity surfaces (the sequence stratigraphic approach) proved to the be the most predictive with the least amount manual modelling.

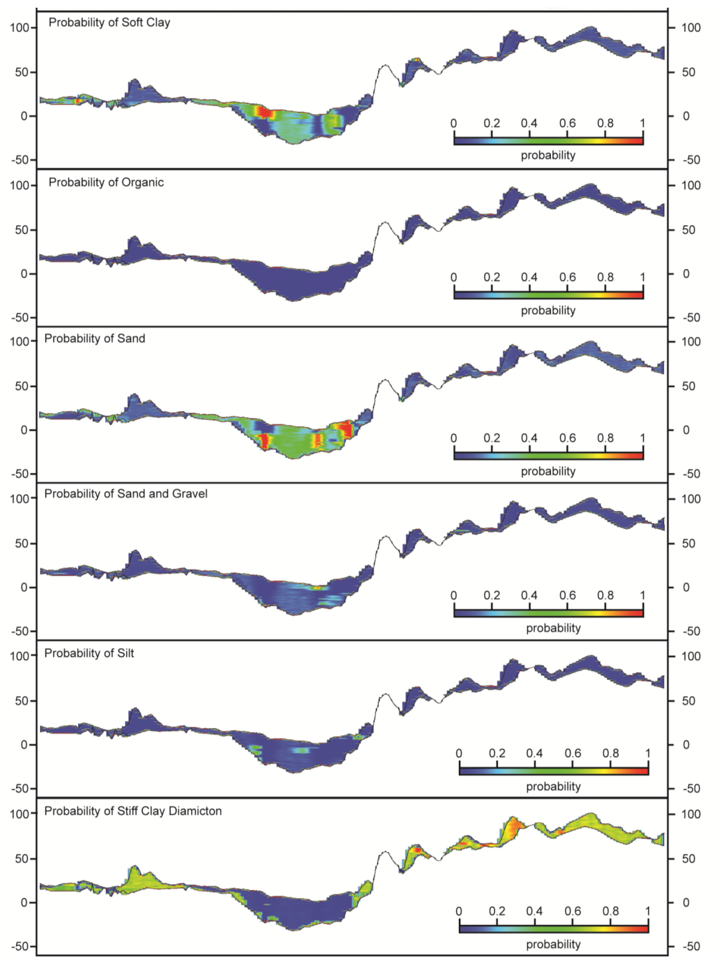
However, it is possible that due to the highly clustered nature of urban datasets ~60% predictability may be the upper limit of these models.

7. Best way to display the results of a stochastic simulation

Displaying stochastic model show the most probable lithology at any one cell in the grid does not differentiate those areas of the model where there is relatively low probability of any one lithology being present. We advocate that to represent this uncertainty it is better to show the probability of individual lithologies.

It is also important in any display of a 3D model to show the observational data (boreholes) used to create the model in the final delivery.

Figure 7.1 Cross sections showing the probabilities of each of the separate lithologies from 500 realisations of the Sequential Indicator Simulation.



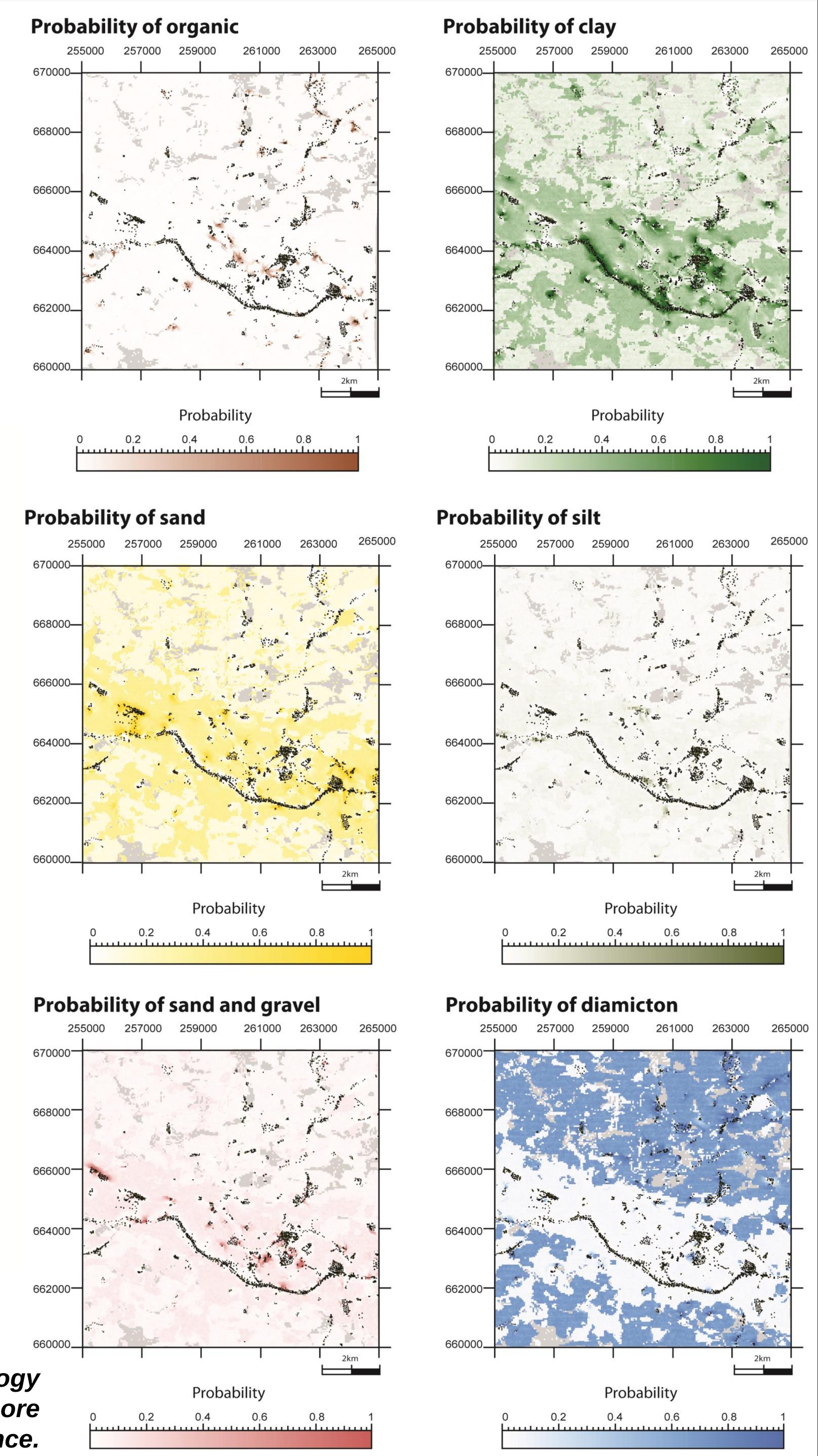


Figure 7.2 Probability maps of individual lithology coloured up in such a way that makes them more understandable to a non-technical audience.

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Powell, R. D., 1981. A model for sedimentation by tidewater glaciers. Annals of Glaciology, 2, 79-84.
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