

## Regional geochemical soil data as aid to the reconstruction of Mid-Pleistocene ice flows across Central and Eastern England

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**ABSTRACT:** Principal component analysis of high-density, regional soil geochemical data was used to reveal element associations within Mid-Pleistocene glacial till deposits across Central and Eastern England. Results have helped to characterise tills by their geochemical composition at a regional scale, leading to a better understanding of, (i) which parent materials tills have been derived from, (ii) sediment transportation paths and flow trajectories of the British Ice Sheet, and (iii) the evolution of the British Ice Sheet during the Mid-Pleistocene.

**KEYWORDS:** *Soil geochemistry, glacial till deposits, PCA, ice flow reconstruction*

### INTRODUCTION

Tills are the most difficult superficial deposits to interpret and classify, but are crucial to the reconstruction of former glaciations and understanding the coupling between ice sheet behaviour and climate change (Evans, 2007). Geochemical surveys of tills in Finland and Canada have successfully demonstrated that geochemical data contain vital information for refining glacial stratigraphy, determining till sediment provenance, and reconstructing ice flow trajectories (McClenaghan *et al.*, 1992; Klassen, 2001; Sarala, 2005). Anglian-age (c. 450 ka) glacial deposits of Central and Eastern England are complex and have been studied in various detail, but studies have not yet utilised the vast resource of high-density soil geochemical data held by the British Geological Survey (BGS). The aim of this study was to investigate the potential of this regional soil geochemical data help to characterise and classify glacial till deposits as well

as to reconstruct glacial flow trajectories and its sediment sources. This was tested by using multivariate principal component analysis (PCA), which is a helpful means to manipulate and interpret multi-element geochemical data as shown by Grunsky and Smee (1999) and Ali *et al.* (2006).

### MATERIALS AND METHODS

#### Study area and data

The study benefits from access to a geochemical database containing analytical data from ~ 27,500 soil samples collected since 1986 by the Geochemical Baseline Survey of the Environment (G-BASE) (Johnson *et al.*, 2005). The area presented in this study covers more than 40,000 km<sup>2</sup> of Central and Eastern England (Fig.1). Soils were collected at a density of one sample every two km<sup>2</sup> of the British National Grid (BNG). At each site, samples were collected, from (5-20 cm) and (35-50 cm), of which latter were used in this study. Each sample

comprising a composite of material of five sub-samples collected at the corners and centre of a 20 m square. A more detailed account on the sampling procedures used and sample preparation can be found in Johnson *et al.* (2005). Major and trace element determinations were carried out by X-ray fluorescence spectrometry (XRFS) giving a range of up to 53 elements. However, this study used only 25 elements (Ba, Ca, Co, Cr, Cu, Fe, Ga, K, La, Mg, Mn, Mo, Nb, Ni, P, Pb, Rb, Sn, Sr, Ti, U, V, Y, Zn and Zr) as some elements were excluded on quality issues. Prior to PCA, analytical data were log-transformed, as investigated by Reimann *et al.* (2002).

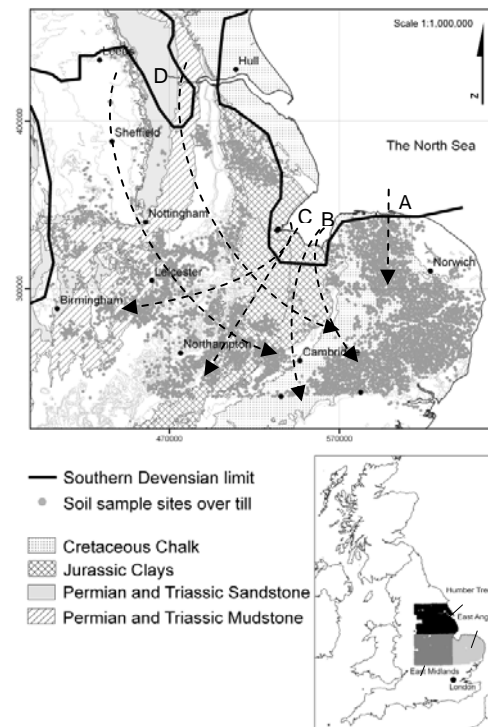
A spatial join of the analytical data with BGS DiGMapGB-50 Superficial Geology returned data for ~ 4,700 soil samples, which had been collected over glacial till deposits (Fig.1) of Mid-Pleistocene, Anglian age.

### Geological setting

Central and Eastern England is almost entirely underlain by sedimentary rocks that young from west to east. Four major geological sub-divisions are presented in Figure 1. Permian and Triassic mudstone and sandstone dominate the East Midlands and parts of Yorkshire; Jurassic clays crop out within the centre of the study area and Cretaceous chalk underlies most of Central East Anglia.

Figure 1 shows the distribution of sample sites located directly over Anglian till deposits, covering approximately a quarter of the study area. North of the Devensian limit (also known as Dimlington re-advance) occur younger till deposits of the Devensian glaciation. More than half of the sample sites were located over diamictons of the Lowestoft Formation (LOFT) of East Anglia. The remaining tills are classified as Mid-Pleistocene diamictons (TILMP), and the Oadby Till (ODT) and Thrussington Till (THT) members of the Wolston Formation in the Midlands. Several possible ice flow scenarios could account for the spatial

and lithological distribution of these tills (Perrin *et al.*, 1979).



**Fig. 1.** Distribution of soil sample sites collected over glacial till deposits, ice flow scenarios (A to D) and main bedrock strata of the study area.

Ice trajectory scenarios are A) ice flowing southwards from the North Sea Basin and into northern East Anglia, B) ice flowing into East Anglia and East Midlands through The Wash Basin radiating to the east and C) west. The fourth scenario (D) describes ice moving down from northern Central England into the Midlands in southerly direction and then radiating into East Anglia.

### RESULTS

PCA is a popular approach for analysing large multi-element datasets for two reasons. Firstly, the reduction of the number of variables to form a small number of independent principal components and secondly, the creation of more interpretable combined variables (Ali *et al.*, 2006). The analysis was carried out using a correlation matrix in order to reduce the effects of magnitude that are

attributed to elements such as Ca, Fe, K and Mg (Grunsky and Smee, 1999). A total of 15 principal components were calculated until 95 % of the variance was explained. Eigenvalues returned from PCA were plotted in a scree plot (Fig. 2), which gives an indication as to the significance of the derived PCs (Grunsky and Smee, 1999).

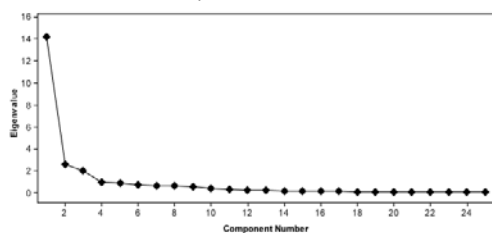


Fig. 2. Scree plot of eigenvalues

PCs with high eigenvalues are assumed to best represent the geochemical variability and characteristics of the data. Components 4 and higher returned Eigenvalues below 1.0 and were excluded from further interpretation, as discussed by Mandal *et al.* (2008).

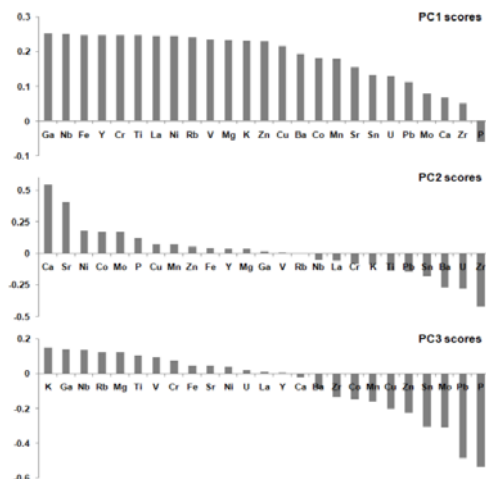


Fig. 3. Score loadings for PC1 to 3

PC1 represents 57% of the total variance of the data with an eigenvalue of 14.2. PC2 accounts for a further 10 % and PC3 for 8.0% of the total variance with eigenvalues of 2.6 and 2.0 respectively.

Element loadings of the first three PCs are displayed in Figure 3. PC1 includes all selected elements with only P being

inversely related. Loadings of PC2 present a much clearer variation in the data and correspond to Ca-Sr association, thought to be related to limestone and chalk bedrock.

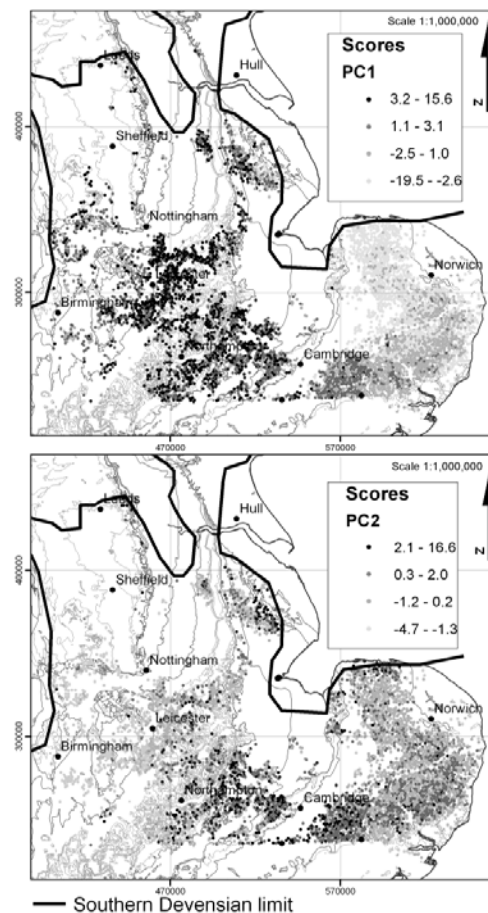


Fig. 4. Spatial distribution of PC1 and PC2 loading scores across Central and Eastern England.

Positive loadings of K, Ga and Nb in PC3 are indicators for clay rich soils. Negative loadings correspond to heavy metals and may indicate an anthropogenic component. Figure 4 displays spatial distribution of scores of PC1 and PC2. High scores of PC1 are mainly located over the East Midlands area, whilst the northern half of East Anglia, with low or negative scores, appears relatively deficient in these elements. High scores of PC2 are located between Northampton and the east of Cambridge, south of the Humber estuary at Hull and along the

northern coastline of East Anglia. Tills in these areas were derived from calcareous and Sr-bearing strata, most likely Cretaceous Chalk (Fig. 1).

## CONCLUSIONS

This study is in progress and gives only preliminary results. However, the application of multivariate analysis has already highlighted various geochemical characteristics and associations within soils collected over Mid-Pleistocene tills. Findings can be summarised as:

(1) Regional geochemical soil data can provide vital information on the composition and provenance of glacial till deposits in Central and Eastern England.

(2) PCA has highlighted some clear regional divisions within the tills, especially between the East Midlands and East Anglia

(3) Ice flow scenario A is unlikely. Scenarios B and C have occurred mainly in a southerly direction, carrying chalky material and possibly overriding earlier ice flow D.

(4) To classify tills, most significant indicator elements are Ga, Mg, K, Rb, Ca, Sr and P.

(5) Further investigation should involve the integration of lithological and grain-size data as well as other methods of data analysis.

## ACKNOWLEDGEMENTS

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