Investigating the use of geochemical signatures in glacial tills as a means of identifying ice margins and ice flow direction

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Numerous attempts have been made to constrain the maximum extent of the late Devensian British-Irish ice-sheet (18-25 ka BP) through mapping ice-marginal landforms, e.g. end moraines and lateral meltwater channels. However, in the south-west Pennines (Figure 1) geomorphological signatures are unclear and uncertainty remains regarding the location of the ice margin with five different ice limits for the Late Glacial Maximum having been proposed by previous authors (Figure 2). This has implications for understanding the retreat of ice sheets and the complex engineering solutions required when working in formerly glaciated terrain. This project focusses on the analysis of till geochemistry in order to determine whether it can assist in the identification of former ice limits in inland locations where the geomorphological signatures are absent or unclear.

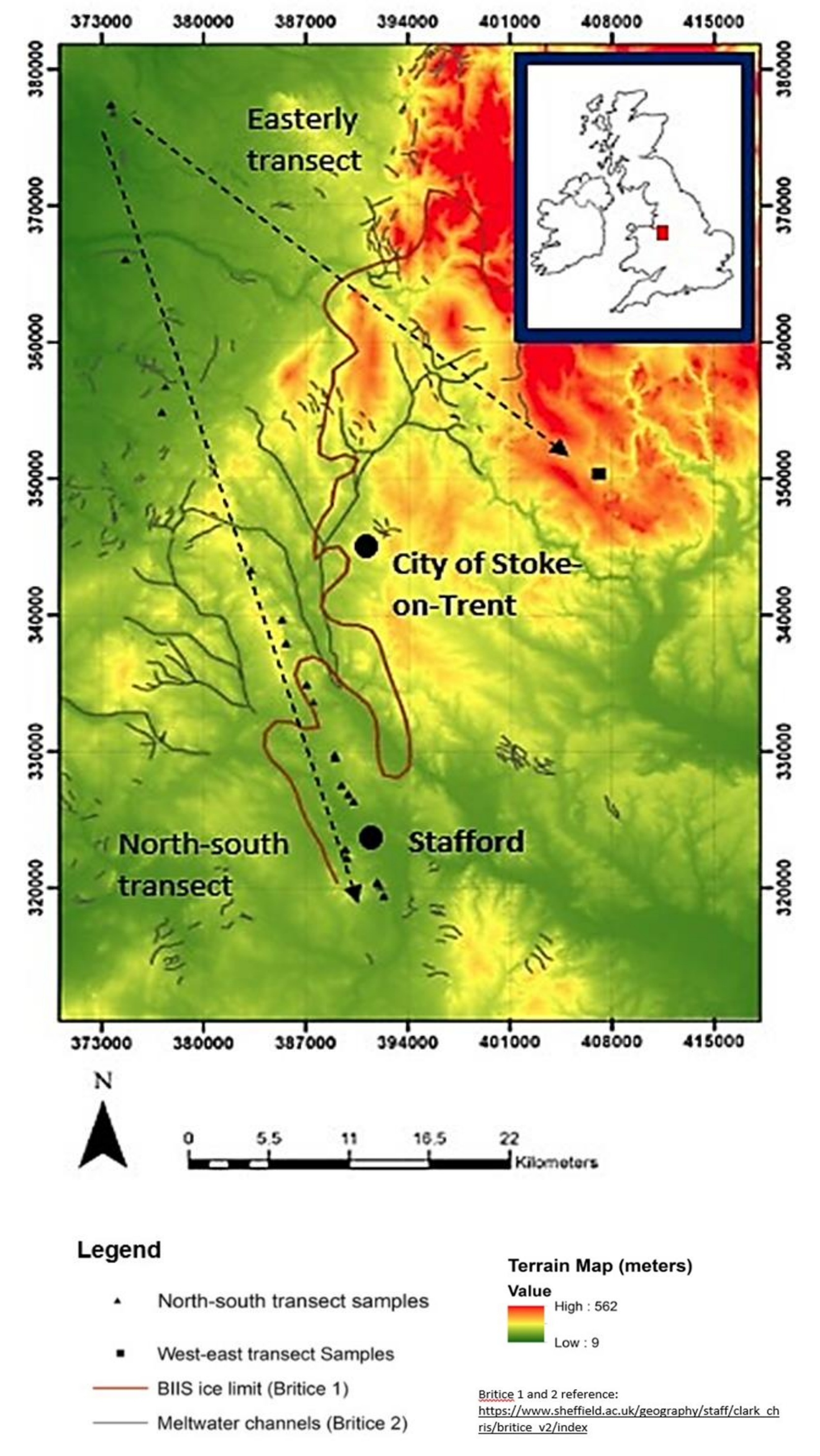

Figure 1: Study Location (*n*=54 till samples)

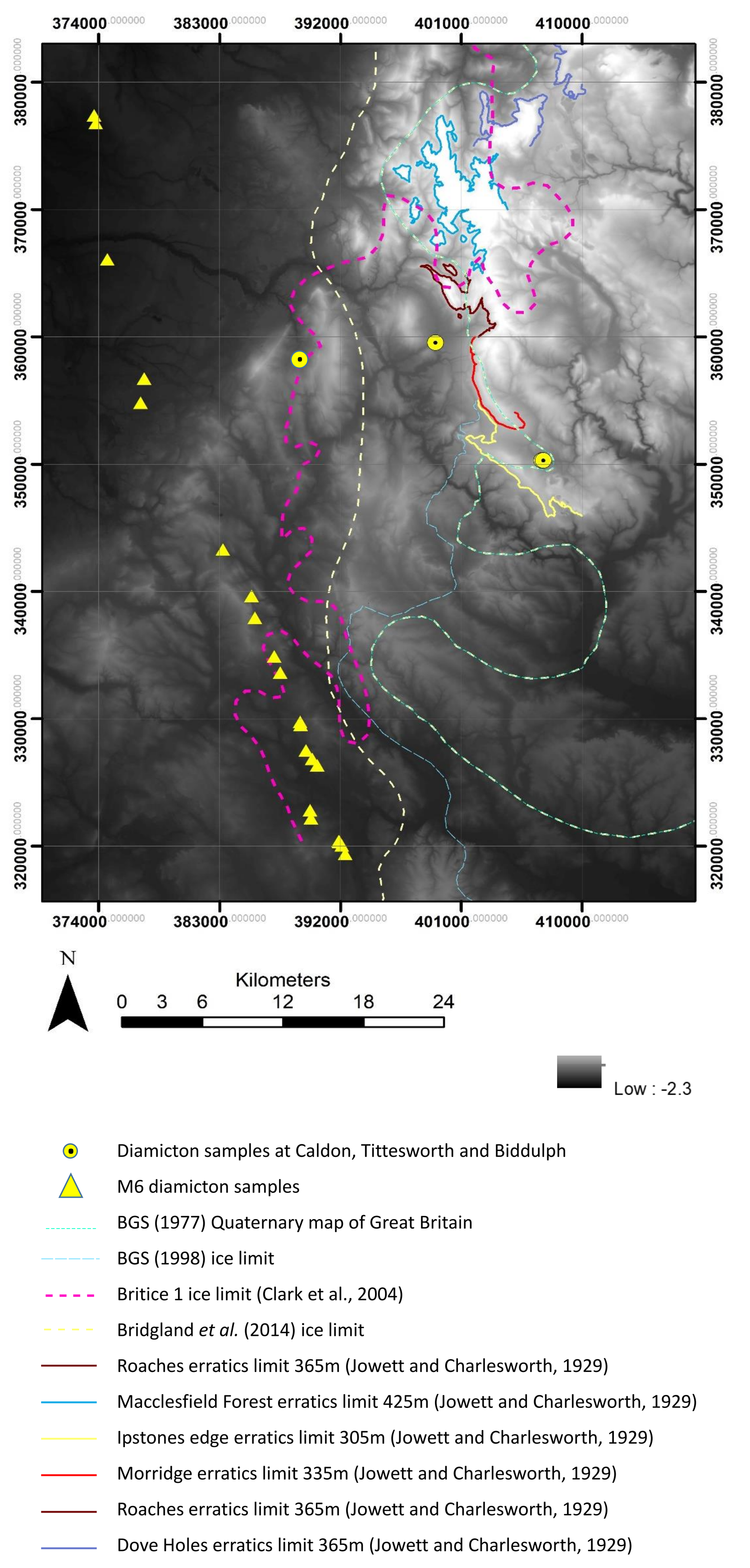

Figure 2: Mapped 'Devensian' till deposits and erratic limits

1:25 000 Scale Colour Raster [TIFF geospatial data], Scale 1:25000 and OS Terrain 5 [XYZ geospatial data], Scale 1:10000 (2018) Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service. Maps created in ArcGIS 10.2.2

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Statistical analysis and plots created using:
The jamovi project (2021). jamovi. (Version 1.8) [Computer Software]. Retrieved from https://www.jamovi.org.
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Geochemical analysis of glacial tills

Major element analysis was carried out on 54 sediments from 14 different boreholes along the M6 in the Cheshire Plain, with some boreholes providing multiple samples to a maximum depth of 15 m below ground level. Three sites in the southwest Pennines were also analysed (Figure 2).

Multivariate statistical analysis

A number of different multivariate methods were used to investigate the difference between the till samples (Figures 3-7) with the aim of finding out whether the boreholes contained homogenous sediments at all depths, or evidence of variation in geochemistry which could be attributed to ice flow direction and source area lithology.

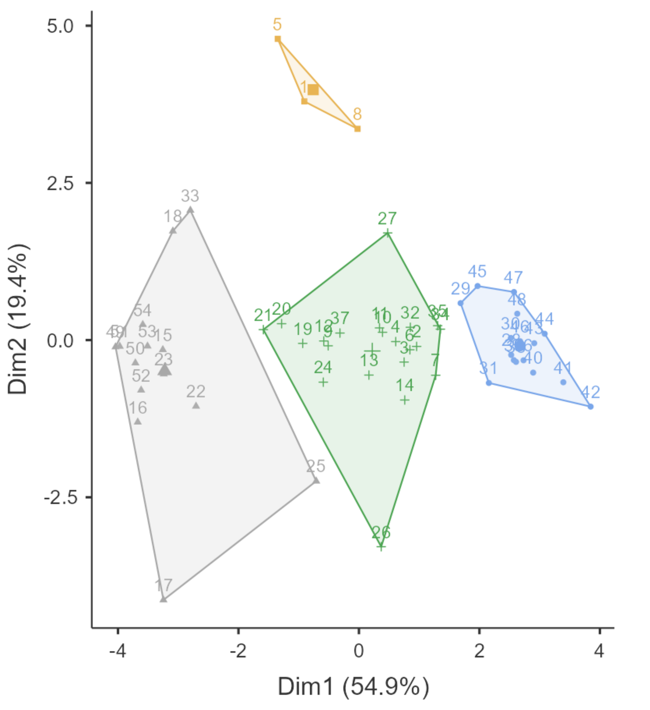


Figure 3: K-means cluster plot (Lloyd algorithm) identified four clusters as being optimal. Numbers represent individual samples (*n*=54). K-means clustering aims to identify unknown groups in complex datasets.

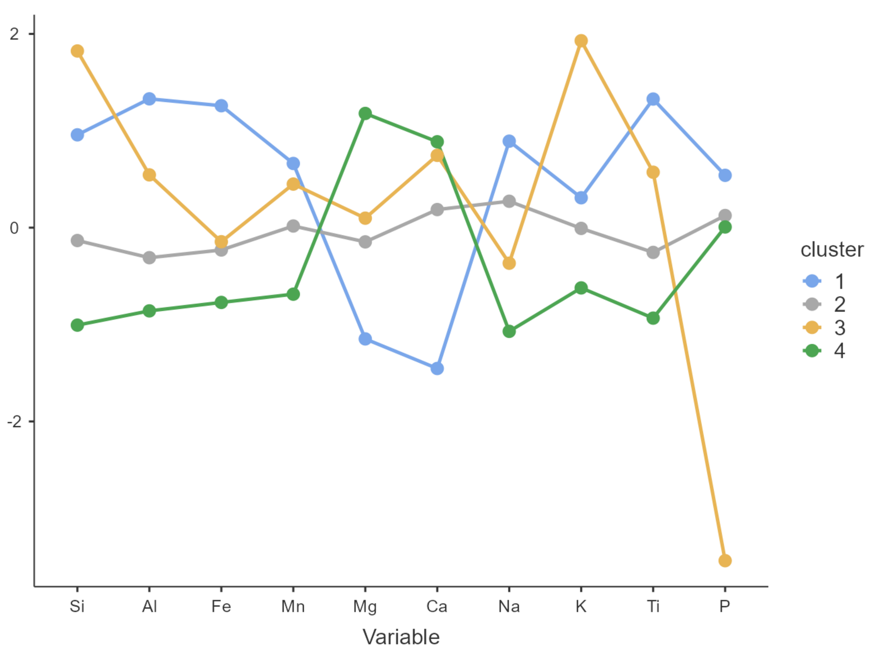


Figure 4: K-means cluster plot of standardized means (center log-ratio transformed data). Illustrates a strong inverse relationship between Mg and Ca in clusters 1 and 4. Cluster 3 contains low P, but high levels of Si and K.

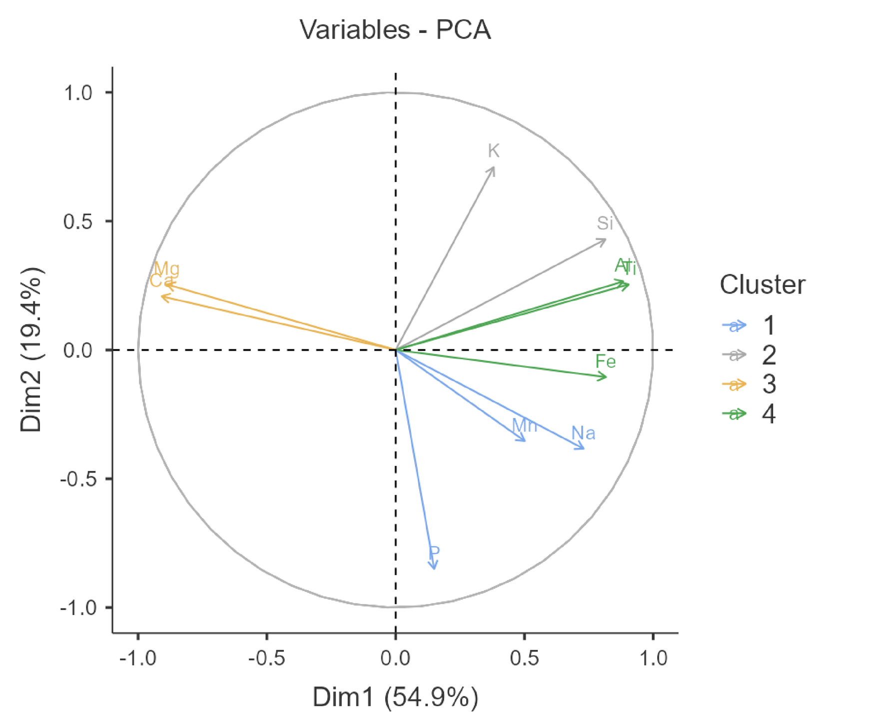


Figure 5: Principal Component Analysis. The PCA scree plot identified four clusters as being significant. PC1 (Dimension 1) accounts for 54.9% of the variance; PC2 (Dimension 2) for 19.4%. PC3 and PC4 (not shown) account of 9.6% and 9% respectively. PCA analysis captures the data showing the most variation in a dataset.

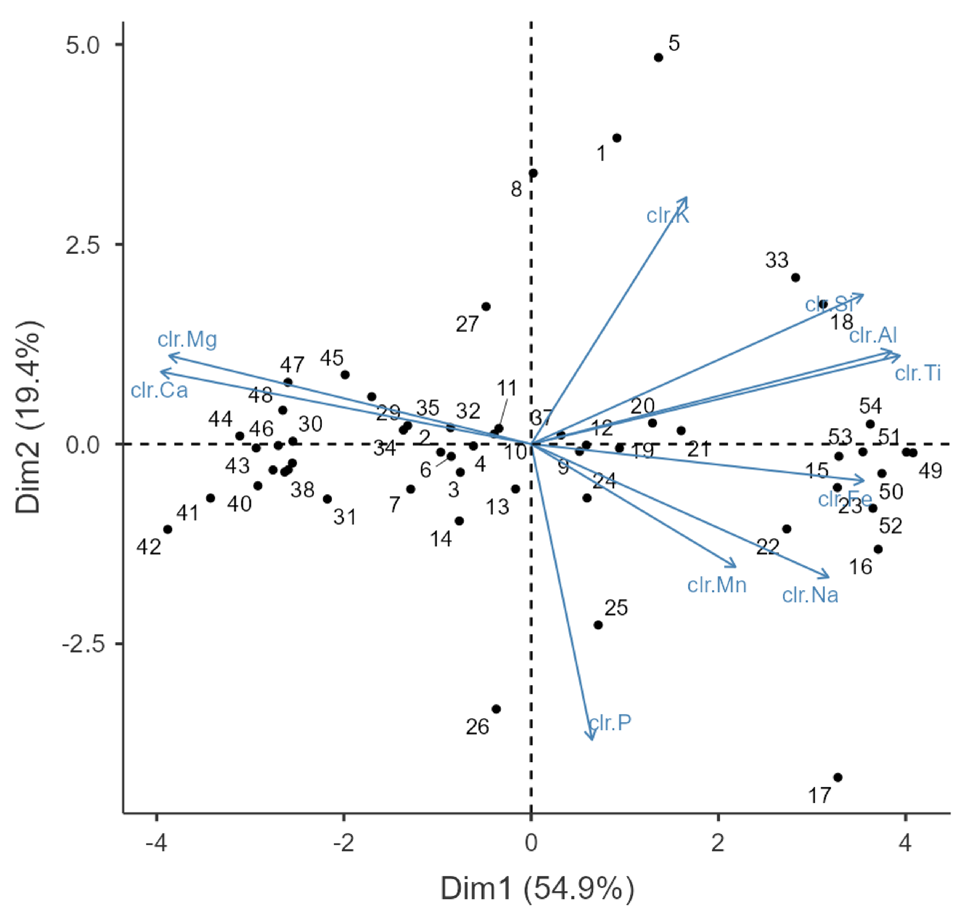
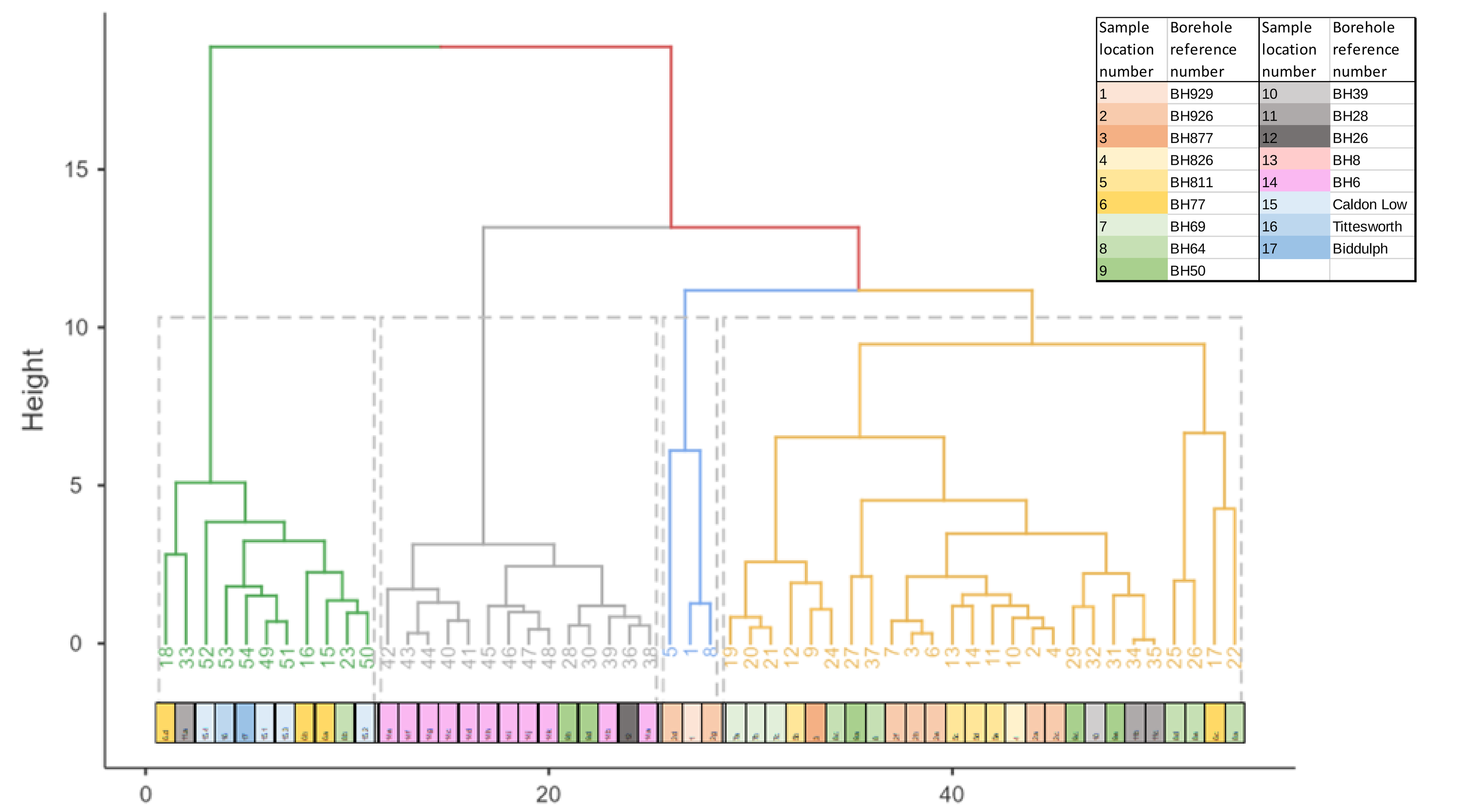


Figure 6: PCA Biplot. Plots the sample number in relation to PC1 (Dimension 1) and PC2 (Dimension 2). Some consistencies can be seen with the results of the cluster dendrogram (e.g. samples 1,5 and 8).



Sample location number	Borehole reference number	Sample location number	Borehole reference number
1	BH929	10	BH39
2	BH926	11	BH28
3	BH877	12	BH26
4	BH826	13	BH8
5	BH811	14	BH6
6	BH77	15	Caldon Low
7	BH69	16	Tittesworth
8	BH64	17	Biddulph
9	BH50		

Figure 7: Hierarchical cluster dendrogram. Based on 4 clusters determined from the eigenvalue scree plot (Ward's method). Colours beneath the dendrogram relate to location. Samples from all depths in an individual borehole are plotted in the same colour. It is apparent that some boreholes (e.g. 14) contain similar geochemical compositions at all depths whilst others (e.g. 7) show variability. Cluster analysis aims to illustrate similarities between samples.

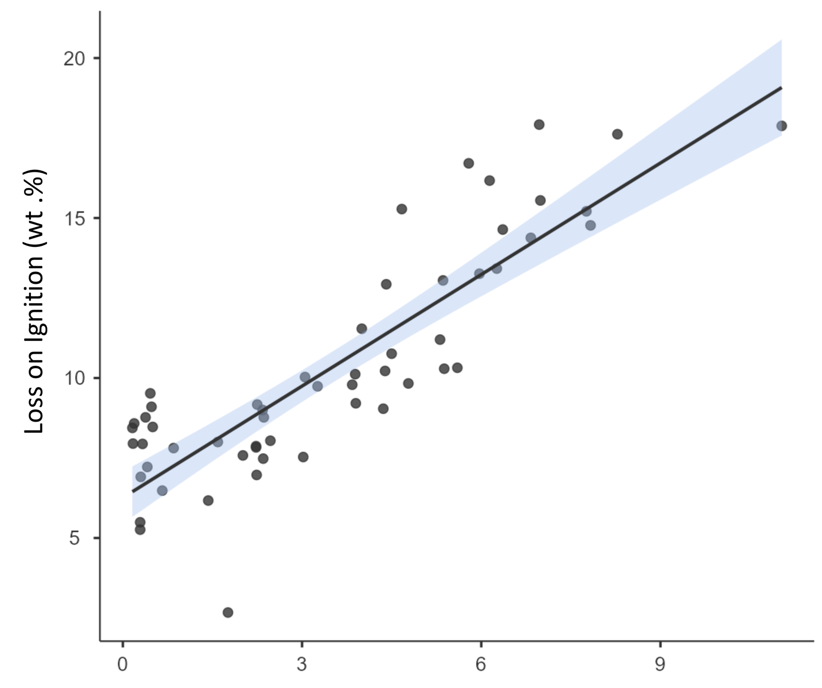


Figure 8: Scatterplot Loss on Ignition vs CaO. The positive correlation indicates the presence of carbonate in some of the samples, indicating limestone or dolomite influence.

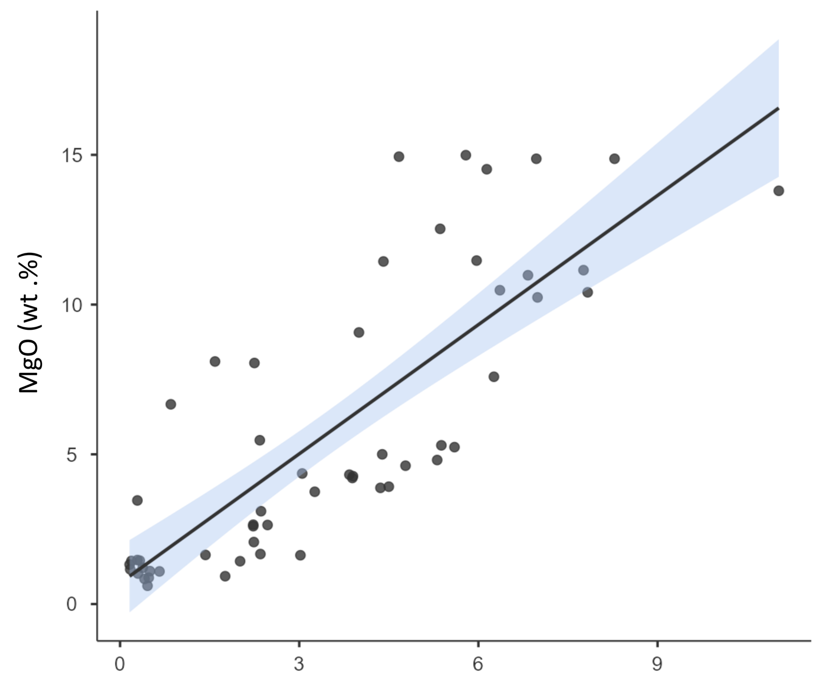


Figure 9: Scatterplot MgO vs CaO. The positive correlation indicates the presence of dolomite [$CaMg(CO_3)_2$] in some of the samples, indicative of ice flow direction from bedrock.

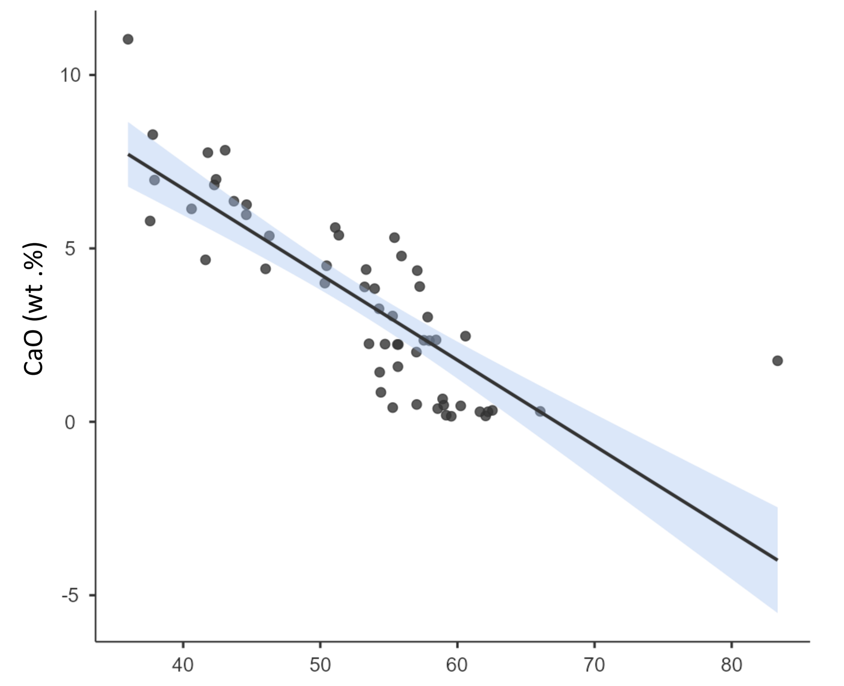


Figure 10: Scatterplot CaO vs SiO_2. The negative correlation indicates that samples with high carbonate content have lower abundances of SiO2-bearing minerals such as quartz.

This initial analysis has identified a number of boreholes containing homogenous sediments at all depths, and also those showing a distinct geochemical difference within the borehole. It also clearly determined a spatial variation in geochemistry related to the input of different lithologies into the sediments (Figures 8-10), indicating that the method can be used to identify ice flow direction and source area lithology.

Next steps to consider
- **analysing the trace elements with PCA**
- **analysing the rare earth elements with PCA**
- **identifying the most suitable visual images for sample discrimination and provenance characterisation**