The application of regional-scale geochemical data in defining the extent of aeolian sediments: the Late Pleistocene loess and coversand deposits of East Anglia, UK

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Introduction

The ‘European Coversand Sheet’ is a discontinuous ‘sheet’ of aeolian (windblown) loess and coversand that extends through eastern and southern England, across the English Channel into northern France, Belgium and the Netherlands (Kasse, 1997; Antoine *et al*., 2003). Whilst some of the earlier aeolian sediments date from the Middle Pleistocene, most correspond to the Late Pleistocene Weichselian / Devensian and earliest Holocene stages. East Anglia contains considerable accumulations of aeolian sediment. Although several valuable studies have attempted to determine the spatial extent of aeolian material (e.g. Catt, 1977, 1985), defining their margins has proved largely difficult because aeolian material is highly susceptible to reworking and removal by various natural and anthropogenic agents.

Within this study, we use regional-scale geochemical data from soils to reconstruct the extent of aeolian sediments in East Anglia. A specific geochemical signature, defined by elevated concentrations of Hafnium (Hf) and Zirconium (Zr), is strongly characteristic of soils developed on aeolian deposits within the United States, China, Europe and New Zealand (Taylor *et al*., 1983). The data suggests that the approach is sufficiently sensitive to identify a residual aeolian component within soils even where deposits may be thin and un-mappable by conventional methods, or if the material has been largely eroded.

Extent of aeolian deposits in East Anglia

During the Late Pleistocene glacial period, East Anglia lay largely beyond the southern limit of the British Ice Sheet, with ice impinging on the north Norfolk coast between Cley and the eastern fringes of the Wash Basin (Straw, 1960; Brand *et al*., 2002; Riding *et al*., 2003; Pawley *et al*., 2006). Although much of East Anglia wasn’t glaciated, it was subjected to intense periglacial processes that resulted in the localised generation of patterned ground and other periglacial phenomena such as pingos and palsa (West *et al*., 1974; French, 1996; Murton, 2009; British Geological Survey, 2010).

Aeolian sediments were also deposited across parts of East Anglia and these form accumulations of loess, coversand and drift sands with related dune systems (Chorley *et al*., 1966; Bateman, 1995; Hoare *et al*., 2002) (Figure 1). The distribution of these aeolian deposits in East Anglia, determined from detailed examinations of particle size and mineralogical properties of soils, was previously defined by Perrin *et al*. (1974) and Catt (1977, 1985) and placed into a European context by Antoine *et al*. (2003). Loess material consists mostly of silt size particles and requires a sustained source, adequate wind energy to transport the material and a suitable accumulation site (Pye, 1995). According to previous work, it is distributed across northeast and east Norfolk, and southern Suffolk and Essex where it is typically less than 2 metres thick. Coversand by contrast, is composed of fine sand grade material and is distributed across the Breckland of west Norfolk (Figure 1) and the eastern part of the Fen Basin (Bateman, 1995). Radiometric age determinations demonstrate several distinctive phases of coversand accretion and dune mobility spanning the Devensian and Holocene periods (Bateman and Godby, 2004; Clarke *et al*., 2002; Hoare *et al*., 2002; Hitchens, 2009).

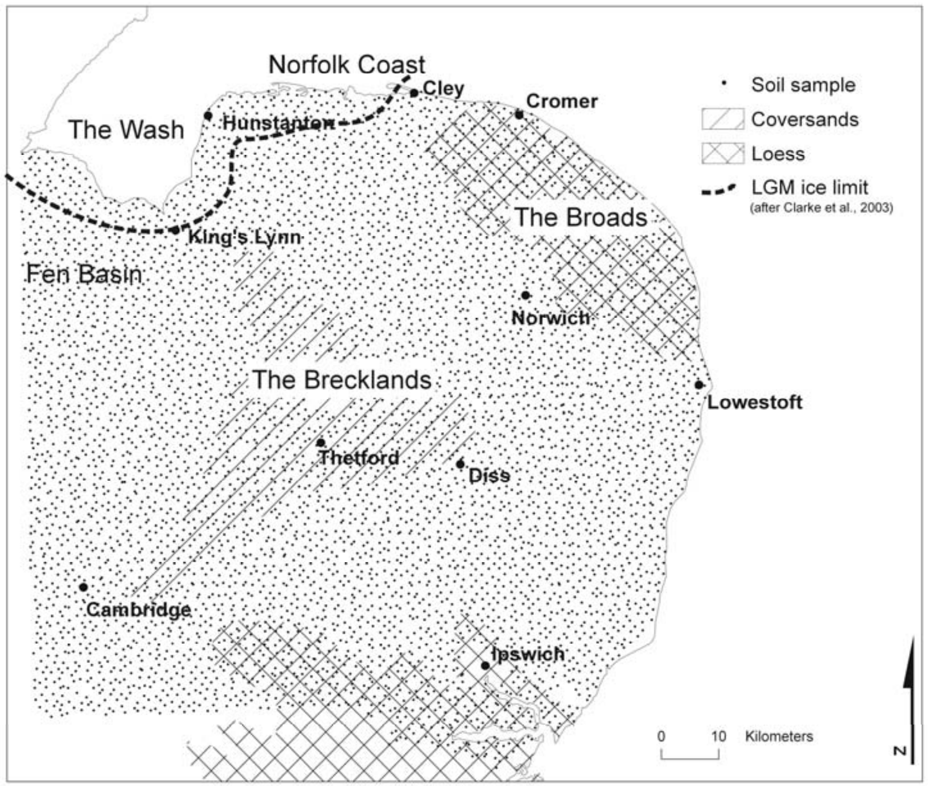

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Figure 1: Location map of the study area indicating G-BASE soil sample sites and the extent of loess and coversand deposits based on Catt (1977, 1985) and Antoine et al. (2003).

Soil Geochemical data

Sampling and analysis

In this study we examine soil geochemical baseline data from East Anglia. These data were generated as part of the British Geological Survey's Geochemical Baseline Survey of the Environment (G-BASE) between 2000 and 2004. In this study we used geochemical data from 5745 topsoil samples, which cover an area of some 11,000 km^2 (Figure 1) at 2 km^2 resolution (Johnson *et al*., 2005). Two samples were collected from each site representing topsoil (5-20 cm depth) and profile soil (35-50 cm depth).

Each sample comprises of a composite of five sub-samples collected at the corners and centre of a 20 m square. Samples were collected using a hand held Dutch soil auger. Within the laboratories, soil samples were dried and sieved to < 2 mm, sub-sampled and pulverised in agate ball mills, then pelletised. Major and trace elements were determined by dispersive wavelength (WD) and energy dispersive (ED) X-ray fluorescence spectrometry (XRFS) for up to 53 major and trace elements. Duplicate and replicate samples and primary and secondary reference materials were all included in every batch of 100 samples submitted for analysis. These control samples are required to assess the data quality, in particular precision and accuracy of the data. Analytical data underwent a series of data conditioning procedures involving levelling data between analytical batches to ensure seamless geochemical maps (Johnson *et al*., 2008).

Geochemistry of Hafnium (Hf) and Zirconium (Zr)

Hafnium, atomic number 72, has six naturally-occurring stable isotopes, of which ^{177}Hf, ^{178}Hf and ^{180}Hf, are the most abundant and with ^{180}Hf accounting for 35% of the mass. It is a fairly low-abundance lithophile metal, present at a concentration of about 5.8 mg/kg in the upper continental crust and is the third-row equivalent of Zr in the Periodic Table. Since it possesses similar properties of ionic radius and oxidation state, its behaviour is almost identical, although it is less naturally abundant. Consequently Hf occurs in the same minerals as Zr. The Hf:Zr ratio is usually around 2 %.

Zirconium, atomic number 40, has one main oxidation state and five naturally occurring stable isotopes, ^{90}Zr, ^{91}Zr, ^{92}Zr, ^{94}Zr and ^{96}Zr, of which ^{90}Zr makes up 51.5% of the total mass. It is a relatively abundant trace lithophile element (mean value of 165 mg/kg in the upper continental crust), which forms several typical minerals including the common zircon ($ZrSiO_4$) and rarer baddeleyite (ZrO_2). The Zr^{4+} ion is incompatible with most common rock-forming silicate mineral lattices, and it is therefore strongly partitioned into zircon and other accessory minerals such as sphene. In sedimentary lithologies, the abundance of Zr largely depends on the presence of residual detrital heavy minerals such as zircon and sphene. At the Earth's surface, Zr displays very low mobility under most conditions, mainly due to the very high stability of the principal host mineral zircon and the low solubility of the hydrate $Zr(OH)_4$. Due to the extremely resistant nature of zircon, mineral grains may be preserved through several geological cycles of mountain building and erosion over hundreds of millions of years. Zircon is a common heavy mineral constituent of various Quaternary marine, fluvial and glacial sediments in East Anglia (Madgett and Catt, 1978; Perrin *et al*., 1979; Lee *et al*., 2006; Lee, 2009).

Results

Descriptive statistics of the soil geochemical data for Hf and Zr are given in Table 1. Both are non-normally distributed and are slightly positively skewed. Scatter plot in Figure 2 shows that Hf and Zr are strongly correlated with a positive Spearman correlation factor of 0.92. This is also reflected by the Kolmogorov-Smirnov normality test results of 0.075 (Hf) and 0.079 (Zr). Calculated Hf:Zr ratios, shown in histogram of Figure 2, are all very close to the median of 2.6 %.

	Hf	Zr
Min	0.5	1.0
Max	31.5	1076
Mean	6.9	261
Median	6.7	256
Standard Deviation	2.6	95
Skewness	1.19	1.08
p value	< 0.005	< 0.005

Table 1: Descriptive statistics of Hf and Zr for 5745 topsoil samples; concentrations in mg/kg.

Further to the statistical presentation of the data, which showed that Hf and Zr concentrations are significantly correlated, maps were generated to determine if elements show a similar spatial distribution (Figures 3 and 4). Geochemical maps were compiled using the Inverse Distance Weighting (IDW) methodology with a search radius of 1500 m and cell size of 500 m.

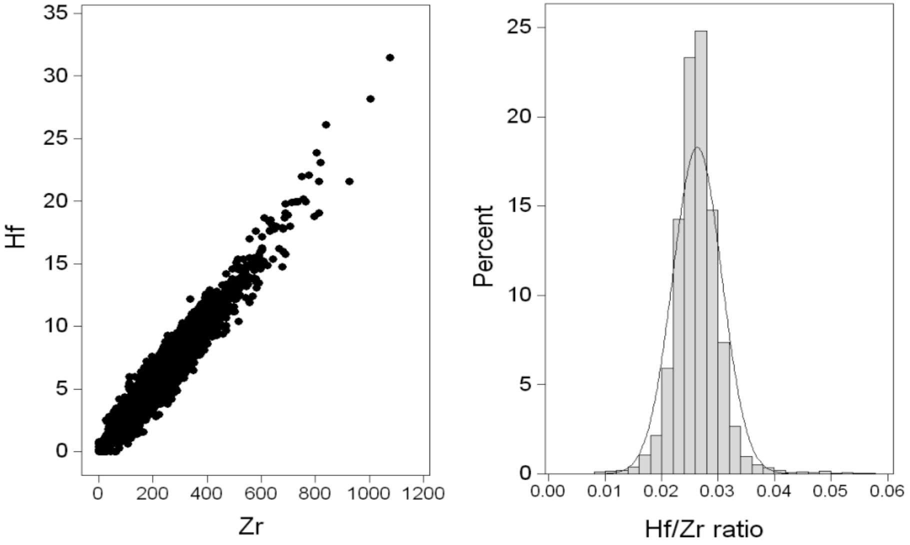

Figure 2: Scatter plot of Hf and Zr (concentrations in mg/kg) and histogram of Hf/Zr ratios (median 0.026).

Concentration ranges have been classified using the 25th, 50th, 75th, 90th percentile classes. Soil samples, for which concentrations are greater than the 90th percentile class (Hf > 9.8 mg/kg and Zr > 370 mg/kg) were reported in several areas: (1) northeast Norfolk extending southwards to Lowestoft; (2) south Suffolk and Essex; (3) the Breckland and eastern Fen and Wash margin. The white blank area, seen in Figure 3 and 4, in the centre of the Breckland near Thetford is a Ministry of Defence (MOD) military training area where sampling was not possible due to the presence of live ordnance.

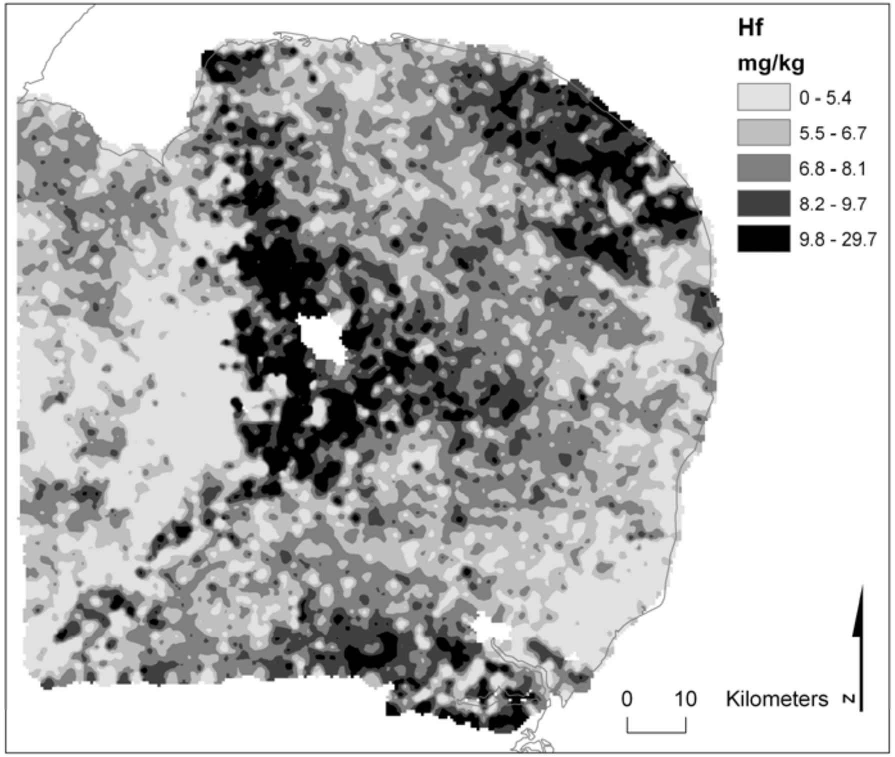

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Figure 3: Interpolated map of Hf in topsoils (5-20cm); Concentration ranges are based on the 25th, 50th, 75th, 90th percentile classes

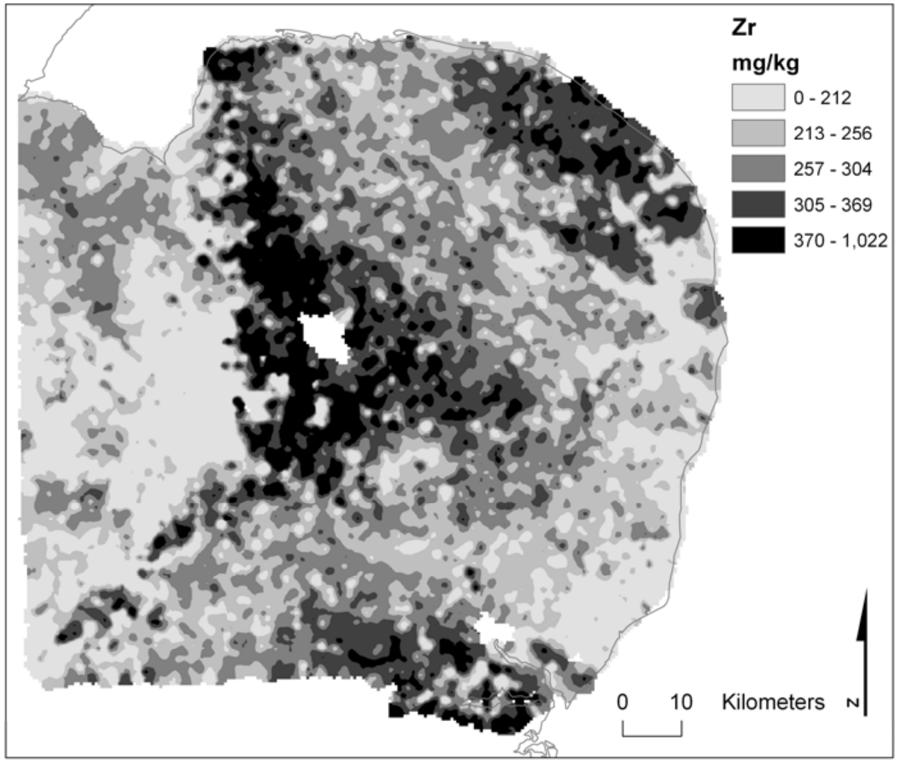

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Figure 4: Interpolated map of Zr in topsoils (5-20cm); Concentration ranges are based on the 25th, 50th, 75th, 90th percentile classes.

Discussion

Depositional indicator

Taylor *et al*. (1983) have already shown that concentrations of Hf and Zr are elevated in aeolian deposits such as loess and coversand deposits, and hence are good geochemical indicator elements for these deposits. Our geochemical soil data supports this. The enrichment of Zr and Hf in the silty to sandy fraction of aeolian sediments is due primarily to two factors, the resistant nature and the high density (4.6-4.7) of zircon mineral grains. Such minerals can withstand chemical and physical weathering over long geological periods and their density leads to preferential accumulation during wind-related sorting processes.

The geochemical distribution of Hf and Zr are almost identical due to their similar chemical properties and behaviour. The distribution patterns of elevated levels of both elements in soils show significant correlation with the outline of the aeolian sediments identified by Catt (1977, 1985) and Antoine *et al.* (2003) (Figure 1). This paper therefore supports earlier work that highlight Hf and Zr as good indicators of aeolian sedimentation.

Mapping the extent of aeolian sedimentation

The distribution of elevated levels of Hf and Zr shows a strong similarity to the distribution of aeolian deposits as stated previously. However, several additional areas with elevated concentrations of Hf and Zr are evident. They include the Hunstanton area of northwest Norfolk where coversand has recently been recognised (Hitchens, 2009), and the region around Lowestoft where blown sand was identified by a recent geological mapping survey (Moorlock *et al*., 2000). Furthermore, spatial plots of Hf and Zr also reveal moderate concentrations within the northern part of the Fens and elsewhere across much of East Anglia where aeolian deposits have not previously been mapped.

Comparison of the G-BASE data with the regional topography and point auger-hole data collected as part of the Thetford geological survey (British Geological Survey, 2010) demonstrates that moderate to low concentrations of Hf and Zr are often present at localities where aeolian deposits are either very thin (<0.3m) or apparently absent. It suggests that Hf and Zr have strong residual signals and that they may be present in these moderate concentrations in certain geological situations where: (a) only thin accumulations of aeolian sediment were ever deposited; (b) or thicker aeolian sequences have been markedly eroded by various physical and anthropogenic processes. Areas of low Hf and Zr concentrations by contrast, correspond to areas of geology dominated by modern alluviums and peats. These are confined to the lower reaches of modern river systems, wetland and marshland areas: (a) the Norfolk Broads and the lower sectors of the Wensum and Waveney rivers; (b) eastern Suffolk from Southwold southeastwards to the River Orwell near Ipswich; (c) eastern Fen Basin.

Taken at face value, the geochemical evidence demonstrates an aeolian sediment signal within soils across much of East Anglia. Furthermore, that the whole region was probably covered by an aeolian sediment veneer of variable thickness during the Devensian and early Holocene as suggested originally by Catt (1977). The precise number of depositional events plus the provenance of the aeolian material still remains unresolved. Equally unclear is precisely how much aeolian sediment has been removed by deflation, slope processes and rivers since it was deposited. However, the small Hf and Zr content within modern floodplains of rivers, wetland and marsh areas suggests a stable contemporary landscape with only minor (localised) reworking of aeolian sediment.

Conclusions

Based on results presented here, we demonstrate that regional-scale baseline soil geochemical data for Hf and Zr can be used to identify the distribution of aeolian sediments across East Anglia. Application of this technique demonstrates that the distribution of aeolian material across the region is much more extensive than previously considered and that during the Late Devensian and early Holocene, aeolian material was probably deposited across the whole region. This approach has the potential to develop generalised palaeoenvironmental maps showing the distribution of aeolian sediments and the authors are currently applying the technique to soil samples from the Vale of York and continental Europe.

Acknowledgments

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