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The mineral magnetic signatures of fire in the Kromrivier wetland, South Africa

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Abstract
Purpose Almost 50 % of wetland types in South Africa are regarded as critically endangered. Erosion is extensively present in many wetlands and has been primarily attributed to human activities. However, many researchers have suggested that the erosion of some wetland types is a long-term naturally recurring process and may be preceded by fire events. Wetland sediments are highly affected by processes of dissolution diagenesis, so that very little evidence of catchment processes would be expected to be preserved by their magnetic signatures. However, previously published research has shown that the magnetic signatures of fire can be preserved in some wetland and lake sediments.
Materials and methods The mineral magnetic properties of sediment cores were examined to attempt to identify the signatures of historical fires in the Kromrivier wetland, a palmiet dominated wetland in the Eastern Cape of South Africa. This wetland has recently been burnt by a large fire event in 2011. The burning of catchment soils and sediments in controlled laboratory experiments was used to replicate the processes of magnetic enhancement taking place in the wetland.
Results and discussion The majority of wetland sediment was very weakly magnetic due to processes of dissolution diagenesis. However, deposits of extremely magnetic sediment were found within the wetland. These deposits were attributed to the high temperature combustion of the wetland magnetically enhancing the fine-grained (<25 μm) sediment trapped in vegetation. These magnetically enhanced sediments were then selectively transported and concentrated in narrow channels flowing through the wetland. The rapid burial of enhanced grains (in the super paramagnetic–single domain size range) below the permanent water table is the most likely explanation for the good preservation of the fire signature.
Conclusions A history of fire events was preserved within the wetland sediments, which showed that combustion has taken place throughout its history. A complex process of sediment (particle size specific) magnetic enhancement, transport and storage results in the preservation of magnetic grains despite a highly reducing wetland environment.

Keywords Fire · Magnetic enhancement · Magnetism · Palmiet · Wetland

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1 Introduction

Wetlands provide a range of valuable ecosystem services yet are one of the most threatened ecosystems in South Africa, with almost 50 % of wetland types regarded as critically endangered (Nel et al. 2011). Palmiet dominated wetlands have been lost through erosion across the range of their natural distribution. Their loss has been linked to more prevalent flood events and less reliable base flows (Rebelo 2012). Additionally, rather than acting to reduce the sediment supply to downstream dams, degrading wetlands instead act as a source of sediment, shortening the lifespan of crucial water resources (Rebelo 2012). The loss of Palmiet wetlands also threatens this unique ecosystem that is dominated by the robust endemic plant, *Prionium serratum*, and its associated plant communities (Sieben 2012). Fire events have been identified as causing the loss of wetland vegetation (Salvia et al. 2012), increasing the susceptibility of a wetland to erosion by water.

Understanding the causes of wetland degradation in South Africa and other locations worldwide is important due to the large cost of constructed structures to prevent the formation and expansion of gullies in many wetlands. Without a proper understanding of wetland processes, there is a risk that such interventions will disrupt natural wetland cycles of erosion and deposition that are part of a natural dynamic.

This paper explores the potential for the mineral magnetic properties of deposited wetland sediments to provide information regarding long-term wetland processes in the Kromrivier wetland, South Africa. The mineral magnetic properties of historically deposited sediments have been extensively used to reconstruct past environmental changes (Jelinowska et al. 1995; Reynolds et al. 1999; Blake et al. 2006b). Mineral magnetic properties have been shown to be representative of both sediment source as well as diagenetic and authigenic processes (Verosub and Roberts 1995). Research conducted in the South African Karoo has suggested that in its lake sediments, magnetic signatures are generally conservative and primarily represent sediment source but can undergo dissolution diagenesis in some lakes (Pulley et al. 2015a). Wetlands are characterised by a gleyed layer below the soil's surface. In this layer, iron oxides are reduced and mobilised, although the iron will precipitate as mottles in oxygenated zones in the soil or will form oxides in river water (Vepraskas 1992). Such a reduction of iron oxides has been used to identify hydric wetland soils using a reduction in magnetic susceptibility (Zwanka et al. 2007). Because of the loss of magnetic minerals, it would be expected that the magnetic signature of diagenesis and authigenesis would dominate and largely overwrite any sediment source signature in a wetland. Attempts at tracing the sources of sediments in waterlogged reducing conditions have been shown to potentially result in very large errors due to processes of dissolution (Pulley et al. 2015b). For this reason, sediment source tracing studies aimed at reconstructing historical changes in sediment provenance within wetland catchments are rare.

Despite the potential loss of much of the sediment source signature in wetland sediments, a magnetic record of diagenetic and authigenic processes representing changing environmental conditions can be preserved in these sediments. The dominant magnetic signature of wetland sediments is likely to be that of the reducing environment causing the dissolution of magnetic grains, resulting in a low magnetic susceptibility (Simms and Lobred 2011). Some magnetic minerals have however been found to form in these conditions. Iron sulphides such as gregite and pyrite have been found in wetland and lake sediments and can increase the magnetism of samples (Tuttle et al. 1990; Tuttle and Goldhaber 1993). The formation of these iron sulphides has been linked to the reducing conditions created during organic matter decomposition (Roberts 1995).

The magnetic properties of sediments have also been used to reconstruct the history of fires in lake sediments (Rummery 1983). A number of characteristic magnetic properties are associated with high-temperature combustion, which has been shown to enhance saturation isothermal remanence magnetisation (SIRM) by up to 1.5 to 16 times (Clement et al. 2011). Oldfield and Crowher (2007) identified the production of fine magnetic grains by fire which occupied a specific envelope on a bi-plot of χarm/ χ_{lf} and χarm/χ_{fd}. Other signatures of magnetic enhancement by combustion are the conversion of high coercivity weakly magnetic minerals such as goethite to low-coercivity type highly magnetic minerals such as maghemite (Clement et al. 2011). Such a conversion could potentially lead to the release of nutrients as goethite is a strong absorber of phosphorus (Clement et al. 2011). The presence of organic matter and formation of reducing conditions during combustion has been shown to be a major factor controlling the conversion of iron oxy-hydroxides to more magnetic maghemite type minerals (Oldfield et al. 1981; Hanesch et al. 2006). Using the magnetic properties of sediment, Blake et al. (2006b) identified that post-fire rainstorm events account for 89 % of total reservoir sedimentation in the Nattai arm of Lake Burragorang in New South Wales, Australia. However, the dissolution of fine-grained pyrogenic magnetites in lake sediments complicated the analysis of the sediments magnetic properties. Therefore, the presence of large amounts of organic matter in wetlands may lead to greater magnetic enhancement by fire and the reducing conditions may lead to the accelerated dissolution of the formed minerals. It is therefore unclear how fire in a wetland may change the magnetic properties of its sediments. Despite the uncertainties associated with the interpretation of historically deposited fire-enhanced deposits, they have been shown to be preserved over millennial timescales in some environments (Gedye et al. 2000; Mighall et al. 2009).

2 Site description

The Kromrivier is located in the Eastern Cape of South Africa and flows from close to the town of Kareedouw into the Indian Ocean. It is the most important water resource for the Nelson Mandela Metropole providing water to two large dams. The catchment has a total area of 1125 km^2 and forms a narrow area sandwiched by the Tsitsikamma and Suuranys Cape Fold Mountain Ranges. The mountains reach a maximum altitude of 1251 m and the area of the wetland investigated in this study is at 320 m above sea level. The catchment's geology is almost entirely composed of sandstone of the Cape Supergroup with a very narrow strip of shale along much of the length of the valley floor. The catchment has an average annual rainfall of 614 mm (Rebelo 2012) which is highly seasonal, with the majority of rainfall occurring in spring

(September, October) and autumn (March, April). Land use adjacent to the wetland was primarily the cultivation of fruit trees in the past but more recently has been dominated by pasture production for cattle grazing (Rebelo 2012). The land within the catchment is primarily fynbos and renosterveld, which is dominated by shrubs and gaminoid taxa, with thicket or Afromontane forest comprising the woody vegetation that occurs in steep-sided valleys (Rebelo 2012).

The Kromrivier wetland occupies the upper third of the catchment of the Krom River, and the area examined in this study is approximately in the centre of the wetlands' catchment (Fig. 1). Four large alluvial fans enter the study area, which are formed by small river channels that drain the high altitude hills on either side of the wetland. The wetland's vegetation is primarily composed of Palmiet. Palmiet is a robust palm-like plant with thick stems of up to 10 cm in diameter and reaches heights of up to 3 m. The plants have extensive root systems that contribute to peat formation and the creation of a solid organic substratum that effectively traps sediment (Sieben 2012). Palmiet is well adapted to recovery after fire events by sprouting from terminal and epicormic buds (Boucher and Withers 2004). The thick leaves and stems of palmiet also act as effective sediment traps, accumulating sediment in its above ground vegetation and root system following large floods.

A concrete structure was constructed at the bottom of the study area in 2003 to prevent the upstream propagation of a large gully which formed downstream of this section of wetland with no evidence of channels. However, there is evidence of the presence of partially infilled gullies on the alluvial fans (Fig. 1). The wetland burns infrequently with the last major fire event having taken place in 2009, which burnt through the entire study area (this information was provided by the landowner).

3 Methods

A series of nine transects of 4 to 8 cores each were sampled across the wetland (Fig. 1). An additional 5 shorter transects were sampled in the upper centre of the wetland where unusual magnetic signatures were found. Some additional samples were also collected close to a point of unusual magnetic signatures in the bottom centre of the wetland. Each core was retrieved using a steel gouge corer of 3 cm internal diameter and 1 m length. Cores were collected until refusal which was typically a layer of sand 2 to 4 m below the wetland surface. Additional samples were collected from the alluvial fans and catchment hillslopes to determine the magnetic properties of catchment topsoils. These samples were also collected using the steel gouge corer and were collected to a depth of approximately 10 cm.

To keep the number of samples to a manageable number for analysis, only the top 10 cm of each core was retrieved,

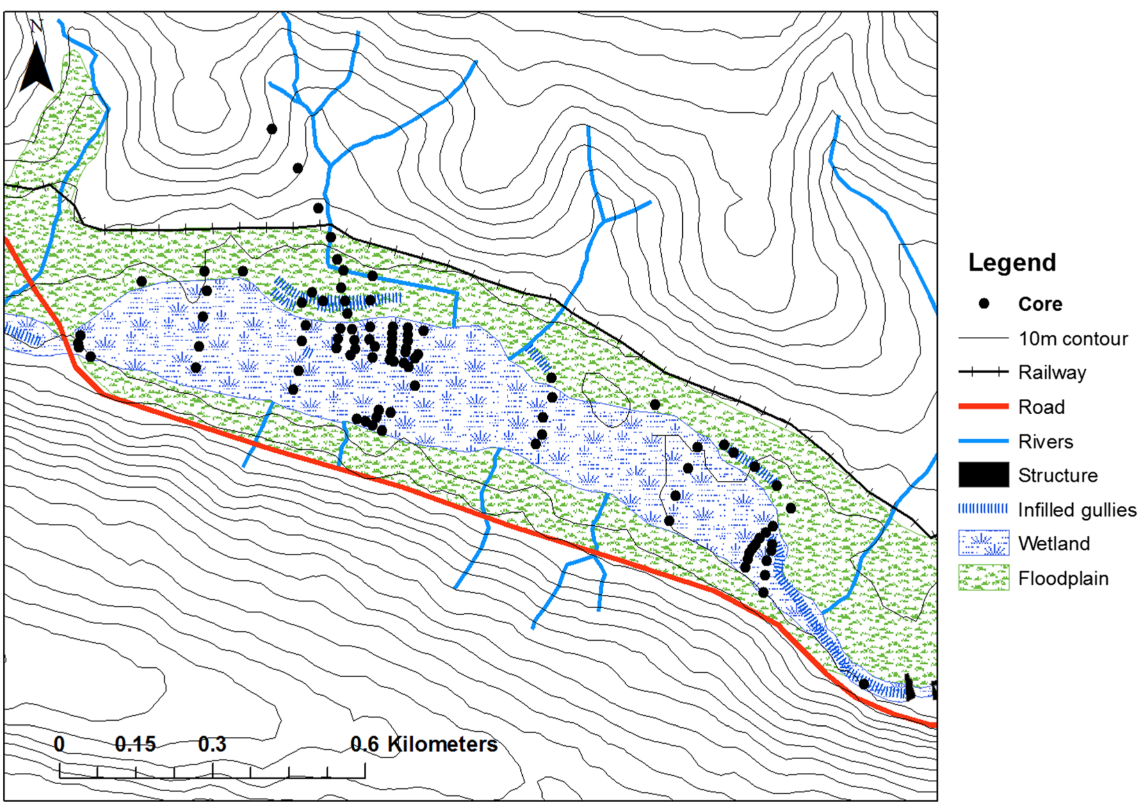

Fig. 1 The study catchment with coring locations. The study area is located at 33° 52′ 45.31″ S 24 ° 3′ 46.73″ E

along with samples of material collected at depth when the texture or colour of the sediment changed. This equated to an average of 3 to 4 samples for each core. The depth of each sample used for analysis was recorded.

Each sample was oven dried at 40 °C and gently disaggregated using a pestle and mortar prior to analysis. For the measurement of mineral magnetic signatures, 5 to 10 g of each sample was tightly packed into a 10-ml sample container and measured according to the methods laid out by Lees (1997) and Foster et al. (2008). The magnetic properties measured, instrument used and description of their sensitivity to different magnetic grain types is presented in Table 1.

The organic matter content of the sediment was calculated using low temperature loss on ignition at 450 °C for 4 h in a muffle furnace based upon the methods of (Grimshaw et al. 1989). Magnetic signatures were corrected for organic matter dilution using the methods of Smith (1999).

The organic matter in the wetland sediments was dated by Beta Analytic using Accelerator Mass Spectrometry Carbon—14 dating. Carbon – 14 ages were calibrated using the SHCAL13 database (Hogg et al. 2013) and the methods of Talma and Vogel (1993).

The particle size of the samples was determined using a Malvern Mastersizer 3000 laser granulometer. Prior to analysis, the organic matter in the samples was removed using 5 ml

Table 1 The magnetic signatures measured as by Foster et al. (2008), with a description of the mineral types measured by each property (Walden 1999; Yang et al. 2010; Wang et al. 2012)

Property, abbreviation and units	Instrument/calculation used	Sensitivity
Low frequency susceptibility (χ_{lf}) (10^{-6} m^3 kg^{-1})	Bartington Instruments MS2b sensor (470 Hz)	Primarily determined by magnetic mineral type and concentration. Ferrimagnetic minerals will dominate where present. Where only low concentrations of ferrimagnetic grains are present canted anti-ferromagnetic grains will dominate. χ_{lf} is also sensitive to mineral grain size.
High frequency susceptibility (χ_{hf}) (10^{-6} m^3 kg$^{-1)}$	Bartington Instruments MS2b sensor (4700 Hz)	Measured for the calculation of χ_{fd}.
Frequency dependant susceptibility (χ_{fd}) (%)	Expressed as the percentage of χ_{lf} dervied from the frequency dependant component	Primarily sensitive to ultrafine (<0.02 μm diameter) super paramagnetic (SP) grains. These grains are formed in topsoils and have also been shown to be produced during combustion. Expressed as the total χ_{fd} as well as the percentage of χ_{lf} contributed by χ_{fd}.
Anhysteretic Remanent Magnetisation ($ARM_{(40\mu T)}$) (10^{-3} Am^2 kg^{-1})	Molspin® anhysteretic remanent magnetiser, Molspin® slow-speed spinner magnetometer	Sensitive to single domain (SD) ferrimagnetic grains in the 0.02 to 0.4 μm size range. These grains have been shown to be primarily created during soil formation, by bacteria in lake sediments and during combustion; as well as being present in rock parent material.
Susceptibility of ARM (χ_{ARM}) (10^{-6} m^3 kg^{-1})	ARM × 3.14 × 10	ARM normalised to field strength.
Saturation Isothermal Remanent Magnetisation (SIRM) (10^{-3} Am^2 kg^{-1})	Molspin® pulse magnetiser, Molspin® slow-speed spinner magnetometer	Measures the presence of almost all remanence carrying ferrimagnetic and canted antiferromagnetic grains by exposing the samples to a 1 T magnetic field.
Soft Isothermal Remanent Magnetisation ($IRM_{(-100mT)}$) (10^{-3} Am^2 kg^{-1})	Molspin® pulse magnetiser, Molspin® slow-speed spinner magnetometer	After exposure to the 1 T magnetic field, the samples are exposed to a reversed polarity field of 0.1 T. This backfield has been shown to be capable of reversing the polarity of the majority of low coercivity magnetite type grains in a sample.
S ratio	$-1 \times (IRM\text{-}_{100mT}/IRM_{1T})$	The ratio of soft (magnetite type) and hard (high coercivity haematite and goethite type) remanence carrying minerals.
SIRM/χ_{lf}	Ratio	Represents the ratio between remanence carrying grains to grains exhibiting a magnetic susceptibility. This ratio is commonly used to identify the presence of greigite in historically deposited sediments. It also roughly represents the ratio of large magnetic grains to smaller magnetic grains.

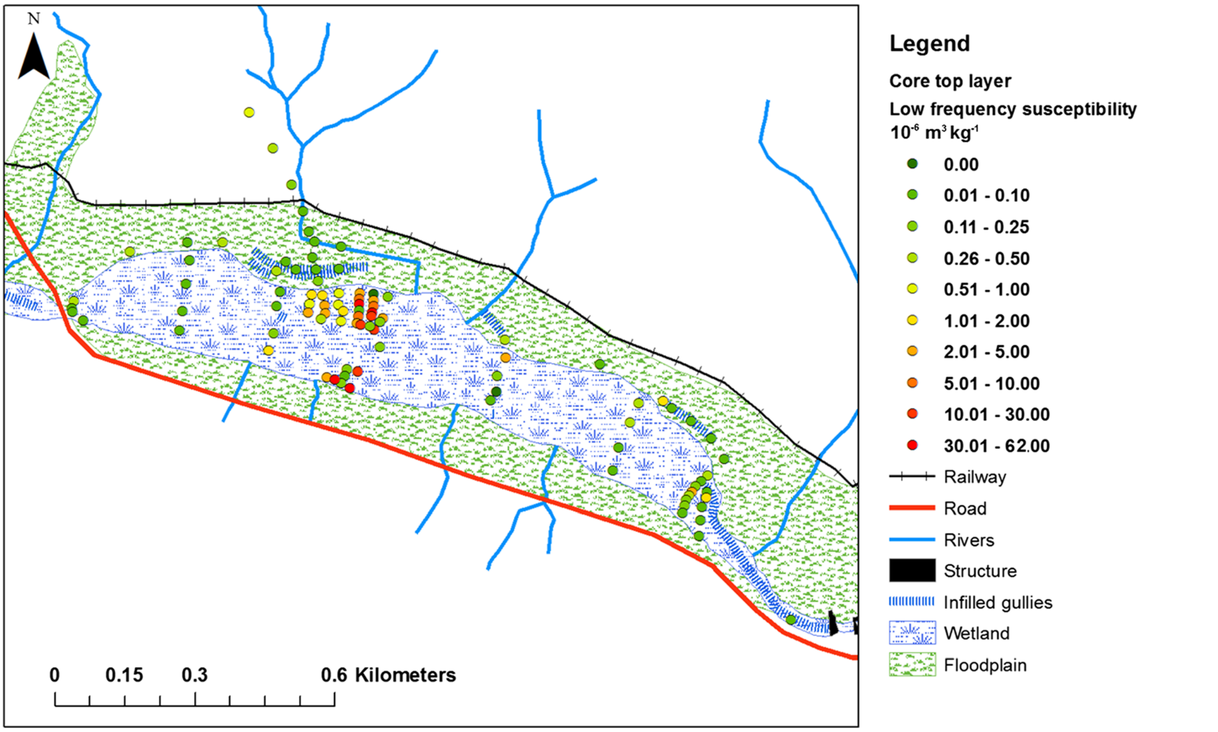

Fig. 2 The χ_{lf} of the topmost layer of each core retrieved

of 30 % hydrogen peroxide (Gray et al. 2010). Samples were then dispersed using 5 ml of 3 % sodium hexametaphosphate solution and 2 min of ultrasonic dispersal. The median (D50) particle diameter of each sample was recorded as a measure of its particle size.

4 Results and discussion

4.1 The magnetic susceptibility of wetland sediments

An examination of the χ_{lf} of the core samples showed that most surface and almost all subsurface sediment samples exhibited very little χ_{lf} (Fig. 2), as would be expected with material derived from a sedimentary geology deposited in anoxic reducing conditions. There were, however, sediments with very high χ_{lf} values present in some parts of the wetland, which were especially concentrated at the surface at 1/3 along the length of the wetland in small channels of 30 cm to 1 m depth and width. These χ_{lf} values are over an order of magnitude higher than those found in the soil and alluvial fan sediment samples collected outside of the wetland. The high χ_{lf} values found were well in excess of any other samples of soil or sediment found in South Africa by the authors of this paper. For example, highly magnetic igneous dolerite soils in the Karoo were shown to have mean χ_{lf} values of up to 6.45 (standard deviation: 4.12) depending upon the particle

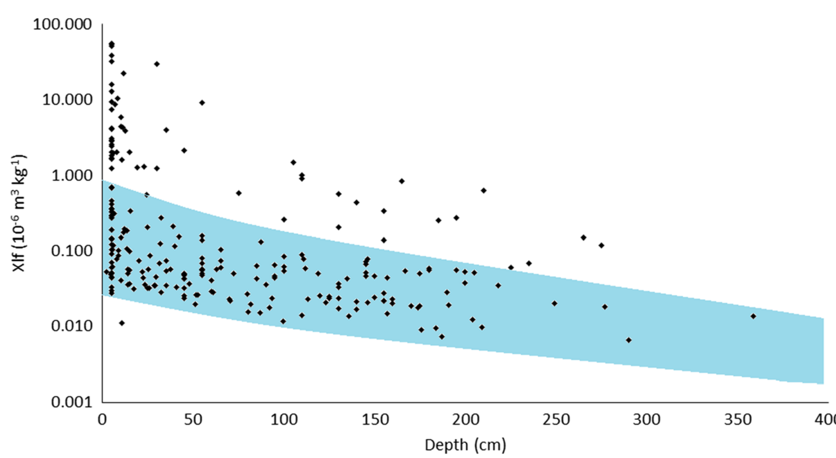

Fig. 3 χ_{lf} plotted against depth in all wetland sediment samples; the *blue area* represents the trend shown by the majority of samples

Fig. 4 An example of highly magnetic sediments in a wetland core

size being examined (Pulley et al. 2015a). The highest χ_{lf} values found in the Kromrivier wetland (up to $61.82 \times 10^{-6}\ m^3\ kg^{-1}$) fall within the upper range of χ_{lf} values expected to be found in burnt soils and overlaps the range expected for pure samples of some ferrimagnetic minerals (Dearing 1999). Pure samples of magnetite and maghemite have χ_{lf} values of $570 \times 10^{-6}\ m^3\ kg^{-1}$ and samples of haematite of 0.6–6 and goethite of $0.7 \times 10^{-6}\ m^3\ kg^{-1}$ (Van Oorschot 2002). Therefore, the χ_{lf} values found in the wetland are exceptionally high indicating significant concentrations of magnetite or maghemite and would not ordinarily be expected in a wetland environment.

Most samples for which χ_{lf} was measured fall within a band highlighted in blue in Fig. 3 which shows a slight decrease in χ_{lf} with depth. This likely represents the dissolution of the magnetic minerals in deposited sediment over time. The highly magnetic surface sediments have χ_{lf} values elevated well above the samples in the blue area. There are, however, a number of sediment samples at depths of up to 2.8 m which have χ_{lf} values elevated above the main grouping, although, none of the deep samples have the extremely high χ_{lf} values (greater than $10 \times 10^{-6}\ m^3\ kg^{-1}$) found in some of the surface samples.

Evidence of the enhanced χ_{lf} of deeper wetland sediment deposits can be seen in the photograph of a core shown in Fig. 4, where an orange-brown layer of highly magnetic sediment is evident near the top of the core, below which is very weakly magnetic black organic sediment which makes up almost all of the material in the wetland. Deeper in the core (40 to 50 cm below surface), there is a light brown layer which is highly magnetic. Almost all deposits of highly magnetic material were in thin layers up to 10 cm thick. This result suggests that the χ_{lf} enhanced sediments can remain present for long periods of time after their initial deposition. ^{14}C (AMS conducted by Beta Analytic) dates of the sand layer acting as the point of refusal for most cores estimate that the

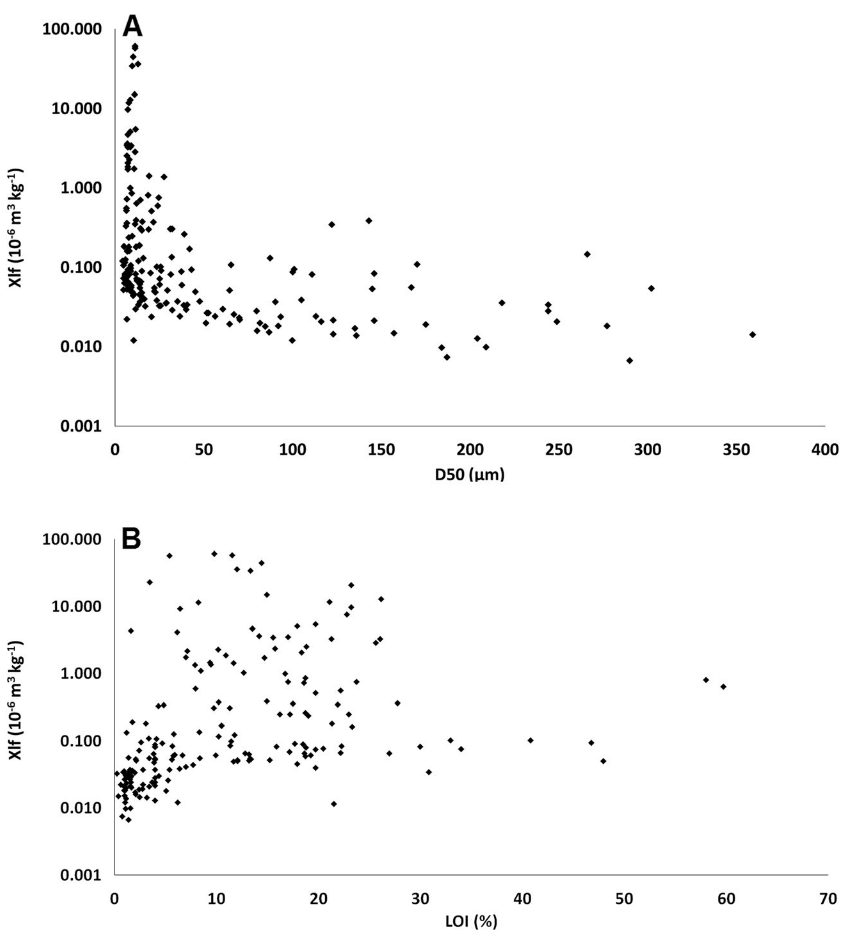

Fig. 5 The relationship between χ_{lf} and D50 particle size for all wetland and alluvial fan samples

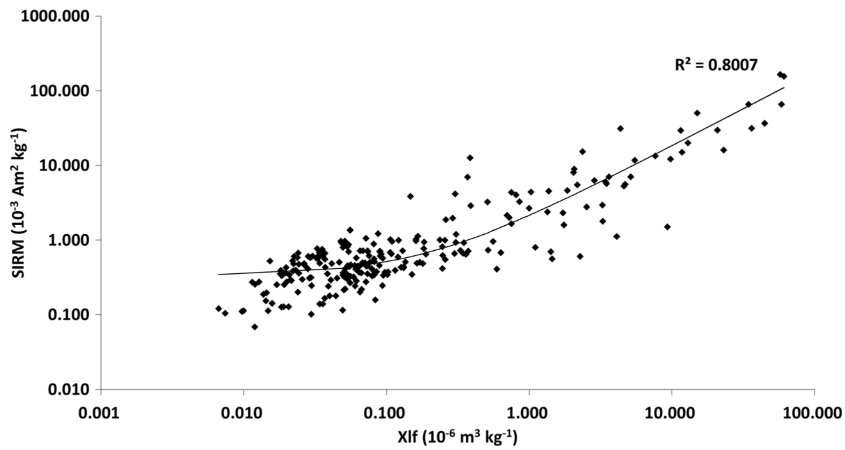

Fig. 6 Bi-plot of χ_{lf} and SIRM for wetland samples

deepest wetland sediments were deposited 6930 ± 30 cal a BP. ^{14}C dates of the highly magnetic layer 40 to 50 cm below surface shown in Fig. 4 indicate that it was deposited 940 ± 30 cal a BP.

The most highly magnetically enhanced sediments have a fine particle size (D50 values in the range of 7.24–13 μm; Fig. 5a). The particle size of sediments has previously been shown to be a major controlling factor on its magnetic properties in other catchments (Foster et al. 1998; Maher 1998; Blake et al. 2006a, b; Oldfield et al. 2009). There is a rough trend of the sediments with the lowest χ_{lf} values having a low LOI (below 3 %) and the more magnetic but not fire enhanced sediments having higher LOI values (Fig. 5b). However, there appears to be no relationship between χ_{lf} and LOI in the fire enhanced sediments (defined as having χ_{lf} values above 0.1 (10^{-6} m^3 kg^{-1})). Therefore, it is unlikely that a lack of organic matter in the magnetically enhanced deposits can be used to explain the preservation of minerals in a highly reducing wetland environment.

4.2 Explaining the presence of highly magnetic sediments

There is a roughly linear relationship between SIRM and χ_{lf} in all wetland and alluvial fan soil samples (R^2 = 0.803; Fig. 6),

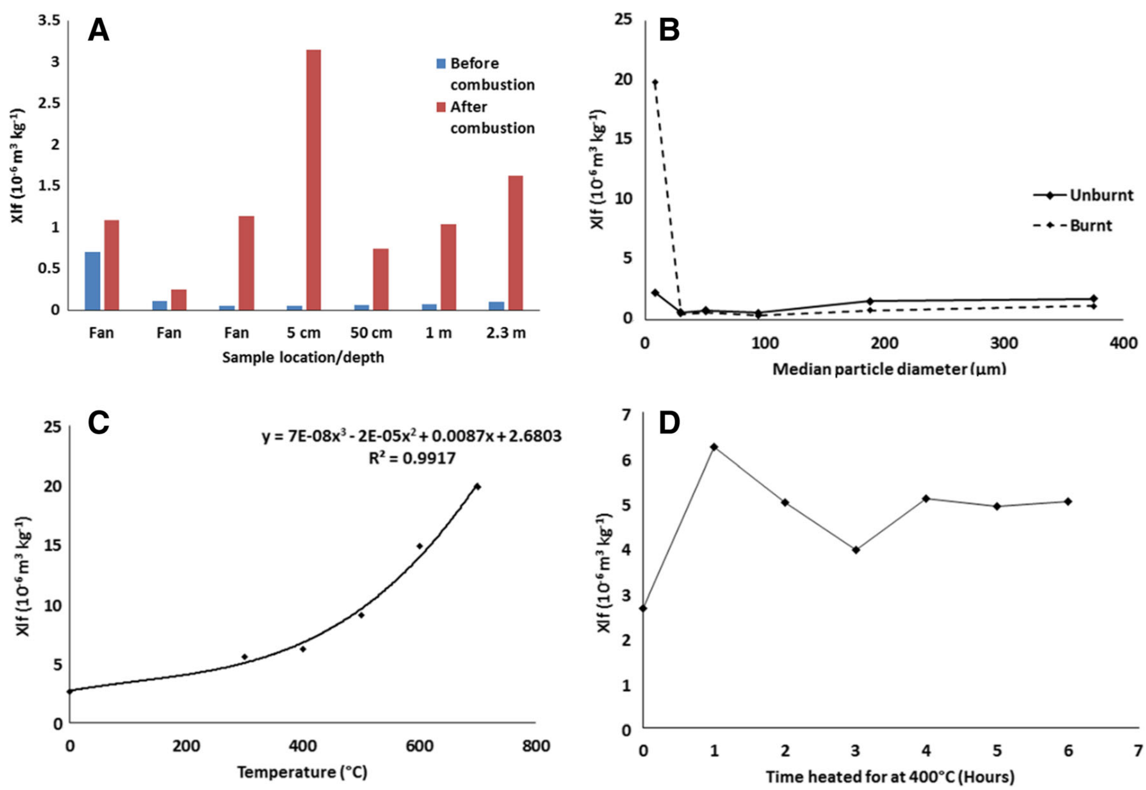

Fig. 7 The relationship between particle size and χ_{lf} in burnt and unburnt samples (**a**) and the effect of temperature on magnetic susceptibility of <25 μm fraction of an alluvial fan sample (**b**), χ_{lf} compared to time heated at 400 °C (**c**) and the effect of combustion at 700 °C on different sediment samples (**d**)

suggesting that the samples with high χ_{lf} values are composed of a similar sedimentary material to that present in the rest of the catchment. The highly magnetic samples also have a mean χ_{fd}% of 5.93 (standard deviation: 3.86) suggesting that it is of soil origin rather than being caused by anthropogenic contaminants such as waste iron or steel within the wetland (Dearing et al. 1996).

Having identified that anthropogenic pollution is unlikely to be an explanation for the high magnetic signatures found; the combustion of wetland vegetation is a possible explanation. To determine the effects of combustion on the sediments' magnetic properties, randomly selected sediment samples from the wetland and catchment topsoils were initially burnt in a furnace for 4 h. Details of the maximum combustion temperature of Palmiet wetlands are not available in the published literature, but a temperature of 700 °C was initially selected to represent the upper limit of plausible temperatures at which the wetland vegetation might burn. It was found that significant enhancement of magnetic signatures took place making χ_{lf} 1.5 to 65 times higher than for unburnt samples (Fig. 7a). However, the enhanced χ_{lf} remained over an order of magnitude lower than the highest values found in the wetland sediments.

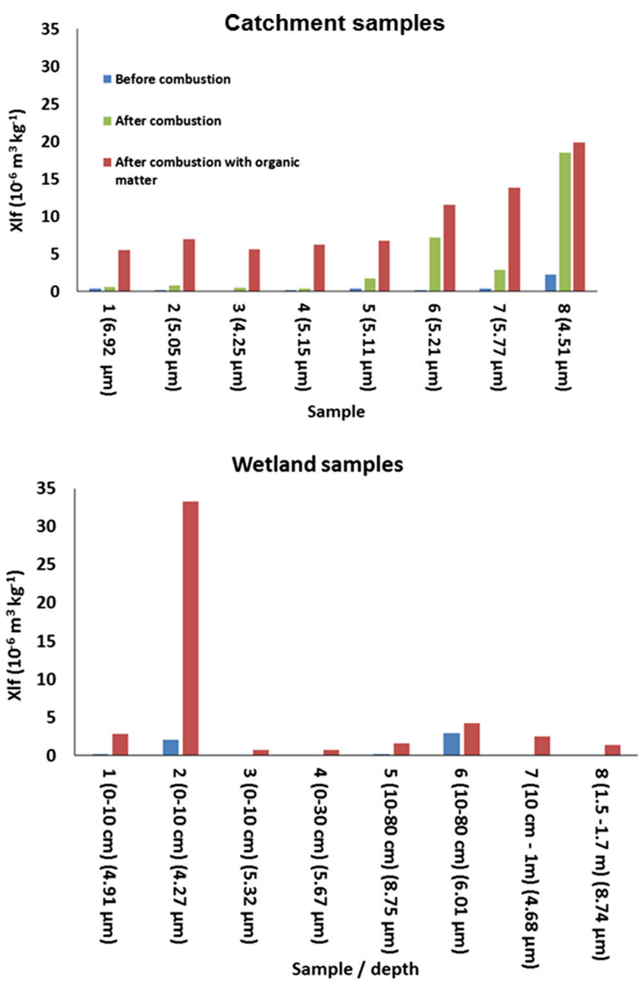

Fig. 8 The effect of combustion on the χ_{lf} of alluvial fan (**a**) and wetland (**b**) sediments sieved to <25 μm and heated in a crucible with a lid in the presence of 10 g of organic matter. The D50 particle size of each sample is provided

Blake et al. (2006a, b) showed that particle size exerts a strong influence on the amount of magnetic enhancement present after combustion. To examine the effect of particle size on magnetic enhancement, the most magnetic alluvial fan sample was fractionated to six different particle size fractions between 250 and <25 μm. The χ_{lf} of each sample was measured before and after heating at 700 °C for 4 h. It was found that before heating, the <25 μm fraction of the sediment was slightly more magnetic than the larger size fractions (Fig. 7b). Additionally, upon heating, the <25 μm fraction became magnetically enhanced to a χ_{lf} value comparable to that found in the heavily magnetic wetland sediments. However, the magnetic enhancement of the coarser size fractions was small. When the <25 μm size fraction was heated at different temperatures, it was found that the amount of magnetic enhancement was highly temperature dependant and that a high temperature is required to achieve the very high magnetic signatures found in the wetland sediments (Fig. 7c). Heating at a lower temperature (400 °C) for longer than 1 h resulted in a lower magnetic enhancement than heating for a single hour at the same temperature (Fig. 7d).

Published literature has suggested that the formation of a reducing environment during combustion is necessary for significant magnetic enhancement (Hanesch et al. 2006). For this reason, alluvial fan sediment samples were then heated in the absence and presence of 10 g of organic matter with lids on the crucibles to exclude oxygen. It was found that a greater magnetic enhancement took place when the organic matter was added (Fig. 8). The amount of magnetic enhancement was however highly variable between samples, with only three samples reaching high χ_{lf} values (above 10×10^{-6} m^3 kg^{-1}). For comparison, a selection of 8 randomly selected wetland samples were also sieved to <25 μm and heated in the presence of organic matter. It was found that only one wetland sediment sample was significantly magnetically enhanced (Fig. 8), in contrast to alluvial fan samples, where every sample was magnetically enhanced to a χ_{lf} above 5×10^{-6} m^3 kg^{-1}. This is possibly due to the leaching of iron from the wetland sediments by dissolution, which removes the iron minerals needed for conversion into highly magnetic grains during combustion. Similarly, it can be noted that the samples with the highest initial χ_{lf} values are more magnetically enhanced than those with lower χ_{lf} values which may also demonstrate that samples which have been partially gleyed lack a sufficient concentration of iron minerals for substantial magnetic enhancement to take place. Particle size also appeared to be a contributing factor, with the most magnetically enhanced wetland and alluvial fan samples having a D50 below 5 μm (Fig. 8). However, some samples with a D50 below 5 μm had far smaller χ_{lf} values, suggesting that particle size is not the only controlling factor on magnetic enhancement.

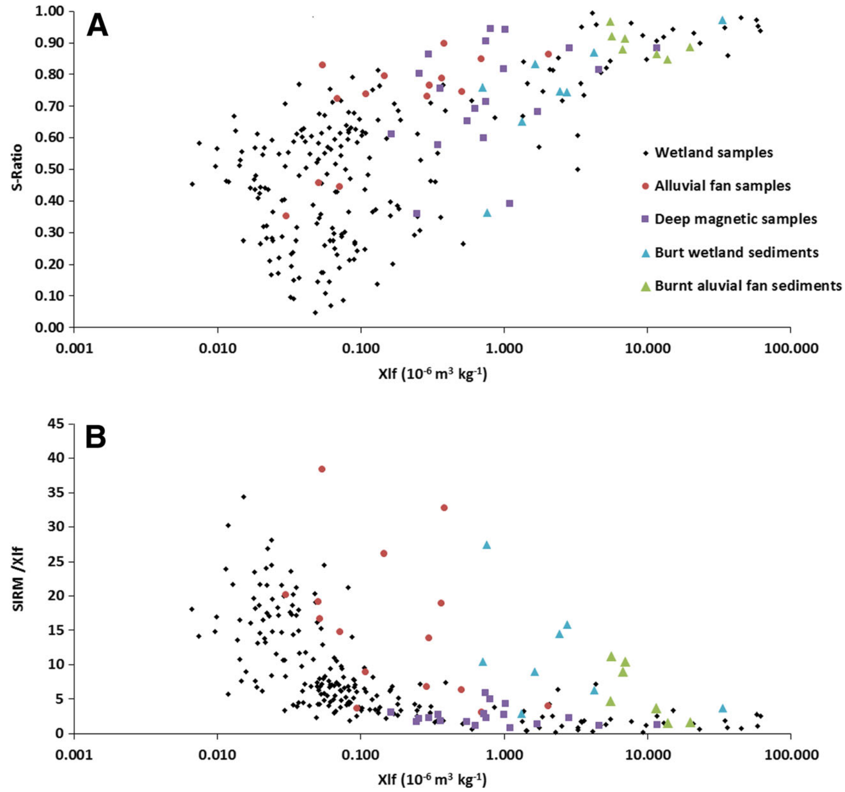

Fig. 9 S-ratio (**a**) and the SIRM/χ_{lf} ratio (**b**) plotted against χ_{lf}

4.3 The properties of magnetically enhanced sediments

4.3.1 Magnetic mineralogy

An examination of the magnetic properties of the naturally present wetland sediments showed that the sediments with a high χ_{lf} also had a high S-ratio, with the most magnetic samples having an S-ratio close to 1 (Fig. 9a). Similarly, the most magnetic samples had very low SIRM/χ_{lf} ratios (Fig. 9b). This result suggests the presence of low-coercivity magnetite or maghemite type minerals in the highly magnetic sediments (Maher 1986; Thompson 1986; Verosub and Roberts 1995). These minerals, especially maghemite, have previously been shown to be formed by combustion (Clement et al. 2011). There was no increase in the χARM/SIRM ratio with increasing χ_{lf} ($R^2 = -0.0002$) which would be expected with greater relative importance of SD grains to the overall magnetism of the sample (Hanesch and Petersen 1999). However, plotting χARM/χ_{fd} (%) against χ_{lf} shows a strong linear relationship ($R^2 = 0.894$) suggesting a greater abundance of SD grains in relation to SP grains in magnetically enhanced sediment (Fig. 10). This finding combined with the high χ_{fd} % (5.4 %) and high mean χARM/SIRM ratio of 1.15 of the enhanced grains suggests the formation of grains primarily in super paramagnetic and single domain size range during combustion with a coarsening of grain size in the most highly enhanced grains. This finding is comparable with that of Oldfield and Crowher (2007) in the Cotswolds region of England and Gedye et al. (2000) in Lago di Origlio

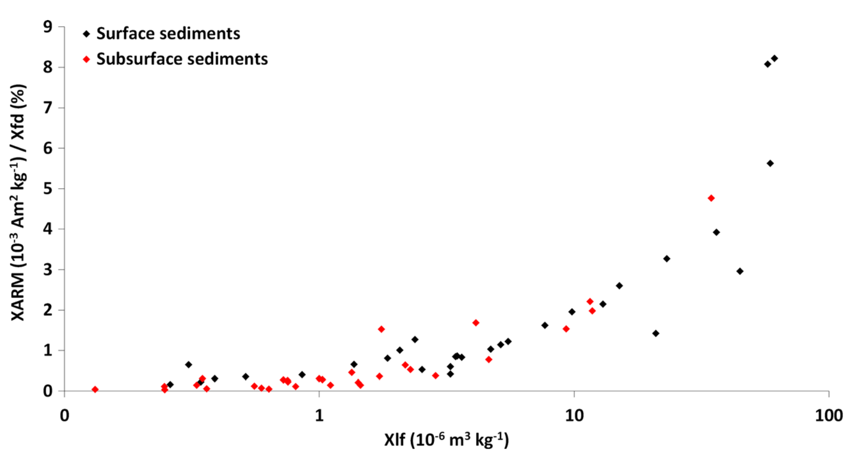

Fig. 10 The XARM/χ_{fd} (%) ratio plotted against χ_{lf}

in the Swiss Alps who found the enhancement of SD and SP grain sizes by fire.

The highly magnetic wetland sediments found deeper than 20 cm do not appear to have a significantly different magnetic mineralogy to the highly magnetic surface sediments, other than typically being less magnetic (Figs. 9 and 10). Therefore, the post depositional alteration of multidomain maghemites formed through combustion appears to be the simple dissolving and leaching of all grain sizes over time. The weakly magnetic wetland sediments have SIRM/χ_{lf} values approaching 30, suggesting that the magnetic mineralogy of these samples is dominated by iron sulphides such as greigite (Walden 1999).

4.3.2 Comparing the mineralogy of artificially burnt samples to that of wetland sediments

The magnetic properties of the samples burnt in the furnace (Fig. 8) were compared to the natural wetland sediments (surface and subsurface) and the catchment soil samples (Fig. 9a, b). The properties of the magnetically enhanced sediment beneath the top 20 cm of the wetland's surface as well as the catchment soil and alluvial fan samples were also highlighted in the plots. The artificially burnt catchment soil and alluvial fan samples have an S-ratio close to 1, falling within the range found in the magnetically enhanced wetland sediments (Fig. 9a). The artificially burnt wetland sediments also had S-ratios which fell within the range found in the wetland sediments. Three of the burnt catchment topsoil samples had a low SIRM/χ_{lf} ratio which fell within the range of the highly magnetic wetland sediments (Fig. 9b). However, four samples had an elevated SIRM/χ_{lf} ratio for their χ_{lf}, falling outside of the range found in the naturally present wetland sediments. Similarly, in the artificially burnt wetland sediments, only two samples had SIRM/χ_{lf} ratios in the range of the natural wetland sediments. A possible explanation for this difference is that the finer magnetic grains produced by combustion are lost through dissolution in the wetland, as the SIRM/χ_{lf} ratio has been shown to decrease with increasing grain size (Opdyke and Channell 1996). Therefore, the dissolution of fine grain sizes (SP) which have been shown to be preferentially dissolved over larger grains (Anderson and Rippey 1988) is a plausible explanation for this discrepancy. However, no evidence of a change in the χARM/χ_{fd} (%) ratio was observed when comparing surface and subsurface enhanced sediments in the wetland, suggesting there is not significant preferential dissolution of smaller SP grains. It is also possible that a greater relative abundance of SP grains is present in the wetland sediments and is suppressing the SIRM/χ_{lf} ratio. The formation of SP may be related to differences in the redox conditions present during the combustion of the laboratory and wetland sediments rather than any post depositional change in magnetic mineral composition.

5 Conclusions

We propose that the presence of highly magnetic sediments in the Kromrivier wetland can be explained by the following sequence of events.

1: Palmiet traps sediment within its leaves during high flow events, creating deposits of sediment which has freshly moved from the catchment and is protected from dissolution diagenesis within the wetland.

2: During periods of drought, the dense palmiet vegetation combusts, creating high temperature conditions and a reducing atmosphere. Fine sediment particles (<25 μm) are most heavily affected, with the conversion of weakly magnetic minerals such as goethite to highly magnetic grains predominantly in the super paramagnetic to single domain size range.

3: After combustion, the wetland is more easily eroded and small channels 30 cm to 1 m deep are formed in its sediments. A number of these channels also exist prior to the fire events.

4: The selective transport of fine-grained particles through the mat of palmiet roots and vegetation to the small channels concentrate the highly magnetised fine-grained (<25 μm) sediment particles into localised areas of deposition, creating the observed very highly magnetised sediment deposits.

5: These deposits are slowly lost through dissolution diagenesis which is the simple dissolution of all of the magnetic grains created through combustion. However, enhanced magnetism can persist for long time periods (up to 7000 years) and can even be preserved under more recent unburnt sediments which have been heavily gleyed. The reason for the preservation of the magnetic minerals is unclear, however, may be related to the rapid post-fire burial of the enhanced deposits below the permanent water table. As a result, the magnetic evidence of historical fire events is preserved in the wetland.

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