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Post-European settlement impacts on erosion and land degradation; a case study using farm reservoir sedimentation in the Eastern Cape, South Africa

KATE ROWNTREE[1], IAN FOSTER[1,2], TIM MIGHALL[3], LEANNE DUPREEZ[1] & JOHN BOARDMAN[4,5]

1 *Department of Geography, Rhodes University, PO Box 94, Grahamstown 6140, Eastern Cape, South Africa*
k.rowntree@rhodes.ac.za

2 *Department of Molecular and Applied Biosciences, School of Biosciences, University of Westminster, Cavendish Campus, 115 New Cavendish Street, London W1W 6UW, UK*

3 *Dept of Geography and Environment, University of Aberdeen, Elphinstone Road, Aberdeen AB24 3UF, UK*

4 *Environmental Change Institute, Oxford University Centre for the Environment, Dyson Perrins Building, South Parks Road, Oxford OX1 3QY, UK*

5 *Department of Environmental and Geographical Science, University of Cape Town, Rondebosch 7701, South Africa*

Abstract We present data from a farm reservoir constructed in 1843, which retains a complete and undisturbed sedimentary record exceeding 4 m in depth. A small number (27) of potential sediment sources were sampled and characterised by their mineral magnetic fingerprints. Similar signatures were measured on the reservoir sediments. While yet to be dated, analysis of mineral magnetic properties of the reservoir sediments suggest that they contain significant quantities of super-paramagnetic minerals produced by pedogenesis, but are not strongly overprinted by magnetic signatures that could be attributed to bacterial magnetite or greigite produced within the reservoir. Preliminary results from the source tracing show that the sediments are probably derived from colluvial topsoils punctuated by inputs from river channels or badlands.

Key words sediment sources; environmental magnetism; gamma-emitting radionuclides; Karoo; South Africa

INTRODUCTION

Evidence from many parts of the New World, especially Australia, South Africa and the USA, suggests that the arrival of European settlers since the 18th century brought with it episodes of clearance, cultivation and overgrazing that significantly increased erosion rates (Cooke *et al.*, 2003). The semi-arid landscape of the Karoo, in the Eastern Cape of South Africa, is an area that is believed by some to exemplify this scenario (Acocks, 1988), but the supporting evidence is more equivocal (Dean *et al.*, 1995). The lake-catchment ecosystem framework has seldom been used in Southern Africa to test ideas about landscape disturbance; this study forms part of a research initiative between UK and South African universities to reconstruct and explain historic changes in sediment dynamics in the Karoo using sediments accumulating in farm reservoirs (see Foster *et al.*, 2005, 2007, 2008).

This paper focuses on Cranemere Reservoir located between the towns of Graaff Reinet and Somerset East on the plains of Camdeboo. Initially constructed in 1843, it is believed to have the longest post-settlement sediment records in the region. The reservoir at capacity has an area of 19 ha and drains a 40 km^2 predominantly rangeland catchment. The region comprises horizontally-bedded Upper Permian to Triassic sandstones and mudstones of the Karoo Supergroup which are capped by Jurassic dolerites (McCarthy & Rubidge, 2005). Holmes *et al.* (2003) report that Holocene colluvium in this region of the Karoo covers the footslopes and valley bottoms to a depth of several metres, but the valley fill in the Cranemere catchment is considerably thinner (1–2 m).

METHODS

The dry bed of the reservoir was cored at a central location some 50 m away from the dam wall, in August 2007, using a manually operated “Russian” corer. Samples were extracted at 2 cm intervals to a depth of 4.3 m, sealed in plastic bags and transported to the UK for analysis. Twenty-seven samples were collected from a range of locations representing different potential sources: topsoils and subsoils, channel banks and badlands, for the major lithologies present in the catchment. Laboratory preparation methods follow those described in detail by Foster *et al*. (2007, 2008). In brief, a range of mineral magnetic parameters and gamma emitting radionuclides were measured after drying samples at 40°C overnight and gently disaggregating the samples with a pestle and mortar. Following Foster *et al.* (2007), potential source samples were screened to <250 μm in order to more closely match particle size distributions of the reservoir deposits. The measured and calculated mineral magnetic parameters included χarm, χlf, χfd%, SIRM, HIRM and the S ratio. Several of these parameters were also expressed as ratios (e.g. χarm/SIRM, SIRM/χlf) in order to determine the dominant magnetic mineral assemblages. Measurement of ^{210}Pb and ^{137}Cs to derive a chronology, and other gamma-emitting radionuclides to be used as source tracers, is ongoing, but analysis is as yet incomplete. This paper will focus on the mineral magnetic measurements of the reservoir sediments and of potential sediment sources.

In order to make an accurate interpretation of sedimentary sequences it is necessary to first check for evidence of magnetic mineral dissolution or additions derived from bacterial magnetosomes or authigenic greigite within the sediment column (see Oldfield, 1999; Foster *et al*., 2008), as such *in situ* changes would distort the magnetic signature. Evidence for mineral dissolution often comes from steep declines in all concentration parameters and is associated with parallel declines in χarm/SIRM and χarm/lf, both indicative of changes in mean magnetic grain size that could be associated with selective dissolution. Initial indications of a strong bacterial magnetosome presence can be established using the χarm/SIRM ratio, since magnetosome dominated samples often have values in excess of 2×10^{-3} mA (Oldfield, 1999). It has been recognised that the ferrimagnetic sulphide greigite (Fe_3S_4) could contribute to the apparent "magnetite" signatures of sediments in a wide range of contexts. Oldfield (1999) suggested that one clear indicator is a high SIRM/χlf ratio, with values above 30×10^3 Am^{-1}.

RESULTS

The Cranemere reservoir sediments

Downcore trends in four magnetic ratios and two magnetic concentration parameters are plotted in Fig. 1. All values of χarm/SIRM lie below 2 (Fig 1(a)) and all SIRM/χlf ratios lie below 30 (Fig. 1(b)) suggesting that the magnetic signatures of these deposits are not strongly overprinted by the presence of either bacterial magnetite or by greigite. The concentration parameters of Fig. 1(c) and (d) show little evidence of dissolution diagenesis as the concentrations generally increase rather than decrease with depth in the core.

The range of magnetic susceptibility values (χlf) (Fig. 1(c)), all of which are greater than 0.1×10^{-6} m^3 kg^{-1}, suggest that the magnetic properties of the Cranemere sediments are dominated by ferrimagnetic minerals such as magnetite or maghemite (Dearing, 1999). χfd% values are consistently in excess of 8% except for the basal river sediments that underlie the reservoir sediments and the two samples between 125 and 150 cm depth. A high χfd% is strongly suggestive of the presence of superparamagnetic grains frequently associated with pedogenesis (Dearing, 1999). The high S ratios below 150 cm depth also support the notion that the sediments are dominated by magnetite-type minerals with a soft remanence. A harder remanence (<0.7) is found upcore of 150 cm indicating that a magnetic signature from antiferromagnetic minerals, such as haematite or goethite, was more important in relative terms. However, the S ratios for the whole core indicate that although the magnetic properties appear to be predominantly ferrimagnetic, the magnetic mineral assemblage is mainly antiferromagnetic and certainly includes haematite (Walden, 1999).

Sediment sources

The sediment sources sampled from within the catchment have been classified into four major groups. The first three groups are: topsoil sources, including valley fill and cultivated valley fill

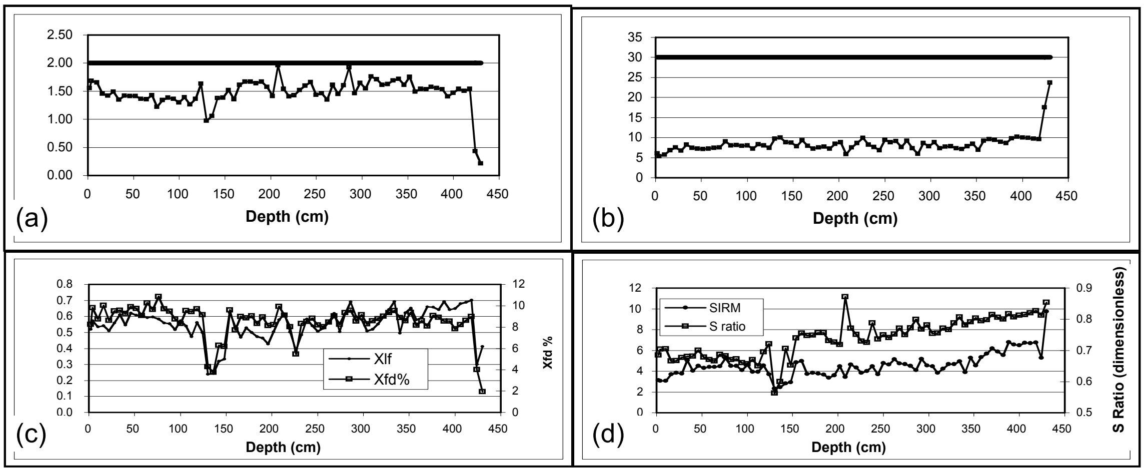

Fig. 1 Downcore trends in χarm/SIRM (a), SIRM/χlf (b), χlf and χfd% (c), SIRM and the S Ratio (d).

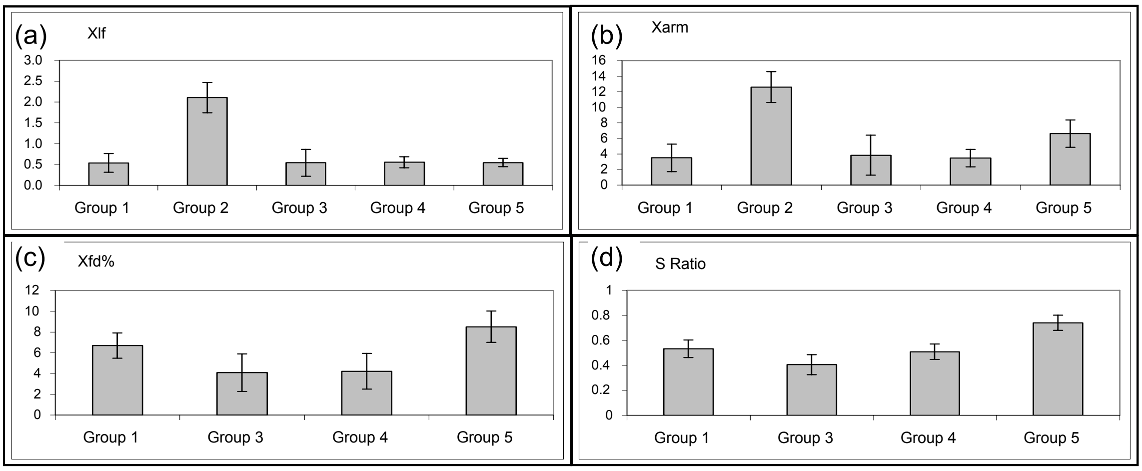

Fig. 2 Mineral magnetic characteristics of potential sediment sources. χlf (a), χarm (b), χfd% (c) and S Ratio (d). Groups 1–4 represent potential sources (1–3 topsoils from colluvium, dolerite and sandstones), group 4 represent subsoil colluvial sources. Group 5 are reservoir sediments. Error bars are ± 1 standard deviation of the mean.

topsoil (Group 1), dolerite (Group 2) and sandstone (Group 3); Group 4 is made up of subsoil colluvial sources, including channel sides and badlands. Figure 2 shows plots of two magnetic concentration parameters and two magnetic ratios for the potential sources in addition to Group 5 sediments, which are from the reservoir.

The data of Fig. 2(a) and (b) indicate that topsoil derived from dolerite has a very different signature from the reservoir sediment and it is suggested that it makes a relatively minor contribution to the sediments deposited in the reservoir. The plots of Fig. 2(c) and (d) therefore omit this potential source. The data of Fig. 2(c) and (d) indicate that the range of values within Group 5 plot outside the ranges of the potential sources. There are three possible explanations for this observation. First, not all sources were identified and sampled; secondly the choice of 250 µm as the cutoff particle size for sources was too coarse and, thirdly, the characteristics of the potential sources have changed through time (see Foster & Lees, 2000). While this last possibility is debatable, a change in source hypothesis may be supported by the upcore trends in Fig. 1 that show a slight decline between the base and top of the core in χlf, and a much stronger decline in SIRM and the S ratio. This general trend was punctuated by a phase when there appears to have been a very significant source change between 125 and 150 cm depth. The general declining trends upcore could indicate that the entire landscape has suffered long-term degradation and significant topsoil losses through time, thereby reflecting a change in source characteristics. If this hypothesis is correct, it suggests that European settlement has had a long-standing and devastating impact on the landscapes of the Karoo that may take decades or even centuries to recover.

CONCLUSION

The evidence suggests that the mineral magnetic signatures in Cranemere reservoir are not affected by post-depositional diagenesis and therefore can be assumed to be diagnostic of sediment sources. The majority of the reservoir sediment is derived from non-dolerite topsoil sources within the catchment, with a short period of major disturbance when channel bank and badland sources were probably important. There is some evidence to suggest that the landscape has suffered continuous degradation since the 1840s, as reflected in the harder remanence of recent sediments and a decline in SIRM and χlf. Further analysis of radionuclides to provide a chronology of sedimentation that can be correlated with climatic variability and changes to land management practices will provide further insight into sediment dynamics of this semi-arid catchment.

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