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Colour as reliable tracer to identify the sources of historically deposited flood bench sediment in the Transkei, South Africa: A comparison with mineral magnetic tracers before and after hydrogen peroxide pre-treatment

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ABSTRACT

The fingerprinting of historically deposited sediment has shown valuable potential for reconstructing past environmental changes over the previous < 100 years. However, changes to sediment particle size distribution, organic matter content, and post-depositional chemical alterations to tracers are significant sources of uncertainty. Most tracers are also expensive to measure, creating barriers to wider adoption of the source fingerprinting approach. Sediment colour represents an inexpensive tracer which can make the method more accessible, provided that it is conservative in the environment and can adequately discriminate between potential sediment sources. The sediment provenance results derived using colour and mineral magnetic tracers are compared to determine if colour can be a reliable tracer when used with historically deposited sediment. This study also explores the usefulness of hydrogen peroxide (H_2O_2) pre-treatment to reduce uncertainties associated with sediment-associated organic matter. Neither tracer type could discriminate between surface and subsurface sources. However, both could discriminate between igneous and sedimentary sources. The H_2O_2 treatment had little effect on source discrimination. There was a good agreement between source apportionment results derived using the treated and untreated colour and magnetic tracers in three of the four cores analysed. Both tracer types identified that low sediment contributions from distal igneous sources reach the catchment outlet during low magnitude floods, but distal igneous sources are important during high-magnitude floods. A poor agreement was found between the results derived using magnetic and colour tracers for one core, which was likely caused by a low rate of sediment deposition and the fine particle size distribution of the sediments when compared to the sieved source materials. Colour was a useful tracer for use with historically deposited flood bench sediments. Its usefulness is, however, dependent upon a comparable particle size distribution between sources and sediments, low sediment-associated organic matter concentrations and minimal post-depositional alterations to the sediment. The H_2O_2 treatment proved to potentially be an additional source of uncertainty rather than a method to reduce it.

1. Introduction

Sediment source fingerprinting when used with historically deposited sediment can allow for the reconstruction of past environmental changes within a river or lake catchment (Foster et al., 2011). A variety of tracers have been used in published research including mineral magnetism (Oldfield et al., 1985; Oldfield and Wu, 2000), geochemistry (Collins et al., 1997a), radionuclides (Wallbrink et al., 1998; Foster et al., 2007), stable isotopes (Revel-Rolland et al., 2005), biomarkers (Hancock and Revill, 2013; Reiffarth et al., 2016) and colour (Martínez-Carreras et al., 2010a). However, the measurement of tracers is often expensive and time consuming, preventing the wider use of the technique (Collins and Walling, 2002). The analysis of sediment cores which are commonly sectioned into 20–40 individual subsamples further adds to this cost. This paper focuses on the use of colour signatures as inexpensive, non-destructive tracers with, thereby, the potential to increase the adoption of the fingerprinting of historically deposited sediments more generally. At present, there is little established use of colour in the context of historically deposited sediments, meaning that expensive analytical equipment is a necessity before tracing sources. The sediment source apportionment results derived using colour are compared to those generated using mineral magnetic tracers, which

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have a well-established basis for use with historically deposited sediment.

Sediment and soil colour is controlled by various soil constituents, such as carbon (Chabrillat et al., 2011; Bayer et al., 2012), iron (Schulze et al., 1993) and carbonate content (Sánchez-Marañón et al., 1996). The measurement of colour tracers is non-destructive, fast and can potentially be undertaken without the need for specialist equipment using only a colour scanner (Pulley and Rowntree, 2016). The use of more specialist spectroradiometers can, however, increase the range of wavelengths which can be measured outside that of visible light, and increase the resolution of colour measurements (Martínez-Carreras et al., 2010a). For these reasons, the application of colour as a tracer with suspended or recently deposited sediments has been growing in recent years (Martínez-Carreras et al., 2010b; Brosinsky et al., 2014; Tiecher et al., 2015). However, colour does not, at present, have an established background of use for tracing the origins of historically deposited sediments.

Mineral magnetic tracers have an extensive history of use (Walling et al., 1979; Thompson and Morton, 1979; Oldfield et al., 1985; Foster et al., 2008; Manjoro et al., 2017). They are sensitive to differences in iron oxide concentration and speciation between potential sediment sources and therefore can be effective source discriminators. They have been shown to be able to discriminate between soils over different lithologies (Owens et al., 1999; Pulley et al., 2015a), whilst their propensity for being created and altered during soil formation and subsurface colluvium/alluvium storage (Dearing et al., 1996; Foster et al., 1998) also provides a robust basis for sediment source discrimination. They are also strongly affected by fire providing a useful means of tracing post-fire sediment movement (Blake et al., 2006). Recent work on historically deposited sediment in the Eastern Cape of South Africa by Pulley et al. (2015a) identified mineral magnetic tracers as being highly conservative in six of seven artificially-constructed small farm dam lakes investigated. Colour tracers are also likely conservative in some recently transported sediments in the semi-arid Eastern Cape (Pulley and Rowntree, 2016). Therefore, both types of tracer have potential for use as inexpensive fingerprints for application in source tracing investigations within South Africa, and with the use of historically deposited sediments. This is important as South Africa continues to have both on-site and off-site environmental problems associated with soil erosion and subsequent sediment delivery to receptors including lakes, dams and rivers (Le Roux et al., 2007; Foster et al., 2017). Despite the clear wider utility of colour-based sediment source tracing in South Africa and the continued need for information for supporting improved soil and sediment management strategies, colour remains an underutilised tracer when compared to magnetism, especially in the context of historically deposited sediments.

Against the above background, numerous uncertainties are associated with the use of colour and mineral magnetic tracers and, indeed, sediment fingerprinting methodologies as a whole (D'Haen et al., 2012; Koiter et al., 2013; Pulley et al., 2015b; Collins et al., 2017). Alterations to sediment particle size distribution and organic matter content, alongside tracer non-conservatism, are perhaps the most commonly cited reasons for uncertainty. Both colour and magnetism are affected by sediment particle size (Maher, 1988; Blake et al., 2006; Pulley and Rowntree, 2016) and organic matter content (Webster and Butler, 1976; Ben-Dor et al., 1998; Smith, 1999). These issues have a greater probability of masking sediment provenance in a lake or floodplain setting where particle size selective deposition may take place (He and Walling, 1997), and organic matter may also be selectively deposited or produced in situ (Hein et al., 2003). Additional uncertainties are particularly associated with the tracing of historically deposited sediment (Collins et al., 1997a; Collins et al., 1997b; Foster and Lees, 2000; D'Haen et al., 2012; Pulley et al., 2015c; Collins et al., 2017), such as the dissolution and transformation of tracers under reducing conditions (Barron and Torrent, 1986; Anderson and Rippey, 1988; Roberts and Turner, 1993; Foster et al., 1998), the ingrowth of bacterial magnetites (Maher and Thompson, 1999; Oldfield and Wu, 2000) and the formation of iron sulphides (Snowball and Thompson, 1988). Such transformations clearly have the potential to mask sediment provenance and thereby generate misinformation for guiding catchment sediment management strategies.

Against the above background, this paper focuses on the use of colour as an inexpensive, non-destructive tracer for discriminating and apportioning recent (< 100 years) historical sediment sources in a South African environment. It aims to determine if the source apportionment results produced by colour can be reliable by using a comparison with mineral magnetic tracers, and determining if the results fit with an understanding of the geomorphology in the study catchment. In addition, hydrogen peroxide (H_2O_2) treatment is evaluated to determine the impact of organic matter and organic coatings of sediment particles on the source fingerprinting results, and to assess if the treatment can assist in mitigating these sources of uncertainty. H_2O_2 is widely used to remove organic matter from samples prior to particle size analysis (Schumacher, 2002; Mikutta et al., 2005; Gray et al., 2010), and chemical treatments such as hydrochloric acid have been used to remove in-grown magnetic grains from sediments (Maher et al., 2009). Therefore, for historically deposited sediment, H_2O_2 treatment may have significant advantages when used with a tracer, such as colour, which is strongly affected by the presence of organic matter.

2. Study area

The Vuvu study catchment is in the north-east of the Eastern Cape of South Africa, and forms a tributary of the Thina River and the larger Umzimvubu River. The 65 km^2 catchment has an average annual rainfall of 707 to 928 mm, much of which occurs in high intensity summer storms (Mucina et al., 2006; Nel, 2008; Nel et al., 2010).

The upper catchment is underlain by igneous Drakensberg Group basalts and dolerites, and the lower catchment is underlain by sedimentary Clarens Formation sandstones and Elliot Formation mudstones (Fig. 1). Valley floors in the lowest part of the catchment are filled by colluvium which is up to 6 m thick, as well as alluvium deposits (Fey et al., 2010). In contrast, soils on hillslopes are shallow (~20 cm deep) and poorly developed, except where deeper colluvium accumulates. The hillslopes in the igneous upper catchment are primarily used for light grazing whereas valley bottoms in the sedimentary lower catchment are used for more intensive grazing, habitation and small-scale crop production. Valley bottom soils and colluvium deposits are heavily degraded by soil pipes, rills and gullies due to their dispersive nature (Van der Waal, 2015).

3. Methods

3.1. Field and laboratory methods

Sediment sources were assigned into to four categories for sampling: topsoils overlying an igneous geology, subsurface soils and sediment overlying an igneous geology, topsoils overlying a sedimentary geology, and subsurface soils and sediment overlying a sedimentary geology. A total of 178 samples were collected in the following proportions: igneous subsurface, 42, igneous surface, 42, sedimentary subsurface, 45 and, sedimentary surface, 45 (Fig. 1). At each sampling point, both a surface and subsurface sample was collected where possible (incised colluvium). Surface samples were identified by their darker *in situ* colour, whereas subsoils had a much lighter colour. The surface samples were collected from the top 10 cm, characterised by the uniform colour of the soil profile, using a non-magnetic steel auger. Subsurface samples were collected from the middle horizons (1–3 m below surface) of visibly eroding gullies and landslides close to the points of surface sample collection.

Sediment cores were retrieved from floodplain benches in the lower reaches of the catchment using a Eijkelkamp percussion corer with a