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Luminescence dating, sediment analysis, and flood dynamics on the Sabie River, South Africa

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A B S T R A C T

Floods on sediment-rich semiarid rivers often lead to significant geomorphic change, but luminescence dating of sediments deposited by past flood events has hitherto been unable to meaningfully inform on past flood dynamics. This is important because luminescence dating has commonly been applied to flood sediments, but the calculated sediment ages are in almost all cases older than the ages of known floods responsible for sediment deposition. Correctly interpreting these older ages in the context of flood dynamics is therefore a key problem. This study addresses this problem by discussing relationships between luminescence dating, sediments, and reach-scale geomorphology along the semiarid Sabie River, northeastern South Africa. Twelve luminescence ages were obtained from near-surface sediments (<10 cm depth) from five sites across a 60-km distance of the lowland part of the river. Luminescence ages of 26–163 years suggest that sediments are differentially mobilized by successive floods and that high suspended sediment concentrations in the water column were insufficient to effectively zero the luminescence signal of the quartz grains. Analysis of equivalent dose values and distributions from individual dated samples using abanico plots shows the relative degree of bleaching, thus informing of the mixed composition of the sample and its likely source. Different landforms (bars, fans, flood drapes) were developed during maximal and waning flow stages, followed by fallout from suspension across the flooded valley that formed a drape that thins toward the upper flood limit. Different grain size properties and luminescence signals are found in these different fluvial settings. These landform and sediment properties can help explain why differential bleaching took place during fluvial sediment transport, which gave rise to the scatter in equivalent doses found within the dated samples. A model is proposed that describes these corelationships and provides a hypothesis of these relationships to test in future studies.

1. Introduction

Rivers in semiarid environments tend to be characterized by high seasonality of precipitation and thus river discharge, high event-scale precipitation rates giving rise to rapid overland flow and river sediment yield, and flashy discharge regimes giving rise to high flow turbulence and sediment carrying capacity during maximal flood stages (Pickup, 1991; Ashworth et al., 2000; Grenfell and Ellery, 2009; Tooth et al., 2013). As such, semiarid rivers are often associated with high flood hazard. In the semiarid areas of northeast South Africa, incoming cyclones from the Indian Ocean have led to some significant flood events over the last 20 years (e.g., in 2000, 2012) that have resulted in loss of life as well as major geomorphic change within the river systems (Rountree et al., 2000; Heritage et al., 2004). Many previous studies of semiarid rivers globally have focused on the geomorphic impacts of flood events, using a combination of aerial surveys, satellite imagery, and LiDAR in order to produce geomorphological maps and/or for change analysis (e.g., Ashworth et al., 2000; Rountree et al., 2000; Heritage et al., 2001, 2004; Croke et al., 2013; Buraas et al., 2014; Hooke, 2016). However, reach-scale patterns may vary significantly even along the same river, reflecting spatial changes in bedrock controls and sediment connectivity (Heritage et al., 2003, 2015; Croke et al., 2013; Entwistle et al., 2015). The landforms and sediments (sediment type, sorting, mineralogy) found along individual reaches can also inform on flood dynamics during maximal and waning flow stages (e.g., Pettit et al., 2005; Grenfell and Ellery, 2009; Keen-Zebert et al., 2013; Knight and Evans, 2017).

More recently, luminescence dating of flood-transported sediments (either as slackwater drapes or maximal flood stage bars or fans) has been commonly used to provide chronologies of palaeoflood events over the late Holocene, linked to climate (e.g., Sim et al., 2014; Roskosch et al., 2015; Larkin et al., 2017; Zhao et al., 2017). Issues concerned with this approach include the age-model chosen, which can significantly affect the calculated age and thus climatic interpretation of age results (Kunz et al., 2013; Muñoz-Salinas et al., 2016). Other studies have also examined the luminescence signatures of flood layers

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deposited by known historical or recent floods (e.g., Cunningham and Wallinga, 2012; Colarossi et al., 2015; Heritage et al., 2015). A significant issue in luminescence dating of river flood deposits is that the luminescence signal is incompletely zeroed within the sediment grains, owing to only partial exposure to sunlight during sediment transport and deposition (Hu et al., 2010; Colarossi et al., 2015; Cunningham et al., 2015a, 2015b; Przegiętka et al., 2016). This results in dated river sediments being older than they should be; for example, along the Sabie River, South Africa, luminescence ages of ~200–600 years were derived for river sediments deposited by major floods in 2000 and 2012 (Heritage et al., 2015). Although Bayesian analysis and sediment mixing models can be used to partly resolve this issue (Cunningham et al., 2015a, 2015b), some studies also suggest that floodplain and shallow-water sediments yield better results than deep-water channel sediments (Weckwerth et al., 2013); and coarse grains are better than fine grains, and suspension transport is better than bedload transport (Hu et al., 2010). Many luminescence studies, however, are more concerned with producing dates than in examining the field context and meaning of the dated samples, and sediment transport conditions of these samples are commonly not well known from field evidence.

A key approach to this problem therefore is integrating luminescence and sedimentological/geomorphic data from individual river reaches, in order to derive a better understanding of the processes of sediment transport during floods, which can then provide the context for interpreting the luminescence data. To this end, we use an integrated field and lab approach to examine reaches of the Sabie River, northeast South Africa. This semiarid river is known to have been strongly affected by recent floods, which have been argued to cause wholesale sediment stripping and scouring down to bedrock and thereby 'resetting' the river's geomorphic and sediment patterns and giving rise to 'old' luminescence ages for dated sediments (Heritage et al., 2015). The aim of this research is to investigate the relationship between the luminescence ages and reach-scale geomorphology and sediment patterns along a semiarid river. The Sabie River is therefore an ideal location to examine these relationships.

2. Study area

The Sabie River (catchment of 6320 km^2) is a mixed bedrock–alluvial river system that drains from the Eastern Escarpment of southeast Africa eastward into the Corumana Dam in Mozambique before entering the Indian Ocean (Fig. 1). The highly variable hydrological regime of this river reflects a marked precipitation gradient, from ~2000 mm/y in mountain headwaters to ~600 mm/y in lowland reaches. In particular, tropical cyclones tracking from the Indian Ocean result in intense and sustained rain events that give rise to extreme floods on the Sabie and adjacent rivers during the austral summer. Discharge of the Sabie River (station X3H015, 25°08′58.3″S, 31°56′26.4″E, 1 Jan 1995–31 Dec 2014) varies substantially on a seasonal basis, from a winter average low flow of ~2–3 m^3 s^{-1}, to a summer average of ~20–50 m^3 s^{-1} with peak flood values of 300–400 m^3 s^{-1}. Exceptionally, over the last 20 years, discharge values have exceeded 7000 m^3 s^{-1} on two occasions (in Jan 2001 and Jan 2012) and with other significant floods in 1996, 2000, and 2006.

Bedrock geology in headwater regions of the Eastern Escarpment (~900 m asl) includes shale, quartzite, basalt, and diabase (Pretoria Group, Precambrian). In middle and lower river reaches on the low-relief surface of the Lowveld (~200–300 m asl), bedrock includes rhyolite, basalt, and sandstone (Karoo Supergroup, Jurassic) (Bristow et al., 1986; Schutte, 1986; Viljoen, 2015). Bedrock geology has an indirect impact on catchment soils and vegetation (Venter, 1986; Munyati et al., 2013). In lower reaches where there are patches of bedrock and surface sediments, studies have noted significant differences in flood responses (Heritage and van Niekerk, 1995; van Niekerk et al., 1995; Rountree et al., 2000; Heritage et al., 2003). Along the Sabie River, floods cause a change from a single to a distributary channel system, as elevated water levels (commonly by ~6–10 m) allow the river to spread across the floodplain. This behaviour is particularly found in the lowermost part of the catchment within the protected area of Kruger National Park (KNP) where a mix of bedrock and sediment reaches are present and where floodwater flow is not impeded by damming, engineering,

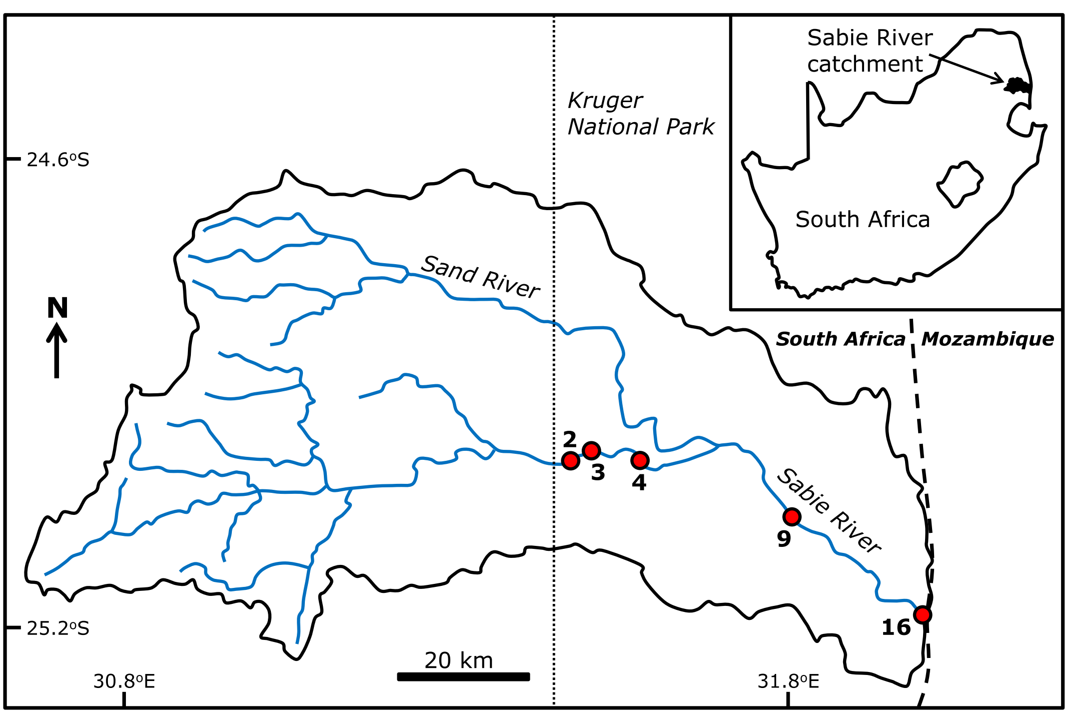

Fig. 1. Location of the Sabie River in northeast South Africa, showing the five study sites (numbered 2, 3, 4, 9, 16). Kruger National Park lies to the east of the thin dashed line and within South Africa. The international border with Mozambique, the location of site 16, is marked with the thick dashed line.