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Evidence for bioturbation of luminescence signals in eolian sand on upland ridgetops, southeastern Minnesota, USA

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ABSTRACT

This study sought to identify the age of eolian sand on narrow ridges in the Root River valley of southeastern Minnesota. The ridges in the region are cored by Ordovician dolomite and Cambrian sandstone, but the ridge tops are typically covered with Late Wisconsin Peoria and older loess units. In some locations Peoria loess is absent and the ridgetops are covered with up to 3 m of eolian sand that was likely sourced from local river valleys and transported to the uplands by sand ramps. We studied nine ridgetop soil profiles and collected seventeen OSL samples from eolian sand at depths ranging from 0.3 to 2.6 m below the present ground surface. All OSL samples were analysed using small aliquots where 90–150 μm quartz grains were applied to the inner 2 mm of 10 mm aluminum disks. The OSL ages ranged from 12.3 to 1.5 ka indicating a significant amount of age variability, and potentially suggesting nearly continual eolian deposition throughout the Holocene. However, several key differences were identified between those samples taken from within 1 m of the ground surface compared with samples that were more deeply buried. Those samples collected from depths of greater than 1 m yielded ages that were tightly clustered between 12.3 and 10.3 ka, while samples taken from depths of less than 1 m showed ages with much higher spread that ranged from 1.5 to 10.1 ka. The samples collected from within 1 m of the present ground surface also commonly showed higher spread in their equivalent dose distributions and higher overdispersion values relative to the samples that were more deeply buried. This suggests the luminescence signals from the upper portions of these deposits were reset after burial, most likely by bioturbation, and that the OSL ages are not depositional ages. This interpretation is supported by evidence from a core sample collected from one of our sites that shows primary eolian lamina are preserved below 1.4 m depth but not above this depth. Presumably, the bioturbation agents were effective at both resetting the luminescence signal and disturbing the primary bedding to depths of at least 1 m. If bioturbation occurred below this threshold it apparently did not impact either of these indicators. Our findings suggest the upper 1 m of these profiles were impacted by bioturbation and that all of the eolian sand on these ridgetops was likely deposited prior to 10.1 ka.

1. Introduction

OSL ages are generally used to estimate the last time sediment grains were exposed to sunlight prior to burial. However, several studies have noted post-depositional mixing by physical and biomechanical processes limit the reliability of age dating with OSL (see Bateman et al., 2003, 2007; Forrest et al., 2003). These post-depositional processes are a particular problem in sediment that is present within ~1 m of the ground surface. Luminescence ages can theoretically be adversely impacted by post-burial processes in a number of ways. Older grains can be moved vertically upward in a profile, resulting in OSL ages that could be much older than the sediment's actual age. Potentially of more importance, grains can be bleached or partially bleached at the ground surface and moved vertically downward in the sediment profile, causing age estimates that are younger than expected. The nature of the stratigraphy and the local pedoturbating agents will dictate the specific effects on OSL ages. Although the term bioturbation is generally used in the literature, purely physical mixing processes (e.g. cryoturbation) may be an important process in some cases.

The advent of single-grain OSL apparatus has allowed researchers to study grain to grain variability and to attribute

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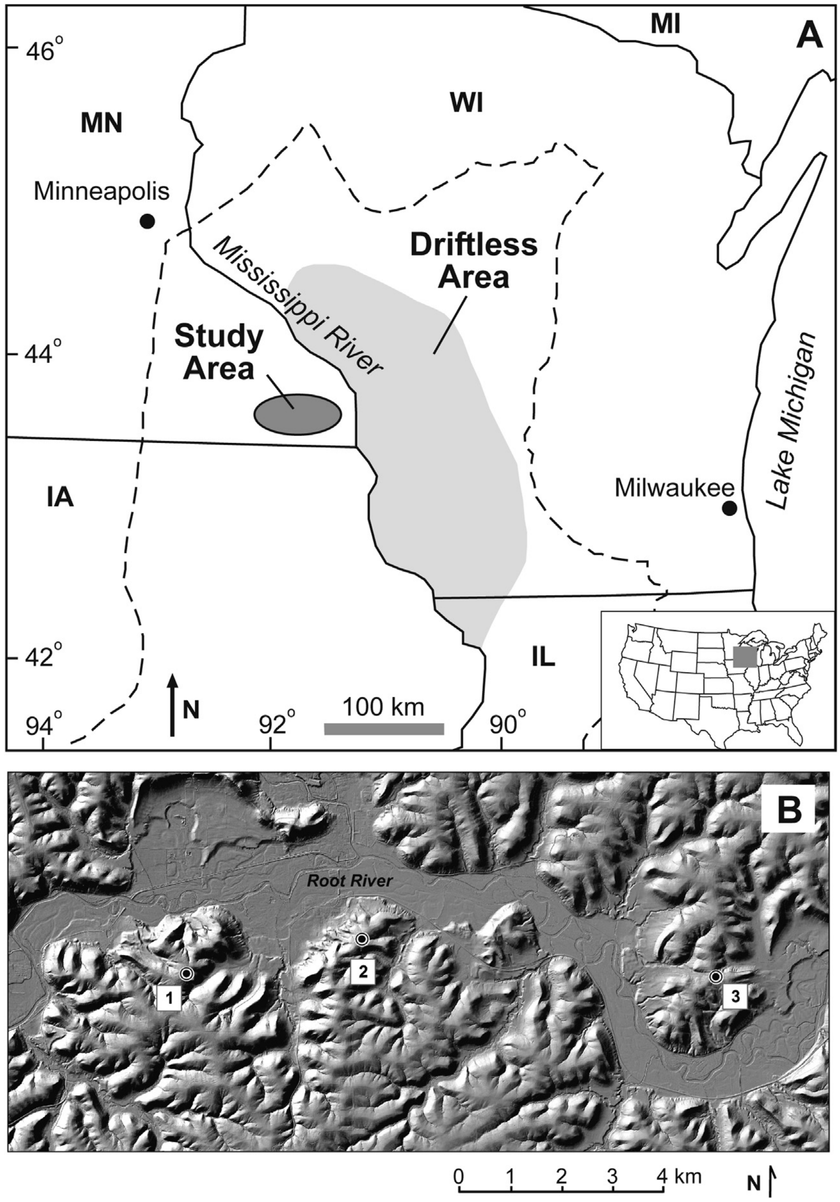

Fig. 1. Fig. 1A. Study area location in the Root River Valley in Minnesota. Shown are the Driftless Area, the Mississippi River, and the limit of the last Glacial Maximum (dashed line). Fig. 1B. Hillshade from digital elevation model constructed from LiDAR data. Shown are the three study sites along the uplands adjacent to the Root River valley, including the Peterson (Site 1), Rushford South (Site 2) and Vinegar Ridge (Site 3) study locations.

anomalous grains or skewed D_e distributions in these high resolution data sets to phenomena such as partial bleaching and pedoturbation processes (Feathers, 2003). Single-grain analysis also allows for anomalous grains or groups of grains to be identified and removed from a population, allowing workers to better estimate the depositional age. Early studies using single-grain dating equipment showed the presence of younger grains embedded in older samples, presumably the result of post-depositional bleaching and mixing processes. Forrest et al. (2003) used single-grain analysis to show that grains with very low D_e values were present in older samples from a paleolithic site in Portugal. Feathers (2003) identified the broadening of D_e distributions from sand samples collected from the Southern High Plains, USA as a consequence of bioturbation.

While younger or older grains may be present in some OSL samples due to post-depositional processes, the greatest concern is the degree to which these anomalous grains are adversely affecting OSL ages that are intended to represent a sample's burial age. Most OSL ages are generated using multiple-grain aliquots, which can at least to some degree, mask the effects of bioturbation by homogenizing luminescence signals from hundreds of grains. While the benefits are apparent, the impacts of bioturbation in multiple-grain aliquots can be difficult to identify and mitigate. Recent studies have interpreted problems with bioturbation using multiple-grain aliquots. Working in eolian sands in Wisconsin's Central Sand Plain, Rawling et al. (2008) noted generating younger OSL ages from samples collected within the upper ~ 1.5 m of the ground surface relative to those collected from below 1.5 m depth. The younger ages from the upper portion of these profiles were attributed to the downward movement of bleached or partially bleached grains from the ground surface. Bateman et al. (2007) interpreted the presence of relatively old grains in a matrix of