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Abandonment ages of alluvial landforms in the hyperarid Negev determined by luminescence dating

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ABSTRACT

Dating the time of abandonment of geomorphic surfaces in the arid mid latitudes is necessary for studies ranging from tectonics, landscape evolution and paleoclimate. It has often been hampered by the limited material suitable for conventional isotopic methods and the uncertainties inherent in cosmogenic radionuclide methods. We propose luminescence dating as a suitable method for dating the time of abandonment of aggradational geomorphic surfaces in the hyperarid regions. We dated the top of such surfaces with different age ranges and geomorphic settings in a sequence of alluvial fans in Nahal Shehoret in the southern Negev and in a sequence of terraces in Nahal Ze'elim and in Nahal Zin, two adjacent drainage basins in the Judean Desert, Israel. Samples were collected from beneath the gypsic horizon at a depth of 0.3–0.7 m, below which sand grains do not penetrate. Depositional ages for the uppermost beds of the landforms, which are proxies for abandonment, range from ~90 ka to ~5 ka. In all three basins, the ages are in morphostratigraphic order and agree well with relative age estimates based on soil chronosequences and on Lake Lisan levels. Abandonment ages for an individual alluvial fan cluster within ±10–20%, therefore it is possible to distinguish between surfaces with ages differing by more than 20%. Thus, in hyperarid areas, the luminescence methods can be used for surface dating.

1. Introduction

Determining ages of alluvial fans in hyperarid areas is difficult because datable material, whether organic matter for radiocarbon or pedogenic carbonate for U-series disequilibrium dating, is scarce. This in the past hindered research on Quaternary landscape evolution, fluvial responses to climate change, palaeoenvironmental and palaeoseismological studies, and assessment of phases and rates of aggradation and incision (e.g., Bull, 1991). Dating landforms in semi-arid and arid regions has often been based on the limited application of isotopic dating methods such as U–Th on pedogenic carbonates (Sharp et al., 2003) or on stratigraphic correlations with independently dated landforms and deposits such as lacustrine terraces, ash layers, marine shorelines and basalt flows (e.g., Bull, 1991; Harvey and Wells, 2003; McDonald et al., 2003; Wells et al., 1987). Semi-quantitative and relative dating methods have included morphostratigraphy, degree of soil development (Amit et al., 1993; Birkeland et al., 1991; Harrison et al., 1993; McDonald et al., 2003; Rockwell et al., 1994) and clast rubification (Helms et al., 2003). These methods require calibrations against known ages which in the hyperarid regions are frequently absent (Noller et al., 2000).

In situ cosmogenic radionuclides have been applied to date surfaces of aggradation landforms (e.g., Gosse and Phillips, 2001; Granger and Muzikar, 2001; Schildgen et al., 2002). While promising, these methods provide model ages that rely on parameters that are partially known: erosion rates, nuclide inheritance and the complex history of the measured clasts (e.g., Clapp et al., 2000; Hancock et al., 1999; Liu et al., 1996; Matmon et al., 2003; Putkonen and Swanson, 2003; Repka et al., 1997; Watchman and Twidale, 2002).

In the past decade, luminescence methods (Aitken, 1998), which date the last exposure of mineral grains to sunlight, have greatly improved the prospects of dating the aggradation phases of alluvial fans and terraces (Rittenour, 2008 and references therein). However, dating the time of alluvial fan abandonment – the age of the geomorphic surface – still remains a challenge. While terraces and alluvial fans have been dated in arid to humid regions

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(Rittenour, 2008), sediments close to surfaces and unconformities were generally avoided as they could have been disturbed by pedoturbation. Even if not observed today, pedoturbation could have introduced grains with reset or partially reset luminescence signal into the soil profile (Bush and Feathers, 2003; Bateman et al., 2003, 2007; Mee et al., 2004), resulting in an underestimation of sediment age.

Detailed infrared stimulated luminescence (IRSL) dating of a Late Pleistocene alluvial fan in Nahal (meaning ephemeral stream; hereafter N.) Shehoret located in the hyperarid region of southern Israel, found that the top ~1.5 m of the alluvial fan accreted within a relatively short time period – between 67 ka and 60 ka – compared to the underlying alluvial units which gave ages of 75–100 ka (Porat et al., 1997). Most likely, the age of sediment at the top of a terrace is the time of the final event of deposition just prior to abandonment of the alluvial fan, and it should provide the best estimate for the time of the surface formation.

Pedoturbation in hyperarid regions is minimal, as demonstrated by IRSL ages from the same Late Pleistocene alluvial fan in N. Shehoret (Porat et al., 1996). The eastern part of the fan was partially buried at ~35 ka due to faulting, but the original surface could still be detected at some depth in trenches by the buried reg soil profile. Samples collected from the exposed and buried fan surface, 30–50 cm below the top of the reg soil profile, gave identical luminescence ages of 56 ka (Amit et al., 2002; Porat et al., 1996), implying that the exposed surface retained its integrity over that time period and was not modified more than the buried surface with regard to the luminescence age of the sand grains. These results suggest that grains with reset luminescence signals do not infiltrate from the surface down below the gypsic soil horizons (at a depth of 30–70 cm) even over tens of thousands of years of exposure and that the luminescence ages of samples collected from beneath that horizon represent deposition ages.

These combined observations; that the uppermost part of alluvial fans is deposited rather rapidly, and that in hyperarid regions surfaces are essentially impenetrable to sand grains, prompted us to exploit this to the benefit of dating geomorphic surfaces using luminescence. The ages would represent the last exposure of mineral grains to sunlight and would provide the time of the last deposition of sediments underlying the surface. When the reg soil profile is still fully intact, implying no substantial erosion, the luminescence ages are somewhat older than surface abandonment, but close in time to the actual event. Multiple sampling from the same surface will provide the timing of this abandonment.

Here we report ages of well preserved alluvial fans and terrace surfaces from the hyperarid (<75 mm/year) region of the Negev, Israel (Fig. 1). Independent age control for verifying our results was based on (a) morphostratigraphy; (b) well dated lacustrine shorelines; and (c) the degree of soil development on the dated surfaces.

2. Study sites

The study sites are located in the southern Negev and Judean Desert (Fig. 1). The climate in this region is hyperarid with mean annual rainfall ranging from 30 mm in N. Shehoret to 75 mm in N. Ze'elim (Horowitz, 2001). Most precipitation falls in autumn to spring during very short, high intensity storms, with dry conditions most of the time (Barzilai et al., 2000). At present there is no vegetation on the terraces and fans because of high surface and subsurface salinity. The absence of calcic horizons in these soils, despite abundant Ca sources, indicates that vegetation cover needed for their formation was limited throughout soil formation history (Amit et al., 2006).

The N. Shehoret site consists of a succession of faulted alluvial fan surfaces that have been studied in detail for

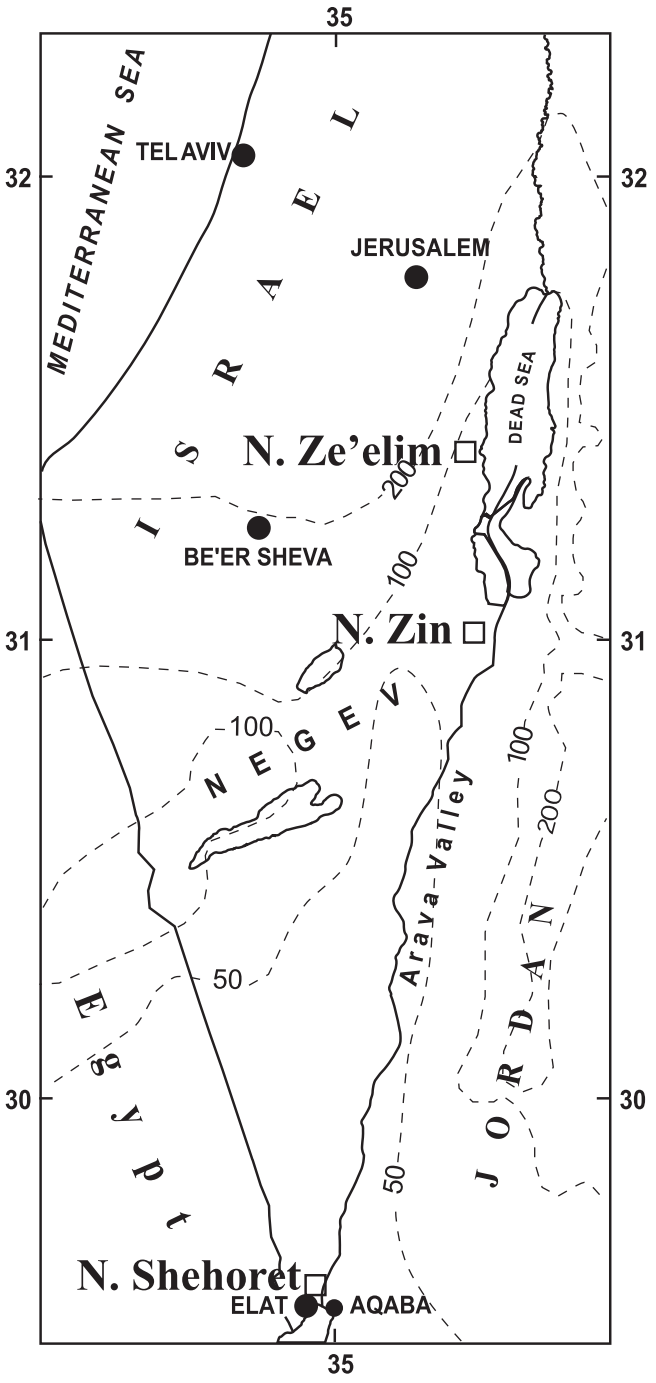

Fig. 1. Location map. Squares denote the studied wadis (Nahal). The 50 mm, 100 mm and 200 mm isohyets are shown.

palaeoseismological purposes (Amit et al., 1999; 2002; Enzel et al., 1996; Gerson et al., 1993; Porat et al., 1996; 1997; 2009). The extensive alluvial surfaces are well-defined in aerial photographs and in their reg soil characteristics (Amit et al., 1996). They provide an excellent case-study for testing the range of ages measured under a single alluvial fan surface and for checking the consistency of ages against the alluvial surface morphostratigraphy and soil chronosequences (Amit et al., 1996).

N. Zin is located near the southwestern margin of the Dead Sea while *N. Ze'elim* drains into the Dead Sea further to the north. The reaches of these two wadis are controlled by the levels and the