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Radioisotopic age, formation, and preservation of Late Pleistocene human footprints at Engare Sero, Tanzania

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ABSTRACT

We report on the radioisotopic age, formation, and preservation of a late Pleistocene human footprint site in northern Tanzania on the southern shore of Lake Natron near the village of Engare Sero. Over 400 human footprints, as well as tracks of zebra and bovid, are preserved in a series of volcaniclastic deposits. Based on field mapping along with geochemical and grain-size analyses, we propose that these deposits originated as proximal volcanic material from the nearby active volcano, Oldoinyo L'engai, and were then fluvially transported to the footprint site. Stable isotope results ($\delta^{18}O$ and $\delta^{13}C$) suggest that the footprints were originally emplaced on a mudflat saturated by a freshwater spring and were later inundated by the rising alkaline waters of Lake Natron. We employed the $^{40}Ar/^{39}Ar$ and ^{14}C dating methods to investigate the age of the site and determined that the footprint level is older than 5760 ± 30 yrs. BP and younger than 19.1 ± 3.1 ka. These radioisotopic ages are supported by stratigraphic correlations with previously documented debris avalanche deposits and the stable isotope signatures associated with the most recent highstand of Lake Natron, further constraining the age to latest Pleistocene. Since modern humans (*Homo sapiens*) were present in Africa ca. 200 ka, Engare Sero represents the most abundant and best-preserved footprint site of anatomically modern *Homo sapiens* currently known in Africa. Fossil footprints are a snapshot in time, recording behavior at a specific moment in history; but the actual duration of time captured by the snapshot is often not well defined. Through analog experiments, we constrain the depositional window in which the prints were made, buried, and ultimately preserved to within a few hours to days or months.

1. Introduction

Fossil human footprint sites constitute unique records of behavior at specific moments in deep time, providing information otherwise unavailable in the fossil record. Experimental studies have demonstrated that individual footprint morphologies and assemblages of footprints can reveal data on foot anatomy, body size, gait kinematics, and possibly other behavioral traits of our bipedal ancestors (e.g., Day and Wickens, 1980; Tuttle et al., 1990; Raichlen et al., 2008, 2010; Bennett et al., 2009; Crompton et al., 2012; Bennett and Morse, 2014; Dingwall et al., 2013; Hatala et al., 2013, 2016). Additionally, studies of the geology surrounding footprint sites (hominin and other) can provide clues to local paleoenvironment and preservation mechanisms (e.g., Leakey and Hay, 1979; Laporte and Behrensmeyer, 1980; Hay, 1987; Deocampo, 2002; Ashley and Liutkus, 2002; Scott et al., 2010). Unlike most paleoecological data that are time-averaged over years or even millennia, footprints and the associated paleoenvironmental indicators preserved in footprinted layers can provide unique information about the environment in which the printmakers lived on the scale of hours to days (e.g., Cohen et al., 1991, Webb et al. 2006; Roach et al., 2016). Late

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Quaternary *Homo sapiens* footprint sites (<200 ka) are found throughout the world, and have recently been documented in South America (Aramayo, 2009), Mexico (Gonzalez et al., 2006), Nicaragua (Schmincke et al., 2009), South Korea (Kim et al. 2010), Europe (Duday and Garcia, 1983; Pastoors et al., 2016), Australia (Webb et al., 2006) and many other locations (see review by Bennett and Morse, 2014). Numerous *Homo sapiens* footprint sites have been documented in Africa, including in Namibia (Kinahan, 1996; Morse et al., 2013; Bennett et al., 2014) and South Africa (Roberts, 2008).

Here, we report on the age, formation, and preservation of an exceptionally well-preserved late Pleistocene human footprint site in northern Tanzania on the southern shore of Lake Natron near the village of Engare Sero. Field research at the Engare Sero footprint site began in August 2009 and, since that time, over 400 human footprints have been uncovered making it the largest assemblage of late Pleistocene *Homo sapiens* prints in Africa. What is equally remarkable is the exquisite preservation of these footprints in conjunction with the detailed geologic history recorded within the footprinted substrate.

2. Site location and regional geology

The Engare Sero site (Fig. 1) is located in northern Tanzania, on the southern shore of Lake Natron within the Natron-Engaruka explosion crater area. The site is bounded on the west by the Nguruman Escarpment, the western border fault of the East African Rift (EAR) in southern Kenya and northern Tanzania, and on the east by two extinct shield

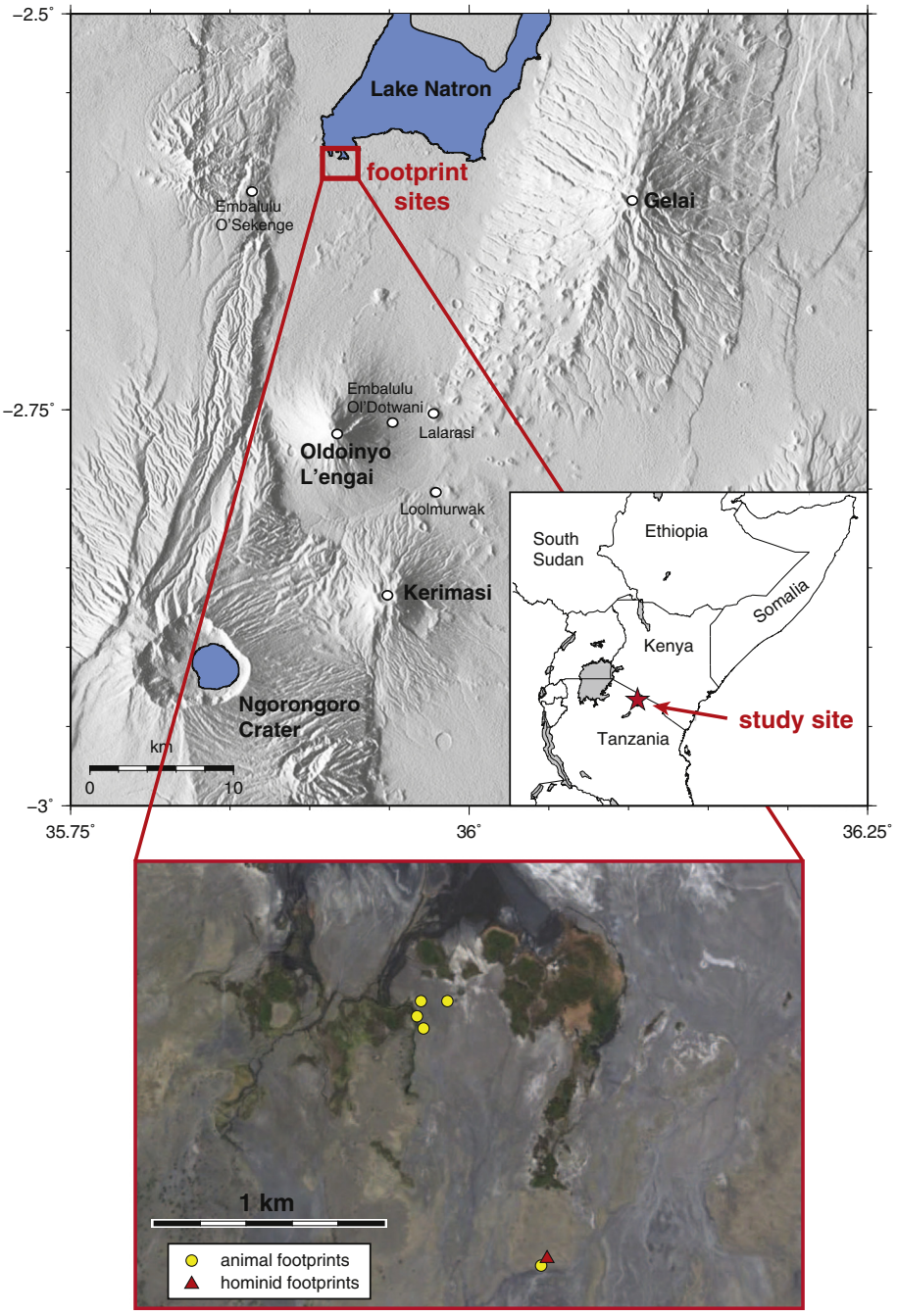

Fig. 1. Position of the footprint sites within the Engare Sero region. The East African Rift escarpment runs North-South along the left side of the map. The Engare Sero footprint site sits to the south of Lake Natron (denoted by the red box, which is enlarged below.) Smaller volcanic centers analyzed as part of this study are labeled. Base map for enlargement from Google Earth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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