Mediterranean Geoscience Reviews
https://doi.org/10.1007/s42990-020-00023-8

ORIGINAL PAPER

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Identifying the Brazil nut effect in archaeological site formation processes

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Received: 14 November 2019 / Revised: 6 March 2020 / Accepted: 26 March 2020

Abstract
The Brazil nut effect (BNE) is a physical phenomenon by which large granular particles (i.e., archaeological artifacts) in a bed of small disturbed particles (i.e., soil), rise to the top surfaces. This paper examines the physical forces acting on archaeological artifacts—scattered on the surface and buried underground—to identify the major elements of site formation processes (SFPs). Combining theoretical advances in archaeology, pedology, granular physics and spectroscopy, we conducted accelerated laboratory tests on seven typical Israeli soils to form a SFP model. We suggest that the SFPs are the result of two opposing and continuous processes: soil coverage of the site started soon after human activity has ceased, and a force(s) that tends to lift buried artifacts up to exposed surfaces, acting in accordance with Brazil nut effect (BNE). The post-burial forces pressuring artifact movement upward are affected by the artifacts' density and size, soil characteristics and the local environment. As a result, some archaeological artifacts reach exposed surfaces, some are lifted to higher soil deposits but remain buried, and the rest remain in their original burial context.

Keywords Archaeological site formation · Field survey · Brazil nut effect · Soil · Pedology · Granular physics · Spectroscopy

Introduction

Site formation process (SFP): preface

An SFP is any event involving interactions of physical forces, human activity and the environment that affect the characteristics of the archaeological record (Sullivan and Dibble 2014). An understanding of SFPs is obligatory for any rigorously assessed scientific reconstruction of the cultural past. As such, SFPs belong among the core concepts of any archaeological inquiry (e.g., Schiffer 1987, 2010; Karkanas and Goldberg 2018). Controlling for the impacts of SFPs is crucial to the discipline because archaeologists use the patterns of artifact dispersal in the ground to infer behaviors (Stein 2001). One of the major challenges, therefore, is the identification of patterns that are created by ancient behaviors as opposed to those created by later cultural and natural processes. In this respect, one of the major research avenues in the study of SFPs deals with post-depositional and recovery processes (e.g., Schiffer 1972, 1983, 1985; Clarke 1973; Sullivan 1978). According to O'Shea (2002: 212), post-depositional theory is concerned with what happens after an object has left the systemic archaeological context; whereas, recovery theory is concerned with how the actual process of archaeological discovery and recovery can distort or bias the perception of the archaeological record. After several decades of intensive research in these areas, however, the basic physics of the forces impacting scattered archaeological remains on and under the surface remains surprisingly understudied.

The archaeological aspects

One of the major pillars of archaeological investigation is the field survey: searching for sites and collecting information about the location, distribution and organization of past human cultures across a large area (e.g., Schiffer et al. 1978;

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Bintliff and Snodgrass 1988; Banning 2002; Tartaron 2003; Bintliff 2014; Banning et al. 2017). Surface surveys are often complementary to excavations, with the advantage of being less expensive and minimally disruptive (Faust and Katz. 2012; Shai and Uziel 2014). From the spread of artifacts on the surface and their quantitative and typological analysis, the settled areas and relative populations in different prehistorical and historical periods are estimated (e.g., Broshi and Finkelstein 1992; Postgate 1994; Finkelstein 1996; Bintliff and Sbonias 1999; Osborne 2004; Chamberlain 2006). Despite a large range of geomorphic factors, such as the processes of alluviation or colluviation, environmental disturbances (cryoturbation or bioturbation) and developmental processes (e.g., ploughing), the validity of the surface survey for locating archaeological sites has been proven on numerous occasions. For instance, in the archaeology of the southern Levant, this is evidenced in the numerous rescue surveys performed along the route of the Cross-Israel Highway before its construction (Dagan 2010), which correctly attested 125 new sites. Nevertheless, a number of sites were not located during the surface survey, and were only eventually discovered in the course of construction activities or during different stages of salvage excavations (Dahari and Ad 1998). Inconsistencies such as these have been noted in both Israel (e.g., Dagan 2009; Garfinkel and Ganor 2010) and worldwide (e.g., Whallon 1979; Alcock and Cherry 2004; Wossink 2009: 46–48; and references therein). The reasons for these discrepancies have never been properly analyzed or understood.

The other side of the same coin with regard to SFPs concerns the presence of artifacts from earlier levels in the later levels of multi-period and multi-stratum sites (archaeological tells) (e.g., Villa 1982; Finkelstein and Zimhoni 2000). This well-known phenomenon is usually considered to be related to subsequent construction activities, which utilized materials (such as mud) that introduced earlier artifacts into later strata, to differences in erosion between different parts of the site, or to mole rat activity (Sapir and Faust 2016). This may be so and indeed, there are many additional components that may affect SFPs. Nevertheless, before one embarks on clarifying particularities such as these, it is essential to understand the basic physics and dependencies underlying the accumulation of artifacts from different periods on the surface or at boundaries between strata in archaeological sites, and their movements, if any, in different types of soils. Similarly, it is imperative to understand why in certain types of soil, we do not observe archaeological scatters on the surface, despite the presence of archaeological sites beneath.

The physical and geological phenomena

The Brazil nut effect (BNE)

The BNE refers to the phenomenon by which large granular particles, in a bed of small vibrating particles, rise to the top (Fig. 1). The same result occurs with both vertical and horizontal vibrations. Thus, shaking a box of cereal leads to spontaneous ordering of the largest particles toward the upper part of the container, ostensibly against the intuitive assumption that objects will become randomly mixed when jostled. This phenomenon occurs even if the larger particles have a higher density than the smaller ones (Möbius et al. 2001). However, when changing the shaking conditions, the same large particles may sink to the bottom due to what is known as the reverse Brazil nut effect (RBNE) (Breu et al. 2003; Schnautz et al. 2005; Schröter et al. 2006; Garzó 2008). It has also been demonstrated that factors which might at first glance appear inconsequential (e.g., air pressure, starting height, etc.) can change the outcome from a lifting to a sinking. Therefore, these granular systems can be considered out of equilibrium at almost any level (Kudrolli 2004; Shinbrot and Muzzio 2000).

Although these phenomena have long been known and abundantly observed and described (e.g., Williams and Shields 1967; Ahmad and Smalley 1973; Rosato et al. 1987),

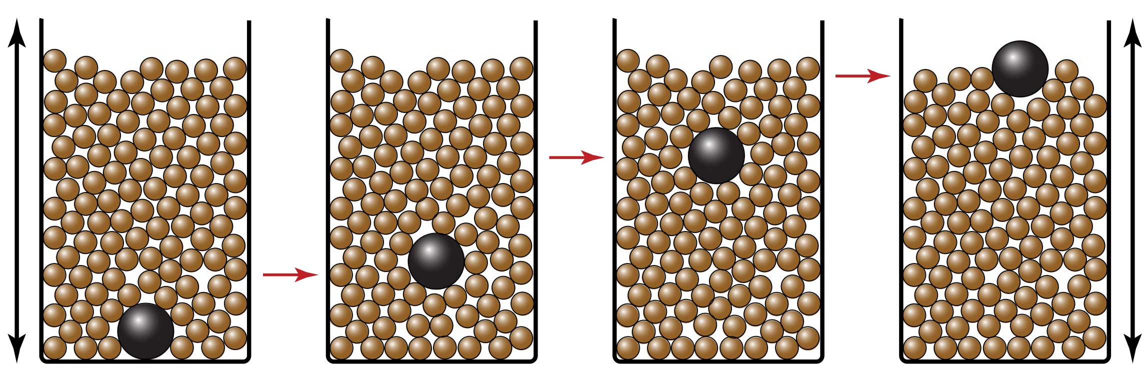

Fig. 1 Simplified representation of the BNE as a result of vertical vibration. Credit: by I. Ben-Ezra