ARTICLE IN PRESS

Quaternary International xxx (2016) 1–14

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Intra- and inter-site high-resolution geometrical analyses of Natufian bedrock features

Sagi Filin [a,*], Vera Miller [a], Danny Rosenberg [b], Dani Nadel [c]

[a] Department of Transportation and Geo-Information Engineering, Technion – Israel Institute of Technology, Haifa, 32000, Israel
[b] Laboratory for Ground Stone Tools Research, Zinman Institute of Archaeology, University of Haifa, Mount Carmel, Haifa, 3498838, Israel
[c] Zinman Institute of Archaeology, University of Haifa, Mount Carmel, Haifa, 3498838, Israel

ARTICLE INFO

Article history:
Received 21 April 2016
Received in revised form
19 September 2016
Accepted 22 September 2016
Available online xxx

Keywords:
Bedrock features
Photogrammetry
3D modeling
Geometrical analyses
Natufian
Southern levant
Raqefet Cave
Rosh Zin
Ground stone tools

ABSTRACT

Bedrock features such as mortars and cupmarks were first documented in the southern Levant from the late 1920's. They first appear in Natufian sites (15,500–11,500 Cal BP), found in all ecological settings and in some cases encompassing tens and even more than 100 specimens per site. Recent advances in photogrammetry and 3D modeling technology provide new avenues for high-resolution documentation, characterization and analysis of these stone hewn features. Here, we extend our previous analyses and use our characterization method to analyze and compare a variety of mortars and cupmarks from two Natufian sites in distinct ecological settings: Raqefet Cave (Mt. Carmel) and Rosh Zin (Negev desert). We document the richest clusters of bedrock features at each site and quantitatively analyze their geometric form. Detailed analysis is provided for 13 specimens from both sites. We then perform an intra- and inter-site analysis of the mortars morphology and spatial characteristics, *e.g.*, density and volume related.

1. Introduction

Bedrock features such as hewn mortars and cupmarks are common in many Natufian (ca. 15,500–11,500 Cal BP) and Pre-Pottery Neolithic A (PPNA; ca. 11,500–10,500 Cal BP) sites in the southern Levant (*e.g.* Garrod and Bate, 1937: 11, plate V; Nadel and Lengyel, 2009; Rosenberg and Nadel, 2011b, Rosenberg and Nadel, this volume). These features first appeared in the Natufian, apparently as yet another component of profound processes of change and innovation characterizing this culture (Bar-Yosef and Belfer-Cohen, 1992; Bar-Yosef, 1998, 2002). The large numbers and wide variety of Natufian ground stone tools and bedrock features attest to their use in a variety of functions, many of which relate to subsistence patterns and food producing economies (*e.g.* Bar-Yosef, 1998, 2002; Bar-Yosef and Belfer-Cohen, 1989; Belfer-Cohen and Bar-Yosef, 2000; Garrod, 1957; Henry, 1989, 1995; Wright, 1991, 1992). Importantly, Natufian sites with bedrock features are located in all ecological settings of the Levant, from the Mediterranean to the deserts (*e.g.* Eitam, 2009; Goring-Morris et al., 1999; Janetski and Chazan, 2004; Johnson et al., 1999; Nadel and Rosenberg, 2010; Nadel et al., 2009a; Richter and Maher, 2013; Rosenberg et al., 2010; Terradas et al., 2013).

Since about a decade ago, interest in these archaeological features in the southern Levant grew and resulted in several focused projects addressing their documentation and analysis (*e.g.* Eitam, 2008, 2009; Nadel and Lengyel, 2009; Nadel and Rosenberg, 2010; Nadel et al., 2009b; Rosenberg and Nadel, 2011b, 2011a, 2011b; Terradas et al., 2013; Weinstein-Evron et al., 2013). Until recently efficient documentation was limited, especially of the deep narrow specimens, as they were commonly documented by hand-drawings, sometimes supplemented by photography. The acquired level of accuracy prevented consistent, high-resolution characterizations and comparisons between specimens.

New methods using laser scanners, photogrammetry, and 3D modeling are constantly opening novel research avenues and are increasingly incorporated in archaeological field projects. We developed a method for high resolution recording and geometric analysis of derived 3D models, and analyzed several case studies in

* Corresponding author.
E-mail address: filin@technion.ac.il (S. Filin).

http://dx.doi.org/10.1016/j.quaint.2016.09.042
1040-6182/

Please cite this article in press as: Filin, S., et al., Intra- and inter-site high-resolution geometrical analyses of Natufian bedrock features, Quaternary International (2016), http://dx.doi.org/10.1016/j.quaint.2016.09.042

our first endeavor (Miller et al., 2014; Nadel et al., 2015). The aims of the current paper are to use our protocol, now enhanced and improved, in order to characterize, analyze and compare two distinct types of bedrock features on intra- and inter-site levels. As case studies we address the richest clusters of features at two distinct Natufian sites, Raqefet Cave in Mt. Carmel and Rosh Zin in the Negev desert, two sites different in every possible aspect and yet their bedrock features are similar in their dimensions and shapes. We thus compare samples from both sites in terms of geometry on the one hand, and spatial distribution, including density and volume aspects, on the other hand.

2. Materials and methods

2.1. Raqefet Cave

Raqefet Cave is located in Wadi Raqefet, Mt. Carmel (Fig. 1). The cave has five chambers and was first excavated by Noy and Higgs (1971). The renewed excavations focused on the Natufian graveyard and adjacent bedrock features in the first chamber (Figs. 2 and 3), dated here to ca. 14,000–11,700 Cal BP (Nadel and Lengyel, 2009; Nadel et al., 2013). There are approximately 100 bedrock features in the cave and its adjacent terrace, and some were found with Natufian remains buried in them. The features range in types and dimensions and include tiny, coin-size holes, cupules, cupmarks, bowl-like depressions, deep narrow mortars and a huge basin (Lengyel et al., 2013; Nadel et al., 2008; 2009a, 2012). The cluster studied here is the densest at the site ($n = 33$), located in the middle of the floor of the first chamber.

2.2. Rosh Zin

Rosh Zin is an open-air Late Natufian site located in the central Negev, at an elevation of 520 m a.s.l., covering an area of 900 m^2 on the top of a hill (Fig. 1). The site was discovered in 1969 and was tested and excavated between 1969 and 1972 (Henry, 1973, 1976). The stone bases of oval walls and a pavement were found, with three occupation phases. Bedrock features were documented at the site, and 18 were measured (Henry, 1976). We returned to the site in 2007 and surveyed it again for bedrock features; we found and documented 25 specimens (Fig. 4; see Nadel et al., 2009b). A cluster of 12 features was found on a narrow elongated rock exposure; it is the densest at the site and thus incorporated in the current analysis (Fig. 5).

2.3. 3D modeling

We presented our method of using photogrammetry to construct high-resolution 3D models of bedrock mortars in our previous case study (Miller et al., 2014; Nadel et al., 2015). In short, close-range images from a variety of angles allow for detailed mapping of deep and shallow bedrock features. In order to facilitate sufficient illumination we placed mirrors directing light into the deep mortars. We used about 20 images per bedrock feature, and sets of scale bars were used during photography to ensure proper scaling. The image orientation phase (estimation of the cameras pose parameters – position and orientation) was followed by a 3D point-cloud generation of both the feature and the surrounding bedrock (*cf.* Furukawa et al., 2010; Snavely et al., 2008). Density and spatial distribution of the point-cloud were analyzed via triangulation of the pointset and assessment of the average arc-length and entrapped area per triangle. In Raqefet Cave, integration of the photogrammetric data and the 3D point-cloud of the cave floor obtained by laser scanning was carried out by 3D registration of the individual mortar related points into the overall surface cave model.

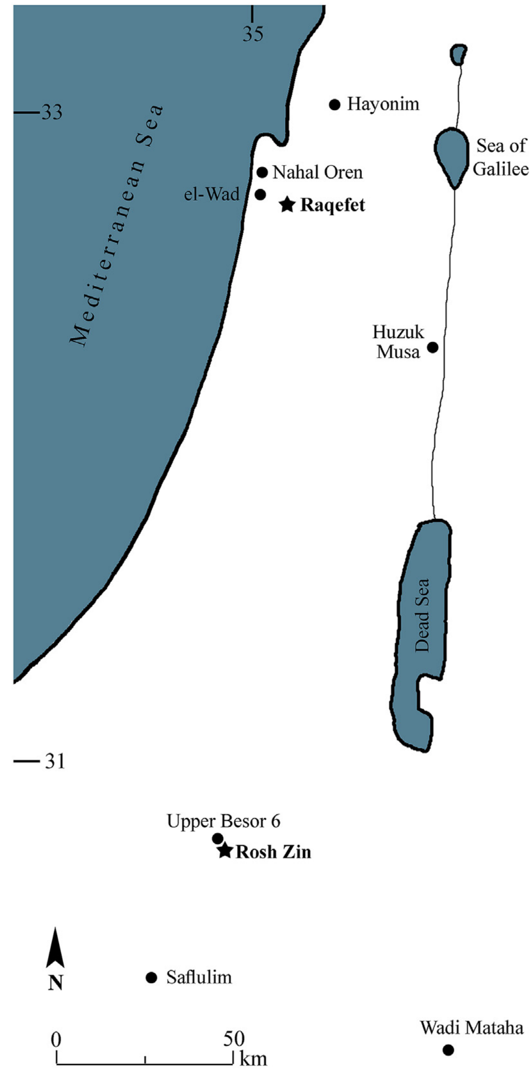

Fig. 1. Map with selected Natufian sites with bedrock features.

For data acquisition we used a Nikon D-70s camera with a 24 mm f/2.8 lens for field photography. The camera was calibrated (to recover its intrinsic parameters – focal length, principal point, and lens distortions) before and after each imaging sequence. Point-cloud extraction was performed using the Photomodeler Scanner software (www.photomodeler.com), while extraction of the mortars' geometrical measures was implemented in Matlab (www.mathworks.com). Both point-cloud extraction and computation of metrical data were performed on a standard desktop computer. The Raqefet Cave floor was scanned by the Leica C-10 terrestrial laser scanner with modeled surface precision of ±2 mm and ±60 μrad in angle measurements. Scans spanning 360° horizontally and ±45° vertically were taken in order to document the settings and objects therein.

2.4. Metric characterization of the mortar point-clouds

We characterize the mortars both in reference to their footprint on the bedrock surface, which is defined by the rim, and as volumetric entities. For either analysis, the mortar-related point-cloud needs to be separated from the surrounding bedrock surface, which was also modeled photogrammetrically. Defining the edge of the