Palaeogeography, Palaeoclimatology, Palaeoecology 470 (2017) 1–10

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Last interglacial sea level high-stand deduced from well-preserved abrasive notches exposed on the Galilee coast of northern Israel

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ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form 28 December 2016
Accepted 7 January 2017
Available online 8 January 2017

Keywords:
Abrasive notches
Galilee coast
Israel
MIS5e
Sea-level
High-stand

ABSTRACT

This study investigates the morphometry and structure of abrasive notches exposed along the tectonically-stable, micro-tidal Galilee coast, Israel, south-eastern Mediterranean, since they can serve as past sea-level indicators. The characteristics of the notches, height (H), vertex (D) – distance of maximum retreat point from cliff face, height of retreat point from the floor and roof (H_F and H_R, respectively), etc., were surveyed using LIDAR and a digital laser rangefinder, and elevations were measured using DGPS. Rock resistance was measured by Schmidt hammer tests, which show that the most developed and best preserved notches were formed within the more resistant host rocks of the Cenomanian chalk and the Pleistocene aeolianite sandstone.

The elevations of the abrasive floors of the exposed notches indicated a sea level slightly higher than at present at the beginning of MIS5e, with an upper limit between +0.5 and +0.75 m. The morphometry of the MIS5e notches, which are larger than modern notches in the study area, suggests mechanical erosion by broken waves, where an energetic wave-dominant sea batters a sheltered coastal cliff. Two sub-units of MIS5e (the *Yasaf* Mb.) were deposited within the notches: (a) a conglomerate containing the diagnostic fossil *Strombus bubonius* which was found on the notch floor, and (b) a younger bioclastic sandstone sub-unit which fills and covers parts of the notches. These unique field relationships link the formation of the notches to the beginning of MIS5e, indicating an erosive phase which parallels large-scale MIS5e sea level evidence, suggesting relatively long stand-stills at an elevation of about +1 m. The early MIS5e erosive phase was followed by a depositional phase during the later stage of MIS5e.

1. Introduction

Notches are commonly differentiated by the mechanism that created them: supra-littoral (wave-cut), mid-littoral and bio-erosional notches (Pirazzoli, 1986; Evelpidou et al., 2012a; Pirazzoli and Evelpidou, 2013; Murray-Wallace and Woodroffe, 2014, p. 116; Trenhaile, 2015). Genetic classification of notches is based on three factors: a) elevation relative to the high and low tides; b) shape; and c) texture (Pirazzoli, 1986). Both abrasive and tidal notches are a relatively symmetrical U- or V-shape (Wziatek et al., 2011). Their genesis is, however, different, resulting in different surface textures: smooth vs. porous. Abrasive notches typically have smooth surfaces, due to their formation by mechanical erosion caused by the impact of waves on the coastal cliffs (Carobene, 2015 and Refs. Therein). Furthermore, the morphometry of notches can give a qualitative estimate of the stage of development of the notch, from embryonic to mature, and therefore a general idea of the time required for its formation (Carobene, 2015).

Notches are considered to be optimal markers of past sea levels, mainly in micro-tidal regimes such as the Mediterranean Sea (e.g. Pirazzoli, 1986; Kershaw and Guo, 2001; Pirazzoli and Evelpidou, 2013; Bini et al., 2014; Murray-Wallace and Woodroffe, 2014, p.118; Antonioli et al., 2006, 2015; Trenhaile, 2015 and Refs. Therein). The notches are shaped at or near Mean Sea Level (MSL), during prolonged stand-stills, when the rates of erosional processes are on par with the pace of relative sea level change (Antonioli et al., 2006; Evelpidou et al., 2012a). This limits notch formation mainly to either stand-still or slowly rising sea levels, while beach deposits are commonly related to sharp sea level changes (e.g. Zazo et al., 2003; Dumas et al., 2005; Hearty et al., 2007; Dabrio et al., 2011). This has been demonstrated

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http://dx.doi.org/10.1016/j.palaeo.2017.01.008
0031-0182/

by the formation of Holocene notches, ascribed to a sharp decrease in the rate of sea level rise since about 6.8 ka (Lambeck et al., 2011; Antonioli et al., 2015). Notches can serve as accurate sea level indicators, especially in tectonically-stable regions (Neumann and Hearty, 1996; Antonioli et al., 2006; Hearty et al., 2007; Rodríguez-Vidal et al., 2007).

The correlation of notches, mainly tidal, to sea level has been used for measuring relative sea level in the Mediterranean in various periods ranging from MIS5e to the Holocene (e.g. Kershaw and Antonioli, 2004; Antonioli et al., 2006; Carobene, 2015; Goodman-Tchernov and Katz, 2016), where they were also used as indicators of tectonic movements (e.g. Morhange et al., 2006; Cooper et al., 2007; Evelpidou et al., 2012a, b; Pirazzoli and Evelpidou, 2013; Boulton and Stewart, 2015). Compared with other sea level markers commonly used in the Mediterranean (e.g. archaeology, marine terraces, beach deposits, etc.) tidal notches display a relatively small vertical error in indicating past sea levels. Carobene (2015) assumed a total error of approximately ±20 cm in the elevation measurements of sea levels reconstructed from tidal notches. However, the significance of abrasive notches as sea level markers is more difficult to interpret from their genetic typology alone (Bini et al., 2014). Previous studies on abrasive notches in meso-macrotidal areas, such as the Canadian coast, Pacific Islands and the Patagonian coast, related their retreat point (vertex) to the mean high tide (Bini et al., 2014 and Refs. Therein), while on the Brazilian coast the spring high tide was related to the floors of abrasive notches (Irion et al., 2012). In the micro-tidal western Mediterranean, the floors of abrasive notches were also used as markers closely related to sea level, while the notch itself develops mainly above sea level (Carobene, 2015 and Refs. Therein).

The main limitation in using notches as a reliable sea level indicator is dating. Several studies used radiocarbon ages of organisms attached to the notch (Pirazzoli et al., 1994; Morhange et al., 2006), whereas other studies used elevation correlations to other datable markers, such as nearby core samples (Kershaw and Antonioli, 2004; Antonioli et al., 2006; Rodríguez-Vidal et al., 2007; Evelpidou et al., 2011). Relative age estimate of notches is often obtained by comparing micro-erosion rates and dimensions of the notch. However, the rates of notch evolution in Mediterranean carbonate cliffs vary significantly – between 0.20 and 1.28 mm yr^{-1} (Pirazzoli and Evelpidou, 2013), or even between 0.02 and 2.10 mm yr^{-1} (Antonioli et al., 2015). These variations depend on various factors, including: rock type, $CaCO_3$ content, bio-erosion, chemical dissolution processes in the intertidal zone, wetting and drying cycles and exposure to wave action (Wziatek et al., 2011; Evelpidou et al., 2012a, b; Trenhaile, 2014; Moses et al., 2014). The rates of erosion are not gradual and continuous, and can present a wide range of variability, even at the same sites (Pirazzoli and Evelpidou, 2013). Recent observations from the Mediterranean show that these factors are intertwined in the notch evolution, and are therefore difficult, or even impossible, to separate (Antonioli et al., 2015).

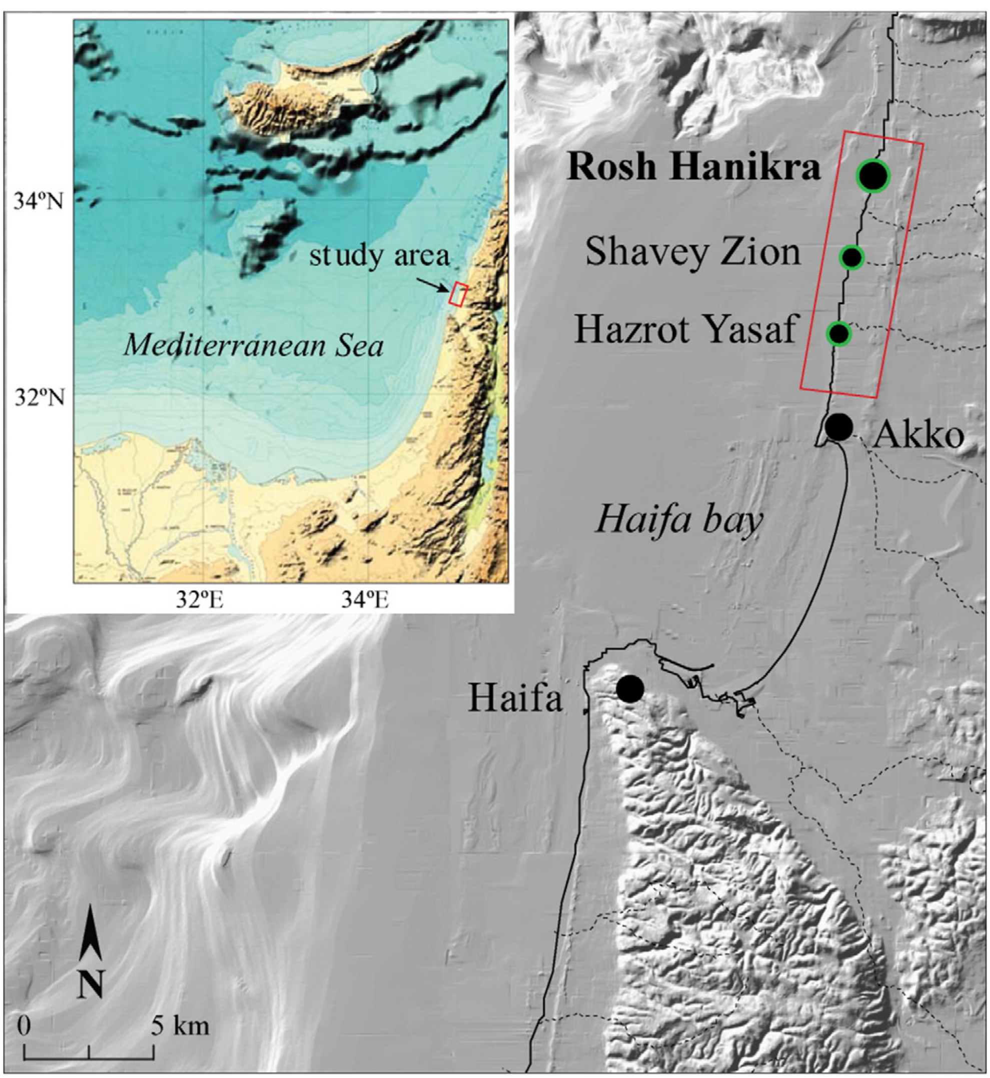

Fig. 1. Location map of the study area and study sites along the Galilee coast, northern Israel. The main study site is Rosh Hanikra (RH).