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# Holocene-era submerged notches along the southern Levantine coastline: Punctuated sea level rise?

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ABSTRACT

The study presented here reports on erosional notches, pits, and potholes observed at present sea level and submerged at a series of sites along the southern Levantine coastline. For such submerged features to be formed and preserved, there must be a period of relative sea level stagnation, followed by drowning. This process can occur in response to sea level change, tectonic or isostatic offsets. The specific coastline hosting these features is not considered tectonically or isostatically affected, and therefore, for much of the Mediterranean, is viewed as a eustatic sea level reference point. While similar features have been observed elsewhere in the eastern Mediterranean, confining their ages has been difficult due to the much older ages of the host rocks, in many cases encompassing multiple glacial cycles. Here, for the first time they are located in relatively young host rock (<65,000 years) confining their production age to the most recent glacial cycle. These features might suggest that a step-like, more punctuated process of sea-level rise occurred along this coastline, providing a window into what might be expected in the future as warming trends continue and the sea level responds.



## 1. Introduction

Marine notches have long been considered a useful sea-level proxy and important contributor to reconstructing the timing, rate, and magnitude of sea-level change. While broad trends in sea-level change are generally well-established (Fairbanks, 1989; Fleming et al., 1998; Peltier, 2002; Waelbroeck et al., 2002; Siddal et al., 2003; Lambeck et al., 2014) the more refined, localized sea level curves and sub-millennial resolution varies regionally in detail and scope (e.g. Morhange and Pirazzoli, 2005; Stocchi and Spada, 2007), and observations globally of variations in the rates and trends have motivated further investigation and ample debate (Cronin, 2012). Here, submerged erosional notches located along the southern Levantine coastline are reported for the first time and their origin, timing, and ramifications with respect to local and global sea level curves are considered. The current work presents quantified observations of the depth and morphology of notches and erosional pits along the Israeli coastline present at current sea level and submerged. Then, their observed setting was compared to tectonic and sea-level records in an effort to better understand the nature of the post LGM sea level rise along the Israeli coastline and its global implication.

Glacial and interglacial cycles are marked by the movement of water between ice caps and marine basins. These shifts produce sea level fluctuations in which sea level is lower during the height of an ice-age, and higher during the peak of an interglacial. Sea level change has the power of altering the coastal landscape dramatically. An approximate 120 m eustatic sea level rise during the past ~20,000 years has been established based on multiple isotopic studies from coral records, ice cores and extensive dating and modeling (Shackleton, 1987; Fleming et al., 1998; Siddall et al., 2003; Peltier and Fairbanks, 2006; Lambeck et al., 2014).

In the modern system, sea level changes are recorded instrumentally using means such as tidal gauge records and satellite imagery (see Church and White, 2006). Local relative sea level (RSL) reconstructions have been performed using a wide range of sea level indicators such as micropaleontology (e.g. salt marsh foraminifera and thecamoebians, Gehrels, 1999; Scott and Medioli, 1978; Scott et al., 2001), abrasion and tidal notches (e.g., Nixon et al., 2009; Evelpidou et al., 2012a, 2012b, 2012c; Marriner et al., 2014), beachrocks (Vousdoukas et al., 2007; Desruelles et al., 2009; Mauz et al., 2015), benches and shore platforms (Rovere

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et al., 2011; Vacchi et al., 2012; Mastronuzzi et al., 2014), archeological features (Sivan et al., 2001; Marriner and Morhange, 2007; Goodman et al., 2009), or marsh and peat deposits (Cronin et al., 2007; Engelhart and Horton, 2012; Engelhart et al., 2015). The smaller the range of vertical error and the more accurately the marker can be dated, the better the sea level marker. Some markers provide a bracketed 'supratidal' or 'sub tidal' indicator which confine the minimum and maximum values in meter resolution, while some proxies, such as saltmarsh microfossils, can give an accuracy of less than a decimeter (Scott and Medioli, 1978).

All sea-level markers face the challenge of differentiating between eustatic sea-level change and localized relative sea level that is a result of tectonic offsets and glacio-hydro-isostatic effects (Walcott, 1972; Chappell, 1974; Lambeck and Chappell, 2001). Therefore, efforts are made through comparisons of models to field observations and established sea level curves from relatively passive, seismically quiet regions as a means for comparison.

### *1.1. Archaeological sea-level markers*

Coastal archaeological features with distinctive elevations and depths relative to sea level (e.g. mooring holds, piers, wells) and well-constrained ages are useful for sea level reconstruction. For example, an intact submerged, dated, mosaic floor discovered offshore at five meters water depth could provide a supratidal indicator because it most likely was not installed underwater. A well-developed harbor floor (fine muds, organic enrichment, artifacts (Reinhardt et al., 1994; Marriner and Morhange, 2007) would provide a constraint on the minimum water depth (such as >~1 relative to harbor floor). Features with more limited vertical constraints, such as harbor mole features, bollards, fishponds (piscina), or shipshed ramps, provide even more refined relative sea-level data and have been used successfully in many regions worldwide such as northwest Pacific coastlines (Fedje and Rosenhans, 2000), Pacific Islands (Dickinson, 2001), Atlantic Ocean and Gulf of Mexico (Bailey and Flemming, 2008). The Mediterranean is especially rich in well-dated coastal archaeological features and therefore has perhaps the most extensive sea level datasets and studies incorporating archeological observations (e.g. Flemming et al., 1969; Flemming and Webb, 1986; Galili and Sharvit, 1998; Sivan et al., 2004; Evelpidou et al., 2012b).

### *1.2. Geomorphological sea-level markers*

Independent from archaeological features, natural sea level markers can be present such as marine notches, erosional pits and potholes. Marine notches are horizontal incisions (centimeters to meters size range) formed from biochemical and/or mechanical erosion (Alexander, 1932), which is later referred to as sea corrosion (Pirazzoli, 1986). Tidal notches are a specific form of marine notch that occur as a result of biological, chemical, and physical erosion at the tidal zone and have been used as sea-level markers because they are formed during sea-level stands that are long enough to permit their production (Pirazzoli, 1986; Kershaw and Guo, 2001; Benac et al., 2004; Wziatek et al., 2011, Evelpidou et al., 2012a; Trenhaile, 2014, 2015). The notch itself is semi-indicative of the tidal regime as its shape and dimensions have some association to the maximum and minimum tidal positions with the central dimensions typically correspond to mean sea level (Evelpidou et al., 2012a, Fig. 1), though recent observations also indicate that the notch can also exceed those limits (Antonioli et al., 2015; also see response by; Evelpidou and Pirazzoli, 2015). Rapid changes, either due to sea level change or vertical displacement, can lead to the preservation of these features, making them useful earthquake or sea level indicators (Neumann, 1966; Pirazzoli, 1986; Neumann and Hearty, 1996; Rust and Kershaw, 2000; Kershaw and Guo, 2001; Benac et al., 2004; Nixon et al., 2009; Vacchi et al., 2014).

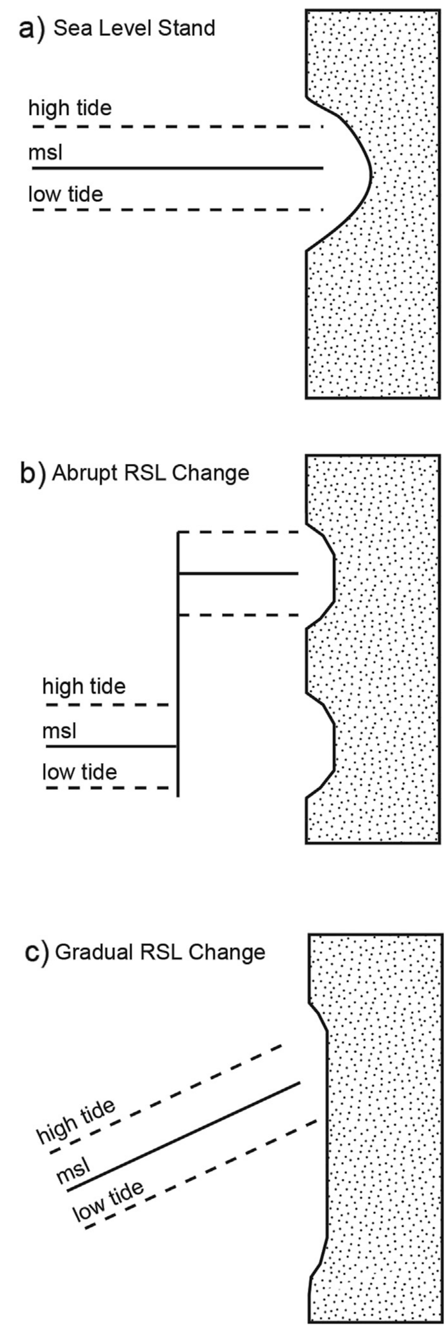


**Fig. 1.** Schematic diagram of an idealized notch development during stable sea level, rapid sea level change, and gradual change (adapted from Evelpidou et al., 2012a). Recent work by Antonioli et al., 2015 shows that the relationship between tidal range and notch size varies.

Certain circumstances, such as gradual sea level change or secondary erosion during later sea-level stands, can lead to their erasure or alteration, and specific sets of conditions can prevent their production (absence of biological assemblages or too hard/too soft substrates) (Evelpidou et al., 2011, 2012b; Pirazzoli and Evelpidou, 2013, see discussion in Antonioli et al., 2015). Therefore, when present, they are a clear indication of a period of continuous sea-level stand.

Once formed, preservation of notches depends on a range of variables, most importantly the fabric of the notch and