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Post-Roman sea-level changes on Pag Island (Adriatic Sea): Dating Croatia's "enigmatic" coastal notch?

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ABSTRACT

The presence of a regional-wide notch (45 to 115 cm below present biological mean sea level [BMSL]) along the Adriatic coast of Croatia, at a string of sites between Zadar and Rijeka, provides evidence for a rapid but poorly constrained subsidence event(s) after Roman times. For more than a century, this geomorphological tidal level indicator has attracted rich scientific debate but many unresolved questions remain. In this paper, we present new results from Caska Bay (Pag Island) looking at notch morphology and Holocene salt-marsh stratigraphy to constrain the chronology of this crustal deformation on Pag Island. The typical salt-marsh stratigraphy comprises low to high salt-marsh muds interjected by an unconformable marine layer (which lies between −50 and −100 cm BMSL) consistent with an abrupt transgression. The palaeoecological record shows an abrupt shift in assemblages across the salt-marsh mud–sand sediment contact translating abrupt coastal changes. Geochronological data constrain this event to around 1000 to 1200 cal. AD. The altitude of the layer is coeval with the submerged notch attested on limestone cliffs around the bay. The U-shape of the notch profile, coupled with the sharp palaecological contacts and submerged Roman pier, implies that sea-level rise was episodic and not gradual as suggested by regional numerical models. Together, our findings shed new light on the chronology of the "enigmatic" Croatian notch on the island of Pag, and highlight the need to couple geomorphological studies of rocky coasts with high-resolution sediment records.

1. Introduction

Tectonic activity in coastal areas can engender rapid sea-level changes, archived in the geological record by a variety of geomorphological midtidal features (e.g. notches and benches), bioconstruction forms and palaeoecological changes on clastic coasts (e.g. salt-marshes). The eastern and central Mediterranean, in particular, has attracted significant research interest due to its seismotectonically-active setting and the plethora of its geomorphological and archaeological evidence attesting to rapid sea-level movements since the mid-Holocene (Pirazzoli et al., 1994a,b, 1996; Pirazzoli, 1996; Stiros et al., 2000; Stiros, 2001; Morhange et al., 2006a,b; Marriner and Morhange, 2007; Auriemma and Solinas, 2009; Stewart and Morhange, 2009; Evelpidou et al., 2012; Marriner et al., 2012; Mastronuzzi and Sansò, 2012; Faivre et al., 2013; Vacchi et al., 2014). Nonetheless, in many instances, chronological difficulties persist in relation to certain types of displaced rocky-coast erosional forms, particularly notches and platforms (Pirazzoli, 2005a, 2007).

The rocky Adriatic coast of Croatia, on a 150-km stretch of coast between Zadar and Rijeka, is particularly rich in erosional forms and has a long history of research (Fig. 1). In effect, since Suess (1885–1908), Tamino (1948), Schneider (1976), Pirazzoli (1980) and others, scholars have shown the importance and quasi-continuity of a submerged notch, between 50 and 115 cm below present sea level, where sheltered topography and resistant limestone outcrops have been conducive to its formation and preservation (Fouache et al., 2000; Faivre and Fouache, 2003; Benac et al., 2004; Fouache et al., 2005a,b; Fouache, 2006; Benac et al., 2008; Faivre et al., 2010; Furlani et al., 2011). In the Mediterranean, intertidal bioerosion of limestone can be up to 1 mm/year (Pirazzoli, 1986; Laborel et al., 1999; Evelpidou et al., 2011; Furlani et al., 2011) and, in this instance, the depth and the continuity of the Croatian notch support a formation phase lasting several centuries, attributed by most scholars to the

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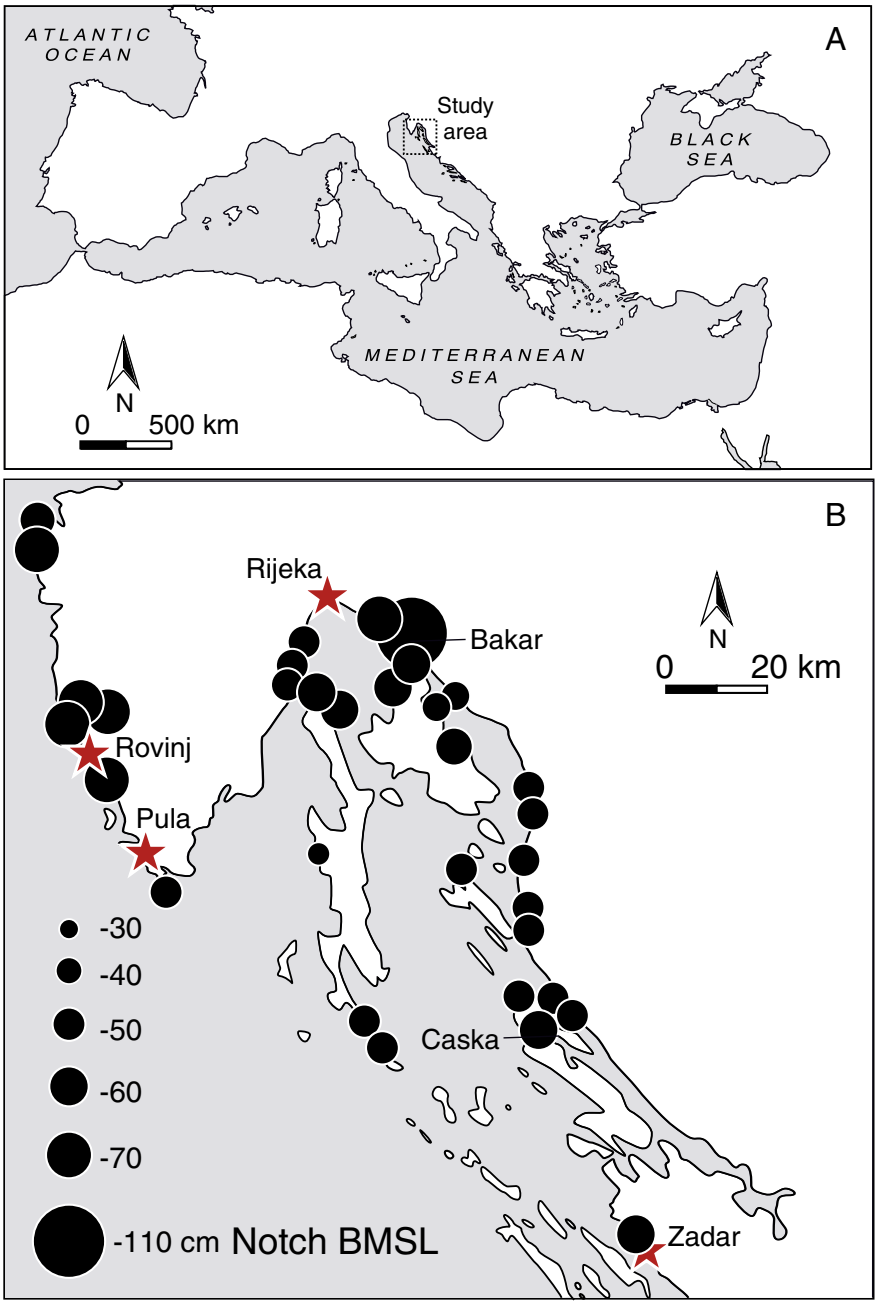

Fig. 1. A. Location of the study area in the central Mediterranean. B. Adriatic coast of Croatia between Rijeka and Zadar. The depth of the notches is denoted by proportional black circles and have been measured relative to local biological mean sea level (BMSL). Data from Pirazzoli (1980), Fouache et al. (2000), Faivre and Fouache (2003), Benac et al. (2004, 2008) and Furlani et al. (2011).

Roman period (Fouache et al., 2000; Fouache, 2006). On the basis of present-day lowering rates, Furlani et al. (2009) have suggested a formation period spanning ~500 ± 100 years. On the Croatian coastline, the notch vertex is at a mean depth of ~55 cm relative to present mean sea level, except around Bakar where it can range up to 115 cm, with increased subsidence probably associated with a reactivated thrust (Stiros and Moschas, 2012; Fig. 1). Despite the prevalence and relative regional continuity of the notch, it has never been precisely dated and the processes and event(s) responsible for its quasi-regional subsidence have generated significant debate (Pirazzoli, 2005b; Pirazzoli and Evelpidou, 2012).

Given the present knowledge gap, the aim of this paper is to shed new light on the chronology of Croatia's "enigmatic" submerged notch and to compare and contrast the rocky coast evidence with late Holocene salt-marsh records on the island of Pag (Antonioli et al., 2004; Stiros and Moschas, 2012). Previous research has looked to correlate submerged archaeological remains with the notch (Degrassi, 1955; Fouache et al., 2000; Faivre and Fouache, 2003; Fouache et al., 2005a,b; Fouache, 2006; Faivre et al., 2010), suggesting that it formed around 2000 years ago during a period of relative sea-level stability. However, the chronological details of the notch's submersion are poorly understood and in many instances earlier studies have only provided evidence of when the notch formed (i.e. during the Roman period), not when the submersion actually occurred. We propose to overcome these difficulties using salt-marsh records from Caska Bay (Pag Island, see Figs. 2 and 3), where the notch is particularly well developed on limestone outcrops rimming the bay (Fig. 4). Like their mid-latitude counterparts, Mediterranean salt-marshes record evidence for relative sea-level changes (e.g. Sornoza et al., 1998; Vella and Provansal, 2000; Vella et al., 2005; Carmona and Ruiz, 2011) but remain a vastly