Geomorphology 220 (2014) 93–103

Contents lists available at ScienceDirect

Geomorphology

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

Tectonic constraints on the late Pleistocene-Holocene relative sea-level change along the north-eastern Adriatic coast (Croatia)

Maša Surić [a,*], Tvrtko Korbar [b], Mladen Juračić [c]

[a] Department of Geography, University of Zadar, Tuđmanova 24 i, 23000 Zadar, Croatia
[b] Croatian Geological Survey, Sachsova 2, 10000 Zagreb, Croatia
[c] Department of Geology, Faculty of Science, University of Zagreb, Horvatovac 102 a, 10000 Zagreb, Croatia

ARTICLE INFO

Article history:
Received 8 October 2013
Received in revised form 26 May 2014
Accepted 1 June 2014
Available online 9 June 2014

Keywords:
Relative sea-level change
Tectonics
North-eastern Adriatic
Croatia

ABSTRACT

In spite of very favourable coastal features, late Pleistocene-Holocene relative sea-level changes along the eastern Adriatic coast are still not completely resolved mostly due to the intensive and complicated regional and local neotectonics. We gathered current knowledge that generally presents the north Adriatic area as subsiding one, and proposed a reconstruction in new light of possible very slow (local) uplift (average rate of 0.1–0.25 mm/a for last 80 ka) which is supported by well-dated submerged speleothems and tectonic reconstruction. In addition, such a scenario supports also the formation of tidal notches that are common in the north Adriatic region, but not yet entirely understood. However, according to the latest Mediterranean data on sea level during the marine isotope stage (MIS) 5.1 being at +1 m 80 ka ago, we do not dismiss the possibility of subsidence which would have been 0.18–0.23 mm/a on average for the last 80 ka, but notch formation under such condition would not have been realistic. Apparently, the position of the north-eastern Adriatic coast on a convergence area requires extensive palaeoenvironmental studies, including structural, lithostratigraphical, palaeontological, archaeological and radiometric data and application of isostatic modelling.

1. Introduction

Prediction of the future sea-level changes at each particular coast requires understanding of the past geographical and temporal variability in sea-level changes, which are driven by global factors (climate changes, thermal expansion of the sea water), regional responses (glacio- and hydro-isostasy that follow the deglaciation) and local response (e.g. tectonics) (Lambeck et al., 2010). The principal process leading to sea-level changes is the exchange of the water between oceans and continental ice sheets (Lambeck and Purcell, 2005). These global (eustatic) changes lead to the temporally and spatially constrained process of glacial isostatic adjustment (GIA) which is, in fact, viscoelastic response of the solid Earth to the changes in surface loading and unloading of the continental ice (glacio-isostatic component) and water in ocean basins (hydro-isostatic component) (Stocchi and Spada, 2009; Tuccimei et al., 2012). The contribution of glacio- and hydro-isostatic components to the relative sea-level (RSL) change depends on the location of the studied site with respect to the ice sheets (Tuccimei et al., 2012), thus the sea-level response is not expected to follow a eustatic trend but to vary geographically (Antonioli et al., 2007). Apart from these predictable isostatic signals, tectonic processes are less predictable and usually of episodic nature (Lambeck and Purcell, 2005; Lambeck et al., 2011a). In order to reconstruct relative sea-level changes for a particular site, all of these components must be taken into consideration.

GIA-modelling has been developed in order to investigate regional deviation from the eustatic trend and has been used extensively in Mediterranean region (Lambeck, 1997; Lambeck and Bard, 2000; Lambeck et al., 2004a, 2004b; Lambeck and Purcell, 2005; Stocchi et al., 2005; Antonioli et al., 2007; Spada and Stocchi, 2007; Scicchitano et al., 2008; Antonioli et al., 2009; Stocchi and Spada, 2009; Anzidei et al., 2011; Furlani et al., 2011a; Lambeck et al., 2011a; Tuccimei et al., 2012). These works rely on ice models ICE-1 (Peltier and Andrews, 1976), ICE-3G (Tushingham and Peltier, 1991) and ICE-5G (VM2) (Peltier, 2004), or on their adaptation such as by Di Donato et al. (2000) and hybrid ice models ICE1 + A3 and MDCR by Stocchi and Spada (2009). However, in spite of implementing different model parameters (lithosphere thickness, upper and lower mantle viscosity etc.) RSL predictions made upon these isostatic models generally agree qualitatively both in sign and in amplitude, as shown in detail in Antonioli et al. (2009) for the models of Lambeck et al. (2004a) and Spada and Stocchi (2007).

Rocky limestone coast with low tidal range, diverse coastal biocenosis, repeatedly submerged karstified bedrock (with caves and speleothems within them), as well as an early establishment of the civilization with numerous facilities from the Roman Age, provide exceptional potential for the reconstruction of sea-level changes along the Eastern Adriatic.

* Corresponding author. Tel.: +385 23 345022; fax: +385 23 311228.
E-mail addresses: msuric@unizd.hr (M. Surić), tkorbar@hgi-cgs.hr (T. Korbar), mjuracic@pmf.geol.hr (M. Juračić).

http://dx.doi.org/10.1016/j.geomorph.2014.06.001
0169-555X/

Yet, the reconstruction appears to be difficult and delicate due to the complex tectonics related to the kinematics of Adriatic (Apulian) microplate (Márton et al., 2010). Such structural fabric, i.e. tectonically active region, is not suitable for eustatic sea-level reconstruction. On the contrary, the global sea-level curve, together with associated glacio-hydro-isostatic models, should be used in order to reconstruct regional/local tectonics since paleo-sea level provides a reference surface for quantifying rates of vertical tectonic movements (Lambeck et al., 2010).

Ever since the first scholars noted submerged Roman facilities (e.g. Fortis, 1774; Surić et al., 2007), and further throughout history up to the present, almost all authors generally regarded Croatian Adriatic coast as subsiding one. As for the North Adriatic, recent works based on appropriate and well-documented physical evidence (tidal notches, archaeological remnants etc.) conclude: "… The northern Adriatic is a shallow sea basin affected by tectonic subsidence" (Pirazzoli, 2005) or "… NE Adriatic coast is a subsiding environment…" (Antonioli et al., 2007) and "….generalized subsidence of the northern Adriatic coast…" (Antonioli et al., 2009). Firstly, it must be emphasised that these conclusions usually relate only to the northernmost part which includes the Gulf of Venice, Gulf of Trieste and western Istrian coast. However, following the common subdivision of the Adriatic Sea (Northern, Central and Southern), the Northern Adriatic encompasses a much wider region, at least to the Ancona – Zadar line, including the Kvarner region (Fig. 1). According to recent studies (Surić et al., 2009), Kvarner might have had completely different neotectonic history, that could be related to its rather complex position within External Dinarides orogenic belt (Korbar, 2009). Very few studies argue the uplift manner – e.g. movement of southeastern block of the Adria plate implying a "…trend from weak uplift to strong subsidence towards the north…" summarised by Ferranti et al. (2006), whilst Orlić and Pasarić (1994) suggest tectonically induced "…rising of the middle and south Adriatic coast relative to the north Adriatic coast at 1 mm/a speed". In addition, diapir-related uplift history was revealed for a group of small Central Adriatic offshore islands (Grandić et al., 2001; Geletti et al., 2008), e.g. Velika Palagruža (Korbar et al., 2009) and Brusnik (Babić et al., 2012a). Within the north Adriatic, Antonioli et al. (2009) discuss a few cores drilled in the Gulf of Trieste where "…the tectonic subsidence reaches lower values, or even weak uplift."

The objective of this study is to gather present knowledge in order to: i) revise formerly examined sea-level indicators which had been regarded as evidence of subsidence; ii) consider them in the light of recently proposed uplift history of some parts of the north-eastern Adriatic that was revealed from the U-series dated submerged speleothems from Krk Island (Surić et al., 2009), and iii) re-examine uplift history, taking into consideration the latest evidence of marine isotope stage 5.1 (MIS 5.1) global sea level proposed by Dorale et al.

Fig. 1. Study area and the locations of mentioned sea-level indicators (submerged speleothems, marine terraces, tidal notches, marine deposits, archaeological sites).