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Proučavanje promjena morske razine na arheološkim nalazištima u priobalju

The study of sea-level changes at coastal archaeological sites

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Promjene morske razine konstantan su proces za koji potvrde nalazimo u nizu geoloških, geomorfoloških, bioloških i ekoloških indikatora te u brojnim arheološkim i povijesnim izvorima. Proučavanje tih promjena omogućuje nam rekonstrukciju obalne crte i ostalih geomorfoloških značajki određenog obalnog krajolika tijekom povijesnih razdoblja. Geološki, biološki, arheološki i drugi indikatori daju nam podatke o relativnim promjenama morske razine, tj. o uzajamnom odnosu mora i kopna u određenom vremenu i na određenom prostoru. One su zbroj eustatskih, tektonskih i glacio-hidro-izostatskih čimbenika i, shodno tome, posljedice su globalnih, regionalnih i lokalnih pojava. U radu se sažeto prikazuje složena

Changes in sea levels are a constant process for which confirmations can be found in many geological, geomorphological, biological and ecological indicators, and in numerous archaeological and historical sources. The study of these changes makes it possible to reconstruct coastlines and other geomorphological features of specific coastal landscapes during various periods. Geological, biological, archaeological and other indicators provide data on the relative sea-level changes, i.e., on the interaction between sea and land in specific periods and in specific places. They are the sum of eustatic, tectonic and glacio- and hydro-isostatic factors and, consequently, of global, regional and local phenomena. This work concisely presents problematika promjena morske razine tijekom prošlosti, s ciljem približavanja svim stručnjacima koji se izravno njome ne bave, ali se s njome susreću tijekom arheoloških istraživanja u priobalju i plitkome podmorju.

Ključne riječi: promjena morske razine, obalna crta, arheološki markeri, geomorfološki markeri, biološki markeri

the complex topic of sea-level change over the course of the past, with the objective of bringing together all experts who do not directly deal with it but nonetheless encounter this problem during archaeological research at the shoreline and submerged sites.

Key words: sea-level change, coastline, archaeological markers, geomorphological markers, biological markers

1. Uvod

Proučavanje promjena morske razine omogućuje nam rekonstrukciju obalne crte i ostalih geomorfoloških značajki određenog obalnog krajolika tijekom povijesnih razdoblja. Iako je riječ o značajnim informacijama, često neophodnim za odgovarajuću interpretaciju arheoloških nalaza, za sada na priobalnim arheološkim nalazištima u Hrvatskoj nije provedeno nijedno sustavno istraživanje, pa je shodno tome i količina spoznaja o obalnim paleokrajolicima na vrlo skromnoj razini. Usporedba proučavanja prapovijesnih obalnih paleokrajolika u svijetu[1] s izoliranim pokušajima analize prapovijesnih potencijala u hrvatskom podmorju,[2] te uopćenim zaključcima koji se često iznose u slučaju nalazišta iz kasnijih vremenskih razdoblja, ukazuju na potrebu intenziviranja takvih istraživanja.

Svrha je rada sažeto prikazati složenu problematiku promjena morske razine tijekom prošlosti i učiniti je pristupačnom svim stručnjacima koji se izravno njome ne bave, ali se s njome susreću tijekom arheoloških istraživanja u priobalju i plitkome podmorju.[3] Upućenost u osnove te problematike olakšava postavljanje primjerenih znanstvenih pitanja, sustavno prikupljanje svih dostupnih podataka neovisno o izravnom znanstvenom interesu u okviru matične znanosti te uspostavu interdisciplinarnog istraživačkog tima.

U fizičko-geografskom smislu obala je dio kopna koji je u dodiru s morem. Ovisno o nagibu kopna i rasponu oscilacija morske razine ona zahvaća širi ili uži pojas. Obalna crta razdjelnica je između kopna i mora, a duž hrvatske obale ona je danas određena srednjom razinom visokih voda na mareografima u Dubrovniku, Splitu, Bakru, Rovinju i Kopru u epohi 1971.5 i kao takva ucrtava se na pomorske i topografske karte.[4] Obalnu crtu karakterizira četverodimenzionalnost, tj. promjene u prostoru i vremenu.[5] Osim morske razine na njezin izgled utječu i drugi čimbenici, kao što su mehaničko djelovanje valova i morskih struja, sedimentacija materijala (naročito intenzivna na riječnim ušćima) ili razne ljudske aktivnosti.

1 Flatman *et al.* 2005, koji uključuje pregled najvažnijih radova o temi morem preplavljenih kulturnih krajolika.

2 Benjamin, Bonsall 2009; Benjamin, Črešnar 2009.

3 Ovaj rad prilagodba je poglavlja *Arheološka baština i promjene morske razine* iz doktorskog rada pod naslovom *Problematika prapovijesnih i antičkih nalazišta u hrvatskom podmorju*, obranjenog na Sveučilištu u Zadru 2011. godine.

4 Duplančić Leder, Leder 2010, str. 121.

5 Duplančić Leder, Leder 2010, str. 123.

1. Introduction

The study of sea-level change makes it possible to reconstruct the coastline and other geomorphological features of a specific coastal landscape during specific historical periods. Even though this is important information - often essential for an adequate interpretation of archaeological finds - thus far no systematic research has been conducted at coastal archaeological find-sites in Croatia. Consequantly, the amount of knowledge on palaeo-landscapes is rather meagre. A comparison between the study of coastal palaeolandscapes in the world[1] and the isolated attempts to analyse the prehistoric potential at Croatian submerged sites,[2] as well as the generalized conclusions which are often drawn in the case of sites from later periods, indicate the need to intensify such research.

The purpose of the work is to present the complex topic of sea-level change over the course of the past and to make it more accessible to all experts who do not directly deal with it, but nonetheless encounter it during archaeological research at the shoreline and submerged sites.[3] Familiarity with the essence of this set of problems eases the formulation of suitable research questions, the systematic gathering of all available data regardless of direct scholarly interest within the framework of the core research field, and the establishment of interdisciplinary research teams.

In the physical geographical sense, the coast is the part of land that meets the sea. Depending on the gradient of the land and the range of oscillations between sea levels, it may encompass a broader or narrower belt. The coastline is the boundary between land and sea, and all down the Croatian coast it is today determined by the mean level of high waters on the mareographs in Dubrovnik, Split, Bakar, Rovinj and Kopar to an epoch of 1971.5 and it is delineated as such on maritime charts and topographic maps.[4] The coastline is characterized by four-dimensionality, i.e., changes over space and time.[5] Besides sea levels, its appearance is also influenced by other factors, such as the

1 Flatman *et al.* 2005, which includes an overview of the most important works on submerged cultural sites.

2 Benjamin, Bonsall 2009; Benjamin, Črešnar 2009.

3 This work is an adaptation of the chapter “Arheološka baština i promjene morske razine” [‘The archaeological heritage and sea-level changes’] from the doctoral dissertation entitled *Problematika prapovijesnih i antičkih nalazišta u hrvatskom podmorju* [The problems of prehistoric and Antique sites in the Croatian undersea zone] defended at the University of Zadar in 2011.

4 Duplančić Leder, Leder 2010, p. 121.

5 Duplančić Leder, Leder 2010, p. 123.

Promjena morske razine često se spominje u slučaju antičkih nalazišta, ali nam tek u novije vrijeme znanstvena istraživanja nude odgovore te u nekim slučajevima iz temelja mijenjaju dosadašnje spoznaje i zaključke.[6] Uopćena pretpostavka o promjenama morske razine, koje duž istočne jadranske obale iznose 1 mm godišnje, ne može se koristiti za preciznije rekonstrukcije i interpretacije.[7]

Sva priobalna, dijelom ili u cijelosti morem preplavljena nalazišta na kojima nepokretni arheološki nalazi leže *in situ*, potencijalno su koristan izvor podataka za proučavanje relativnih promjena morske razine. Problem nastaje kad se od arheologa traži točna interpretacija i datiranje nalaza, oboje neophodni za korektno korištenje arheoloških podataka. Arheološko istraživanje složen je metodološki proces koji se dodatno usložnjava u podmorskim uvjetima rada. Stoga nam donošenje zaključaka isključivo na osnovi površinskog pregleda terena može priskrbiti tek vrlo ograničenu količinu upotrebljivih podataka.

Osnovni poticaj za ovaj pregled bila su dva sintetska rada, od kojih jedan tumači osnovna načela proučavanja promjena morske razine,[8] dok se drugi koncentrira na njihovu dosadašnju primjenu duž hrvatske obale.[9] Iako je riječ o člancima objavljenim 2009. i 2010. godine, njihov nam sadržaj i danas omogućuje relativno brzo i lako upućivanje u osnovnu problematiku o kojoj je riječ. Za ilustraciju te problematike iskorišteno je nekoliko arheoloških i geomorfoloških markera s hrvatskih arheoloških nalazišta.

U trenutku pripreme ovog rada izašao je iz tiska još jedan pregledan rad opremljen sveobuhvatnim popisom literature, koji je, prema riječima autora, iz geomorfološke i arheološke perspektive objedinio dosadašnje rezultate istraživanja promjena morske razine u središnjem i istočnom dijelu Mediterana tijekom posljednjih 132 000 godina te upozorio na postojeće praznine i tekuće rasprave.[10]

2. Indikatori promjena morske razine

Promjene morske razine konstantan su proces, za koji potvrde nalazimo u nizu geoloških, geomorfo-

mechanical action of waves and sea currents, sedimentation of materials (especially intensive at river mouths) or various human activities.

Sea-level change is often mentioned in conjunction with sites dating to Antiquity, but only more recently has scholarly research offered answers, and in some cases they thoroughly change all previous knowledge and conclusions.[6] Generalized hypotheses on sea-level change, which amounts to 1 mm annually all down the Adriatic coast, cannot be used for more precise reconstructions and interpretations.[7]

All coastal, partially or wholly submerged sites at which immovable finds lie *in situ* are potentially useful sources for the study of relative sea-level changes. A problem arises when archaeologists are asked to provide precise interpretations for and dating of such finds, both essential for the proper use of archaeological data. Archaeological research is a complex methodological process that becomes even more so in underwater conditions. So drawing conclusions based solely on a surface inspection of the terrain can only yield a very limited quantity of useful data.

The basic impetus for this overview came from two synthetic works, of which one interprets the basic principles for the study of sea-level change,[8] while the other concentrates on their application on the Croatian coast up to this point.[9] Even though these are articles published in 2009 and 2010, their content even today provides relatively rapid and simple orientation in the basic set of problems in question herein. Several archaeological and geomorphological markers from Croatian archaeological sites were used to illustrate this problem.

At the time of writing of this work, another overview with a comprehensive bibliography was published; according to its authors, it has consolidated all previous results of research into sea-level change in the central and eastern parts of the Mediterranean over the past 123,000 years from the geomorphological and archaeological perspectives, highlighting existing lacunae and ongoing debates.[10]

6 Usp. npr. Faivre *et al.* 2010; Fouache *et al.* 2005a; Fouache *et al.* 2005b; Marriner *et al.* 2014.

7 Mjerenja morske lokacije na četiri lokacije na istočnoj jadranskoj obali u posljednjih četrdeset godina pokazuju porast razine između 0,53 i 0,96 mm godišnje, odnosno pad razine između 0,50 i 0,82 mm godišnje, kao rezultat lokalnog uzdizanja, odnosno spuštanja obale zbog tektonskih poremećaja, Barić *et al.* 2008.

8 Lambeck *et al.* 2010.

9 Surić 2009.

10 Benjamin *et al.* 2017.

6 Cf. e.g., Faivre *et al.* 2010; Fouache *et al.* 2005; Fouache *et al.* 2005a; Marriner *et al.* 2014.

7 Measurement of marine points at four locations on the eastern Adriatic coast over the past forty years has shown increased levels between 0.53 and 0.96 mm annually, and a decline between 0.5 and 0.82 mm annually, as a result of local rising and falling of the coast due to tectonic disruptions, Barić *et al.* 2008.

8 Lambeck *et al.* 2010.

9 Surić 2009.

10 Benjamin *et al.* 2017.

loških, bioloških i ekoloških indikatora nekadašnje obalne crte te u brojnim arheološkim i povijesnim izvorima.

2.1. Geomorfološki indikatori promjena morske razine

Najočitiji dokazi promjene morske razine geomorfološke su prirode, a najčešće se očituju u oblicima nastalim sedimentacijskim (npr. sedimentne stijene zvane *beachrocks*, tj. *stijene plaža*[11] ili *plažne stijene*) ili erozivnim procesima (npr. marinske terase, plimne i valne potkapine i dr.).[12] Dok valne potkapine mogu nastati na različitim visinama, od najvišeg mjesta do kojeg dopiru valovi do mjestâ ispod razine morskih mijena,[13] najdublje su točke plimnih potkapina uglavnom odraz srednje razine mora tijekom duljeg stabilnog razdoblja.[14]

2.1.1. Plažne stijene

Plažne stijene su slabije ili jače cementirane sedimentne stijene koje se oblikuju unutar otvorene plaže, u zoni plime i oseke,[15] a sastoje se od karbonatnih čestica cementiranih izlučivanjem karbonata i fosfata.[16] Iako točan proces njihova nastajanja još uvijek nije do kraja objašnjen, riječ je o oblicima kalkarenita koji u sebi sadrže stanovitu količinu ulomaka školjaka i ostalih morskih organizama, koji su, po tradicionalnom tumačenju, posljedica kontakta stabilne morske vode i slatke vode u morskom dnu.[17] Morska voda koja se nalazi u porama tla (porna voda) pri normalnoj slanosti i taloženju koje se odvija u normalnim marinskim uvjetima ne izaziva kemijsku reakciju s mineralnim sastojcima okolnog tla, ali se situacija mijenja u trenutku kad porna voda promijeni svoj sastav. Do toga dolazi difuzijom ili istiskivanjem pornih voda iz dubljih naslaga, što u blizini granice sedimenta i vode uzrokuje izlučivanje mineralnog cementa.[18] Cementiranje se može dogoditi

11 Tišljar 1994 rabi termin *stijene plaža*. Autor ga u više navrata označava navodnicima, navodeći u zagradi i termin na engleskom jeziku, što ukazuje na činjenicu da je riječ o prijevodu koji u trenutku nastanka publikacije nije zaživio u stručnoj geološkoj terminologiji.

12 Pirazzoli, Pluet 1991. Za oblikovanje i očuvanje tih indikatora potrebna je bar kratkotrajna stabilizacija morske razine. Benjamin *et al.* 2017.

13 Pirazzoli 1994; Laborel *et al.* 1999.

14 Spencer 1988.

15 Gary *et al.* 1972.

16 Tišljar 1994, str. 138-139.

17 Benjamin *et al.* 2017, str. 33.

18 Tišljar 1994, str. 138-139.

2. Indicators of sea-level change

Sea-level change is a constant process, for which confirmations can be found in a series of geological, geomorphological, biological and ecological indicators of the former coastline and in numerous archaeological and historical sources.

2.1. Geomorphological indicators and sea-level change

The most obvious evidence of sea-level change is geomorphological in nature, most often manifested in forms caused by sedimentation (e.g. sedimentary rocks called beachrocks[11]) or erosion (e.g. marine terraces, tidal or wave-formed caves, etc.).[12] While marine notches may be formed at various elevations, from the highest point reached by waves to places below the level of tidal action,[13] the deepest points of marine notches generally reflect the mean sea level during extended stable periods.[14]

2.1.1. Beachrocks

Beachrocks are friable or more well-cemented sedimentary rocks that form on open beaches, in the tidal zone,[15] and they consist of carbonate minerals cemented by carbonate and phosphate secretions.[16] Even though the process of their formation has still not been entirely explained, these are forms of calcarenites which contain a certain quantity of shells and other marine organisms, which are, according to the traditional interpretation, the result of contact between stable seawater and freshwater in the seafloor.[17] Seawater found in pores in the ground (pore water) at the normal salinity and sedimentation that proceeds under normal marine conditions does not provoke chemical reactions with the mineral components of the surrounding soil, but the situation changes at the moment when the composition of water changes. This

11 Tišljar 1994 coined the term *stijene plaža*. At several places, he put the term in quotation marks, adding the English translation, beachrock, in parenthesis, which points to the fact that this was a Croatian translation which at the time of publication had not yet taken root in official geological terminology.

12 Pirazzoli, Pluet 1991. The formation and preservation of these indicators requires at the very least a brief stabilization of the sea level. Benjamin *et al.* 2017.

13 Pirazzoli 1994; Laborel *et al.* 1999.

14 Spencer 1988.

15 Gary *et al.* 1972.

16 Tišljar 1994, pp. 138-139.

17 Benjamin *et al.* 2017, p. 33.

u izrazito kratkom vremenskom razdoblju od samo desetak godina, kako ispod tako i iznad prosječne morske razine.[19] Pretpostavka je kako do njega dolazi zahvaljujući kalcijevom karbonatu iz slatke vode koja prodire iz močvarnog zaleđa, ali je fenomen potvrđen i na mjestima gdje slatke vode nema,[20] a plažne stijene mogu se formirati i kao posljedica riječnih poplava, oluja ili tsunamija.[21]

Erozijom plaže tijekom vremena sedimentna stijena izlazi na vidjelo i postaje elementom koji se, iako s velikim oprezom, može koristiti pri proučavanju promjena morske razine.[22] Zbog izrazito pravilnog, vodoravno položenog, pravocrtnog oblika ona često podsjeća na umjetno izrađenu podnicu ili zid, zavaravajući oko geološki neupućenog promatrača. Plimni rukavci koji je presijecaju komunikacija su unutrašnje lagune i otvorenoga mora,[23] pa se stijena čini sastavljenom od pravilnih kamenih blokova, što dodatno pothranjuje dojam o tvorevini izgrađenoj ljudskom rukom.

Apsolutno datiranje plažnih stijena o kojima je riječ nije i apsolutno pouzdan podatak za datiranje nastanka tih formacija. Kontaminacija starijim karbonatima može biti uzrokom rezultata koji ukazuje na pretjerano star datum nastanka, dok pretjerano mladi datumi mogu biti uzrokovani postdepozitnim promjenama karbonata ili sedimentacijom u više faza.[24] Osim toga, nemogućnost određivanja točnog mjesta na kojemu se u odnosu na prosječnu morsku razinu događa proces cementiranja, dodatno otežava korištenje plažnih stijena u funkciji preciznih markera morske razine. Ograničenja na koja su stručnjaci upozorili već prije više od trideset godina[25] i danas su uglavnom prihvaćena u stručnoj literaturi, ali se time ne isključuje korištenje opisanih sedimentnih stijena u funkciji indikatora i markera promjena morske razine.

Upečatljive plažne stijene nalaze se na nekoliko poznatih podmorskih arheoloških nalazišta poput onih u uvali Caski na otoku Pagu, s vanjske strane pješčanog ninskog poluotoka Ždrijaca (sl. 1) te između

19 Lambeck *et al.* 2004a, str. 1570.

20 Beach rock (2010). U: Encyclopaedia Britannica. Encyclopaedia Britannica Online, http,//www.britannica.com/EBchecked/topic/57110/beach-rock. O radovima o toj temi vidi Kelletat 2006, str. 1558.

21 Benjamin *et al.* 2017, str. 33.

22 Kelletat 2006, str. 1560, 1562. Autor upozorava da je zaključke izvedene na temelju sedimentnih stijena potrebno komparirati s rezultatima proučavanja ostale geološke i arheološke evidencije.

23 Tišljar 1994, str. 366.

24 Lambeck *et al.* 2004a, str. 1570.

25 Hopley 1986.

can be a result of the diffusion or ejection of pore water from deeper sediments, which causes the secretion of mineral cement at the boundary between the sediment and water.[18] Cementing may occur during an extremely brief period of only about ten years, both below and above the average sea level.[19] The assumption is that it occurs thanks to calcium carbonate from fresh water that flows in from the marshy hinterland, but the phenomenon has also been confirmed at places where there is no fresh water,[20] and beachrocks may also form as a result of river floods, storms or tsunamis.[21]

Over time, as a result of erosion on a beach, sedimentary rocks emerge and become an element which may be used - albeit with great caution - to study sea-level change.[22] Due to their exceptionally ordered, horizontally arranged, linear form, they often recall an artificially made floor or wall, deceiving geologically less-astute observers. The tidal channels that intersect them serve as the communication between internal lagoons and the open sea,[23] so that the rocks appear to be made of cut stone blocks, which additionally bolsters the impression that they are structures crafted by human hands.

The absolute dating of the beachrocks considered herein does not constitute absolutely reliable information to date the emergence of these formations. Contamination with older carbonates may be the cause for results which show an excessively old date of formation, while excessively recent dates may be caused by post-deposit changes of carbonates or sedimentation in several phases.[24] The impossibility of determining the exact place at which the cementing process occurs in relation to average sea levels additionally hampers the use of beachrocks as precise sea-level markers. The limitations pointed out by experts already over thirty years ago[25] is still accepted in the scholarly literature today, but this does not exclude the use of the described sedimentary rocks as indicators and markers of sea-level change.

18 Tišljar 1994, pp. 138-139.

19 Lambeck *et al.* 2004a, p. 1570.

20 Beach rock (2010). In: Encyclopaedia Britannica. Encyclopaedia Britannica Online, http,//www.britannica.com/EBchecked/topic/57110/beach-rock. For works on this topic, see Kelletat 2006, p. 1558.

21 Benjamin *et al.* 2017, p. 33.

22 Kelletat 2006, pp. 1560, 1562. The author stressed that conclusions derived on the basis of sedimentary rock must be compared to the results of study of other geological and archaeological evidence.

23 Tišljar 1994, p. 366.

24 Lambeck *et al.* 2004a, p. 1570.

25 Hopley 1986.

Sl. 1. Plažna stijena Ploče uz poluotok Ždrijac u Ninu (zračna snimka: Turistička zajednica Nin)
Fig. 1. Beachrocks called Ploče next to Ždrijac Peninsula in Nin (aerial photograph: Nin Tourism Board)

obale i otočića Sv. Justina u Pakoštanima (sl. 2).[26] U sva tri slučaja u određenom su kraćem ili dužem vremenskom razdoblju bile proglašene djelom ljudskih ruku, a u literaturi se i u novije vrijeme susreće takav sud.[27]

2.1.2. Plimne potkapine

Plimne potkapine razvijaju se usporedo s razinom mora kombinacijom fizičke i biološke abrazije te kemijskim i biološkim otapanjem.[28] Drugim riječima, one su rezultat bioerozije, tj. procesa razaranja stjenovitih obala djelovanjem organizama koji naseljavaju međuplimnu i potplimnu zonu. Oni razaraju stijene kemijskim[29] i mehaničkim procesima,[30] a njihov je učinak osobito vidljiv na mekšim stijenama poput vapnenca. U međuplimnoj je zoni napredovanje razornih procesa najintenzivnije, pa plimna potkapina koja se stvara tijekom razdoblja stabilne morske razine poprima konkavan oblik. U trenutku nagle pozitivne

26 Da je riječ o plažnim stijenama, višestruko su potvrdili F. Antonioli, S. Faivre, N. Marriner, S. Miko, C. Morhange i G. Papatheodorou tijekom stručnih očevida na navedenim lokalitetima, provedenih u suradnji s autoricom teksta. Plažna stijena u Pakoštanima zabilježena je u literaturi kao prirodna pojava na temelju stručnog očevida koji je u suradnji sa S. Gluščevićem provela S. Faivre (Gluščević 2001).

27 Usp. npr. Jelić 1898, str. 121; Brusić 2007, str. 14-15.

28 Kershaw, Guo 2001.

29 Benac *et al.* 2004; Faivre *et al.* 2013. Organizmi poput litofitskih cijanobakterija, kamenotočnih spužvi i školjkaša izravno otapaju stijenu svojim izlučevinama.

30 Ježinci i puževi mehanički razaraju (stružu) površinu stijene.

Sl. 2. Plažna stijena Brak između Pakoštana i otočića Sv. Justina; dio koji viri iz mora je hrid Garofulin (zračna snimka: Turistička zajednica Pakoštane)
Fig. 2. Beachrocks called Brak between Pakoštane and the Islet of Sveti Justin; the part jutting from the sea is the reef called Garofulin (aerial photograph: Pakoštane Tourism Board)

Some rather striking beachrocks can be seen at several well-known submerged archaeological sites, such as those in Caska Cove on the island of Pag, on the external side of the Ždrijac Peninsula in Nin (Fig. 1) and between the coast and islet of Sv. Justin at Pakoštane (Fig. 2).[26] In all three cases, they were proclaimed the work of human hands over certain shorter or longer periods, and such assessments can even be found in the more recent literature.[27]

2.1.2. Tidal notches

Tidal notches develop parallel to the sea-level by a combination of physical and biological abrasion and chemical and biological dissolution.[28] In other words, they are the result of bioerosion, i.e., the process of destruction of rocky shores by the action of organisms which inhabit the inter-tidal and sub-tidal zones. They decompose rocks via chemical[29] and mechanical

26 That these are in fact beachrocks has been confirmed a number of times by F. Antonioli, S. Faivre, N. Marriner, S. Miko, C. Morhange and G. Papatheodorou during expert examinations at these sites, conducted in cooperation with the writer of this text. The beachrocks at Pakoštane were recorded in the literature as a natural phenomenon based on an expert examination which was conducted by S. Faivre in cooperation with the S. Gluščević (Gluščević 2001).

27 Cf. e.g. Jelić 1898, p. 121; Brusić 2007, pp. 14-15.

28 Kershaw, Guo 2001.

29 Benac *et al*. 2004; Faivre *et al.* 2013. Organisms such as lithophytic cyanobacteria, boring sponges and shellfish erode rocks with their secretions.

Sl. 3. Plimna potkapina u uvali Klopotnici u Paškom zaljevu (foto: L. Damelet)
Fig. 3. Wave-cut notch in Klopotnica Cove in Pag Bay (photo: L. Damelet)

promjene razine mora, uzrokovane tektonskim poremećajima, potkapina se spušta u podmorje i, ako ponovo uslijedi mirno i stabilno razdoblje, ostaje dobro očuvana.[31] Nastanak plimnih potkapina stimuliran je postojanjem podmorskih izvora slatke vode te položajem i tvrdoćom stijena.[32]

Nažalost, erozijska priroda potkapina velika je prepreka za datiranje, koja se nastoji prevladati raznim korelacijama i izračunima.[33] Usprkos tome, postojanje takvih pojava na različitim dubinama ili visinama siguran je dokaz nagle promjene morske razine nakon dužeg razdoblja stagnacije.

Proučavanje plimnih potkapina osnovno je obilježje dosadašnjeg geomorfološkog pristupa proučavanju promjena morske razine na sjevernom dijelu hrvatske obale,[34] a u nekoliko su navrata one iskorištene i u kombinaciji s arheološkim nalazima (sl. 3, 4).[35]

31 Surić 2009, str. 183.
32 Slatka voda potiče koroziju stijene. Furlani *et al.* 2014; Radulović *et al.* 2015. Potkapina se brže formira na mekšim stijenama izloženim otvorenome moru. Benjamin *et al.* 2017.
33 Benjamin *et al.* 2017, str. 37.
34 Benac, Šegota 1990; Benac 1996a; Benac 1996b; Benac, Juračić 1998; Faivre, Fouache 2003; Fouache *et al.* 2000; Fouache *et al.* 2005; Benac *et al.* 2004; Benac *et al.* 2008; Antonioli *et al.* 2017; Lagares 2008; Surić 2009, str. 183; Faivre *et al.* 2010a.
35 Usp. npr. Marriner *et al.* 2014, u vezi s nalazištem u uvali Caski na Pagu, ili Radić Rossi, Antonioli, u tisku, u vezi s nalazištem u podmorju Pakoštana.

Sl. 4. Plimna potkapina na vanjskoj strani Velog škoja uz obalu Pakoštana (foto: F. Antonioli)
Fig. 4. Wave-cut notch on the external side of Veli škoj next to the shore at Pakoštane (photo: F. Antonioli)

processes,[30] and their impact is particularly apparent on softer rocks such as limestone. In the inter-tidal zone, the progress of destructive processes is the most intense, so tidal notches that are created during stable sea-level periods assume a concave form. At a time of sudden positive sea-level change caused by tectonic disruptions, notches are submerged and, if a calm and stable period again ensues, they remain well preserved.[31] The formation of wave-cut notches is stimulated by the existence of undersea freshwater springs and the position and hardness of the rock.[32]

Unfortunately, the erosive nature of notches is a major barrier to their dating, so that various correla-

30 Urchins and slugs mechanically erode (scrape) the surface of rocks.
31 Surić 2009, p. 183.
32 Fresh water spurs the corrosion of rocks. Furlani *et al.* 2014; Radulović *et al.* 2015. Notches are formed more quickly on softer rocks exposed to the open sea. Benjamin *et al.* 2017.

2.1.3. Ostali geomorfološki indikatori promjene morske razine

Kao sigurni indikatori promjene morske razine spominju se i sige (speleotemi) u preplavljenim speleološkim objektima.[36] Kako njihov nastanak nije moguć u podvodnom ambijentu, njihova je prisutnost izravan dokaz da su se špilje nekada nalazile na kopnu.[37] Prednost je siga u mogućnosti apsolutnog datiranja njihovih slojeva radiometrijskim metodama (^{14}C, U-Th i dr.), a time i apsolutnog datiranja promjena morske razine koje su izazvale drastičnu promjenu okolišnih uvjeta u špiljama.

Paleokorita i kanjoni rijeka, poput kanjona Rječine, Zrmanje, Krke, Cetine i Neretve, batimetrijski praćeni do dubine od 100 m, također su očit dokaz promjene morske razine,[38] a zahvaljujući istaloženoj sedri mogu se apsolutno datirati u razdoblja niže morske razine. Pokušaj datiranja sedrenih barijera iz potonulog kanjona rijeke Krke rezultirao je zaključkom kako je početkom 5. tisućljeća pr. Kr. morska razina bila 14 m niža od današnje.[39]

2.2. Biološki indikatori promjene morske razine

Među najbolje biološke indikatore promjene morske razine ubrajaju se organizmi koji žive u zoni plime i oseke (eng. *inertidal / litoral zone*) ili u plitkome moru, koji na mjestu gdje su živjeli ostavljaju trajne tragove svog života. Na hrvatskoj obali takvi su organizmi npr. mediolitoralne crvene alge roda *Lithophyllum* koje u pojasu plime i oseke grade vapnenačke istake[40] ili npr. prstaci (*Lithophaga lithophaga*), koji na mjestima gdje se nekada nalazilo plitko more ostavljaju tragove ubušavanja.[41] Njihovi fosilni ostatci, uspoređeni s današnjim primjercima, mogu se koristiti za određivanje nekadašnje razine mora s velikom točnošću.[42]

Stratigrafija slanih močvara (koje se u nekim slučajevima nalaze u neposrednoj blizini arheoloških

36 Lambeck *et al.* 2010, str. 76.

37 Od 234 do sada poznata speleološka objekta duž hrvatske obale i otoka, u njih 140 evidentirana je prisutnost siga. Surić 2006; Surić 2009, str. 184.

38 Surić 2009, str. 184-185; Rječina: Benac, Šegota 1990; Zrmanja: Fritz 1972; Belij 1985; Krka: Juračić, Prohić 1991; Juračić 1992; Cetina: Baučić 1967; Neretva: Alfirević 1965.

39 Šegota 1968.

40 Faivre *et al*. 2010b; Faivre *et al*. 2013.

41 Surić 2009, str. 185-186.

42 Laborel, Laborel-Deguen 1995, str. 56-57; Morhange *et al.* 2001, str. 321; Lambeck *et al.* 2010, str. 76; Faivre *et al*. 2010b; Faivre *et al*. 2013.

tions and computations are employed in an attempt to overcome this.[33] Despite this, the existence of such phenomena at different depths and heights is certain evidence of sudden sea-level changes after extended periods of stagnation.

The study of tidal notches is based on the features of previous geomorphological approaches to the study of sea-level change on the northern section of the Croatian coast,[34] and several times they were also used in combination with archaeological finds (Figs. 3, 4).[35]

2.1.3. Other geomorphological indicators of sea-level change

Also noted as certain indicators of sea-level change are stalactites (speleothems) in flooded caverns.[36] Since their formation is impossible in a submerged environment, their presence is direct evidence that the cave was once above water.[37] The advantage of stalactites is the possibility of absolute dating of their layers using radiometric methods (^{14}C, U-Th, etc.), and thereby also absolute dating of sea-level changes that caused drastic changes in the environmental conditions in caverns.

Palaeochannels and river canyons, such as the canyons of the Rječina, Zrmanja, Krka, Cetina and Neretva Rivers, bathymetrically gauged to depths of 100 m, are also obvious evidence of sea-level change,[38] and thanks to sedimented tufa they can be absolutely dated to periods of lower sea levels. An attempt to date the tufa barriers from the sunken canyon of the Krka River resulted in the conclusion that at the beginning of the fifth millennium BC, the sea level was 14 m lower than that of the present.[39]

33 Benjamin *et al.* 2017, p. 37.

34 Benac, Šegota 1990; Benac 1996; Benac 1996a; Benac, Juračić 1998; Faivre, Fouache 2003; Fouache *et al.* 2000; Fouache *et al.* 2005; Benac *et al.* 2004; Benac *et al.* 2008; Antonioli *et al.* 2007; Lagares 2008; Surić 2009, p. 183; Faivre *et al.* 2010.

35 Cf., e.g. Marriner *et al.* 2014, with reference to the site in Caska Cove on Pag, or Radić Rossi, Antonioli, in press, on the submerged site at Pakoštane.

36 Lambeck *et al.* 2010, p. 76.

37 Out of the 234 thus far known speleological sites on the Croatian coast and islands, the presence of stalactites has been recorded in 140. Surić 2006; Surić 2009, p. 184.

38 Surić 2009, pp. 184-185; Rječina: Benac, Šegota 1990; Zrmanja: Fritz 1972; Belij 1985; Krka: Juračić, Prohić 1991; Juračić 1992; Cetina: Baučić 1967; Neretva: Alfirević 1965.

39 Šegota 1968.

Sl. 5. Mala mediteranska močvara u dnu uvale Caske (foto: L. Damelet)
Fig. 5. Small Mediterranean marsh at the base of Caska Cove (photo: L. Damelet)

Sl. 6. Geološko sondiranje u močvari u dnu uvale Caske (foto: L. Damelet)
Fig. 6. Geological test digging in the marsh at the base of Caska Cove (photo: L. Damelet)

lokaliteta, sl. 5, 6),[43] zasnovana na proučavanju kombinacija mikrofosila (*Foraminifera*),[44] također je uspješna metoda proučavanja promjena morske razine, a time i nekadašnje obalne crte.

2.3. Arheološki indikatori promjene morske razine

Arheološki nalazi čine zasebnu skupinu indikatora promjena morske razine,[45] koja se ponekad koristi i u kombinaciji s indikatorima iz ostalih skupina (npr. tragovi morskih mekušaca na arheološkim nalazima na kopnu, koji ukazuju na određeno razdoblje u kojemu je razina mora bila viša[46]). U interpretiranju arheoloških izvora kao indikatora morske razine pionirski je posao obavljen krajem šezdesetih i tijekom sedamdesetih godina prošloga stoljeća,[47] a u posljednje vrijeme takav se pristup počeo ozbiljnije primjenjivati i u hrvatskom podmorju.[48]

Velika većina arheoloških svjedočanstava duž hrvatske obale pogodnih za proučavanje promjena morske razine pripada antičkom dobu, dok je u manjoj mjeri riječ o arheološkoj baštini prapovijesnoga, srednjovjekovnoga i novovjekovnog doba. U tome smislu koriste nam dvije velike skupine nepokretnih nalaza, pri čemu u prvu ubrajamo građevine koje su se originalno nalazile na kopnu, dok se u drugoj nalaze

43 Marriner *et al.* 2014.
44 Lambeck *et al.* 2010, str. 79-80.
45 Pregled arheoloških indikatora i načina njihovoga korištenja u Auriemma, Solinas 2009.
46 Morhange *et al.* 2001.
47 Flemming 1969; Caputo, Pieri 1976; Pirazzoli 1976.
48 Faivre, Fouache 2003; Fouache *et al.* 2000; Fouache *et al.* 2005a; Fouache *et al.* 2005b; Antonioli *et al.* 2017.

2.2. Biological indicators of sea-level change

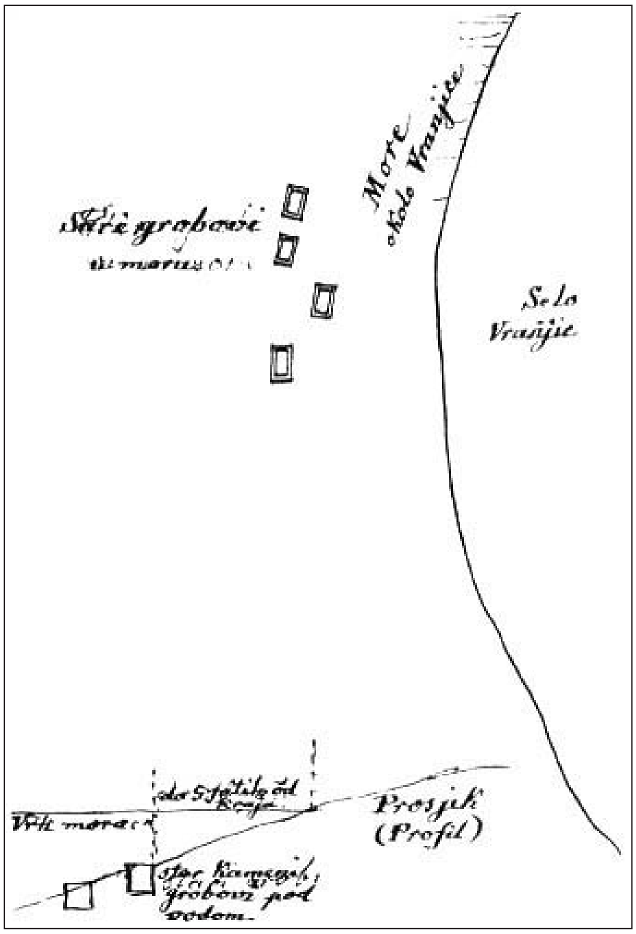
Organisms that live in the intertidal (littoral) zone or in shallow waters are counted among the best biological indicators of sea-level change, because they leave traces of their existence on the places on which they lived. On the Croatian coast, such organisms include, for example, the *Lithophyllum* species of eulittoral red algae, which build limestone outcroppings in the intertidal zone[40] or, for example, date mussels (*Lithophaga lithophaga*), which leave traces of boring at places where there had once been shallow seas.[41] Their fossil remains, compared to modern examples, may be used to determine former sea levels with great accuracy.[42]

The stratigraphy of coastal salt marshes (which are in some cases located in the immediate vicinity of archaeological sites, Figs. 5, 6)[43] is based on a combination of microfossils (*Foraminifera*),[44] another successful method of studying sea-level change, and thereby also former coastlines.

2.3. Archaeological indicators of sea-level change

Archaeological finds account for a separate group of sea-level change indicators,[45] which are sometimes

40 Faivre *et al*. 2010b; Faivre *et al*. 2013.
41 Surić 2009, pp. 185-186.
42 Laborel, Laborel-Deguen 1995, pp. 56-57; Morhange *et al.* 2001, p. 321; Lambeck *et al.* 2010, p. 76; Faivre *et al*. 2010b; Faivre *et al*. 2013.
43 Marriner *et al.* 2014.
44 Lambeck *et al.* 2010, pp. 79-80.
45 An overview of archaeological indicators and methods for their use in: Auriemma, Solinas 2009.



Sl. 7. Skica vranjičkih sarkofaga iz putne bilježnice Mijata Sabljara (Arhiv Ministarstva kulture RH)
Fig. 7. Sketch of the Vranjic sarcophaguses from the travel notebook of Mijat Sabljar (Archives of the Croatian Ministry of Culture)

one građevine koje su bile izgrađene u moru, ali im se gornja površina nekad nalazila iznad morske razine ili na samoj razini mora (molovi, lukobrani, operativna obala, izvlačilišta, tj. navozi za brodove, ribnjaci, zamke za ribu i dr.). Nalazi iz obje skupine duž hrvatske obale i na otocima stoljećima su bilježeni od strane putopisaca, prirodoslovaca i zaljubljenika u starine, a polovicom 18. stoljeća počeli su se koristiti i u prilog teoriji o promjenama morske razine.[49]

2.3.1. Najraniji primjeri korištenja arheoloških indikatora iz hrvatskog podmorja za proučavanje promjena morske razine

Pedesetih godina devetnaestog stoljeća povjerenik Narodnog muzeja u Zagrebu Mijat Sabljar, u svoje je putne bilježnice pri obilasku Dalmacije unio skice

49 Donati 1999, str. XII-XIII.

used in combination with indicators from the other groups (e.g., traces of marine molluscs at archaeological sites on land, which indicate a certain period during which the sea level was higher[46]). Pioneering work on the interpretation of archaeological sources as indicators of sea-level change was done at the end of the 1960s and during the 1970s,[47] while in recent years this approach also began to be more seriously applied in the Croatian subsea.[48]

The vast bulk of archaeological testimony all down the Croatian coast suitable for the study of sea-level change dates to Antiquity, and to a lesser extent to the archaeological heritage of the prehistoric, medieval and early modern eras. In this regard, two large groups of fixed finds are of use: structures originally located on dry land are counted among the first, while the second includes those originally built at sea, but their upper surfaces were once above or at sea level (piers, breakwaters, operational docks, slipways for ships, fish nurseries, fish traps, etc.). Finds from both groups on the Croatian coast and islands have been recorded for centuries by travel writers, natural history scholars and lovers of antiquities, and by the mid-18th century they were used to back the theory of sea-level change.[49]

2.3.1. Earliest examples of the use of archaeological indicators from the Croatian seafloor to study sea-level change

During the 1950s, Mijat Sabljar, the commissioner of the National Museum in Zagreb, drew a sketch of two submerged sites (Fig. 7) in his travel notebook during a tour of Dalmatia.[50] This is the oldest illustrated documentation showing submerged finds *in situ* in Caska Cove on the island of Pag and in Vranjic, near Solin. Zuan Battista Giustiniani wrote about the submerged finds of walls and mosaics at Caska in 1553,[51] while the ancient sarcophaguses along the western shore of Vranjic were recorded in 1818 by Anton Steinbüchel von Rheinwall, the director of the Imperial Museum in Vienna, when he visited Dalmatia as a member of the emperor's entourage.[52]

46 Morhange *et al.* 2001.
47 Flemming 1969; Caputo, Pieri 1976; Pirazzoli 1976.
48 Faivre, Fouache 2003; Fouache *et al.* 2000; Fouache *et al.* 2005; Fouache *et al.* 2005a; Antonioli *et al.* 2007.
49 Donati 1999, pp. XII-XIII.
50 Mirnik 1972; Mirnik 1981, pp. 211, 235.
51 Petrić 2003, p. 111; Ljubić 1877, p. 261; Šimunković 2011, p. 220.
52 Steinbüchel 1820. On Stenibüchel's visit to Dalmatia, Špikić 2006.

dvaju značajnih podmorskih lokaliteta (sl. 7).[50] Riječ je o najstarijoj nacrtnoj dokumentaciji koja prikazuje podmorske nalaze *in situ* u uvali Caska na otoku Pagu i u Vranjicu kod Solina. O preplavljenim nalazima zidova i mozaika u Caski pisao je još 1553. godine mletački namjesnik Zuan Battista Giustiniani,[51] a antičke sarkofage uz zapadnu obalu Vranjica zabilježio je 1818. ravnatelj Carskoga muzeja u Beču Anton Steinbüchel von Rheinwall kad je u carskoj pratnji posjetio Dalmaciju.[52]

U početku gledani tek kao zanimljive starine, podmorski nalazi duž istočne jadranske obale polovicom su osamnaestog stoljeća postali dokazom promjene morske razine i izvorom podataka za proučavanje tog fenomena. Koliko je danas poznato, prvi ih je u tu svrhu upotrijebio talijanski prirodoslovac Vitaliano Donati, koji je 1750. objavio knjigu *Della storia naturale dell'Adriatico*, navodeći podmorske arheološke nalaze u Istri i Dalmaciji kao potvrde vlastite pretpostavke o promjeni morske razine od antičkog do njegovog doba.[53] Uz zidove i mozaike Donati je spomenuo i sitne nalaze s antičke nekropole u uvali Stupici na Žirju, koja se tijekom vremena našla na samoj granici s morem, što je uzrokovalo jaku eroziju i potapanje grobnih priloga.

Donatijev rad nastavio je opat Alberto Fortis,[54] a također i mnogi drugi inozemni i hrvatski znanstvenici. Među njima se posebno ističu Anton Gnirs[55] i Niko Andrijašević,[56] koji su početkom dvadesetog stoljeća, svaki na svoj način, iskoristili arheološka nalazišta u plitkome moru za proučavanje navedenog fenomena. Usprkos očitim dokazima Niko Andrijašević sustavno je pronalazio razloge za odbijanje ideje o - kako sam kaže - "vertikalnom podizanju obalne crte", no unatoč činjenici da mu se pretpostavke nisu potvrdile, njegovo je djelo i dandanas vrijedan izvor podataka o mnogim podmorskim arheološkim lokalitetima.

U literaturi iz 19. i početka 20. stoljeća naročito su se često spominjala istarska nalazišta, jer se na području Istre odvijala intenzivna arheološka djelatnost.[57] Pietro Kandler i Anton Gnirs navodili su i opisivali preplavljene arheološke nalaze u priobalju, a sustavan

50 Mirnik 1972; Mirnik 1981, str. 211, 235.
51 Petrić 2003, str. 111; Ljubić 1877, str. 261; Šimunković 2011, str. 220.
52 Steinbüchel 1820. O posjetu Stenibüchela Dalmaciji, Špikić 2006.
53 Donati 1999, XII-XIII; Petrić 2003, str. 112-113.
54 Fortis 1984.
55 Gnirs 1908.
56 Andrijašević 1910.
57 Petrić 2003.

Initially viewed solely as intriguing antiquities, by the mid-18th century subsea finds all down the eastern Adriatic coast became evidence of sea-level change and a source of data to study this phenomenon. As far as it is known today, the first to use them for this purpose was Italian natural philosopher Vitaliano Donati, who published the book *Della storia naturale dell'Adriatico* in 1750, citing undersea archaeological finds in Istria and Dalmatia as confirmations of his own speculation on sea-level change from Antiquity to his own time.[53] Besides walls and mosaics, Donati also mentioned tiny finds from the Antique necropolis in Stupica Cove on the island of Žirje, which over time subsided to the very edge of the sea, causing intense erosion and the submersion of grave goods.

Donati's work was continued by Abbot Alberto Fortis,[54] and also by many other foreign and Croatian scholars. Particularly notable among them were Anton Gnirs[55] and Niko Andrijašević,[56] who - each in his own way - utilized archaeological sites in shallow sea water to study this phenomenon in the early 20th century. Despite obvious evidence, Niko Andrijašević systematically found reasons to reject the idea of – as he said himself - "the vertical rise of the coastline", but despite the fact that his hypotheses were not confirmed, his work remains a valuable source of data on many submerged archaeological sites to this day.

Istrian sites were mentioned in particular in the scholarly literature of the 19th and 20th centuries, because intense archaeological activities were conducted in Istria's territory.[57] Pietro Kandler and Anton Gnirs cited and described submerged archaeological sites along the shoreline, and a systematic description of sites on the near-shore shallow Istrian sea was done in the mid-1930s by Attilio Degrassi.[58]

Many intriguing citations of old writings, legends and tales can be found in the archaeological literature of the 19th century. In 1878, Richard Francis Burton, describing the remains of ancient Siparia, recorded the following information: "In 1770, when, according to the Abbé Laugier, a dangerously low ebb-tide

53 Donati 1999, XII-XIII; Petrić 2003, pp. 112-113.
54 Fortis 1984.
55 Gnirs 1908.
56 Andrijašević 1910.
57 Petrić 2003.
58 Degrassi 1954. Even though the work was published in the mid-1950s, all data contained therein were gathered during field research in 1934, after which Degrassi was officially reassigned to Rome. Therefore, from today's standpoint, the work certainly belongs to an earlier time, in which it constituted a major step forward in methodology and a systematic approach to a well-rounded geographic unit.

opis nalazišta u plitkome istarskom podmorju proveo je polovicom tridesetih godina Attilio Degrassi.[58]

U arheološkoj literaturi 19. stoljeća nailazimo na mnoge zanimljive navode starih zapisa, legendi i priča. Godine 1878. Richard Francis Burton, opisujući potonule ostatke antičkog *Siparisa*, zabilježio je sljedeći podatak: "Godine 1770., kad je, prema opatu Laugieru, opasno niska oseka na ovoj obali ugrozila Veneciju srazmjernom plimom (*una fiera marea*), ruševine, koje su pokrivale oko dvije milje, pokazale su svoje mozaičke podove i dobro izgrađene zidove s vratima i prozorima."[59] Isti su događaj opisali i Kandler, Puschi i Benussi, pojasnivši kako je riječ o prostoru između Sipara i Umaga (rt Katoro).[60]

U prvome času, dakle, arheološkim su nalazima u plitkome podmorju najveću pozornost posvetili prirodoslovci. Tako je i prvo podmorsko istraživanje u Vranjicu kod Solina, iako ga je organizirao i vodio arheolog, bilo zapravo pokušaj dokazivanja poniranja istočne jadranske obale, a ne interpretacije arheološkog nalazišta. Godine 1899. don Frane Bulić organizirao je kratku istraživačku akciju koju s punim pravom možemo nazvati interdisciplinarnom, a kako su se u njezinu fokusu našli podmorski nalazi, ona se ujedno može smatrati i prvim podmorskim istraživanjem organiziranim na znanstvenim osnovama.

U potrazi za dokazima promjene morske razine tijekom protekla dva tisućljeća Bulić je poželio provjeriti nalaze li se kovčezi sarkofaga koje su uz zapadnu vranjičku obalu primijetili i zabilježili Steinbüchel, Sabljar i drugi autori,[61] doista *in situ* ili je riječ o sekundarnom položaju arheoloških nalaza. Uz pomoć pomorske uprave (tal. *Governo Centrale Marittimo*) u Trstu, koja je osigurala ronilačku ispomoć, i lučke kapetanije u Splitu, koja mu je na raspolaganje stavila mali parobrod imenom *Salona*, Bulić je u Vranjic doveo skupinu znanstvenika pod vodstvom bečkog geografa dr. Alberta Pencka. Teški ronilac[62] dijelom je oslobodio nalaze od pijeska i mulja, a potom

58 Degrassi 1954. Iako je rad objavljen polovicom pedesetih godina dvadesetog stoljeća, svi podatci koji su u njemu objavljeni prikupljeni su tijekom terenskih pregleda do 1934. godine, nakon čega je uslijedio Degrassijev službeni premještaj u Rim. Stoga iz današnje perspektive rad svakako pripada ranijem vremenu, u kojemu figurira kao velik iskorak u metodologiji rada i sustavnom pristupu jednoj zaokruženoj geografskoj cjelini.

59 Burton *et al.* 1878. Autori se oslanjaju na djelo opata M.-A. Laugiera 1778.

60 Kandler 1846; Benussi 1928, str. 159.

61 Bulić 1913, str. 27, bilj. 3-4.

62 O ronilačkoj opremi uz pomoć koje je obavljena akcija dokumentiranja sarkofaga vidi Zeljak 2006.

on this coast threatened Venice with a flow in proportion (*una fiera marea*), the ruins, covering some two miles, showed their mosaic floors, and well-built walls pierced with doors and windows."[59] The same event was also described by Kandler, Puschi and Benussi, explaining that this was the area between Siparia and Umag (Cape Katoro).[60]

Initially, then, natural philosophers accorded the most attention to archaeological finds in shallow waters. Thus, even the first subsea exploration in Vranjic, near Solin, although led by an archaeologist, was actually an attempt to prove the sinking of the eastern Adriatic shoreline rather than the interpretation of an archaeological site. In 1899, Fr. Frane Bulić organized a brief research project which may rightfully be characterized as interdisciplinary, and since it focused on undersea finds, it may also be deemed the first undersea research organized on a scholarly basis.

In search of evidence for sea-level change over the past two millennia, Bulić wanted to verify whether the sarcophagus boxes observed and recorded by Steinbüchel, Sabljar and other writers along the western Vranjic shore[61] were indeed *in situ* or if these were secondary archaeological finds. With the help of the maritime authority (Ital. *Governo Centrale Marittimo*) in Trieste, which secured diving assistance, and the port authority in Split, which placed a small steamship named *Salona* at his disposal, Bulić brought a group of scholars to Vranjic under the leadership of Viennese geographer Albert Penck. A diver in heavy gear[62] partially freed the finds from sand and mud, and then documented the ground situation at the site (Fig. 8).[63] Both scholars, Bulić and Penck, jointly concluded that these were finds lying in the same place where they were placed in Antiquity, thereby demonstrating the sea-level change which occurred in the meantime.[64]

59 Burton *et al.* 1878. The authors depended on the work of Abbot M.-A. Laugier 1778.

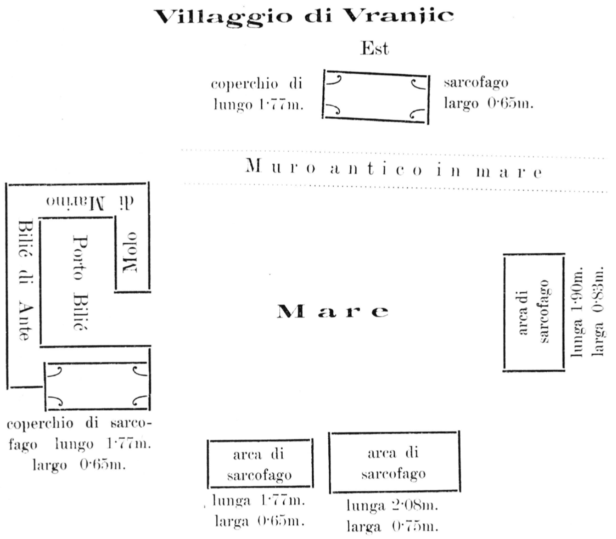
60 Kandler 1846; Benussi 1928, p. 159.

61 Bulić 1913, p. 27, note 3-4.

62 On the diving gear used to conduct the documentation of the sarcophagus, see Zeljak 2006.

63 Experts have confirmed that these are three sarcophagus boxes with their upper surfaces at a depth of approximately 1 m, and which were approximately 8 m from the shore at the time. If, however, Sabljar's ground layout sketch (Fig. 7) is compared to the sketch done by Bulić (Fig. 8), it may be observed that Sabljar drew in four stone boxes. This fourth one was probably already covered with layers of mud in Bulić's time, so that it could no longer be seen on the surface of the sea floor.

64 Bulić 1899, pp. 109-111.



Sl. 8. Skica vranjičkih sarkofaga koju je objavio don Frane Bulić (prema: Bulić 1899)
Fig. 8. Sketch of the Vranjic sarcophaguses published by Fr. Frane Bulić (according: Bulić 1899)

dokumentirao tlocrtnu situaciju nalazišta (sl. 8).[63] Oba znanstvenika, Bulić i Penck, složno su zaključili kako je riječ o nalazima koji leže na istome mjestu gdje su bili položeni u doba antike te time ukazuju na promjenu morske razine koja se u međuvremenu dogodila.[64]

Deset godina nakon Bulićeve akcije Niko Andrijašević osporio je Pencku zaključke o čvrstoj podlozi na kojoj počivaju sarkofazi, kritizirajući općenito ideju o kontinuiranom poniranju istočne jadranske obale ili podizanju morske razine.[65] Osim toga, sugerirao je kako se sarkofazi ne nalaze na originalnome mjestu, već su možda postavljeni s namjerom izgradnje mola, koja nikada nije do kraja realizirana.

Zaštitnim arheološkim istraživanjima provedenima u nekoliko navrata tijekom 2005. i 2006. godine potvrđeno je kako su sarkofazi ipak ležali na čvrstom kamenom grebenu,[66] ali najvjerojatnije u sekundarnome položaju, kao i mnogi drugi slični nalazi u vranjičkom podmorju. Svi su oni poslužili za učvršćenje

63 Stručnjaci su utvrdili kako je riječ o tri kovčega sarkofaga čija se gornja površina nalazila na dubini od oko 1 m, a koji su od tadašnje obale bili udaljeni oko 8 m. Usporedimo li, međutim, Sabljarovu tlocrtnu skicu (sl. 7) s nacrtom koji donosi Bulić (sl. 8) , primijetit ćemo kako je Sabljar ucrtao četiri kamena kovčega. Vjerojatno je onaj četvrti u Bulićevo doba bio već potpuno prekriven naslagama mulja, pa ga više nije bilo moguće primijetiti na površini morskoga dna.

64 Bulić 1899, str. 109-111.

65 Andrijašević 1910.

66 Radić Rossi 2007; Radić Rossi 2008; Radić Rossi 2009.

Ten years after Bulić's work, Niko Andrijašević disputed Penck's conclusions on the firm base upon which the sarcophaguses rested, generally criticizing the idea of the continuous subsidence of the Adriatic shore or a rising sea level.[65] He furthermore suggested that the sarcophaguses were not at their original location, but were rather placed there with the intention of constructing a pier that had never been entirely completed.

Rescue archaeological research conducted on several occasions during 2005 and 2006 confirmed that the sarcophaguses indeed rested on a firm stone ridge,[66] but they were probably in a secondary position, like many other similar submerged finds at Vranjic. All of them were used to reinforce the shore and build piers in late Antiquity or the early Middle Ages, and given changing sea levels, the surface of these structures is today at a depth of 0.5 m.

Even though the Vranjic undersea finds are most often listed in the literature as consisting of only the sarcophagus boxes along the western Vranjic shore, on several occasions Bulić also mentioned other items which the local residents of his time found along the western and southern shores of the settlement.[67] Three sarcophaguses were also seen south of the parish church; the lids were extracted in 1890 and used as construction material, while the boxes were soon filled with mud.[68] Walls were also mentioned along the western and south-eastern shore in the shallow sea, which were already devastated in Bulić's time so the stone could be used for new construction works, or over time they disappeared beneath recent coastal embankments.[69] As noted in Bulić's reports, ancient walls in shallow waters could also be seen east of the islet of Barbarinac, situated opposite of ancient Salona, along the northern shore of the bay.[70]

All later authors generally only superficially touched upon sea-level change, mostly with reference to sites dating to Antiquity, which has resulted in generalized conclusions on sea-level change of approximately 2 m over two thousand years, which is still noted in the archaeological literature to this day.

65 Andrijašević 1910.

66 Radić Rossi 2007; Radić Rossi 2008; Radić Rossi 2009.

67 Bulić 1899; Bulić 1900, p. 108; Bulić 1913, pp. 26-28.

68 Bulić 1913, p. 28.

69 Bulić 1899, p. 108.

70 Bulić 1913, p. 37.

obale i izgradnju molova u vrijeme kasne antike ili ranoga srednjeg vijeka, a s obzirom na promjene morske razine gornja se površina tih konstrukcija danas nalazi na dubini od 0,5 m.

Iako se kao vranjički podmorski nalazi u literaturi najčešće navode samo kovčezi sarkofaga uz zapadnu vranjičku obalu, Bulić je u nekoliko navrata spominjao i druge predmete koje su mještani njegova doba pronalazili duž zapadne i južne obale naselja.[67] Tri su se sarkofaga vidjela i južno od župne crkve; poklopci su izvađeni 1890. i pretvoreni u građevinski materijal, a kovčege je ubrzo zatrpao mulj.[68] Uz zapadnu i jugoistočnu obalu u plitkom se moru spominju i zidovi koji su već u Bulićevo vrijeme razoreni kako bi se kamena građa iskoristila za nove konstrukcije, ili su tijekom vremena nestali pod recentnim obalnim nasipima.[69] Kako saznajemo iz Bulićevih izvješća, antički zidovi u plitkome moru mogli su se vidjeti i istočno od otočića Barbarinca, smještenog nadomak antičkoj Saloni, uz sjevernu obalu zaljeva.[70]

Svi kasniji autori uglavnom su se tek površno doticali promjena morske razine, i to većinom u svezi s antičkim nalazištima, što je rezultiralo prilično uopćenim zaključcima o promjeni morske razine od oko 2 m u dvije tisuće godina, koji se i danas provlače kroz arheološku literaturu.

3. Uzroci promjena morske razine

Svi nabrojeni geološki, biološki i arheološki indikatori, a k tome i mnogi drugi, daju nam podatke o relativnim promjenama morske razine, tj. o uzajamnom odnosu mora i kopna u određenom vremenu i na određenom prostoru. Promjene morske razine zapravo su zbroj više čimbenika i nije ih moguće generalizirati, a u nastavku teksta najvažniji su od njih ukratko opisani.

Prvi je od čimbenika promjena globalne, eustatske, morske razine koja označava razinu svih oceana, a najčešće se računa kao udaljenost između fiksne točke u središtu zemlje i morske površine.[71] Tijekom zemljine geološke prošlosti morska se razina neprestano mijenja. Tektonika ploča uzrokovala je u davnoj prošlosti velike promjene globalne morske razine od nekoliko stotina metara.[72] Promjene do kojih dolazi tijekom kvartara (posljednjih 2,6 mil. godina)

67 Bulić 1899; Bulić 1900, str. 108; Bulić 1913, str. 26-28.

68 Bulić 1913, str. 28.

69 Bulić 1899, str. 108.

70 Bulić 1913, str. 37.

71 Surić 2009, str. 182; cit. Coe, Church 2005.

72 Surić 2009, str. 182.

3. Causes of sea-level change

All of these geological, biological and archaeological indicators, and in this regard many others as well, provide data on relative sea-level changes, i.e., on the mutual boundary between land and sea at specific places at specific times. Sea-level changes are actually the sum of several factors and they cannot be generalized, and the most important of these will be briefly described hereinafter.

The first of the factors consists of changes in global, eustatic, sea-level change which denotes the level of all oceans, and this is most often calculated as the distance between a fixed point in the centre of the Earth and the sea's surface.[71] The sea level has constantly changed during the course of the Earth's geological past. In the distant past, a tectonic plate caused a global sea level change of several hundred meters.[72] The changes which occurred during the quaternary (the last 2.6 million years) have generally been caused by the periodic formation and thaw of ice sheets,[73] i.e., reductions and increases in the volume of the oceans. Global changes may be reconstructed only at rare tectonically stable areas such as Bermuda or the Bahamas,[74] while the remaining factors must be taken into account in tectonically active areas, such as the Croatian coast.[75]

Regional and local tectonics in a given area, which may cause either uplift or subsidence of land, exert a considerable influence relative sea-level changes.[76] Shifts of smaller proportions on the Earth's crust are caused by phenomena such as earthquakes or volcanic activity. The remains of the Roman city of Baiae near Naples in southern Italy,[77] which have been transformed into the modern submerged archaeological park known as *Baia sommersa*, are a lucid example of terrain sunken by volcanic activity.

The third factor influencing relative sea-level changes is called isostasy, which denotes the state of equilibrium that parts of the lithospheric plates attempt to achieve by 'floating' on the viscous mantle. This phenomenon is interpreted by the fact that the mantle below the lithosphere is fluid in nature and that under specific circumstances it changes its shape.

71 Surić 2009, p. 182, cit. Coe, Church 2005.

72 Surić 2009, p. 182.

73 Lambeck, Chappell 2001.

74 Surić 2009, p. 182.

75 Prelogović *et al.* 2003.

76 A brief overview of examples and the relevant literature in Lambeck *et al.* 2010, p. 65.

77 Parascandola 1947; Morhange *et al.* 1999; Morhange *et al.* 2006.

uglavnom su uzrokovane periodičkim nastankom i otapanjem ledenih pokrova,[73] tj. smanjivanjem i povećanjem volumena oceana. Globalne promjene moguće je rekonstruirati samo na rijetkim tektonski stabilnim područjima poput Bermuda ili Bahama,[74] dok je na tektonski aktivnim prostorima, poput hrvatske obale,[75] neophodno uzeti u obzir i ostale čimbenike.

Na relativnu promjenu morske razine znatno utječe regionalna i lokalna tektonika određenog područja, koja može izazvati kako izdizanje, tako i spuštanje kopna.[76] Pomaci zemljine kore manjih razmjera uzrokovani su pojavama poput potresa ili vulkanske aktivnosti. Ostatci rimskoga grada Baiae kod Napulja u južnoj Italiji,[77] koji su danas pretvoreni u podmorski arheološki park poznat pod imenom *Baia sommersa*, zoran su primjer spuštanja kopna izazvanog vulkanskom aktivnošću.

Treći čimbenik koji utječe na relativnu promjenu morske razine naziva se izostazija, a označava stanje ravnoteže koju dijelovi litosfernih ploča nastoje postići 'plutajući' na viskoznom plaštu. Pojava se tumači činjenicom da je plašt koji se nalazi pod litosferom fluidne prirode te da u određenim uvjetima mijenja svoj oblik. Kora, opterećena ledenim pokrivačem, pritišće plašt i udubljuje ga, što izaziva njegovo uzdizanje, a time i uzdizanje zemljine kore na mjestu gdje pritiska nema. Veće ili manje izdizanje uzrokovano je razlikama u udaljenosti od mjesta gdje je pritisak najveći. S nestankom pritiska, tj. otapanjem leda, plašt se ponovo vraća u prethodno stanje, što uzrokuje i pokrete kore u obrnutom smjeru (glacioizostazija). Tim se vertikalnim kretanjima pribraja i kretanje izazvano težinom vode koja pritišće morsko dno. Povećanjem volumena oceana vodeni stup sve jače pritišće i potiskuje morsko dno, što se također odražava u relativnom odnosu mora i kopna (hidroizostazija). Svi su ti procesi daleko složeniji, no već i jednostavno objašnjenje pokazuje koliko je zahtjevno izračunavanje promjena morske razine.

Naime, relativne promjene morske razine zbroj su eustatskih, tektonskih i glacio-hidro-izostatskih čimbenika i, shodno tome, posljedice su globalnih, regionalnih i lokalnih pojava. U njima su sadržani podatci o pomicanju kopna, redistribuciji masa, tj. geoidnim promjenama te promjenama u volumenu i distribuciji

73 Lambeck, Chappell 2001.

74 Surić 2009, str. 182.

75 Prelogović *et al.* 2003.

76 Kratak pregled primjera i literature u Lambeck *et al.* 2010, str. 65.

77 Parascandola 1947, Morhange *et al.* 1999; Morhange *et al.* 2006.

The crust, burdened by ice sheets, presses down on the mantle and deepens it, which in turn causes it to lift, thereby leading to upthrusts in the Earth's crust at places where there is no pressure. Greater or lesser vertical movements are caused by differences in the distance from the point at which the pressure is the highest. When the pressure disappears, i.e., when the ice thaws, the mantle returns to its previous state, which causes movement of the crust in the opposite direction (glacio-isostasy). Movements caused by the load of water pressing on the seafloor are included in these vertical movements. Increases in the volume of the oceans means that the water column increasingly presses and pushes against the seafloor, which is also reflected in the relative relationship between land and sea (hydro-isostasy). All of these processes are far more complex, but even a simple explanation demonstrates how demanding the calculation of sea-level change can be.

Namely, relative sea-level changes are the sum of eustatic, tectonic and glacio-hydro-isostatic factors and, consequently, a consequence of global, regional and local phenomena. They contain within them data on movement of the land, redistribution of mass, i.e., geoid changes, and changes in the volume and distribution of water in the oceans.[78] Each tectonically active area is treated as a separate whole, and a comparison of tectonically stable areas is used to calculate the impact of local and regional factors.

Modelling of the Earth's isostatic reactions to the redistribution of surface loads is an attempt to solve the complex problems of isostatic changes,[79] taking into account the morphology of coasts and the expanse of lithospheric plates. It does not, however, encompass local influences, such as, for example, local tectonics, settlement of layers, river deposits or human influences. If the models prove functional on tectonically stable areas, then the deviations in tectonically active areas are interpreted as the differences caused by one of the aforementioned local factors or the action of several of them. Models adapted to the Mediterranean area, which take also into account the ice cover of the Alps, were compiled by Kurt Lambeck and associates,[80] and models by other authors are also in use.[81]

78 Lambeck *et al.* 2010, pp. 66-67.

79 Lambeck *et al.* 2010, pp. 84-88.

80 Lambeck, Purcell 2005; Lambeck *et al.* 2006.

81 Spada, Stocchi 2006; Stochi, Spada 2007; Stochi, Spada 2009; Peltier 2001; Peltier 2004.

Sl. 9. Drvene priobalne konstrukcije u uvali Caski na Pagu (foto: Ph. Grosscaux)
Fig. 9. Wooden near-shore structure in Caska Cove on the island of Pag (photo: Ph. Grosscaux)

voda u oceanima.[78] Svako se tektonski aktivno područje tretira kao zasebna cjelina, a usporedbom s tektonski stabilnim prostorima izračunava se utjecaj lokalnih ili regionalnih čimbenika.

Složena problematika izostatskih promjena nastoji se riješiti geofizičkim modeliranjem izostatske reakcije Zemlje na redistribuciju površinskih opterećenja,[79] uzimajući u obzir morfologiju obale i prostranost litosfernih ploča. U njemu, međutim, nisu sadržani lokalni utjecaji, poput npr. lokalne tektonike, slijeganja slojeva, nanosa rijeka ili utjecaja čovjeka. Ako se na tektonski stabilnim područjima modeli pokažu funkcionalnima, tada se odstupanja na tektonski aktivnim područjima tumače kao razlika izazvana jednim od navedenih lokalnih čimbenika ili djelovanjem nekoliko njih. Modele prilagođene mediteranskom prostoru, koji uzimaju u obzir i ledeni pokrov Alpa, izradili su Kurt Lambeck i suradnici,[80] a u uporabi su i modeli drugih autora.[81]

4. Ograničenja arheoloških indikatora promjena morske razine

Arheološki nalazi, iako očiti dokazi nastalih promjena, prilično su ograničeni u funkciji indikatora morske razine.[82] Za nalaze iz prve skupine (građevine koje su se originalno nalazile na kopnu) najčešće je nemoguće odrediti na kojoj su se nadmorskoj visini originalno nalazili (i zato ih se ne bi smjelo koristiti

78 Lambeck *et al.* 2010, str. 66-67.
79 Lambeck *et al.* 2010, str. 84-88.
80 Lambeck, Purcell 2005; Lambeck *et al.* 2006.
81 Spada, Stocchi 2006; Stocchi, Spada 2007; Stocchi, Spada 2009; Peltier 2001; Peltier 2004.
82 Auriemma, Solinas 2009.

4. Limitations of archaeological indicators of sea-level change

Archaeological finds, although obvious evidence of changes, are rather limited as indicators of sea-level change.[82] In the case of finds from the first group (buildings that were originally on dry land), it is most often impossible to ascertain the height above sea level at which they were originally situated (and this is why they should not be used to reconstruct sea-level change), while in the case of the submerged structures from the second group it is difficult to provide a conceptual reconstruction up to their original height or determine the depth at which their foundations had originally been laid. Therefore, the most suitable elements are those which we know were situated at roughly the average sea level, such as certain functional sections of fish nurseries[83] or fish traps that made use of tidal ebbs and flows.

An interesting group of submerged archaeological artefacts certainly includes the structures made of organic material, mostly wood, which have been preserved on muddy and sandy beds (Fig. 9). Wooden posts and poles that formerly bore small wooden docks or similar functional seaside structures are often only preserved in their lower sections, so they cannot be used for more precise measurements. On the other hand, in the case of structures made of boards and pylons, assumed to be the remains of former salt pans, it is easier to ascertain the possible original height and use them as indicators of sea levels (Fig. 10).

Reconstruction of the former coastal belt necessitates a rather cautious interpretation and dating of archaeological finds, because any error will be negatively reflected in the final conclusion. In the case of archaeological, and even more so submerged, heritage, every uncertainty or insufficiently precise date should be particularly underscored. This limits the quantity of available data, but also increases the reliability of those that are used in further considerations.[84] In any case, archaeological indicators will be more reliable sources of data insofar as they meet the following criteria:[85]

1) archaeological indicators were scrupulously selected with due consideration of their original purpose, the possibility of precise dating and an estimate of their original functional height in relation to the sea level;

82 Auriemma, Solinas 2009.
83 Lambeck *et al.* 2004a, pp. 564-567.
84 For an example of insufficiently critical use of archaeological data, cf. Šegota, Filipčić 1991.
85 Auriemma, Solinas 2009.

pri rekonstrukciji promjena morske razine), dok je za preplavljene objekte iz druge skupine teško ponuditi idejnu rekonstrukciju do njihove originalne visine ili odrediti na kojoj su dubini originalno temeljeni. Najpogodniji su stoga elementi za koje znamo da su se nalazili na prosječnoj morskoj razini, poput određenih funkcionalnih dijelova ribnjaka[83] ili ribolovnih zamki koje koriste morske mijene.

Zanimljiva skupinu podmorskih arheoloških svjedočanstava svakako su konstrukcije izrađene od organskog materijala, pretežito drva, koje su se očuvale na muljevitim i pjeskovitim terenima (sl. 9). Drveni kolci i stupovi koji su nekad nosili mala drvena pristaništa ili slične priobalne funkcionalne strukture najčešće su se očuvali samo u donjem dijelu, pa nam ne mogu poslužiti za preciznija mjerenja. S druge strane, za konstrukcije izrađene od dasaka i pilona, za koje se pretpostavlja da su ostatci nekadašnjih solana, lakše je odrediti moguću originalnu visinu i iskoristiti ih u funkciji indikatora morske razine (sl. 10).

Pri rekonstrukciji nekadašnjeg obalnog pojasa potrebno je pristupiti vrlo oprezno interpretiranju i datiranju arheoloških nalaza, jer će se svaka pogreška negativno odraziti u konačnom zaključku. U slučaju arheološke, pa k tome još i podmorske baštine, pri objavi nalaza svaku nesigurnost ili nedovoljno precizan podatak valja posebno istaknuti. Time se ograničava količina dostupnih podataka, ali i povećava vjerodostojnost onih koji se koriste u daljnjim razmatranjima.[84] U svakom slučaju, arheološki će indikatori biti vjerodostojniji izvori podataka ukoliko što bolje zadovoljimo sljedeće kriterije:[85]

1) pozoran odabir arheoloških indikatora s obzirom na njihovu originalnu svrhu, mogućnost preciznog datiranja te procjene njihove originalne funkcionalne visine u odnosu na morsku razinu;

2) precizno mjerenje popraćeno korekcijom i evaluacijom dobivenih rezultata uz pomoć posebne metodologije, popraćeno interdisciplinarnom arheološko-geomorfološko-geofizičkom interpretacijom.

5. Mjerenje dubine na kojoj leže arheološki nalazi

Geodetska nula koristi se za mjerenje visina na kopnu. Do 2004. u službenoj je uporabi bila *Normalna nula Trsta* (*NN Trsta*), koja se na nekim mjestima nalazila iznad, a na nekima ispod tzv. *hidrografske nule.*

83 Lambeck *et al.* 2004b, str. 564-567.

84 Kao primjer nedovoljno kritičkog korištenja arheoloških podataka usp. Šegota, Filipčić 1991.

85 Auriemma, Solinas 2009.

Sl. 10. Pretpostavljeni ostatci solana u pakoštanskoj luci (foto: K. Zubčić)
Fig. 10. Assumed remains of a salt pan in the harbour at Pakoštane (photo: K. Zubčić)

2) precise measurements were made, accompanied by the correction and evaluation of results obtained with the help of a special methodology and by an interdisciplinary archaeological-geomorphological-geophysical interpretation.

5. Measurement of depths at which archaeological finds rest

The *geodetic zero* is used to measure elevations on land. Until 2004, the *old geodetic zero* (known as *Normalna nula Trsta*, NNT, in Croatia), which was at places located above and at others below the so-called *hydrographic zero*.

The *hydrographic zero* is used to measure depths, and it has been defined as the mean level of the lowest astronomical tides on the mareographs in Dubrovnik, Split, Bakar, Rovinj and Kopar in the 1971.5 epoch.[86]

According to the Decision on Establishment of Official Geodetic Data and Planar Cartographic Projections of the Republic of Croatia,[87] the *geodetic zero* has been defined as the mean sea level on the mareographs in Dubrovnik, Split, Bakar, Rovinj and Kopar in the 1971.5 epoch.[88] Due to sea-level change it does not correspond to the present *mareographic zero*, i.e., the mean sea-level recorded on the nearest mareograph.[89]

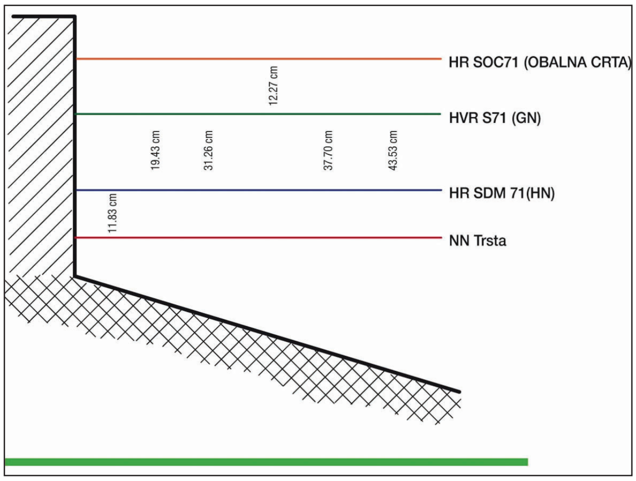
In order to foster a better understanding of this problem, Fig. 11 shows the interrelationship between

86 Duplančić Leder, Leder 2010, p. 122.

87 *Narodne novine* 110/2004.

88 Duplančić Leder, Leder 2010, p. 122.

89 Duplančić Leder, Leder 2010, p. 124.



Sl. 11. Shematski prikaz relativnih odnosa između obalne crte (HR SOC71), geodetske nule (HVR S71), hidrografske nule (HR SDM 71) i Normalne nule Trsta za područje Splita (prema: Duplančić Leder, Leder 2010)
Fig. 11. Schematic of the relative interrelationship between the coastline (HR SOC71), the geodetic zero (HVR S71), hydrographic zero (HR SDM 71) and old geodetic zero for the territory of Split (based on: Duplančić Leder, Leder 2010)

Hidrografska nula koristi se za mjerenje dubina, a određena je srednjom razinom nižih niskih voda živih morskih mijena na mareografima u Dubrovniku, Splitu, Bakru, Rovinju i Kopru u epohi 1971.5.[86]

Prema "Odluci o utvrđivanju službenih geodetskih datuma i ravninskih kartografskih projekcija Republike Hrvatske"[87] *geodetska nula* određena je srednjom razinom mora na mareografima u Dubrovniku, Splitu, Bakru, Rovinju i Kopru u epohi 1971.5.[88] Zbog promjena morske razine ona se ne poklapa s današnjom *mareografskom nulom*, tj. srednjom razinom mora zabilježenom na najbližem mareografu.[89]

Radi boljeg razumijevanja opisane problematike, na sl. 11 prikazan je međuodnos opisanih nula, tj. *Normalne nule Trsta*, važeće *hidrografske* i *geodetske nule* u splitskoj luci i današnje obalne crte.

Neovisno o činjenici započinjemo li istraživanje usmjereno isključivo na arheološku baštinu ili složeni interdisciplinarni projekt, mjere kojima mjerimo dubinu arheoloških nalaza *in situ*, a naročito onih koji se mogu smatrati koliko-toliko pouzdanim indikatorima morske razine, neophodno je uzimati s najvećom preciznošću. Drugim riječima, osim točne dubine na kojoj leže određeni nalazi ili njihovi indikativni dijelovi, the described zeroes, i.e. the *old geodetic zero* and the valid *hydrographic* and *geodetic zero* in the harbor in Split and the current coastline.

Regardless of whether we embark upon research with an exclusive focus on the archaeological heritage or a complex interdisciplinary project, the measurements used to determine the depth of *in situ* archaeological finds, and especially those which may be deemed more-or-less reliable indicators of sea-level change, it is essential that they be taken into account with the utmost precision. In other words, besides the precise depth at which given finds or indicative parts thereof rest, it is essential to specify the date and time of measurement, so that their real depth in comparison to the sea level may be ascertained immediately or at some secondary time. This is accomplished by corrections with the help of data from the nearest mareograph and alignment with the values for air pressure at the time of measurement.[90] For the needs of precise measurement, the *mareographic zero* is used first and foremost.

Another way is used to determine the mean sea level. This is the *biological zero* which is actually the upper limit reached by so-called sub-tidal populations and the point at which eulittoral populations begin to appear.[91]

6. Dynamics of sea-level change after the Last Glacial Maximum

One of the accepted curves of sea-level change during the course of the last glacial cycle is a result of Lambeck's sea-level change model.[92] The assumption is that during the last interglacial period roughly 125,000 years ago, the sea level was very similar to today's, and even several meters higher. After a slight decline during a period of 10,000 years, this was followed by a series of oscillations in levels which ranged from 20 to 75 meters less than today's level. According to current knowledge, the lowest sea level occurred at the time of the Last Glacial Maximum (LGM) roughly 26,000 years ago,[93] when the sea level dropped as low as -135 m, due to the high quantity of water trapped in glaciers. The global thaw of the ice sheets, which began about 19,000 years ago, spurred a rapid and uneven rise in sea levels until roughly 7,000 years ago,[94] i.e., in archaeological terms, up to

86 Duplančić Leder, Leder 2010, str. 122.
87 *Narodne novine* 110/2004.
88 Duplančić Leder, Leder 2010, str. 122.
89 Duplančić Leder, Leder 2010, str. 124.

90 Auriemma, Solinas 2009.
91 Laborel, Laborel-Deguen 1995.
92 Lambeck *et al.* 2010, pp. 66-67, Fig. 4. 2 b.
93 Peltier, Fairbanks 2006; Surić 2009, p. 182.
94 Lambeck, Chappell 2001. On changes on the eastern coast of the Adriatic based on measurements of the age

obavezno je označiti datum i sat mjerenja, kako bi se odmah ili u nekom sekundarnom času mogla utvrditi njihova realna dubina u odnosu na morsku razinu. To se postiže korekcijama uz pomoć podataka iz najbližeg mareografa i usklađivanjem s vrijednostima za tlak zraka u trenutku mjerenja.[90] Za potrebe preciznog mjerenja koristimo se prije svega *mareografskom nulom*.

Još jedan način koristi se za određivanje srednje morske razine. Riječ je o *biološkoj nuli* koja je zapravo gornja granica do koje dosežu tzv. subtajdalne populacije i počinju se pojavljivati mediolitoralne.[91]

6. Dinamika promjena morske razine nakon posljednjega glacijalnog maksimuma

Jedna od prihvaćenih krivulja promjene morske razine tijekom posljednjega glacijalnog ciklusa rezultat je Lambeckova modela promjene morske razine.[92] Pretpostavka je da je tijekom posljednjeg interglacijala prije oko 125 000 godina razina mora bila vrlo slična današnjoj, pa čak i nekoliko metara viša. Nakon laganog opadanja tijekom razdoblja od 10 000 godina uslijedio je niz oscilacija na razinama koje su od 20 do 75 m niže od današnje razine. Prema sadašnjim spoznajama najniža razina mora dogodila se u vrijeme posljednjeg glacijalnog maksimuma (engl. *Last Glacial Maximum - LGM*) prije otprilike 26 000 godina,[93] kad se morska razina spustila na čak -135 m, zbog velike količine vode zarobljene u ledenjacima. Globalno otapanje ledenog pokrova, koje je započelo prije oko 19 000 godina, izazvalo je brz i neujednačen porast morske razine do prije otprilike 7000 godina,[94] tj., arheološki gledano, do vremena prijelaza iz srednjeg u kasni neolitik. U posljednje vrijeme sve je više dokaza da se prije 7600 godina dogodilo naglo podizanje morske razine od oko 5 m.[95]

Kao što nam arheološka baština zorno pokazuje, podizanje morske razine nastavilo se tijekom narednih tisućljeća, ali znatno sporije negoli ranije. Dugo godina među arheolozima uvriježeno tumačenje kako je riječ o promjeni od 1 mm godišnje, danas više ne možemo prihvatiti.[96]

90 Auriemma, Solinas 2009.

91 Laborel, Laborel-Deguen 1995.

92 Lambeck *et al.* 2010, str. 66-67, sl. 4. 2 b.

93 Peltier, Fairbanks 2006; Surić 2009, str. 182.

94 Lambeck, Chappell 2001. O promjenama na istočnoj obali Jadrana na osnovi mjerenja starosti slojeva u sigama iz preplavljenih špilja, Surić 2006. Pregledan grafički prikaz u Benjamin *et al.* 2017, str. 42, sl. 7.

95 Lambeck *et al.* 2010, str. 66, gdje je navedena i relevantna literatura.

96 Surić 2009, str. 186.

the time of the middle and late Neolithic. Recently there has been increasing evidence that a sudden rise in the sea level of approximately 5 m occurred 7,600 years ago.[95]

As lucidly demonstrated by the archaeological heritage, sea-level rise continued during the subsequent millennia, but considerably slower than before. The interpretation that there was an annual change of 1 mm, accepted among archaeologists for many years, can no longer be accepted today.[96]

In the latter half of the 20th century, instruments have recorded a rising global sea level of ~1,8±0,3 mm/yr.,[97] while on the basis of approximately 2,000 year-old archaeological indicators along the tectonically stable Tyrrhenian coast of Italy, during the period which transpired since the Roman early imperial era, a total eustatic change of ~0,13±0,09 m has been calculated.[98] For the central Mediterranean, the impact of glacio-hydro-isostatic factors after the post-glacial stabilization of sea level has been estimated at 0.2-0.8 mm/yr. The values vary from north to south, and they correspond to the sum of glacio-isostatic and hyrdo-isostatic components.[99]

Stated simply, over a period of 2,000 years, we could expect an isostatic change in the sea level of 0.4 to 1.6 m in the central Mediterranean, depending on the geographic position of a specific location (Fig. 12). Adding to it the recorded eustatic change of 0.13 m and subtracting the number so obtained from the real sea-level change measured on the basis of geological, biological and/or archaeological indicators, we obtain a sum which indicates the share of local tectonics. In this manner, using a combination of sea-level models and indicators, we will be able to propose a conceptual reconstruction of the former coast and coastline.

7. Concluding remarks

A brief overview of the study of sea-level change based on archaeological and geomorphological markers is only the first step toward an understanding of the complexity of this problem, which has not been

of layers on stalactites from submerged caves, Surić 2006. Overview chart in Benjamin *et al.* 2017, p. 42, fig. 7.

95 Lambeck *et al.* 2010, p. 66, in which the relevant literature is also cited.

96 Surić 2009, p. 186.

97 Church *et al.* 2004; Surić 2009, p. 183. Such changes are attributed to global warming.

98 Lambeck *et al.* 2004.

99 Lambeck, Johnston 1995; Lambeck, Bard 2000; Lambeck *et al.* 2004a.

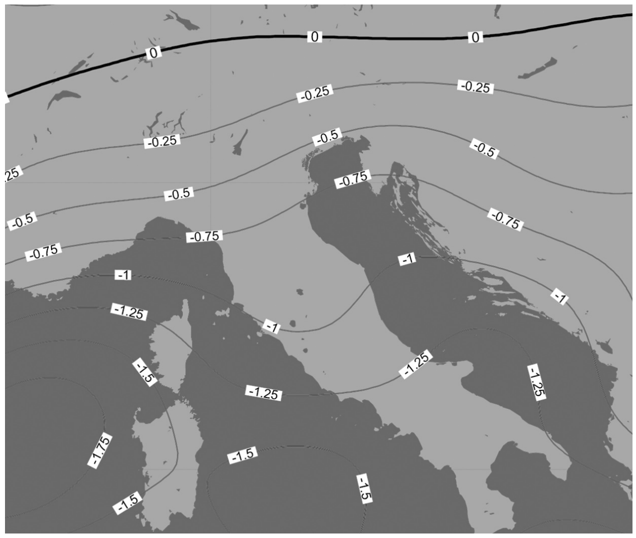
U drugoj polovici 20. stoljeća instrumentima je zabilježen porast globalne morske razine od ~1,8 ± 0,3 mm/god.,[97] dok je na osnovi arheoloških indikatora starih oko 2000 godina duž tektonski stabilne tirenske obale Italije, za razdoblje koje je proteklo od rimskog ranocarskog vremena izračunata sveukupna eustatska promjena od ~0,13 ± 0,09 m.[98] Za središnji Mediteran učinak glacio-hidro-izostatskih čimbenika nakon postglacijalne stabilizacije morske razine procijenjen je na 0,2 - 0,8 mm/god. Vrijednosti variraju od sjevera prema jugu, a odgovaraju zbroju glacio-izostatskih i hidro-izostatskih komponenti.[99]

Pojednostavnjeno rečeno, za razdoblje od 2000 godina u srednjem bismo Mediteranu mogli očekivati izostatsku promjenu morske razine od 0,4 do 1,6 m, ovisno o geografskom položaju određenog mjesta (sl. 12). Pribrajajući joj zabilježenu eustatsku promjenu od 0,13 m i odbijajući dobiveni broj od stvarne promjene morske razine izmjerene na osnovi geoloških, bioloških i/ili arheoloških indikatora, dobit ćemo iznos koji označuje udio lokalne tektonike. Na taj ćemo način, koristeći kombinaciju modela i indikatora morske razine, biti u mogućnosti predložiti idejnu rekonstrukciju nekadašnje obale i obalne crte.

7. Zaključne napomene

Kratak prikaz proučavanja promjena morske razine na osnovi arheoloških i geomorfoloških markera samo je prvi korak prema razumijevanju složenosti te problematike kojoj se dugi niz godina u hrvatskoj arheologiji nije posvećivala odgovarajuća pozornost. Brojne nove spoznaje iz područja prirodnih znanosti, metodologija rada i tehnička oprema toliko su uznapredovale da se bez multidisciplinarnoga i interdisciplinarnog istraživanja teško može zamisliti kvalitetan projekt koji će dovesti do zadovoljavajućih rezultata. Ipak, kao što je rečeno, još uvijek se događa da se arheološka istraživanja u priobalju nedovoljno bave problematikom prirodne preobrazbe obalnog krajolika tijekom vremena, što se ponekad odražava na kvalitetu interpretacije arheoloških zapisa i nedostatak referentnih podataka.

Za razliku od za sada malobrojnih tragova ljudskih naselja koji leže na većim dubinama, brojna nalazišta u priobalju u većini su slučajeva kompleksni kulturni krajolici koji zaslužuju pozornost ne samo kao izvori arheoloških podataka nego i podataka o nekadašnjoj



Sl. 12. Paleogeografska rekonstrukcija morske razine u sjevernom dijelu središnjeg Mediterana prije 2000 godina; navedene vrijednosti odnose se na pretpostavljene promjene morske razine. Odstupanja od navedenih vrijednosti tumače se utjecajem lokalne tektonike (prema: Lambeck et al. *2004a)*
Fig. 12. Palaeogeographic reconstruction of the sea level in the northern part of the central Mediterranean 2,000 years ago; the indicated values pertain to assumed sea-level change. Deviations from these values are interpreted by the influence of local tectonics (based on: Lambeck et al. *2004a)*

accorded adequate attention in Croatian archaeology for many years. Many new discoveries in the natural sciences, as well as new methodologies and technologies, have advanced to such a degree that it is difficult to even conceive of a quality project that will yield satisfactory results without multidisciplinary and interdisciplinary research. Even so, as stated, archaeological research on the coastal belt is still conducted without sufficient consideration of the problem of the natural transformations in the landscape over time, which is sometimes reflected in the quality of interpretations of archaeological records and the absence of referential data.

As opposed to the thus far few traces of human settlements lying at greater depths, numerous sites in the coastal belt are in most cases complex cultural landscapes which merit attention not only as sources of archaeological data, but also data on the past morphology of the coast, on the composition, density and distribution of vegetation and on processes of adaptation of the landscape to the needs of local populations. Such perceptions of submerged sites in shallow seas have still not taken root in the Croatian archaeological sciences, but the first attempts, which accompanied research into marine vessel structures in

97 Church *et al.* 2004; Surić 2009, str. 183. Takva promjena pripisuje se globalnom zatopljenju.

98 Lambeck *et al.* 2004a.

99 Lambeck, Johnston 1995; Lambeck, Bard 2000; Lambeck *et al.* 2004b.

morfologiji obale, sastavu, gustoći i rasprostranjenosti vegetacije te procesima prilagodbe krajolika potrebama lokalnog stanovništva. Takva percepcija podmorskih nalazišta u plitkome moru još se nije uvriježila u hrvatskoj arheološkoj znanosti, ali su prvi pokušaji, koji su na području Pakoštana[100] i Caske[101] pratili istraživanja brodskih konstrukcija, dali odlične rezultate. Zanimljivim rezultatima u pogledu rekonstrukcije paleokrajolika ističe se i spomenuto nalazište u Vranjicu na istočnom kraju Kaštelanskoga zaljeva, koje je, osim toga, pokazalo kakvo se obilje informacija krije pod betonskim obalama suvremenih naselja.[102] U posljednje se vrijeme s ciljem detaljne rekonstrukcije paleokrajolika istražuje i nalazište u uvali Zambratija u Istri.[103]

Zanimljivost, kompleksnost i izazovnost teme te izravna veza s morem i pomorstvom čine ovaj rad prikladnim poklonom dragom kolegi i prijatelju Branku Kiriginu u povodu njegove 70. obljetnice života. Aktivan terenski rad u međunarodnim interdisciplinarnim timovima koji su sustavno istraživali otoke srednje Dalmacije, kao i mnogi pisani tragovi odlično obavljenoga posla, učinili su Branka Kirigina uzorom mladim istraživačima i primjerom promicanja novih metoda, tehnika i ideja u istraživačkom radu. Upravo na tragu te sustavnosti, interdisciplinarnosti i otvorenosti prema novim znanstvenim i tehničkim postignućima trebalo bi se razvijati i proučavanje promjena morske razine te morem preplavljenih prirodnih i kulturnih krajolika. Branko Kirigin za tu je problematiku iskazao iznimno zanimanje, a u trenutku finaliziranja doktorskog rada pružio mi prijeko potrebnu podršku, na čemu mu ovim radom od srca zahvaljujem.

100 Radić Rossi, Antonioli 2008; Antonioli *et al.* 2017.
101 Radić Rossi, Boetto 2012.
102 Radić Rossi 2007; Radić Rossi 2008.
103 Benjamin *et al.* 2011; Benjamin *et al.* 2017, str. 44.

the areas of Pakoštane[100] and Caska,[101] have yielded outstanding results. The aforementioned site in Vranjic on the eastern end of Kaštela Bay also stands out with intriguing results in the sense of reconstruction of the palaeolandscape, and it has additionally demonstrated the wealth of information concealed under the concrete beaches of modern settlements.[102] More recently, research has proceeded at the site in Zambratija Cove in Istria with the aim of a more detailed reconstruction of the palaeolandscape.[103]

The intriguing, complex and challenging nature of this topic and its direct tie to the sea and seafaring make this work a suitable gift to my dear friend and colleague Branko Kirigin on this 70th anniversary of this life. Active field work in international interdisciplinary teams that have systematically researched the islands of central Dalmatia, as well as abundant written evidence of a job well done, have made Branko Kirigin a model for young researchers and an exemplar of someone who promotes new methods, techniques and ideas in research work. It is precisely on this same path of systematic and interdisciplinary work and openness to new scientific and technological achievements that the study of sea-level changes and submerged natural and cultural landscapes should develop. Branko Kirigin demonstrated an exceptional interest in this set of problems, and when work on my doctoral dissertation was in its final stages he offered me much-needed support, for which I thank him by means of this paper.

100 Radić Rossi, Antonioli 2008; Antonioli *et al.* 2017.
101 Radić Rossi, Boetto 2012.
102 Radić Rossi 2007; Radić Rossi 2008.
103 Benjamin *et al.* 2011; Benjamin *et al.* 2017, p. 44.

LITERATURA / BIBLIOGRAPHY

Alfirević 1965 — S. Alfirević, *Geologija Jadrana*, Matica hrvatska Split, Split 1965.

Andrijašević 1910 — N. Andrijašević, *O vertikalnom pomicanju obalne crte u historičko doba na sjevero-istoku jadranskoga mora,* (Doktorska disertacija, odobrena od Filozofskoga fakulteta hr. sveučilišta Franje Josipa I. u Zagrebu), Supplemento al Bulletino di archeologia e storia dalmata 33, Split 1910, 1-45.

Antonioli *et al.* 2017 (in print) — F. Antonioli, I. Radić Rossi, K. Zubčić, *Promjene morske razine i obalne crte na pakoštanskom prostoru tijekom posljednjih šest tisućljeća*, in: Projekt Pakoštane, Kanoantički brodolom kod otočića Velog školja u geološko-geografskom i kulturno-povijesnom kontekstu / The Pakoštane Project, Late Roman shipwreck near the islet Veli školj in the geological, geographical, cultural and historical context, [Arheologija jadranske plovidbe i brodogradnje / Archaeology of Adriatic Shipbuilding and Seafaring], I. Radić Rossi, G. Boetto (eds.), Sveučilište u Zadru, Zadar 2017 (in print).

Auriemma, Solinas 2009 — R. Auriemma, R., E. Solinas, *Archaeological remains as sea level change markers, A review*, Quaternary International 206.1-2, 2009, 134-146.

Barić *et al.* 2008 — A. Barić, B. Grbec, D. Bogner, *Potential Implications of Sea-Level Rise for Croatia*, Journal of Coastal Research 24.2, 2008, 299-305.

Baučić 1967 — I. Baučić, *Cetina - razvoj reljefa i cirkulacije vode u kršu*, Radovi Geografskog instituta Sveučilišta u Zagrebu 6, Zagreb 1967, 1-161.

Belij 1985 — S. Belij, *Glacijalni i periglacijalni reljef južnog Velebita*, [Posebna izdanja Srpskog geografskog društva 61], Beograd 1985.

Benac 1996a — Č. Benac, *Morfološka evolucija Riječkog zaljeva, utjecaj klimatskih i glacioeustatičkih promjena*, Acta Geografica Coatica 31, Zagreb 1996, 69-84.

Benac 1996b — Č. Benac, *Rast morske razine i promjene reljefa na obalama Kvarnera*, Pomorski zbornik 34, Rijeka 1996, 345-359.

Benac, Juračić 1998 — Č. Benac, M. Juračić, *Geomorphological Indicators of Sea Level Changes during Upper Pleistocene (Würm) and Holocene in the Kvarner Region (NE Adriatic Sea)*, Acta Geographica Croatica 33, Zagreb 1998, 27-45.

Benac, Šegota 1990 — Č. Benac, T. Šegota, *Potopljena ris-virmska abrazijska terasa u podmorju ispred Rijeke*, Geološki vjesnik 43, Zagreb 1990, 43-52.

Benac *et al.* 2004 — Č. Benac, M. Juračić, T. Bakran-Petricoli, *Submerged tidal notches in the Rijeka Bay NE Adriatic Sea, indicators of relative sea-level change and of recent tectonic movements*, Marine Geology 212, Amsterdam 2004, 21-33.

Benac *et al.* 2008 — Č. Benac, M. Juračić, I. Blašković, *Tidal notches in Vinodol Channel and Bakar Bay, NE Adriatic Sea, Indicators of recent tectonics*, Marine Geology 248, Amsterdam 2008, 151-160.

Benussi 1928 — B. Benussi, *Dalla annotazione di Alberto Puschi per la carta archeologica dell'Istria*, Archeografo Triestino 14, Trieste 1928, 249-250.

Benjamin, Bonsall 2009 — J. Benjamin, C. Bonsall, *A Feasibility Study for the Investigation of Submerged Sites along the Coast of Slovenia*, The International Journal of Nautical Archaeology 38.1, 2009, 163-172.

Benjamin, Črešnar 2009 — J. Benjamin, M. Črešnar, *Submerged prehistoric site discovery and a proposed application in the Croatian Adriatic*, in, *Jurišićev zbornik*, Hrvatski restaruatorski zavod–Međunarodni centar za podvodnu arheologiju u Zadru, Zagreb 2009, 52-67.

Benjamin *et al.* 2011 — J. Benjamin, L. Bekić, L., D. Komšo, I. Koncani Uhač, C. Bonsall, *Investigating the Submerged Prehistory of the Eastern Adriatic, progress and prospects*, in, *Submerged Prehistory,* J. Benjamin, C. Bonsall, C. Pickard, A. Fischer (eds.) Oxbow, Oxford 2011, 193-206.

Benjamin *et al.* 2017 — J. Benjamin, A. Rovere, A. Fontana, S. Furlani, M. Vacchi, R. H. Inglis, E. Galili, F. antonioli, D. Sivan, S. Miko, N. Mourtzas, I. Felja, M. Meredith-Williams, B. Goodman-Tchernov, E. Kolaiti, M. Anzidei, R. Gehrels, *Late Quaternary sea-level changes and early human societies in the central and eastern Mediterranean*

	Basin, An interdisciplinary review, Quaternary International 449, Amsterdam 2017, 29-57.
Boetto *et al.* 2012	G. Boetto, I. Radić Rossi, S. Marlier, Z. Brusić, *L'épave de Pakoštane, Croatie (fin IVe – début Ve siècle apr. J.-C.). Résultats d'un projet de recherche franco-croate*, Archaeonautica 17, Paris 2012, 105-151.
Brusić 2007	Z. Brusić, *Pakoštanska luka i druga priobalna liburnska naselja u Pašmanskom kanalu u odnosu na gradinska naselja u zaleđu i Aseriju*, Asseria 5, Zadar 2007, 11-38.
Bulić 1899	F. Bulić, *Tre sarcofaghi romani nel villaggio di Vranjic (Urania?) sotto il livello del mare*, Bulletino di archeologia e storia dalmata 22, Spalato 1899, 105-111.
Bulić 1900	F. Bulić, *Ritrovamenti risguardanti i sarcofaghi romani sotto il livello del mare nel villaggio di Vranjic presso Salona*, Bulletino di archeologia e storia dalmata 23, Spalato 1900, 141-142.
Bulić 1913	F. Bulić, *Notizie storiche sul villaggio Vranjic vicino Salona*, Bulletino di archeologia e storia dalmata 36, Spalato 1913, 24-37.
Burton *et al.* 1878	R. F. Burton, A. Scampicchio, A. Covaz, *More Castellieri*, The Journal of the Anthropological Institute of Great Britain and Ireland 7, London 1878, 341-363.
Caputo, Pieri 1976	M. Caputo, L. Pieri, *Eustatic variation in the last 2000 years in the Mediterranean*, Journal of Geophysical Research 81, 1976, 5787-5790.
Church *et al.* 2004	J. A. Church, N. J. White, R. Coleman, K. Lambeck, J. X. Mitrovica, *Estimates of the regional distribution of sea level rise over the 1950-2000 period*, Journal of Climate 17 (13), 2004, 2609-2625.
Coe, Church 2005	A. L. Coe, K. D. Church, *Sea-level change*, in: The Sedimentary Record of Sea-Level Change, A. L. Coe (ed.), Cambridge University Press, Cambridge 2005, 34-55.
Degrassi 1954	A. Degrassi, *I porti romani dell'Istria. Anthemon, scritti di archeologia e di antichità classiche in onore di Carlo Anti*, Firenze 1954, 119-169.
Donati 1999	V. Donati, *Della storia naturale dell'Adriatico*, Ristampa anastatica. T & G edizioni, Venezia 1999.
Duplančić Leder, Leder 2010	T. Duplančić Leder, N. Leder, *Obalna crta u infrastrukturi prostornih podataka o moru*, in: III simpozij ovlaštenih inženjera geodezije - GIS, fotogrametrija i daljinska istraživanja u službi geodezije i geoinformatike, Zbornik radova, Opatija 22-23. listopada 2010, Hrvatska komora ovlaštenih inženjera geodezije, Zagreb 2010, 120-125.
Faivre, Fouache 2003	S. Faivre, E. Fouache, *Some tectonic influences on the Croatian shoreline evolution in the last 2000 years,* Zeitschrift für Geomorphologie, N. F. 47/4, Stuttgart 2003, 521-537.
Faivre *et al.* 2010a	S. Faivre, E. Fouache, V. Kovačić, S. Gluščević, *Geomorphological and archaeological indicators of Croatian shoreline evolution over the last two thousand years*, in: GeoActa - Special Publication 3, Geology of the Adriatic Area, 2010, 125-133.
Faivre *et al.* 2010b	S. Faivre, T. Bakran-Petricioli, N. Horvatinčić, *Relative Sea-Level Change During the Late Holocene on the Island of Vis (Croatia) - Issa Harbour Archaeological Site*, Geodinamica Acta 23/5-6, 2010, 209-223.
Faivre *et al.* 2013	S. Faivre, T. Bakran-Petricioli, N. Horvatinčić, A. Sironić, *Distinct phases of relative sea level changes in the central Adriatic during the last 1500 years - influence of climatic variations?,* Palaeogeography, Palaeoclimatology, Palaeoecology 369, 2013, 163-174.
Flatman *et al.* 2005	J. Flatman, M. Staniforth, D. Nutley, D., D. Shefi, *Submerged Cultural Landscapes*; Proceedings of the Undertanding Cultural Landscapes Symposium, Humanities Research Centre, Flinders University, Adelaide 2005, 1-14.
Flemming 1969	N. C. Flemming, *Archaeological evidence for eustatic change of sea level and earth movements in the western Mediterranean during the last 2,000 years*, Geological Society of America Special Paper 109, 1969.
Fortis 1984	A. Fortis, *Put po Dalmaciji.* Globus*,* Zagreb 1984.

Fouache *et al.* 2000 E. Fouache, S. Faivre, J.-J. Dufaure, V. Kovačić, F. Tassaux, *New observation on the evolution of the Croatian shoreline between Poreč and Zadar over the past 2000 years*, Zeitschrift für Geomorphologie 122, Stuttgart 2000, 33-46.

Fouache *et al.* 2005a E. Fouache, S. Faivre, S. Glušćević, V. Kovačić, F. Tassaux, J.-J. Dufaure, *Evolution of the Croatian shore line between Poreč and Split over the past 2000 years,* Archaeologia Maritima Mediterranea 2/2005, 2005, 115-134.

Fouache *et al.* 2005b E. Fouache, S. Faivre, J.-J. Dufaure, V. Kovačić, F. Tassaux, F. Tronche, *Morska razina u rimsko doba na području Istre*, Vjesnik Arheološkog muzeja u Zagrebu 37, Zagreb 2005, 173-190.

Fritz 1972 F. Fritz, *Razvitak gornjeg toka rijeke Zrmanje*, Krš Jugoslavije 8, Zagreb 1972, 1-16.

Furlani *et al.* 2014 S. Furlani, A. Ninfo, E. Zavagno, P. Paganini, L. Zini, S. Biolchi, F. Antonioli, F. Coren, F. Cucchi, *Submerged notches in Istria and the Gulf of Trieste: results from the Geoswim project*, Quaternary International 332, 2014, 37-47.

Gary *et al.* 1972 M. Gary, Jr. R. McAfee Jr., C. L. Wolf, C. L. (eds), *Glossary of Geology*, American Gological Institute, Washington 1972, D.C.

Glušćević 2001 S. Glušćević, *Hidroarheološke i arheološke aktivnosti na zadarskom području*, Obavijesti Hrvatskog arheološkog društva XXXIII/1, Zagreb 2001, 43-47.

Gnirs 1908 A. Gnirs, *Beobachtungen űber den Fortschritt einer säkularen Niveauschwankung des Meeeres während der letzten zwei Jahrtausende*, Mitteilungen der Geographischen Gesellschaft in Wien 51, 1908, 1-56.

Hopley 1986 D. Hopley, *Beachrock as sea-level indicator*, in: *Sea-Level Research, A Manual for the Collection and Evaluation of Data*, O. Van Der Plassche (ed.), Geo Books, Norwich 1986, 157-173.

Jelić 1898 L. Jelić, *Najstariji kartografski spomenik o rimskoj pokrajini Dalmaciji*, Glasnik Zemaljskog muzeja u Sarajevu 10, Sarajevo 1898, 531-559.

Juračić 1992 M. Juračić, *Sedimentation in some Adriatic karstic river mouths (Are they estuaries or rias?)*, in: Proceedings of the international symposium "Geomorphology and sea", Mali Lošinj, September 22-26 1992, Zagreb 1992, 55-63.

Juračić, Prohić 1991 M. Juračić, E. Prohić, *Mineralogy, source of particles, and sedimentation in the Krka river estuary (Croatia)*, Geološki vjesnik 44, Zagreb 1991, 195-200.

Kamenjarin, Šuta 2011 I. Kamenjarin, I. Šuta, *Antički Sikuli,* katalog izložbe / *Ancient Siculi,* exhibition catalogue, Muzej grada Kaštela, Kaštel Lukšić 2011.

Kandler 1846 P. Kandler, *I porti di Salvore, Catoro e San Giovanni della Cornetta*, L'Istria 1, 1846, 117-119.

Karavanić 2015 I. Karavanić, *Research on underwater Mousterian, The site of Resnik - Kaštel Štafilić, Dalmatia, Croatia*, in: Forgoten Times and Spaces, New perspectives in Paleoanthropological, Paleontological and Archaeological studies, S. Sázelova, M. Novák, A. Mizerová, A. (eds), Institute of Archaeology of the CAS, Brno, Masaryk University, Brno 2015, 73-79.

Kelletat 2006 D. Kelletat, *Beachrock as Sea-Level Indicator? Remarks from a Geomorphological Point of View*, Journal of Coastal Research 22.6, 2006, 1558-1564.

Kershaw, Guo 2001 S. Kershaw, L. Guo, *Marine notches in coastal cliffs. Indicators of relative sea-level change, Perachora Peninsula, central Greece*, Marine Geology 179, Amsterdam 2001, 213-228.

Koncani Uhač 2009 I. Koncani Uhač, *Podvodna arheološka istraživanja u uvali Zambratija*, Histria Antiqua 17, Pula 2009, 263-268.

Laborel, Laborel-Deguen 1995 J. Laborel, F. Laborel-Deguen, *Biological Indicators of Holocene Sea-Level and Climatic Variations on Rocky Coasts of Tropical and Subtropical Regions*, Quaternary International 31, 1995, 53-60.

Laborel *et al.* 1999 J. Laborel, C. Morhange, J. Collina-Girard, F. Laborel-Deguen, *Shoreline bioerosion, a tool for the study of sea level variations during the Holocene*, Danish Geological Journal 45, 1999, 144-148.

Lagares 2008 F. Lagares, *Relevés de profils bathymétriques en Croatie du Nord , indices de pauses holocènes du niveau marin*, Comptes Rendus Geoscience 340, 2008, 49-56.

Lambeck, Bard 2000	K. Lambeck, E. Bard, *Sea level changes along the French Mediterranean coast from the past 30,000 years*, Earth and Planetary Sciences Letters 175, 2000, 203-222.
Lambeck, Chappell 2001	K. Lambeck, J. Chappell, *Sea-level change in Mediterranean Sea since the LGM, model predictions for tectonically stable areas*, Quaternary Science Reviews 24, 2001, 1969-1988.
Lambeck, Johnston 1995	K. Lambeck, P. Johnston, *Land subsidence and sea-level change, contributions from the melting of the last great ice sheets and the isostatic adjustment of the Earth*, in: Land Subsidence. Proceedings of the Fifth International Symposium on Land Subsidence, F. J. Barends, F. J. J. Brouwer, F. H. Schroder (eds.), Balkema, Rotterdam 1995, 3-18.
Lambeck, Purcell 2005	K. Lambeck, A. Purcell, *Sea-level change in the Mediterranean Sea since the LGM, model predictions for tectonically stable areas*, Quaternary Sciences Reviews 24, 2005, 1969-1988.
Lambeck *et al.* 2004a	K. Lambeck, F. Antonioli, A. Purcell, S. Silenzi, *Sea level change along the Italian coast from the past 10,000 yr.*, Quarternary Sciences Reviews 23, 2004, 1567-1598.
Lambeck *et al.* 2004b	K. Lambeck, M. Anzidei, F. Antonioli, A. Benini, A. Esposito, *Sea level in Roman time in the Central Mediterranean and implications for recent change.* Earth and Planetary Sciences Letters 224, 2004, 563-575.
Lambeck *et al.* 2006	K. Lambeck, A. Purcell, S. Funder, K. H. Kjaer, E. Larsen, P. Möller, *Constraints on the Late Saalian to early Middle Weichselian ice sheet of Eurasia from field data and rebound modelling*, Boreas 35, 2006, 539-575.
Lambeck *et al.* 2010	K. Lambeck, C. D. Woodroffe, F. Antonioli, M. Anzidei, W. Roland Gehrels, J. Laborel, A. J. Wright, *Paleoenvironmental Records, Geophysical Modeling, and Reconstruction of Sea-Level Trends and Variability on Centennial and Longer Timescales*, in: Understanding Sea-Level Rise and Variability, J. A. Church, P. L. Woodworth, T. Aarup, W. S. Wilson (eds.), Wiley-Blackwell, Hoboken, New Jersey 2010.
Laugier 1778	M.-A. Laugier, *Istoria della Repubblica di Venezia dalla sua fondazione sino al presente*, Presso Carlo Palese e Gaspero Storti, Venezia 1778.
Ljubić 1887	Š. Ljubić, (ed.), *Commmissiones et relationes Venetae II*, XXXVII. Itinerario di Govanni Battista Giustiniano. Jugoslavenska akademija znanosti i umjetnosti, Zagreb 1887.
Marriner, Morhange 2007	N. Marriner, C. Morhange, *Geoscience of ancient Mediterranean harbours*, Earth-Science Reviews 80, 2007, 137-194.
Marriner *et al*. 2014	N. Marriner, C. Morhange, S. Faivre, C. Flaux, M. Vacchi, S. Miko, V. Dumas, V. Boetto, I. Radić Rossi, *Post-Roman sea-level changes on Pag Island (Adriatic Sea), Dating Croatia's "enigmatic" coastal notch?,* Geomorphology 221, 2014, 83-94.
Mirnik 1972	I. Mirnik, *Prve hidroarheološke zabilješke kod nas*, More - časopis za ribolov i sportove na moru 3, 1972, 13.
Mirnik 1981	I. Mirnik, *Mijat Sabljar u Solinu i Vranjicu god. 1854.*, Vjesnik za arheologiju i historiju dalmatinsku 75, Split 1972, 209-240.
Morhange *et al.* 1999	C. Morhange, M. Bourcier, J. Laborel, C. Giallandella, J. Goiran, L. Crimaco, L. Vecchi, *New data on historical relative sea level in Pozzuoli Phlegrean Fields, Italy*, Physics and Chemistry of the Earth 24, 1999, 349-354.
Morhange *et al.* 2006	C. Morhange, N. Marriner, J. Laborel, M. Todesco, C. Oberlin, *Rapid sea-level movements and noneruptive crustal deformations in the Phlegrean Fields caldera, Italy*, Geology 34, 2006, 93-96.
Morhange *et al.* 2001	C. Morhange, J. Laborel, A. Hesnard, *Changes of relative sea level during the past 5000 years in the ancient harbor of Marseilles, southern France*, Paleogeography, Paleoclimatology, Paleoecology 166, 2001, 319-329.
Parascandola 1947	A. Parascandola, *I fenomeni bradisismici del Serapeo di Pozzuoli*, Pubblicazione in proprio, Napoli 1947.

Peltier 2001	W. R. Peltier, *Global glacial isostatic adjustment and modern instrumental record of relative sea level history*, in: Sea Level Rise, History and Consequences, B. C. Douglas, M. Keamey, S. P. Leatherman (eds.), Academic Press, Oxford, 2001, 65-93.
Peltier 2004	W. R. Peltier, *Global Glacial Isostasy and the Surface of the Ice-Age Earth: The ICE-5G(VM2) model and GRACE*, Annual Reviews of Earth and Planetary Sciences 32, Palo Alto 2004, 111-149.
Peltier, Fairbanks 2006	W. R. Peltier, R. G. Fairbanks, *Global glacial ice volume and Last Glacial Maximum duration from an extended Barbados sea level record*, Quaternary Science Reviews 25, 2006, 3322-3337.
Petrić 2003	N. Petrić, *Počeci podvodne arheologije u Hrvatskoj, povijesno-arheološke bilješke*, Histria archaeologica 32/2001, Pula 2003, 109-131.
Pirazzoli 1976	P. A. Pirazzoli, *Sea level variation in the northwest Mediterranean during Roman times*, Science 194, 1976, 519-521.
Pirazzoli 1994	P. A. Pirazzoli, *Tectonic coast, in, Coastal Evolution, Late Quaternary Shoreline Morphodynamics,* in: Cambridge University Press, R. W. G. Carter, C. D. Woodroffe (eds.), Cambridge 1994, 451-476.
Pirazzoli, Pluet 1991	P. A. Pirazzoli, J. Pluet, *World atlas of Holocene sea-level changes*, Elsvier, Amsterdam 1991.
Prelogović *et al.* 2003	E. Prelogović, B. Pribičević, Ž. Ivković, I. Dragičević, R. Buljan, B. Tomljenović, *Recent structural fabric of the Dinarides and tectonically active zones important for petroleum-geological exploration in Croatia*, Nafta 55 (4), 2003, 155-161.
Radić Rossi 2007	I. Radić Rossi, *Vranjic - zapadna i južna obala*, Hrvatski arheološki godišnjak 3/2006, Zagreb 2007, 451-453.
Radić Rossi 2008	I. Radić Rossi, *Rescue excavations at Vranjic near Split, Croatia*, in: Proceedings of the 13th Annual Meeting of the European Association of Archaeologists, Zadar, Croatia, 18-23 September 2007, I. Radić Rossi, A. Gaspari, A. Pydyn (eds.), Hrvatsko arheološko društvo, Zagreb 2008, 151-166.
Radić Rossi 2009	I. Radić Rossi, *Podmorska arheološka istraživanja u Kaštelanskom zaljevu tijekom 2006.*, Obavijesti Hrvatskog arheološkog društva 39/2, Zagreb 2009, 70-83.
Radić Rossi 2011	I. Radić Rossi, *Problematika prapovijesnih i antičkih nalazišta u hrvatskom podmorju*, doktorska disertacija, Sveučilište u Zadru, Zadar 2011.
Radić Rossi, Antonioli 2008	I. Radić Rossi, F. Antonioli, *Preliminary considerations on the ancient port of Pakoštane (Croatia) based on archaeological and geomorphologic research*, in: Book of abstracts, 14th Annual Meeting of the European Association of Archaeologists, Valetta, Malta, 2008. Valetta, European Association of Archaeologists, Valetta 2008, 98-99.
Radić Rossi, Boetto 2012	I. Radić Rossi, G. Boetto, *Međunarodni istraživački projekt u uvali Caski na Pagu, Prethodno izviješće o rezultatima istraživačke kampanje 2012.,* Histria antiqua 21, Pula 2012, 377-390.
Radulović *et al.* 2015	M. Radolović, T. Bakran-Petricioli, D. Petricioli, M. Surić, D. Perica, *Biological response to geochemical and hydrological processes in a shallow submarine cave*, Mediterranean Marine Science 16/2, 2015, 305-324.
Spada, Stocchi 2006	G. Spada, P. Stocchi, *The Sea Level Equation, Theory and Numerical Examples*, Arcane, Roma 2006.
Spencer 1988	T. Spencer, *Limestone coastal morphology, The biological contribution*, Progress in Physical Geography 12.1, 1988, 66-101.
Steinbüchel 1820	A. Steinbüchel*, Dalmatien. Eine Reiseskizze*, Jahrbuch für Literatur 12, Anzeigeblatt, 1820, 15-16.
Stocchi, Spada 2007	P. Stocchi, G. Spada, *Glacio and hydro-isostasy in the Mediterranean Sea: Clark's zones and role of remote ice sheets*, Annals of Geophysics 50.6, 2007, 741-761.
Stocchi, Spada 2009	P. Stocchi, G. Spada, *Glacio and hydro-isostasy in the Mediterranean Sea, Clark's zones and role of remote ice sheets*, Annals of Geophysics 50.6, 2009, 741-761.
Stocchi, Spada 2009	P. Stocchi, G. Spada, *Influence of glacial isostatic adjustment on current sea level variations in the Mediterranean,* Technophysics 474, 2009, 56-68.

Surić 2006	M. Surić, *Promjene u okolišu tijekom mlađeg pleistocena i holocena - zapisi iz morem potopljenih siga istočnog Jadrana,* doktorska disertacija, Prirodoslovno-matematički fakultet Sveučilišta u Zagrebu, Zagreb 2006.
Surić 2009	M. Surić, *Rekonstruiranje promjena morske razine na istočnoj obali Jadrana (Hrvatska) - pregled / Reconstructing sea-level changes on the Eastern Adriatic Sea (Croatia) - an overview*, Geoadria 14/2, Zagreb 2009, 181-199.
Šegota 1968	T. Šegota, *Morska razina u Holocenu i mlađem dijelu Würma*, Geografski glasnik 30, 1968, 15-39.
Šegota, Filipčić 1991	T. Šegota, A. Filipčić, *Arheološki i geološki pokazatelji holocenskog položaja razine mora na istočnoj obali Jadranskog mora*, Rad Hrvatske akademije znanosti i umjetnosti, Razred za prirodne znanosti 458 (25), Zagreb 1991, 149-172.
Šimunković 2011	Lj. Šimunković, *Dalmacija godine gospodnje 1553. Putopis po Istri, Dalmaciji i Mletačkoj Albaniji 1553. godine, Zapisao Zan Battista Giustinian*, Dante Alighieri, Split 2011.
Špikić 2006	M. Špikić, *Anton Steinbüchel i začetak novog doba u proučavanju dalmatinskih starina*, Kulturna baština 33, Split 2006, 171-186.
Tišljar 1994	J. Tišljar, *Sedimentne stijene*, Školska knjiga, Zagreb 1994.
Zeljak 2006	F. Zeljak, *Teška ronilačka oprema u doba don Frane Bulića*, Aqualung - Magazin za ronjenje i podvodni svijet, 2006, 62-68.