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Shallow water acoustic techniques to investigate transitional environments: A case study over Boka Kotorska Bay

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ABSTRACT

The eastern border of the Adriatic Sea shows several examples of transitional areas marked by fragmented coastlines, islands and coastal bays. Bays and estuaries interact with the main basin influencing it and being influenced by it in terms of circulation patterns and freshwater supply. Coastal and transitional areas represent highly dynamic, rapidly changing environments subjected to multiple interactions with the marine-land-fluvial systems related processes. Processes such as coastal erosion, seawater intrusion, pollution and sediment transport and deposition affect these areas. One of the most important transitional areas along the entire Adriatic coast, from both an environmental and a socio-economic viewpoint, is the bay of Boka Kotorska, where the sea enters inland for over 20 km. The Bay is located along the Montenegro margin and is part of a ria coastal system surrounded by high mountains part of the Dinaric range. Boka Kotorska Bay includes three major basins, connected by two narrow straits with a maximum depth of 67 m. Despite its historical and geostrategic role the morphology and geology of the Bay is poorly known. Coastal areas are among the most urbanized and populated regions; for these reasons the application of geophysical minimally invasive methods are required in order to collect geological and morphological data. High resolution seismic reflection techniques such as CHIRP systems, adopting a non-impulsive source wavelet, are ideal to carry out seismic surveys in transitional environments. Here, we present a detailed description of this system in order to furnish the mathematical basis for forward modelling. Moreover, we outline a procedure to estimate the earth reflectivity by inversion of the recorded signal envelope (reflection strength), i.e., the standard way to store CHIRP data. Reflection strength data alone, characterizing the signal power as a function of time, do not retain all the characteristics of the recorded signal they represent and thus, cannot be further processed and hardly be compared with results from forward modeling. New high resolution multibeam and seismic reflection data collected in the Boka Kotorska Bay reveal unknown details of present-day morphologies and sedimentary infilling geometries. Several processes are involved in shaping the bay and its seafloor. Our results show that the observed morphologies are due to the interaction at different timescales of climate, water circulation, sealevel changes, erosion, sedimentation and tectonics constrained by the geological and structural setting of the area.

1. Introduction

The interactions between climate, sealevel changes, erosion, sedimentation and tectonics determine littoral morphology worldwide. The eastern border of the Adriatic Sea is characterized by fragmented coastlines, islands and coastal bays, that interact with the main basin influencing it and being influenced by it in terms of circulation patterns and freshwater supply (Fig. 1). One of the most important feature along the entire Adriatic coast from both historical and economical viewpoint is the bay of Boka Kotorska, where the sea enters inland for over 20 km. The Bay is located along the coast of Montenegro and is composed by three main basins: Herceg Novi, Tivat and Morinj-Risan-Kotor, connected by two narrow ~350 m wide straits: Kumbor and Verige straits (Fig. 2). The Bay is surrounded by high mountains that are part of the Dinaric range and for this reason is improperly considered as the southernmost fjord in Europe, although its origin is not related to glacial processes [1,2]. Instead, Boka Kotorska Bay is part of a ria coastal system, where the valleys were formed mainly during sealevel lowstands allowing regressive erosion of the landscape since the Messinian Salinity Crisis (~5 Ma). This resulted in a very deeply incised

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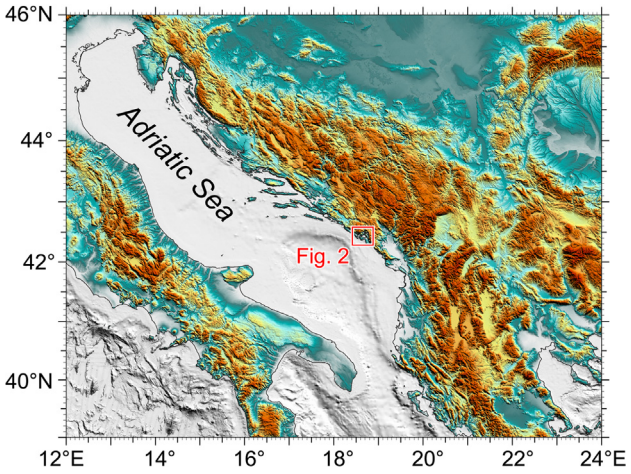

Fig. 1. Shaded relief image of the Adriatic Sea and of surrounding regions. Sun illumination 45° above the horizon, light from NE. The numbered red box refers to the area displayed in Fig. 2.

morphology below modern sealevel by a river flowing NE-SW, orthogonal to the orientation of the main tectonic structures, with its tributaries parallel to them. Narrow and steep valleys were incised in the hard limestone formations, while in the soft flysch layers, the river and tributaries formed wide valleys, causing the NW-SE orientation of the major basins [2,3]. The area is the richest region for precipitations in this part of the Mediterranean and represents one of the most highly karstified areas in the world.

Despite the historical and geostrategic role of Boka Kotorska, little is known on the morphology of its submerged portion. Here, we report on the first detailed morphological and bathymetric mapping of the entire Bay resulting from high resolution seismic reflection profiles, magnetics and swath bathymetry data collected during several geological-geophysical cruises from 2008 to 2013.

2. Geological setting

Montenegro is part of the thrust-and-fold system forming the Dinaric Alps. Relative movements between the European plate and the Adria microplate during the Mesozoic and the Tertiary controlled the evolution of Montenegro and of adjacent areas. The Mesozoic rifting phase related to extension, was followed by continental convergence from the Late Cretaceous/Early Eocene to the Upper Pleistocene, that formed a series of thrust-and-folds belts with associated foreland and back-arc basins [4]. The 200 km-long plate boundary along Montenegro consists of a WNW trending thrust, cut by N-S and rarely ENE oriented strike-slip faults, which laterally segment the major thrust front [5]. Starting from the Adriatic Sea, four NW-SE trending geomorphological provinces can be identified onshore: “Coastal Montenegro”, “Budva-Cukali”, “High Karst” and “Durmitor Zone”.

The Coastal Montenegro Zone is the innermost part of the Ionian-Adriatic Thrust Zone, build up by Cretaceous limestones, anhydrites and dolomites, and Eocene-Oligocene flysch deposits. Thrust-folded over this tectonic unit is the Budva-Cukali Zone consisting of Triassic flysch deposits and carbonates, Cretaceous limestones and Paleocene flysch. Budva-Cukali tectonic unit is overthrust by the High Karst Zone made mainly of Mesozoic limestone and dolomites with thickness reaching several kilometres due to reverse faulting and overthrusting that duplicate the carbonate series. Along the northern sector of Kotor Bay from Morinj to Kotor, across Risan and Perast, this unit is in direct contact with the sea. The northernmost tectonic unit is the Durmitor Zone consisting of different thrust sheets build up by Late Paleozoic and Lower Triassic sedimentary deposits (clay, marl and sand beds), and Jurassic diabases and cherts [6,7].

3. Data and methods

Data were collected during several geological-geophysical cruises from 2008 to 2013 with the Research Vessel (*R/V*) *Dallaporta*, *R/V Urania* and *R/V Maria Grazia* of the Consiglio Nazionale delle Ricerche (CNR), under the framework of ADRICOSM-STAR and MEDPOL projects. Oceanographic cruises ADR08, ADR02_08, MNG01_09, MNG02_09, and MNG03_10 were carried out in 2008, 2009 and 2010, respectively, in order to explore the area with high resolution seismic reflection profiles, magnetics and swath bathymetry data.

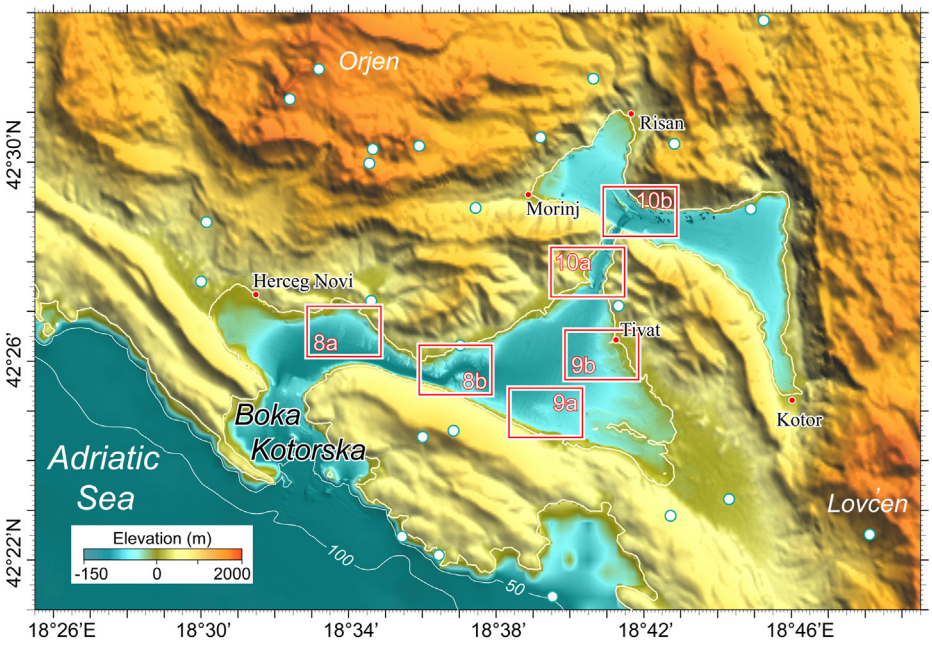

Fig. 2. Topography of the Boka Kotorska Bay. Data are referred to geodetic datum WGS84. Mercator projection at 42.5°N. White dots, earthquake epicentres with magnitude > 4 since 1976 from International Seismological Data Centre. The numbered red boxes refer to the areas displayed in Figs. 8–10.