Paleoenvironmental reconstruction of Holocene sediments in Novigrad Sea and Karin Sea

During the early Holocene, sedimentation in Novigrad Sea, Karin Sea and Velebit Channel was mainly dependant on fluvial processes and sea level rise. As the sea level further rose, it became a primary sedimentary factor in the area. In the last two millennia, marine sedimentation is influenced by terrigenous input due to anthropogenic impact.

Novigrad sea and Karin sea are semi-enclosed bays located in the central part of eastern Adriatic coast (Fig. 1). Karin Sea is a shallow bay (15 m deep) isolated from larger Novigrad Sea by a canyon type of outlet (Karinsko ždrilo). Two small tributary rivers bring sediment from their 88 km^2 catchment. Novigrad Sea (30 m deep) is a part of large Zrmanja river catchment (860 km^2) and smaller Novigrad catchment (190 km^2). It is connected to Velebit channel by similar canyon type of outlet (Novsko ždrilo). This is the area where the Mediterranean and mountainous climates of Dinaric karst meet causing a harsh environment with bora winds (up to 180 km/h) extending back throughout the Holocene. Catchments are dominantly karstified, with terra rossas and cambisols on limestone as dominant soils, and flysh in Karinsko more watershed. Geological background consists mainly of limestones, dolomites and flysch.

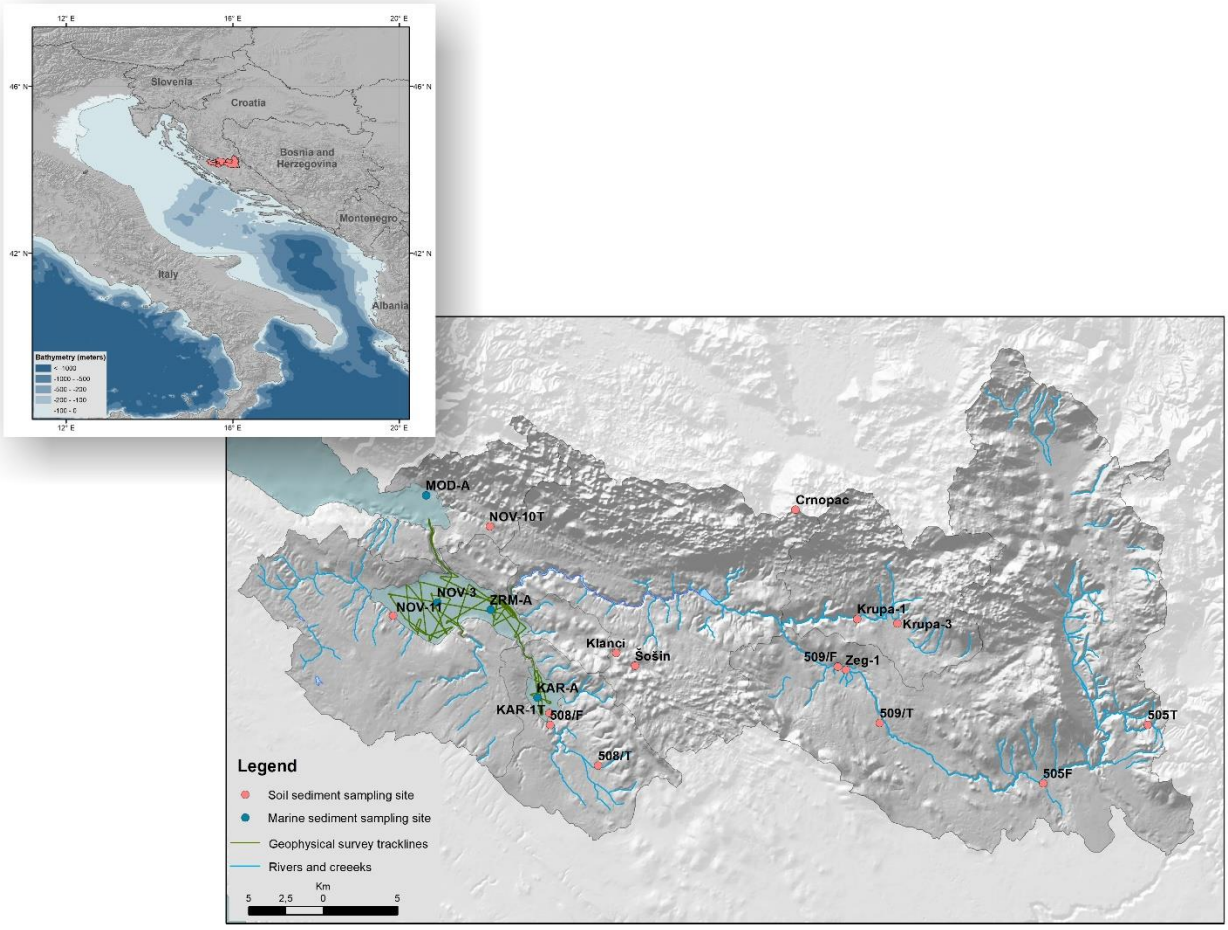

Figure 1. Location of Novigrad Sea, Karin Sea and its catchments with locations of sediment sampling and geophysical survey tracklines.

Based on marine geoacoustic geophysical survey paired with high resolution multiproxy analysis of four long marine sediment cores (at Zrmanja river mouth (ZRM-A), Novigrad Sea (NOV-3), Karin Sea (KAR-A) and Modrič bay (MOD-A)) and fifteen soil sediment cores or profiles (sampled in their respective catchments) (Fig. 1), it was possible to create palaeoenvironmental reconstruction of the Holocene sediment sequence and partially of underlying Pleistocene sediments in the Novigrad and Karin Sea.

During the early Holocene surface of today's area of Novigrad and Karin Sea hosted river channels incised in Pleistocene clastites. Geoacoustic survey data reveal a larger river channel extending from Karin Sea and connected with Zrmanja river near its canyon (Fig. 2). Multiple channels extending thru Novigrad Sea area towards Novsko ždrilo suggest the existence of braided river system (Fig. 2). Larger depressions and erosional forms in clastites were filled with terrigenous sediments. A palaeo-channel from south towards Novigradsko ždrilo is also visible. Geophysical data suggests a possibility that the deepest (eastern) part (65 m.b.s.l.) of the Novigrad Sea area could host a shallow lake (Fig. 2).

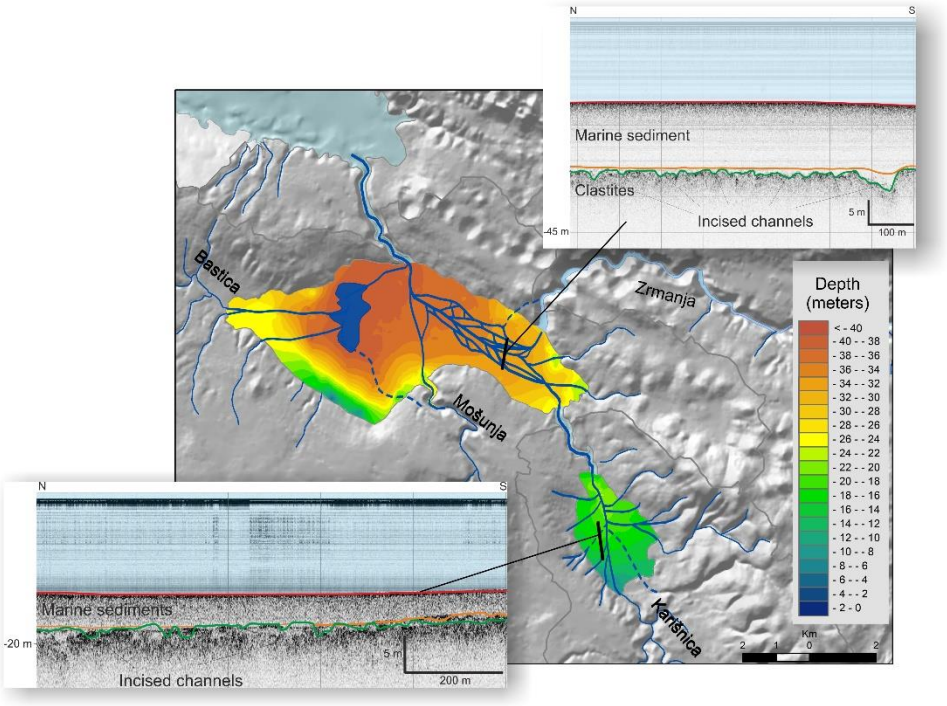

Figure 2. Paleoreconstruction of clastic surface (Pleistocene) with incised river channels also visible in two examples of geophysical profiles. Green line in profiles depicts irregular surface of clastic sediments; yellow lines represent surface of terrestrial sediment fill in Pleistocene irregular surface; red lines represent recent sea bottom.

Three marine sediment cores penetrated marine sediment sequences and terminated in terrestrial alluvial/colluvial/beach sediments predating the Holocene flooding by the Adriatic Sea. Terrestrial sediments have increased siliciclastic component, magnetic susceptibility (MS) and C/N ratio (reaching up to 20). These sediments are poorly sorted with higher grain size than the rest of the core (Fig. 3). Assemblage of palinomorphs and foraminifera (or their absence) indicates alluvial/colluvial/beach sediments.

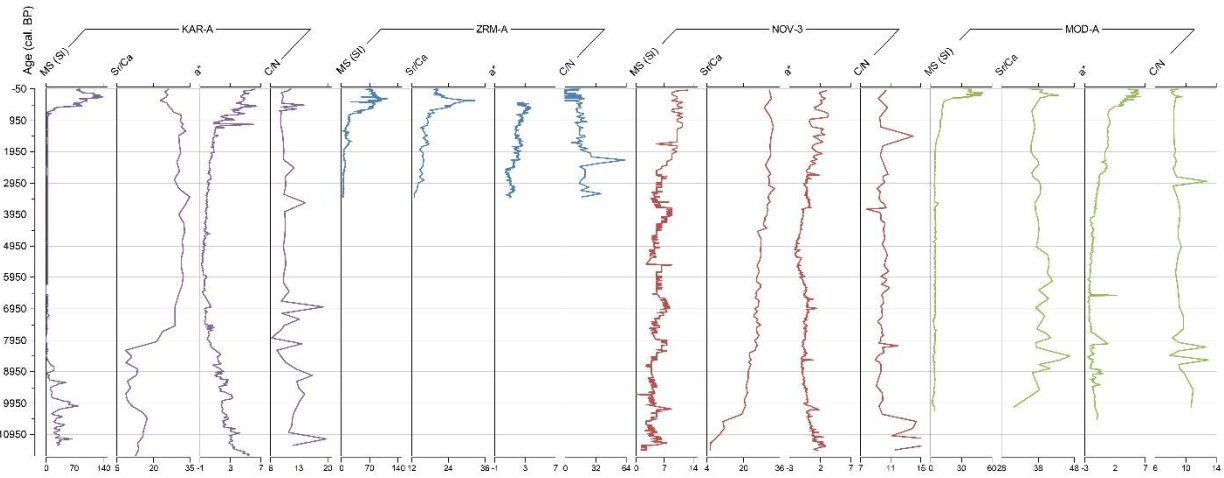

Figure 3. Variability in magnetic susceptibility (MS), Sr/Ca ratio, red/green colour (a*) and C/N ratio in marine sediment cores.

Due to the sea-level rise, seawater intruded Novigrad Sea area thru Novigradsko ždrilo. First evidence of marine environment is evident in core NOV-3 at 11440 cal. yr. BP (Fig. 4 a), than in MOD-A after 10.210 cal. yr. BP (Fig. 4 b), and in KAR-A at 9.870 cal. yr. BP (Fig. 4 c). Determined dates of marine transgression into semi-closed bays fit well with current relative sea-level curves for Adriatic.

Due to the sea-level rise, shallow and isolated Karin Sea bay (today 15 m deep) connected by a canyon type of outlet with the Novigrad Sea (today 30 m deep) shows evidence of a brackish lake/marsh system in the period from 7.480 to 8.500 cal. yr. BP. It is recognized by high Ca concentration and low siliciclastic input typical for karstic lake sedimentation, low Sr/Ca ratio, elevated Sr/Ba, Pb/Al, Mg/Al ratios, elevated C/N, pollen and foraminiferal assemblages.

This period is followed by sedimentation of fine-grained dominantly silty sediments with dominance of calcite and quartz. Darker sediment with low MS, TOC, C/N, Sr/Ca, Mg/Al and Mn/Fe ratios is typical for marine sedimentation, which lasts until today (Fig 4 c). On geophysical survey profiles, it is recognizable as upper unit with uniform (monotonous) sedimentation (Fig. 2) and thickness of 9 m in Karin Sea and 16 m in Novigrad Sea. In sediment cores this interval is recognized by low MS, darker colour, low TOC, C/N, Sr/Ca (Fig. 3).

Upper parts of all marine sediment cores show increase of siliciclastic material input, increase of MS, Pb/Al and C/N ratios, while Ca concentration decreases (Fig. 3). Bimodal grain size distribution suggests variable sediment sources. Colour of the sediment becomes more red/yellow. Those parameters indicate higher terrestrial sediment input mainly due to anthropogenic influence caused by deforestation or agriculture in the catchments. Anthropogenic influence can be traced in sediment cores from Roman period (approximately 1900 cal. yr. BP), while the highest terrestrial siliciclastic material input is visible between 720 and 515 cal. yr. BP. Similar event is visible in the floodplain of Krupa river (tributary to Zrmanja river, location Krupa-1, Fig. 1). Due to deforestation in its catchment, sedimentation of organic peat-like material is around 1900 cal. yr. BP abruptly replaced by terrigenous siliciclastic input.

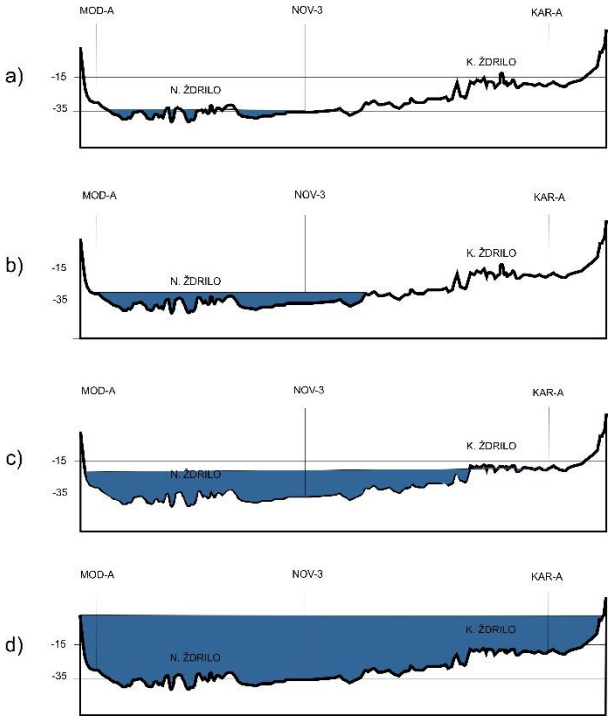

Figure 4. Sea level rise interpretation in Novigrad and Karin Sea from early Holocene until today. From top to bottom: a) entrance of sea to Novigrad area to location NOV-3; b) further sea level rise up to location MOD-a; c) sea level rise to location KAR-A; d)recent sea level situation.