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Seabed and Surface Sediment Map of the Kvarner Region, Adriatic Sea, Croatia (Lithological Map, 1:500,000)

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Abstract

A lithological map of recent marine sediments and the seabed of the Kvarner region (Adriatic Sea, Croatia) is presented on a scale of 1:500,000. The map was compiled from existing published and unpublished data. This is an area characterised by a number of islands located between the Istrian Peninsula and the Vinodol-Velebit coast. Water depths in channels between the islands reach up to 125 m, compared to depths of 40-50 m in the open waters of the adjacent northern Adriatic.

Over most of the Kvarner area, muddy and sandy sediments cover the seafloor. Mud (M) is found on the bottom in Rijeka Bay, the northern part of the Kvarner, in Kvarnerić, and in the Vinodol and Velebit channels, whereas over the rest of the Kvarner region seafloor sandy mud (sM) prevails, with subordinate occurence of gravelly mud (gM). Sandy sediments, i.e. muddy sands (mS) dominate in the SW part to the open Adriatic, and west of Rab Island, in the Pag and Velebit Channels.

Previous investigations indicate that the fine grained particles that are found in deeper parts of Rijeka Bay, Kvarnerić, and Vinodol Channel are of recent origin, and are deposited at water depths below the wave base. Sources of these particles are local permanent and temporary streams and the direct input from weathering processes, along with input by submarine springs (vrulje) near the coast. The large areas of the bottom not covered with sediments, or covered with gravelly and sandy sediments are found above the wave base, i.e. in the erosional wave zone. Coarse-grained material is lithic and/or biogenic.

However, due to the very rapid Late glacial-Holocene transgression, when sea-level rose more than a hundred metres, coarse sandy sediments are found below the recent wave base in the SW part towards the open Adriatic, and west of Rab Island, in the Pag and Velebit Channels. Therefore the sediment distribution in the Kvarner region is only partly in dynamic equilibrium with modern hydrodynamic conditions.

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1. INTRODUCTION

Marine geological cartography has been intensively developed in the World since the 1960s. The systematic mapping of the shelf started in the UK in 1962, and the entire British shelf has already been mapped at the scale of 1:250,000. For each area/sheet at least three maps exist: Seabed sediments & Holocene map, Quaternary geology map, and Solid geology map. In the Adriatic the sediments have also been intensively investigated since the 1960s (BRAMBATI & VENZO, 1967; PIGORINI, 1968; VAN STRAATEN, 1970). An example of the maps comparable to the lithological map of the Kvarner region are the sedimentological textural maps of the Northern and Central Adriatic Sea, also on a scale of 1:250,000 (BRAMBATI et al., 1983, 1988a, b).

The seabed characteristics of the Kvarner region of the Adriatic Sea have been sporadically investigated since the first attempt by LORENZ (1863). In this work we attempted to produce a map of the seabed and surface sediments in the Kvarner region, collecting and evaluating the existing published and unpublished data on surface sediments in that region. The impetus for compiling this map was an attempt to systemise the existing data on sediments and geological structures for the Regional plan of the Primorsko-Goranska County.

The main aim of this map is to produce a synthesis of data and to visualise sediment distribution and bottom textural types, in order to infer sedimentological processes that defined the present sediment pattern. The geological and geomorphologic evolution of the area is discussed. The map may be useful for practical purposes such as fishing, better understanding of the fate of contaminants and pollutants that are introduced into the marine environment, and for any sediment scouring predictions or geotechnical investigations in this area.

2. PREVIOUS INVESTIGATIONS

The first detailed sediment description in the Kvarner region was published by LORENZ (1863), together with a map presenting the sediment types. He indicated that most of the seabed is covered with muddy sediments, and that only to the W and SW of Lošinj Island do sandy sediments cover the sea bottom. ALFIREVIĆ

(1980) indicates that in Rijeka Bay and the Kvarnerić region sandy sediments prevail along the coasts and fine-grained sediments in the central parts. On the basis of the prevalence of zircon and garnets in the transparent fraction of heavy minerals ŠKRIVANIĆ & MAGDALENIĆ (1979) assigned the Rijeka Bay sediments to the Kvarner petrographic province. The border to the Padane petrographic province (which is characterised by garnets, epidote, and hornblende in the transparent fraction of heavy minerals) lies in the southern parts of the Kvarner and Kvarnerić. JURAČIĆ & PRAVDIĆ (1981) indicate that the Rijeka Bay seabed is covered with fine grained sediments (silts and clayey silts) and that the carbonate fraction increases from 16% in the north, to 44% in the south of the Bay. On the generalised sediment map of the Adriatic Sea (HIJRM, 1985) the largest part of the Rijeka Bay appears covered with muddy sand, whereas in the NE part (in front of the Rječina River mouth) sand is found.

3. STUDY AREA

The Kvarner region (Kvarner *sensu lato*) is part of the Adriatic Sea located between the Istrian Peninsula and the Vinodol-Velebit coast. Two chains of larger islands, Cres-Lošinj and Krk-Rab-Pag, divide the area in the Rijeka Bay, Kvarner (*sensu stricto*), Kvarnerić and Velebit-Vinodol Channel.

On the geographic map of the Kvarner with bathymetric data presented, large and puzzling differences in water depth can be observed (Fig.1). Water depths in the open Adriatic, west of the Cres-Lošinj archipelago are between 40 and 50 m, whereas in the Kvarnerić (towards the coast) depths are between 70 and 90 m. In this area several seafloor elevations, isolated shoals, and submerged prolongations of island structures occur. In contrast, the bottom of Rijeka Bay is very flat at approximately 60 m depth. In the very narrow Tihi Channel, which connects Rijeka Bay and the Vinodol Channel, depths reach 60 m, whereas in the much wider northern part of the Vinodol Channel depths do not exceed 40 metres. In relatively narrow and elongated parts of the sea between Krk and Rab islands, and between Rab and Pag islands, depths reach more than 100 metres. The deepest point (125 m) of all the Northern Adriatic has recently been measured in the narrow Krušija Channel between Cres and Plavnik islands.

On land in the Kvarner region lithologies include Lower Cretaceous limestones, Cretaceous breccias, Upper Cretaceous intercalated limestones and dolomites, together with Upper Cretaceous rudist limestones. Palaeogene deposits include foraminiferal limestones and clastic deposits (flysch - marls, sandstones and breccias in alternation) with carbonate breccias (ŠIKIĆ et al., 1969; ŠIKIĆ & POLŠAK, 1973; ŠIKIĆ et al., 1972; ŠIKIĆ & PLENIČAR, 1975; ŠUŠNJAR et al., 1970; GRIMANI et al., 1973; MAGAŠ, 1968; MAGAŠ, 1973; MAMUŽIĆ et al., 1969, 1970; MAMUŽIĆ & MILAN, 1973; MAMUŽIĆ, 1968, 1973; MAMUŽIĆ & SOKAČ, 1973). Carbonates dominate, whereas flysch outcrops are restricted. Quaternary deposits partly cover this bedrock substrate. In most cases, red soil (*terra rossa*) that covers the carbonate substrate in the Kvarner region has a polygenetic origin and was formed by the mixing of insoluble residue of carbonate rocks with weathered and eroded loess and flysch (BENAC & DURN, 1997). Elsewhere, slope deposits and weathered material cover the flysch bedrock.

In accordance with the current knowledge about the formation of the Adriatic and Dinarides (HERAK, 1986; BLAŠKOVIĆ, 1990), the Kvarner region had a very dynamic tectonic evolution. Kvarner and Istria belong to the "Adriatic" geodynamic unit, which is bordered by the "Dinaric" unit to the NE. Regionally the "Dinaric" unit overthrusts the "Adriatic".

Tectogenesis of the Kvarner region is directly related to the subduction of the Adriatic carbonate platform beneath the "Dinaric" during the Tertiary. The different intensity of subduction of Istria and Kvarner (divided by the horizontal dextral Kvarner fault) under the Dinaric region caused a sinusoidal twist of structures with Dinaric strike (NW-SE) into a meridional strike in the western Kvarner (MATIČEC, 1998). Neotectonic movements from the Lower Pliocene to Recent had a dominant role in the formation of the actual relief. These were vertical and horizontal movements of different direction and intensity (PRELOGOVIĆ et al., 1981). Long term vertical movements resulted in: i) the sinking of the bottom of the Rijeka Bay, Kvarnerić and Vinodol Channel; ii) the tilt of the Kastav plateau towards SW, and iii) substantial uplift of the Učka ridge, Gorski Kotar mountains, of the Velebit Mountain, and of some parts of the Cres, Krk, and Rab islands.

Due to these tectonic movements Cretaceous and Palaeogene sedimentary rocks were folded and subsequently reverse faulting and overthrusting occurred. The main structures strike NW-SE.

The diversity of relief in the Kvarner region is a consequence of contrasting lithologies, reshaping of pre-existing structures and formation of new structures, along with geomorphological processes (MIHLJEVIĆ, 1998). Morphological characteristics of the relief, tectonic structures, and high seismicity indicate very active recent tectonic activity (PRELOGOVIĆ et al., 1995, 1998).

As a result of the prevalence of carbonate rocks and intensive tectogenesis, this is a region of well developed karst. Karst features (e.g. dolinas, ponors, caves) are developed both on the mainland and on the islands. Karstification is more pronounced above and near the sea-level and therefore in periods when the sea-level was lowered karstification in the Kvarner region affected deeper levels over a more extensive area. This is why submerged karst features are widespread in the region.

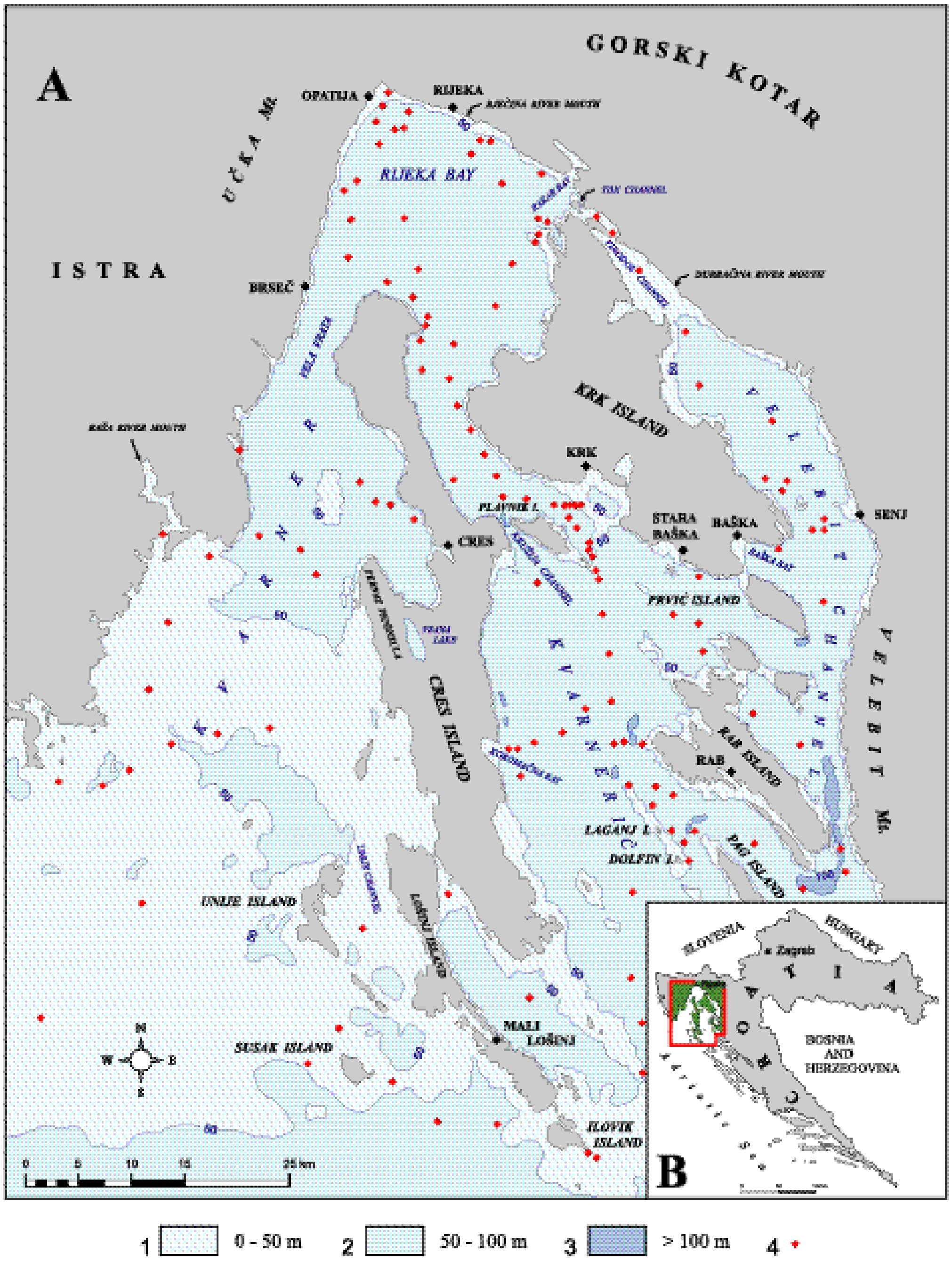

Fig. 1 A) Bathymetric map of the Kvarner. Legend: 1) water depths 0-50 m; 2) water depths 50-100 m; 3) water depths over 100 m; 4) surface sediments sampling stations. B) Location map.

4. METHODOLOGY AND DATA ACQUISITION

Existing data on the granulometry and mineral composition of surface sediments, together with indirect observations of the seabed by subbottom profiler (SBP) and side scan sonar (SSS) were compiled in order to produce a map. Results of granulometric analyses of 136 surface sediment samples of the open waters of Kvarner were used (ŠKRIVANIĆ & MAGDALENIĆ, 1979; JURAČIĆ & PRAVDIĆ, 1981; BENAC, 1994, and unpublished data of the Croatian Hydrographic Institute 1993-1997) (Fig. 1). Moreover, a large number of data on sediments of the coastal area collected primarily during geotechnical investigations were used for the production of the map, which are not presented in Fig. 1. On the basis of these data we attempted to present surface sediment distribution for all of the Kvarner area. Sampling density is relatively high in the eastern part, but sparse in the SW.

Granulometric composition has been determined by wet sieving through standard sieves with diameters 4,000-63 μm, on Fritsch Analysette 3, and by using particle counter Coulter Counter model TA II or standard aerometric method after Casagrande for particles <63 μm. Classification of sediments is simplified after the internationally accepted classification for seabed sediments (FOLK, 1954) where the percentage of gravel (>2 mm) is compared to the sand (2-0.063 mm) and mud (silt+clay <0.063 mm) ratio. The mineral composition of part of the sediment samples has been determined by standard X-ray diffraction technique (diffractometer Philips PW 1050).

In the coastal areas, direct observations by scuba diving were used, along with the existing data, in order to map bottom characteristics.

5. RESULTS - SEABED AND SURFACE SEDIMENT MAP

On the seabed in the Kvarner area four main types of substrate are found: a) rocky bottom, b) gravel and rock fragments, c) sandy sediments, and d) muddy sediments.

On the map at a scale of 1:500,000 (Fig. 2) the following types of bottom could be graphically distinguished:

- rocky bottom, gravel, pebbles, sandy gravel (G, sG);
- gravelly sand and sand (gS, S);
- gravelly muddy sand (gmS);
- muddy sand (mS);
- gravelly mud (gM);
- sandy mud (sM);
- mud (M).

At the bottom in the Kvarner region muddy and sandy sediments prevail. Mud (M) is found in the Rijeka Bay, the northern part of the Kvarner Bay, in Kvarnerić, and the Vinodol and Velebit channels, whereas over the major part of the bottom of the Kvarner area sandy mud (sM) prevails, along with some subordinate zones of gravelly mud (gM).

Prevalently sandy sediments i.e. muddy sand (mS) are found in the south-western part in the transition zone to the open Adriatic Sea and west of Rab Island, in the Pag and southern part of the Velebit Channel. Smaller confined zones of sandy sediments (gmS) are found also near to the Koromačna Bay (Cres Island), between the tip of the Pag Island, Laganj rock and Dolfin Island, and east of Ilovik Island. Moreover, minor patches of sand (S) and gravelly sand (gS) are found near the sources of terrigenous matter (southern part of Krk Island: in the Baška Bay and offshore of the Stara Baška settlement).

Larger zones of rocky bottom, and of bottom covered with gravel (sG) are found in shallow areas above the wave base (SE of Cres and Lošinj islands, near Unije Island). Moreover, such types of seabed are also found in deeper parts (southern part of the Unije Channel, W of Pernat off Cres Island, in Krušija Channel between Cres and Plavnik Islands), where one can presume episodic very strong near bottom residual currents where both buoyancy and wind forcing may be relevant.

Mineral composition was investigated in more detail only in the Rijeka Bay samples. As presented in Fig. 2 the bottom of the bay is covered with fine grained sediments (mud). Mineralogical analyses have revealed that quartz and calcite dominate (>25 %), feldspars and chlorite are abundant (5 - 15 %), and illite, dolomite, high-magnesian calcite, and aragonite are present (<5 %). The carbonate fraction (calcite, dolomite, high-magnesian calcite and aragonite) in sediments gradually increases from 16 % in the northern part to 44 % in the southern part of the bay (JURAČIĆ & PRAVDIĆ, 1981). Around the mouth of Rječina River, the quartz fraction in surface sandy sediments ranges between 75 % and 90 % (BENAC, 1994).

6. DISCUSSION

In accordance with the sea-level changes during geological history, the intensity and location of erosion, karstification and accumulation of sediments changed repeatedly (COWELL & THOM, 1997). Recent land, coastal and submarine relief in the Kvarner region is a consequence of tectonic movements, lithological variations, climatic changes and sea-level fluctuations during the Quaternary, and also a result of erosional and accumulation processes caused by these changes.

Therefore the sediment distribution and bottom types encountered in the Kvarner should be explained in accordance with the morphologic evolution of the region since the Pliocene.

It was assumed that Adriatic sea-level fluctuated up to 150 m during the Upper Pleistocene (VAN STRAATEN, 1970), causing several rises and falls. Transgressive-regressive sequences in Quaternary sediments of the Adriatic Sea indicate such sea-level oscillations (TRINCARDI et al., 1994, 1996; TARI KOVAČIĆ, 1995; CORREGGIARI et al., 1996a). This indicates that there might have been changes from marine to continental environments in the relatively closed Kvarner area. The prevalent carbonate lithology underwent much deeper karstification during periods when sea-level was lowered.

Due to intensive changes of relief caused by tectonic movements, the lay-out of the land and sea in the Kvarner area was somewhat different in the lower part of the Upper Pleistocene compared to the Recent. This period of the morphological evolution created a morphological frame for sedimentation during the last glacial. Older sediments that were deposited in terrestrial, freshwater or marine environments were covered with younger sediments and have yet to be investigated.

On the basis of parallel geomorphological and climatological analyses, a relatively accurate curve of the sea-level fluctuations since 160,000 years before present (yBP) has been produced, i.e. since the end of the Riss glacial (CHAPPELL & SHACKLETON, 1986; TOOLEY, 1993). At the peak of the Riss-Würm interglacial, some 135,000 to 120,000 yBP, the global sea-level was similar to recent or <5 m higher. Afterwards there was gradual decrease of the sea-level until 30,000 yBP. So during a period of 90,000 years in accordance with climatic oscillations sea-level fluctuated with

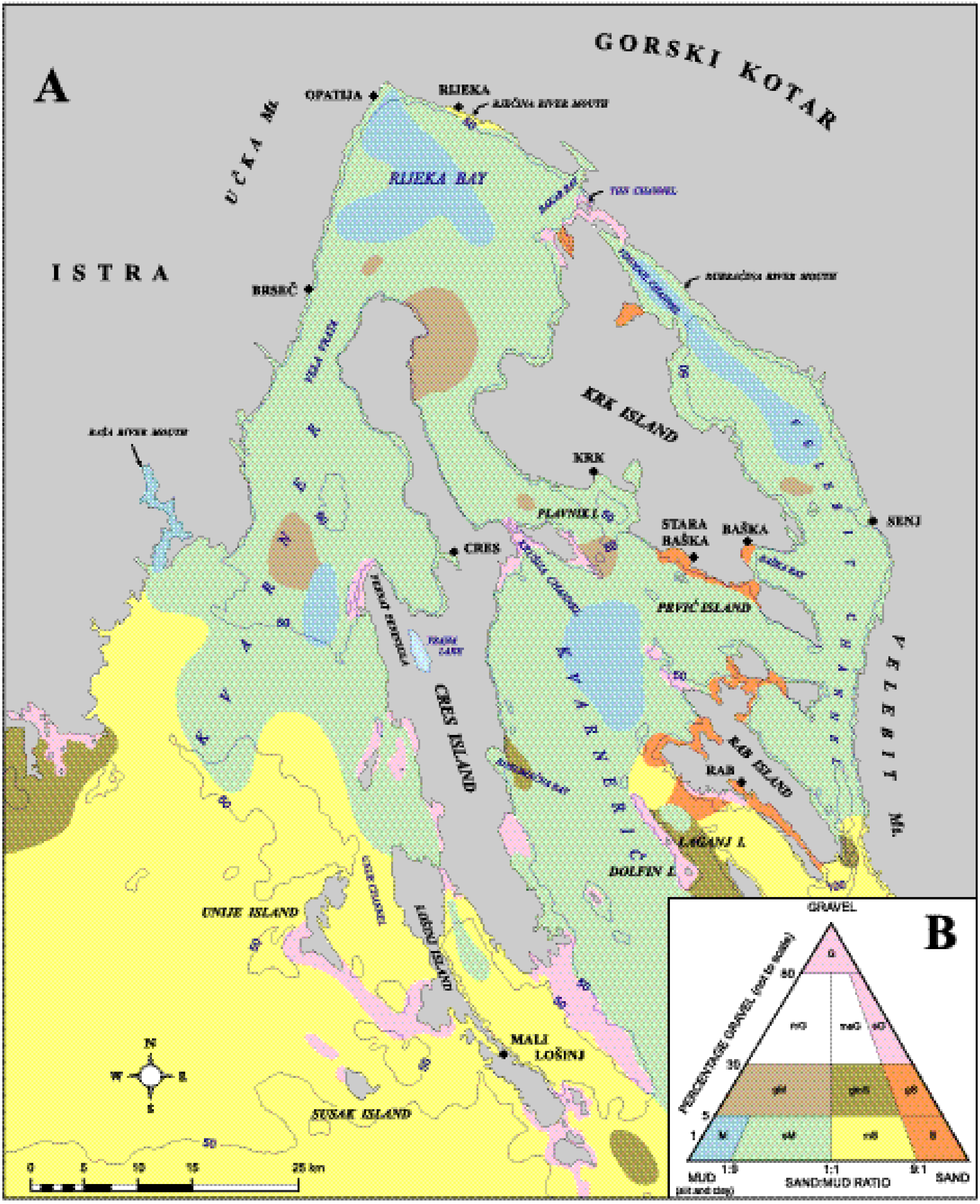

Fig. 2 A) Seabed and surface sediment map of the Kvarner, Scale 1:500,000. Main 50 m and 100 m isobaths are shown. B) Diagram of the relative percentage of gravel, sand and mud with textural types present (simplified after FOLK, 1954); abbreviations explained in the text.

amplitudes from 20 to 30 m, coming at least twice to the -50 or -60 m level. Most researchers agree that during the Würm climatic cold peak sea-level was 100-120 m below present surface (FAIRBRIDGE, 1961; FAIRBANKS, 1989), and most probably in the major part of the northern Adriatic there were terrestrial conditions (D'AMBROSI, 1969; VAN STRAATEN, 1970; COLANTONI et al., 1979; ŠEGOTA, 1982; CORREGGIARI et al., 1996a).

The main relief characteristics of the Kvarner area during the Würm must have been similar to the present, so for that period a more detailed reconstruction is possible. By lowering of the sea to the -50 m level, the circulation of water through Vela Vrata (the strait between Kvarner Bay and Rijeka Bay) was probably interrupted. Water exchange between Rijeka Bay and Vinodol Channel on one side and Kvarnerić and the open Adriatic on the other also became difficult. This could have caused formation of brackish or even freshwater lakes. On the other hand lowering of the erosional base induced stronger karstification of the area and enhancement of the erosional processes in non-karstic but also in karstic areas. A more humid climate during the last glacial could enhance these processes (LOWE & WALKER, 1997). Due to the lower sea-level, deposition of terrigenous material brought into the sea occurred further away from the recent coastline, in areas where terrigenous influence is negligible today. This might explain most of the sandy sediments found at depths deeper than 40 or 50 m. Such terrigenous, mostly sandy sediments are very common in the outer open Adriatic part in the SW part of the investigated area. Most probably, rivers draining the Alpine region brought this sandy material (CORREGGIARI et al., 1996b). The main source of terrigenous material that is deposited in the Adriatic comes by rivers from the Alps (Po, Adige, Soča/Isonzo, Tagliamento, Piave, Reno, Brenta). Today a current system of the Adriatic transports and deposits that material along the Italian coast (ARTEGIANI et al., 1997). During the Würm, i.e. during lower sea-level, Istria and the Cres-Lošinj archipelago prevented deposition of that material in the Kvarner channel zone. Therefore, bottom sediments west of Cres and Lošinj islands are mainly sandy and belong to the Padanian, and those to the east are more silty and belong to the Kvarner petrographic province (ŠKRIVANIĆ & MAGDALENIĆ, 1979). However, zones of sand (S) and of gravelly sand (gS) are also found in the eastern part, around local sources of terrigenous material (flysch and loess) e.g. southern part of the Krk Island (Baška and Stara Baška), around Rab and Susak Islands (Fig. 2).

At the peak of glaciation the whole northern Adriatic became land, whereas the Po River and its tributaries flowed up to Jabuka pit (MORELLI et al., 1969; TRINCARDI et al., 1996). West of the Cres-Lošinj archipelago there was probably an alluvial plain, over which winds brought loess to the Kvarner region (BOGNAR & ZAMBO, 1992). In depressions at the bottom of the recent Rijeka Bay and possibly Vinodol Channel, karst lakes probably remained and/or were formed. The bathymetrically deeper Kvarnerić had contact with the open sea in middle and southern Adriatic for a longer period.

A rapid sea-level rise began 18,000 years ago, along with the onset of the warming of the Globe. Due to melting of the glacial cover sea-level rose very fast and in steps between 17,000 and 6,000 yBP, whereas afterwards the rise substantially decelerated (KIDSON, 1986; FAIRBANKS, 1989; PIRAZZOLI & PLUET, 1991; BARD et al., 1996). Therefore drowning of the northern Adriatic including the Kvarner region started approximately 10,000 yBP, indicating that hydrographic and sedimentation conditions similar to the actual ones initiated in Holocene. The sea drowned karst relief, and due to the fact that input of terrigenous material was relatively small, elevated rocky parts remained uncovered. However, in depressions in the paleorelief deposition of material that nevertheless came from the shore began. This fast sea-level rise until 6,000 yBP has had two effects: a deceleration of erosion/denudation due to rise of the erosional base, and change of place of deposition of fluvial material due to the shift of river mouths (BENAC et al., 1992).

Only in the last 6,000 years, due to deceleration of the sea-level rise and stillstand are the effects of the marine erosion (abrasion) more pronounced. On the Kvarner coasts the effects of abrasion are not very pronounced due to low wave energy and prevalent carbonate lithology. Only on the coast in less resistant material (flysch marls and Quaternary sediments) are marine erosion effects pronounced (BENAC, 1992). Carbonate rocks are primarily affected by karstification and to a lesser extent mechanical weathering. Therefore the terrigenous supply in the Kvarner is less pronounced. Sources of terrigenous particulate material are mostly flysch outcrops in the Rijeka hinterland, and on Krk and Rab islands. Transport of material is either direct from the shores, or only sporadically *via* permanent rivers (Raša, Rječina, Dubračina) and numerous temporary torrential flows.

The direct consequence of marine erosion (abrasion) is the formation of a rocky substrate without sediment cover or with coarse grained sediments. Therefore, on shores exposed to waves, the bottom, to a depth of 20 m is rocky or covered with gravel, whereas in protected coves the bottom is covered with coarse biogenous sand at 2 m depth. An area of reefs SE of Cres Island exists where a large part of the seabed to the 10 m isobath is bedrock, and covered with gravel (sG) to a depth of 20 m. In Kvarner, rocky (erosional) coasts prevail, whereas depositional (gravelly and sandy beaches) coasts are subordinate (BENAC et al., 1998). However, strong currents can prevent deposition of finer particle at greater depths, and this might be the reason why rocky bottoms occur in the southern part of the Unije Channel, west of Pernat peninsula on Cres Island, and in Krušija Channel between Cres and Plavnik islands (Fig. 2).

On carbonate shores in the Kvarner region bioerosion is remarkable in the infralittoral zone. This is, like karstification, a relatively slow geomorphological process. It has been found that organisms dissolve or scrape approximately 11 kg of rock in a year along 1 m of the carbonate coast in the Adriatic (SCHNEIDER, 1976; TORUNSKI, 1979). Part of this material is dissolved and other might be a source for recent clastic sediments.

Muds (>95 % of particles smaller than 0.063 mm) are characteristic cover for sea-bottoms below wave base. For example, in the sheltered Bakar Bay flocculated cohesive mud is found on the bottom at 20 m depth, whereas on shores exposed to waves in Istria near Brseč or along Cres Island muddy sediments are found only at depths greater than 50 metres. It is suggested that fine grained muddy material found in the deeper parts (Rijeka Bay, Vinodol Channel, northern part of the Velebit Channel, Kvarnerić) is of recent origin and is deposited according to recent hydrographic conditions, i.e. beneath the wave base. Sources of this fine grained material are permanent and temporal flows, direct input of weathered material, and probably submarine springs (vrulje) along the coast.

The mineral composition of sediments is known in more detail only for Rijeka Bay. A terrigenous influence in coarse grained sediment is most prominent at the Rječina River mouth where quartz and siliciclastics transported from the flysch hinterland occur. Analogously, sediments at the Dubračina River mouth may have similar composition. According to the prevalence of quartz and siliciclastics in the beach sands of Rab Island (CRNJAKOVIĆ et al., 1998), one can presume similar composition and terrigenous origin of coarse grained sediments offshore the Rab Island. Red soil (*terra rossa*) ubiquitous on the land in Kvarner region is polygenetic, and its distribution is a consequence of erosion and accumulation (BENAC & DURN, 1997). Erosion of these soil deposits may also be a source of particles for bottom sediments.

Part of the sandy particles in Kvarner bottom sediments are also biogenic (calcite, Mg-calcite and aragonite shells, skelets and their fragments). Biological processes of sediment mixing (bioturbation) are most probably responsible for the formation of mixed (fine and coarse grained) sediments found prevalently at the bottom such as muddy sand (mS) and sandy mud (sM). In case of sediments found in the Kvarner region bioturbation most probably causes mixing of the upper layer of fine grained recent sediment with deeper laying residual terrigenous sand.

The thickness of marine Holocene sediments in the Kvarner region is only partially known. Marine seismic techniques (deep seismic profiles) and subbottom profiles (shallow profiles) were systemised only for the Rijeka Bay (BENAC, 1996; JURAČIĆ et al., 1998). They indicate that the base to the first prominent reflector (presumed base of unconsolidated or semiconsolidated Holocene sediment) in open waters of the Rijeka Bay varies from 2 to 10 metres. From the presumed initiation of Holocene marine sedimentation and the measured thickness, the calculated average sedimentation rate of Holocene mud is between 0.2 and 1.7 mm/year (JURAČIĆ et al., 1998). However, near the Rječina and Dubračina River mouths, where terrigenous input dominates, the depth of Holocene sediments is a few tens of metres (BENAC et al., 1992). Holocene sediments more than ten metres thick were also found by exploratory drilling in the vicinity of mouths of ephemeral creeks (torrents).

7. CONCLUSIONS

Sediment distribution on the sea floor of the Kvarner region is a consequence of a few morphogenetic steps correlated with sea-level changes during the Pleistocene. During younger morphogenetic steps traces of the former sea-level fluctuations were destroyed and masked. Sea-level and climatic oscillations during the Würm had a paramount influence on sedimentation in the Kvarner. Due to the much lowered sea-level in some periods of the Würm glacial, connections between Rijeka Bay, Kvarnerić, and Vinodol Channel and the open Adriatic were reduced or even interrupted. During conditions of lower sea-level the elevations of the Cres-Lošinj archipelago were a morphologic barrier that divided the open Adriatic sedimentation zone from the relatively isolated Kvarner basin. Therefore, bottom sediments west of Cres and Lošinj are prevalently sandy and belong to the Padanian watershed, and those to the east, prevalently muddy, belong to the Kvarner petrographic province. When sea-level was lowered, coarse-grained terrigenous sediments were deposited in deeper parts of the Kvarner, where recent hydrographic conditions do not facilitate such deposition. However, restricted zones of sand (S) and gravelly sands (gS) occur near the local sources of coarse terrigenous material, e.g. south of the Krk Island, near Rab Island or in front of the Rječina and Dubračina River mouths. Some of the coarse-grained particles found in sediments are biogenic.

Due to the rapid Late Würm - Holocene transgression, when sea-level rose more than 100 m, parts of the prevalently karstic land were drowned and recent sedimentation environments formed.

The sources of the fine grained material that cover the deepest basins are a few permanent and ephemeral flows, direct coastal weathering, and presumably underwater springs (vrulje) located along the coast. These deposits are in accordance with recent hydrographic conditions. On the other hand, coarse-grained sandy sediments found in open waters SW of Cres and Lošinj islands and between Rab and Pag islands, along with the coarse-grained terrigenous fraction of mixed muddy/sandy sediments are found below the wave base. They were presumably deposited during the Würm or during the Holocene transgression in different hydrographic conditions, and are not concordant with recent hydrographic conditions. These sediments are found on the seafloor where there is not enough terrigenous material to cover them.

This map has been produced on the basis of existing data, and indicates the main sediment pattern of the Kvarner region. Older Quaternary sediments have not yet been investigated thoroughly, and require further research.

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