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SHORE PLATFORMS ALONG THE NORTH-WESTERN ISTRIAN COAST: AN OVERVIEW

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ABSTRACT

This paper examines, by means of a survey of the platform width and repeated morphological observations compared to anemographic features, the morphology and processes concerning the development of shore platforms along the north-western Istrian coast, between Muggia and Piran. Platform width mainly controlled by fetch and wind exposure, ranged from 20 m, in the embayments, to 80 m, next to the headlands. This study, far from being exhaustive, aims at being a starting point in the understanding of local shore platforms. Platform erosion seems to be the result of subaerial weathering on the higher platform, of biological weathering that alternatively protects and attacks intertidal flysch, and of waves, which, by removing sediments, exert abrasive action on the bedrock.

Key words: Shore platforms, Istrian coasts, Adriatic Sea, cliffs

PIATTAFORME COSTIERE LUNGO LA COSTA NORD-OCCIDENTALE DELL'ISTRIA: UNA PANORAMICA

SINTESI

Si esaminano, mediante il rilievo dell'ampiezza della piattaforma e con osservazioni morfologiche ripetute nel tempo comparate con le caratteristiche anemografiche, la morfologia e i processi connessi con lo sviluppo delle piattaforme litorali lungo la costa nord-occidentale dell'Istria, tra Muggia e Pirano. Le ampiezze delle piattaforme locali, controllate in primo luogo dal fetch e dall'esposizione ai venti, variano da un minimo di 20 m nelle baie a 80 m in prossimità dei promontori. Il presente lavoro, lungi dall'essere esaustivo, vuole rappresentare un punto di partenza nella comprensione delle piattaforme costiere locali. L'erosione della piattaforma sembra essere il risultato dell'alterazione subaerea, nelle parti più elevate della piattaforma, dell'alterazione biologica, che alternativamente può proteggere o attaccare il Flysch intertidale e delle onde, le quali esercitano un'azione abrasiva sul substrato roccioso, non direttamente, ma grazie ai sedimenti in carico.

Parole chiave: Piattaforme costiere, coste dell'Istria, Adriatico, falesie

INTRODUCTION

The Holocene transgression gradually brought the sea to its present level, so for 6,000 years, marine and subaerial processes have been working on the shoreline, to create shore platforms. Trenhaile (2001) uses the term "shore platform" to refer to erosional surfaces within the actual intertidal zone, and the term "continental shelf" to the surface extending underneath. He suggests (Trenhaile, 1989, 2001) that subtidal surfaces are much wider when sea level is rising. Sorensen (1968) suggests the lowering of the sea floor is extended far below the surf base, therefore a part of the subtidal rocky shelf could currently be influenced by wave erosion. For this reason it is difficult to define a precise borderline between the actual and the relict bench. In this paper I use the term "subtidal rocky shelf", rather than "continental shelf" to distinguish the "wide rocky bench", showing ancient platform morphologies, from the sandy lower continental shelf.

Along the north-western Istrian coasts there are more than 15 kilometers where wide shore platforms occur, but morphodynamics and evolutive factors of platform development are not fully defined. Thus, purely descriptive terms, such as "shore platform", is preferable (Bird, 1976; Pethick, 1984; Trenhaile, 1987), rather than terms such as "abrasion terrace", always used in local literature, the latter including a genetic connotation (Sunamura, 1992).

Since Flysch is a relatively attachable rock-facies, there are only examples of sloping platforms along the north-western Istrian coasts, without a marked seaward drop (Type B; Sunamura, 1983). This type of platform generally grows with cliff recession; Flemming (1965) describes the first mathematical model, with stable sea level, in which his results were not in accord with the equilibrium theory. Sunamura (1978a) indicate that a platform grows if waves at the cliff foot have sufficient force to cause cliff recession, and stops when the wave assailing force becomes equal to the resisting force of the cliff. When the coastal rock is weaker, if the other factors remain constant, the platform becomes wider and flatter. But these models assume that there is no amount of debris supplied from the cliff and that no subaerial weathering occurs. Bedrock lowering, too, is important in platform development. Bartrum (1916, 1938), Wentworth (1938, 1939), Hills (1949) and Stephenson & Kirk (1998, 2000a, b) support weathering as the formative process, while Dana (1849), Bartrum (1924, 1926), Edwards (1941, 1951), Sunamura (1978b), Trenhaile (1987), Tsujimoto (1987) and Sunamura (1990) support wave action. So, Stephenson & Kirk (2000a) speak about the "wave *vs.* weathering" debate. Understanding these factors is important for the study of ancient and recent evolution of the coast.

This paper aims at providing an overview of the shore platforms along the north-western Istrian coast, at describing their morphology and development, by using morphological analysis. The results of this work were presented, some months ago, in the public debate *"Quanto vale la costa di Muggia"*, in which the impact of the landfill project in Punta Sottile and the opportunity to create a Coastal Reserve from Punta Sottile to Debeli Rtič were evaluated.

MATERIAL AND METHODS

Study area

The north-western Istrian coasts are located in the Gulf of Trieste, on the east coasts of the North Adriatic Sea (Fig. 1). The area involves about fifty kilometers of partly natural shoreline, with about 15 km of shore platforms, and partly human-built shoreline, characterized by the presence of coastal roads, sea walls, landfills and towns.

Geologically, the area belongs to the so-called Grey Istria (Ambert, 1978). Its name derives from the presence of the thick Eocene flysch, consisting of interbedded sandstones and marlstones and carbonate turbidites, with ratio bed thickness changing irregularly (Pavšič & Peckmann, 1996).

Tidal range in the North Adriatic Sea is typically in the order of 1 m, one of the highest in the Mediterranean Sea, but, in particular meteoclimatic conditions, water sea level can rise to 2 m m.s.l. Mean sea level is lower during the winter (4 cm), spring and summer (1 cm), and higher during the autumn (5 cm) (Stravisi, 1988).

Precipitations average about 1,341 mm per year with the highest rainfall observed during June and November (http://www.dst.univ.trieste.it/OM/OM.html).

The northern Adriatic Sea is a shallow basin (mean depth ~20 m), so high frequency waves are quite modified by sea floor and the wave breaking occurs away from the shore, with high loss of energy. Generally, the area is quite protected from waves of the second and third quadrants, with predominant wind directions from northeast, then southeast and northwest. The windiest months are February and October (Stravisi, 1991). The strong northeast winds (*bora*) can produce 2 m high waves in the southern part, particularly at Piran and Rt Ronek. South-eastern waves, 20-50 m long, arrive reflected, but they are not more than 1 m high (Mosetti, 1988). Only sporadic *libeccio* (SW) causes 3.4 m high waves and affects particularly the south-western coast of Debeli Rtič and Punta Sottile, even though there are no high waves due to the limited fetch (Mosetti, 1988).

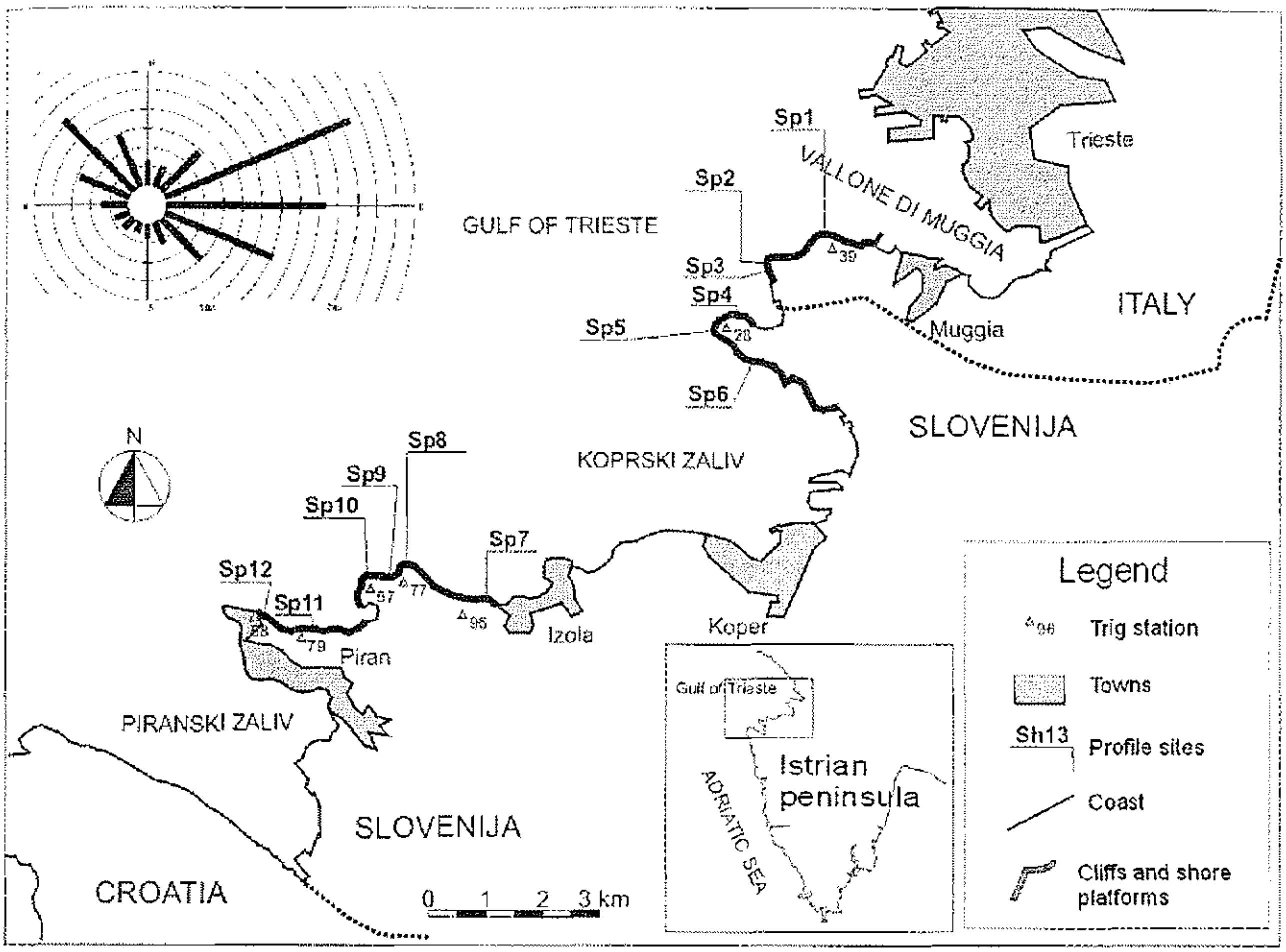


Fig. 1: The north-western Istrian coast, town names and profile sites.
Sl. 1: Severozahodno istrsko obrežje, imena mest in vzorčevalni profili.

Material and methods

Along the Italian and Slovenian shores, twelve sites (Fig. 1) were surveyed in the period between June 2001 and June 2003. Six of the sites are located in the northern sector, between Punta Olmi and Debeli Rtič, and six in the southern sector, between Rt Kane and Piran. Surveys were carried out with the Automatic Level Ertel (Salmoiraghi) to measure elevation and with a rule to measure lengths. Then, profiles were controlled by SCUBA recognition. Some profiles were corrected with tide because of the distance of a trigonometric station. Three profiles, in the Italian sector, were extended offshore with the Echosounding Lowrance X16 operated from a boat.

RESULTS AND DISCUSSION

Sloping platform width is defined as the area between the foot of the cliff and either the low tidal level or the position providing the surf base. We recognized two types of sloping platforms: gently sloping platforms (Type A; Sunamura, 1992) and ramp platforms. The first type of platforms was identified at Sp5 and Sp9. These platforms are located off prominent headlands (Debeli Rtič and Rt Ronek) and display a platform width ranging from 70 to 80 m. They are exposed to the longest fetch length (up to 125 km). As Trenhaile (1999) suggests that platform width increases with wave intensity, I studied the correlation between maximum fetch length and platform width (Tab. 1). At Debeli Rtič and Rt Ronek, for example, the platform is really wide and the sites are exposed to the longest fetches. A good relationship between fetch and platform width was observed along the north-western Istrian coasts (Fig. 2). Allan *et al.* (2002) suggest that fetch length may be used as a surrogate for wave energy. Linear regression analysis reveals a positive correlation between fetch and width (r^2=0.63). Data for Punta Sottile were not included in regression equation because of the presence of the coastal road, which restricts platform width.

Tab. 1: Morphological characteristics of shore platforms along the north-western Istrian coast.
Tab. 1: Morfološke značilnosti obrežnih ploščadi vzdolž severozahodnega dela istrske obale.

	Site	Strike/ dip (°)	Platform width (m)	Shore orientation (°)	Max fetch (km)	Notes
Sp1	Punta Olmi	120/45	26	345 NNW	48	Coastal road on the cliff/platform junction
Sp2	Punta Sottile	330/25	/	265 W	125	Coastal road on the cliff/platform junction
Sp3	Punta Sottile-WSW	320/55	28	245 WSW	125	Coastal road on the cliff/platform junction
Sp4	Debeli rtič-N	325/30	33	355 N	47	/
Sp5	Debeli rtič-SW	320/25	60	250 W	120	/
Sp6	Debeli rtič-SSW	295/12	35	200 SSW	120	/
Sp7	Rt Kane	115/40	20	360 N	42	/
Sp8	Rt Ronek	100/20	70	295 WNW	105	/
Sp9	Ronek-Strunjan	110/20	25	320 NNW	41	/
Sp10	Strunjan rtič	105/15	40	320 NNW	98	/
Sp11	Pacug-Fiesa	100/5	20	15 NNE	38	/
Sp12	Piran	90/10	22	35 NNE	39	/

Ramp platforms have been identified in many sites. They have a steep sloping profile and are found on long straight shores and in embayments. Because of their high gradients, they are narrower than gently sloping platforms.

Inside these two types of platforms, it is possible to recognize a high platform, a "normal intertidal platform" and a low platform. The high platform, near the cliff/platform junction, is barely covered by maximum high tides, the normal intertidal platform is alternatively covered and uncovered by normal tides and the low platform is uncovered only during minimum low tides. At higher elevations, sub-aerial weathering dominates the erosion processes, while slope wash processes remove the weathered debris and transport the material seaward, on the low platform. In the "normal intertidal platform" there is a great incidence of wetting and drying weathering, but also of wave abrasion, due to the action of waves armed with rock particles. These waves hit the bedrock and remove material. Freeze/thaw weathering is not important as temperature is rarely less than 0 °C. In the period between December 2002 – February 2003, temperature reached –3.5 °C. Laboratory simulations (Robinson & Jerwood, 1977) indicate that destructive freezing occurs only when the internal rock temperature drops below –4.5 °C.

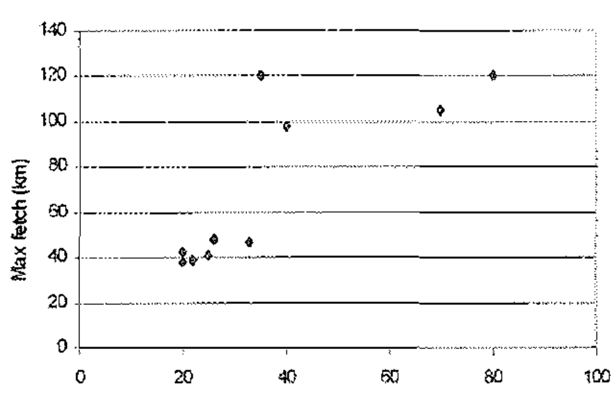


Fig. 2: Correlation of fetch versus shore platform width.
Sl. 2: Razmerje med dolžino in širino obalne ravnice.

Shore platforms from Muggia to Lazaret

The Muggia peninsulá is elongated NW-SE and is characterized by different fetch orientation. From Muggia to S. Bartolomeo the cliff/platform junction is characterized by a coastal road and some harbour structures (Muggia, Porto S. Rocco, Lazzaretto), so actual shore platforms are really narrow. At Punta Olmi (Sp1), there is a cobble beach with trash from coastal road construction (Brambati & Catani, 1988). The shore platform is 26 m wide, with a *Cymodocea nodosa* carpet within sandstone boulders on the lower part; from Punta Olmi to Punta Sottile it is completely hidden by the coastal road and by the recent landfill. Moreover, in Punta Sottile, because of the coastal road, actual bench is narrow or not present, but there is a wide subtidal rocky platform. From Punta Sottile to Piran this surface is really wide, up to 4-500 m (Figs. 3, 6). This surface is characterised by wide sandstone bedrock, sometimes horizontal or nearly horizontal, sometimes dipping NE, and sometimes covered with abundant debris. This outcrop looks like a man-made pavement, the so-called "Roman pavement" (Furlani & Frenopoulos, 2003). Rock debris ends at about 9 m depth, where sand deposition starts.

From Punta Sottile to Lazzaretto, the shore platform is about 30 m wide (28 m in Sp3). Because of the coastal road, only during low spring tide the actual platform is dry (Fig. 4). It is partially covered by clastic sand with *Cymodocea nodosa* within a series of sandstone outcrops, dipping NE, down to 3.50 m depth. Along Punta Sottile and Debeli Rtič shoreline, there are many Roman structures (Gobet, 1983; Župančič, 1990).

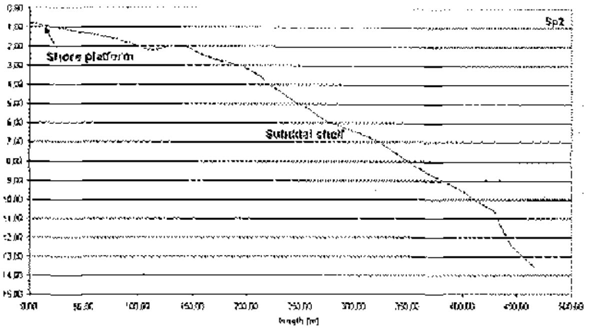


Fig. 3: Profile site Sp2 at Punta Sottile. The shore platform is visible only during the lowest tides, but down to depth of 10.5 m there is a wide subtidal rocky shelf.
Sl. 3: Profilna lokacija Sp2 na Punti Sottile (Tenki rtič). Obrežna ploščad je vidna le med najnižjo oseko, čeprav se široka podbibavična skalna polica razteza do globine 10,5 m.

Shore platforms from Lazaret to Ankaran

At Debeli Rtič, three profile sites show different platform width, according to maximum fetch and wind exposure. In profile Sp4, facing north, shore platform width is 33 m, with a maximum fetch of 47 km. This site is exposed to quadrant I and II. Sp5 is exposed to quadrants I, II and IV. Maximum shore platform width is about 80 m (Fig. 5) and a wide subtidal shelf is visible on aerial photographs. Cliff/platform junction varies from 0.3-0.4 m to more than one-meter m.s.l., with the lowest elevations being scratched by waves during most of the high tidal cycles. A 6.3 m wide cobble ramp links the cliff and the platform. Debris at the cliff toe is 6.3 m wide. Shore platform is partially covered by clastic sand with seagrass (*C. nodosa*) which, together with organic crust, protects the platform from erosion. Most of the shore platform remains below mean sea level, except during the lowest tides (Fig. 7). From 45 m to 80 m there is a vast pebble shoal, lightly rounded, resulting from storm-wave diffraction. From 80 to 100 m, sandstone beds, dipping NE, are covered by terrigenous/ bioclastic cobbles, while marlstone beds are easily exposed to destroying organisms.

In places where cliff/platform junction is low, particularly in the northern exposed sectors, storm waves attack materials at the foot of the cliff very quickly, allowing the formation of interesting cliff morphologies (notches and nips). In the northern sectors between Debeli Rtič and Strunjan Rtič, there are small notches. At Debeli Rtič, the roof of the notch is 2.8 m m.s.l., 2 m high and 15 m long. Longitudinal section follows the bed's strike. The permanent photographic station controls notch and platform development. During the period from June 2001 – June 2003, debris at the cliff base was produced mainly by cliff falling, whereas storm waves removed the debris. The bedrock is alternatively covered with sediment of various sizes or exposed to wave attack and weathering (Fig. 8), thus the depth of sediment cover becomes an important factor for bedrock erosion. In fact, during the rainy period debris is removed seaward to the low platform, while NE winds store up cobbles on the higher platform, thus protecting it from bedrock lowering. Waves seem to be very important to move sediment along the platform and, even though they are not capable to produce erosion, waves can move cobbles and pebbles on the bedrock with abrasive action.

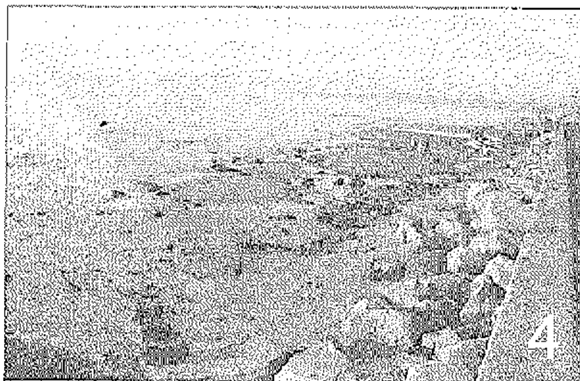
The north-western shoreline of Debeli Rtič is treated as a human structure, parallel to the shoreline, 71 m from the cliff/platform junction, -0.8 m m.s.l. The structure is about 200 m long, maybe built by the ancient Romans. It protects near-shore from wave attacks, so behind this structure there is a wide intertidal sand shoal. Here, cliff/platform junction is high and the cliff is particularly protected, allowing for the growth of abundant vegetation.

Along the south-western sector, the platform is 35 m wide. It has a long maximum fetch, but it is fairly well protected by the dominant winds of the quadrants I and II, thus only during SW and NW and SE storms it is attacked by waves. Between June 2002 – June 2003, waves attacked through this cliff only twice (16.11.02 and 07.12.02). Cliff is less hanging and cliff/platform junction is protected by a cobble beach of various sizes. Recession, in fact, is mainly due to subaerial weathering, and since this sector is not exposed, waves do not easily remove materials.

Along the coastal belt of Debeli Rtič, north cliffs are generally more hanging and shore platform has a narrow ramp, while south-western cliffs are fairly lofty and less hanging; moreover the ramp, linked to debris size, is wider. Robinson (1977) suggests that wider platforms develop with sandy beaches at the cliff base, then with bare bedrock, boulder and talus cone, since the mobility of the deposits of the foot of the cliff determines the degree of protection and the amount of abrasion (Trenhaile, 1999). The size of clastic sediments on the beach depends on the thickness of sandstone beds of the eroding cliff face.

Shore platforms from Izola to Strunjan

Between Simonov zaliv and Strunjanski zaliv there is a 5 km long cliffy coast, bordered by shore platforms. The subtidal rocky shelf is very wide from Izola to Piran, down to 10 m deep. Cliffs are high (up to 90 m m.s.l.,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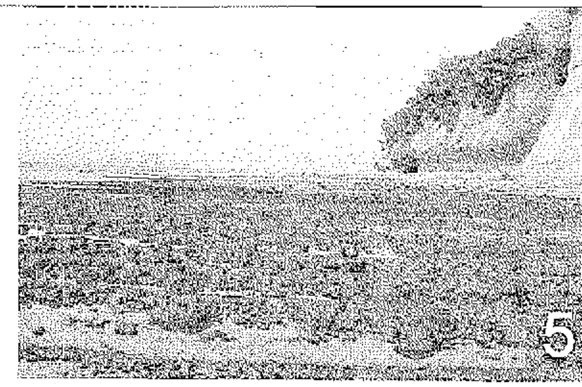
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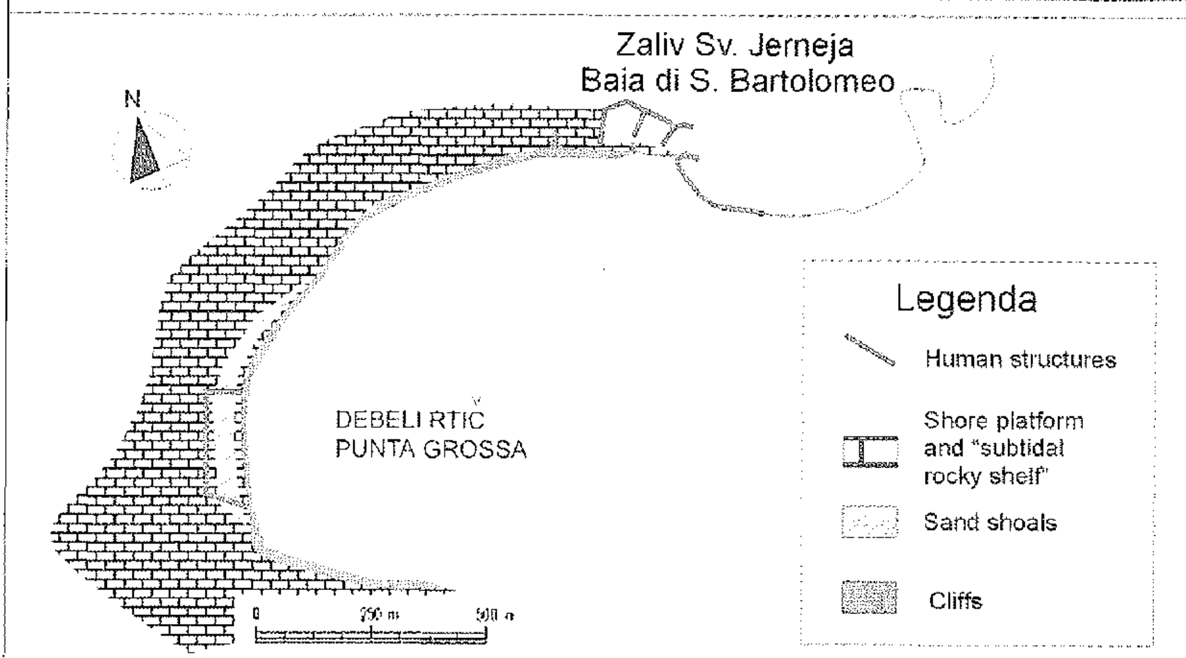
Zaliv Sv. Jerneja
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Legenda
Human structures
Shore platform and "subtidal rocky shelf"
Sand shoals
Cliffs

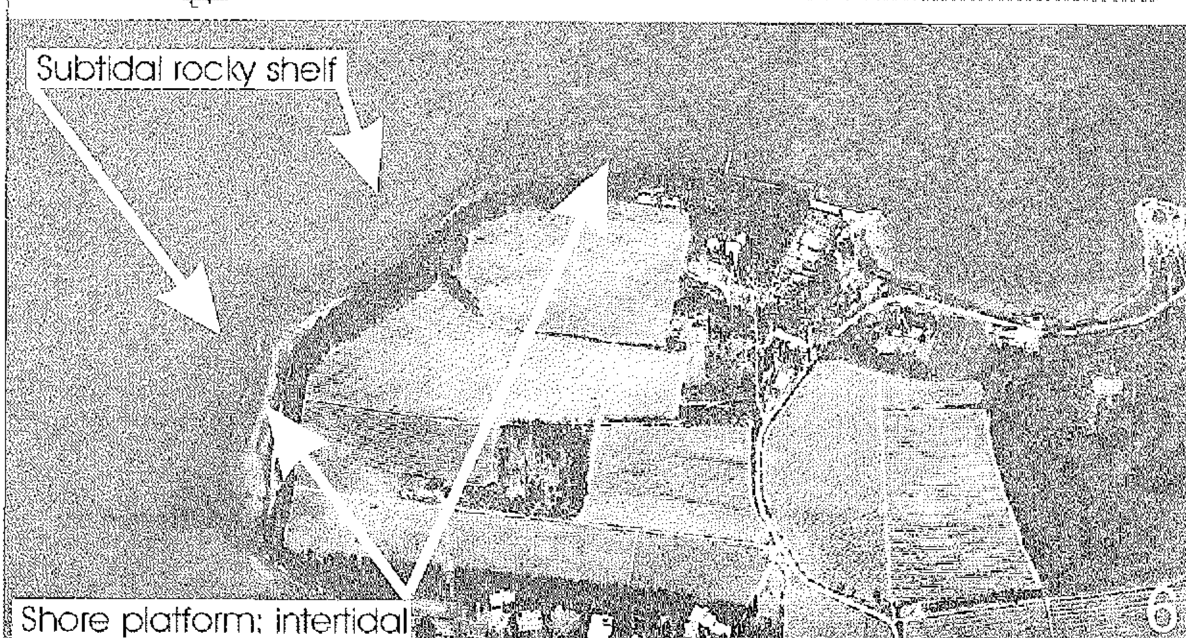

Subtidal rocky shelf
Shore platform: intertidal
6

Fig. 4: At Punta Sottile, the shore platform is visible only during the lowest tides, as the coastal road has been built on the shore platform. (Photo: S. Furlani)

Sl. 4: Pri Punti Sottile (Tenki rtič) je obrežna ploščad vidna le med najnižjo oseko, saj je bila na platformi zgrajena obalna cesta. (Foto: S. Furlani)

Fig. 5: The gently sloping platform at Debeli rtič (15.04.03). The bench consists of bands of sandstone, which outcrop seawards from the cliff base (right). Marlstone interbeds are lower in elevation because of their low resistance and form a sort of channels, sometimes filled with cobble. (Photo: S. Furlani)

Sl. 5: Rahlo spuščajoča se ploščad pri Debelem rtiču (15.04.03). Terasa sestoji iz pasov peščenjaka, ki prihajajo na dan v smeri morja iz klifovega podnožja (desno). Laporjeve medplasti, ki zaradi svoje nizke odpornosti ležijo niže, oblikujejo nekakšne kanale, ki so včasih zasuti s prodniki. (Foto: S. Furlani)

Fig. 6: Aerial view and map of Debeli rtič. It is difficult to define a precise borderline between the actual shore platform and the subtidal rocky shelf due either to the morphological continuity or to the fact that the lowering of sea floor is extended far below the surf base. (By courtesy of Regione Autonoma Friuli Venezia Giulia)

Sl. 6: Zračni posnetek in zemljevid Debelega rtiča. Zaradi morfološke kontinuitete ali pa dejstva, da se morsko dno počasi znižuje, je težko ugotoviti natančno mejo med dejansko obrežno ploščadjo in podbibavično skalnato polico. (Z dovoljenjem avtonomne regije Furlanija-Julijska krajina)

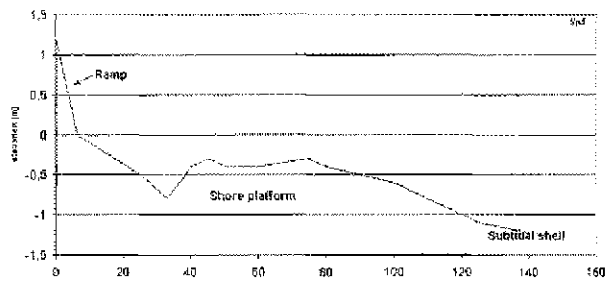


Fig. 7: Profile site Sp5 at Debeli rtič. Diffraction of waves has created a wide cobble shoal.

Sl. 7: Profilna lokacija Sp5 pri Debelem rtiču. Lomljenje valov je povzročilo široko prodnato plitvino.

very steep off the headlands and gently sloping in the embayments. In Rt Kane the cliff/platform junction is charecterised by a thick sandstone bed (more than 1 m) dipping SW. Shore platform is narrow and sandstone blocks protect the cliff base, either for their thickness or for dip and strike. Trenhaile (1999) suggests that platform width decreases with increasing rock dip, but in this case it is quite difficult to evaluate this relation as the most resistant sandstone strata are very thick, thus thickness is more important to protect the cliff base than rock dip.

Between Rt Kane and Strunjan there are four small embayments. I observed that platform deposits were larger in debris size with angular cobbles on the east sides of these bays, and smaller and rounded on the west sides. Past Rt Ronek, seagrass gradually disappears. Between Rt Kane and Rt Ronek, as well as between Rt Ronek and Strunjan Rtič, there are some turbidite beds, like a rampart, which border on actual shoreline (Fig. 9) or cut platforms transversally. Along the shoreline there are some interesting travertine boulders. At Rt Ronek, the actual platform width is 70 m. This gentle sloping platform is similar to Debeli Rtič (Sp5). A narrow ramp, wider than at Debeli Rtič, connects the cliff base with the platform. In the east sector, there is a Flysch bedrock, in which less resistant marlstone strata, always exposed to destroying organisms, produce channels between more resistant sandstones, so marlstone beds are wetter than sandstone beds.

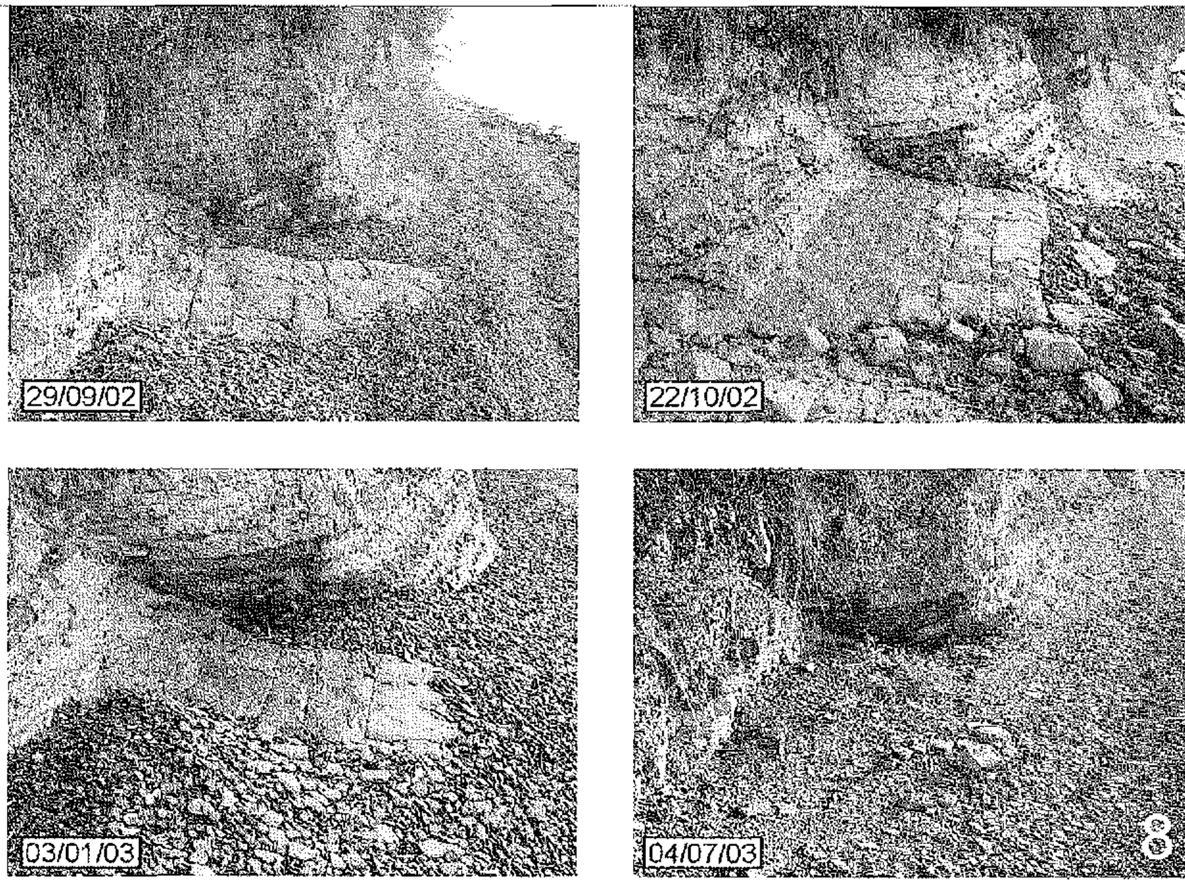
Shore platforms from Strunjan to Piran

In this sector, only ramp platforms occur. Cliffs are up to 79 m high and between Strunjan and Fiesa, cliff/platform junction is hidden by turbidite boulders, originated from a metric turbidite layer, about 20 m m.s.l., on the bordering cliffs (Fig. 10). These boulders are particularly abundant along Pacug – Fiesa and protect the cliff. Flysch strata are near horizontal. The shore platform is narrow (20 m), chiefly because boulders do not allow materials to be removed. Only if there is a lack of boulders, storm waves reach the cliff base and remove the debris, otherwise the bedrock is completely hidden.

Between Fiesa and Madona Rtič, the shore platform is quite narrow, about 25-30 m. Part of the coastal belt is adjoined by a path, built on the shore platform. Cliffs are quite hanging without debris toe. Particularly narrow is the shore platform in front of the Church of St. George's walls in Piran.

CONCLUSIONS

The north-western Istrian shore platforms are features neglected by local researchers, despite their great importance in understanding the actual morphodynamics, sea level rising etc. Along these shores two types of morphologies have been identified: gently sloping platforms and ramp platforms, characterized by widths ranging from 20 to 80 m, with the gently sloping platforms having the widest morphologies. Platforms are particularly wide in front of the headlands (Debeli Rtič,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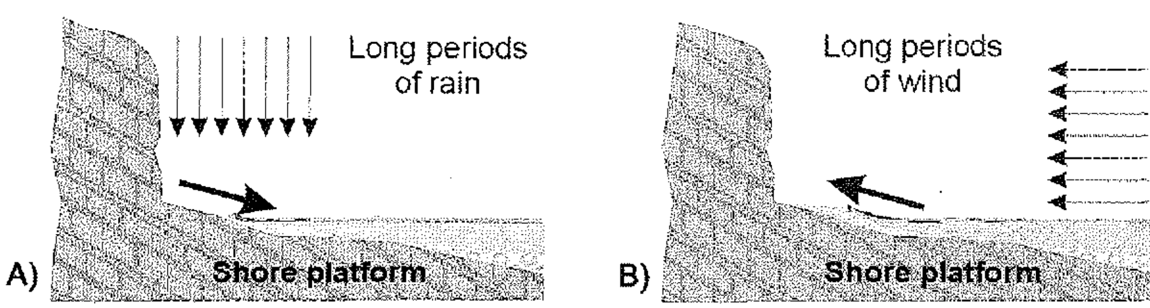
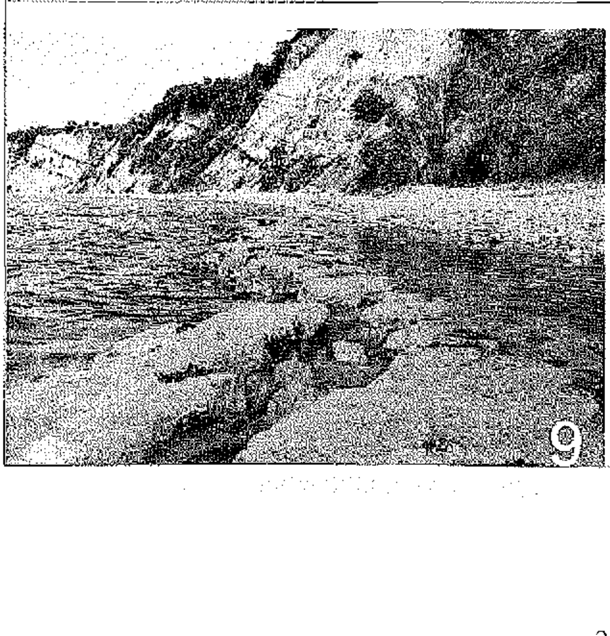

Long periods of rain
Shore platform
A)
Long periods of wind
Shore platform
B)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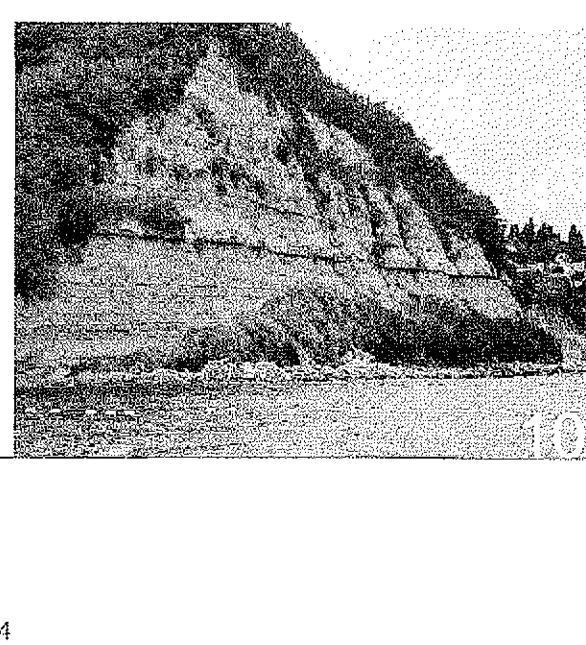
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Fig. 8: Station PG1 at Debeli rtič: The bedrock is alternatively covered with sediment of various sizes or exposed to wave attacks. During rainy periods, debris is removed seaward, while NE winds store up cobbles on the higher platform. (Photos: S. Furlani)

Sl. 8: Postaja PG1 pri Debelem rtiču. Matični substrat izmenično prekrivajo usedline različnih velikosti ali pa je izpostavljen butanjem valov. V deževnih obdobjih naplavine odnese proti morju, medtem ko severovzhodni vetrovi prestavijo prod na višjo ploščad. (Slike: S. Furlani)

Fig. 9: These turbidite beds border on the actual shoreline between Rt Ronek and Strunjan rtič. (Photo: S. Furlani)

Sl. 9: Te turbiditne plasti mejijo na obrežje med Rtom Ronek in Strunjanskim rtičem. (Foto: S. Furlani)

Fig. 10: Between Pacug and Fiesa the shore platform is narrow, chiefly because boulders do not allow the materials to be removed. (Photo: S. Furlani)

Sl. 10: Obrežna ploščad med Pacugom in Fieso je ozka, predvsem zato, ker kamniti bloki preprečujejo odstranitev različnega materiala. (Foto: S. Furlani)

Rt Ronek as well as the wide subtidal shelf of Punta Sottile), mainly because of fetch and wind exposure, in fact relationship between fetch and platform width suggests a positive correlation. Moreover, owing to the morphological continuity, it is really difficult to find a limit between the actual platform structure and the subtidal rocky shelf.

Platform erosion seems to be the result of different processes: 1 – subaerial weathering, particularly on the higher platform and on the normal intertidal platform (wet/dry cycles); 2 – biological weathering, which alternatively protect and attacks bedrock; 3 – wave action, which directly do not exert an erosive action, but exert abrasion by removing cobbles and pebbles.

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OBREŽNE PLOŠČADI VZDOLŽ SEVEROZAHODNEGA DELA ISTRSKE OBALE: PREGLED

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Avtor na osnovi ugotavljanja širine ploščadi in večkratnih morfoloških opazovanj, primerjanih z anemografskimi značilnostmi, v članku raziskuje morfologijo in procese, ki zadevajo razvoj obrežnih ploščadi vzdolž severozahodne istrske obale med Miljami in Piranom. Širina ploščadi, ki je odvisna predvsem od izpostavljenosti valovanju in delovanja vetra, se je sukala med 20 m v zalivih do 80 m ob rtičih. S pričujočo študijo, ki seveda ni izčrpna, želi njen avtor pripomoči k razumevanju lokalnih obrežnih ploščadi. Zdi se, da je erozija ploščadi posledica preperevanja nad gladino morja na višji ploščadi, biološkega preperevanja, ki izmenično ščiti in napada medbibavični fliš, in valov, ki ob odstranjanju sedimentov delujejo abrazivno na matični substrat.

Ključne besede: obrežne ploščadi, istrsko obrežje, Jadransko morje, klifi

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