ARTICLES

SELECTED CASES OF SUBAQUEOUS SOILS IN SLOVENIAN COASTAL WATERS

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ABSTRACT
Selected cases of subaqueous soils in Slovenian coastal waters
The soil is mainly on the mainland, but also in shallow waters, the so-called subaqueous soils. Subaqueous soils form under the water surface, mainly on the bottom of shallow, stagnant waters such as bogs, swamps, lakes, and sea shallows. In St. Bartholomew, three subaqueous soil profiles were studied to investigate them in detail. The sites for recording the soil profiles were selected at random, with the aim of finding a different type of vegetation at each site. We found that the soils were influenced by almost the same factors of subaqueous soil formation; thus, the same soil forming processes of different intensity took place. Therefore, the same, very similar types of subaqueous soils were developed at each site. All samples were collected underwater using drainage pipes and by excavation. The samples were drained in the pipes. In the laboratory, visual observations and standard analysis were performed according to the horizons determined. According to the WRB classification, subaqueous soils in Slovenian coastal waters were classified asreference groups Gleysols and, Arenosols.

KEY WORDS
soil geography, subaqueous soils, soil forming factors, soil forming processes, WRB classification, St. Bartholomew Bay, Slovenia

1. Introduction

A thin layer of soil covers most of the earth's surface. This layer, which is sometimes only a meter or two thick, elsewhere only a few centimetres, seems to be irrelevant given the size of the Earth (Troeh and Thompson, 2005). Soils can be located mostly on land but also in shallow waters. Subaqueous soils are formed below the water level, especially at the bottom of shallow, stagnant waters, e.g., in bogs, swamps and lakes (Bufon et al., 2005) and are poorly studied. There are several reasons for this. Research is extremely difficult, these soils have hardly any economic value, and there are differences of opinion if this material is soil at all. Although some researchers (Kubiëna, 1953; Goldschmidt, 1958; Mückenhausen, 1965) as early as the middle of the last century recognized the material as soils, most of the researchers (geologists, biologists) consider them to be merely underwater sediment (Demas et al., 1996). The ground-breaking study of underwater material in the Maryland area (Demas, 1998) led to a change the definitions in Soil Taxonomy in 1999 (Payne and Turenne, 2009). Researches have continued, although rarely (Balduff, 2007; Turenne, 2010).

Some pedologists believed that the upper limit of the soil should be the atmosphere (Nikiforoff, 1959; Simonson, 1959; Foth, 1978), others shallow waters (Kubiëna, 1953; Goldschmidt, 1958; Mückenhausen, 1965; Ponnamperuma, 1972; Soil Survey Staff, 1975; Demas, 1993; Soil Science Division Staff, 1993; Demas and Rabenhorst, 1999). In its first edition, Soil Taxonomy identified underwater material as soil because it designated shallow water for the upper limit, in addition to air. By definition, they wanted to exclude deep-sea sediments that are too deep due to lack of light (Stolt and Rabenhorst, 2010) to allow plants to root and grow (Soil Survey Staff, 1975). The International WRB Classification included underwater soils with the definition that any material within 2 m from the Earth s surface that is in contact with the atmosphere, with the exclusion of living organisms, areas with continuous ice not covered by other material, and water bodies deeper than 2 m (IUSS Working Group WRB, 2006).

Dokuchaiev in Russia and independently Hilgard in America discovered that a given parent material may form different soils depending on the environmental conditions, particularly climate and vegetation. This was redefined later by adding additional independent factors to his soilformation equation (Jenny, 1941). In 1972 Folger (1972) described the primary factors that influence the composition and distribution of estuarine sediments. Together, the factors of Jenny and Folger thus form a new equation (Balduff 2007):

$$p_e = f(p, cl, o, t, B, F, W, E) + H$$

in which subaqueous soils (ps) are a function(f) soil forming factors: climate (cl), organisms (o), bathymetry (B), waterflow properties (F), parent material (p), time(t), chemical properties of water (W) and extreme events (E). The latter two factors were added later (Balduff, 2007) and human (H) influences were added separately.

1.2 Classification of subaqueous soils

The sediments deposited in the water were examined by geologists. The first initiative that some of the material is also a subject of pedology appeared in 1862, when the Post proposed the terms "gyttja" and "dy", which are still used today (von Post, 1862; in: Demas, 1998). The research continued 100 years later. Kubiena (1953) included underwater soils in his classification of European soils, dividing them into two categories: 1. young soils that are constantly flooded with water and do not form peat, and 2. young subaqueous soils that form peat. Muckenhousen (1965) contributed to the classification of German soils by identifying underwater soils as sub hydric and dividing them into four groups (Table 1).

Table 1: Classification of sub hydric soils by Muckenhousen (1965).

type	properties
protopedon	They consist of different sediments, are free of macroscopic humus and contain different organisms.
gyttja	They consist of organic and/or mineral sediments (mostly lacustrine sediments but also marine). They have a high nutrient content and are mostly found in freshwater environments.
sapropel	They consist of organic sediments with a distinct odour, often containing metal sulphides. They have a high nutrient content and are poorly aerated.
dy	They mostly consist of gels containing humic acid, have a low nutrient content and are poorly aerated.

Soil Taxonomy (Soil Survey Staff, 2010) of underwater soils includes special taxa within the Entisols and Histosols, like "Wassents" and "Wassists". The latest version of the WRB classification (Repe, 2018a) does not have a special underwater group but defines them with special material and qualifiers within Histosols, Technosols, Cryosols, Leptosols, Gleysols, Arenosols and Fluvisols. Underwater soils were included in the Yugoslavina classification (Škorić, 1977; Antić et al., 1984) as subaquatic or subhydric, which is also adopted by the Slovenian classification (Prus, 2000; Repe, 2010), but without any serious research.

The purpose of the research is to investigate the soils along the Slovenian coast that are occasionally or permanently under water, and their inventory, as there has been no research so far. To achieve our purpose, we have set the following goals:

1. Select a location along the Slovenian coast suitable for the study.
2. Identify and determine factors and processes of soil formation.
3. Perform appropriate underwater sampling.
4. Identify properties by field observation and laboratory analysis.
5. Classify the soils of the studied sites according to the WRB (2015) classification.
6. Identify links between vegetation and soils.

2. Methods

For the study we selected underwater soils along the coast of the Slovenian Sea. We were looking for an accumulative, lagoon coastal type (Radinja, 1990; Bat et al., 2003), which gradually descends below the water surface (Figure 2). The field work was carried out at three locations in the Bay of St. Bartholomew (zaliv Sv. Jerneja) near Lazaret, next to the Slovenian-Italian border crossing (Figure 1).

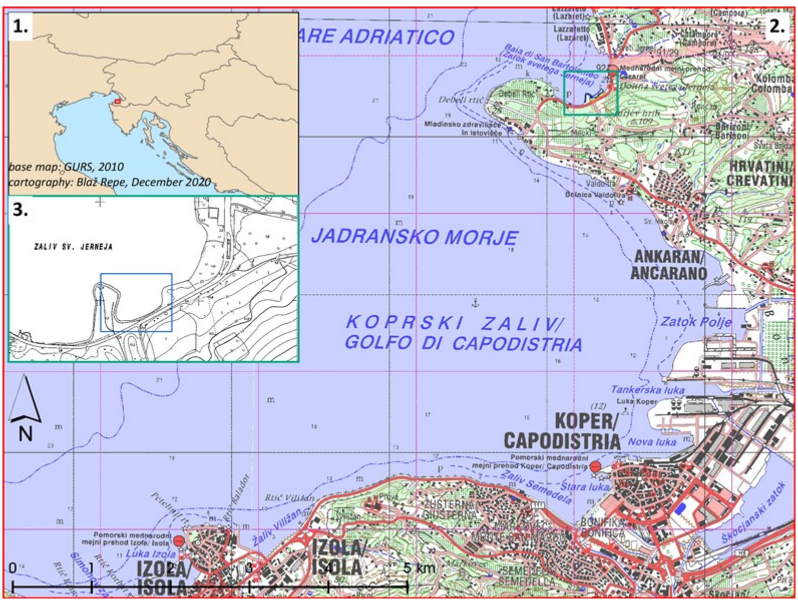

Figure 1: Map of the study area.

The sites were selected based on observing the tidal line and the vegetation adapted to this process. The first site (I.) is located directly on the coastline, where there the flooding with saline water occurs for a short time, the second location (II.) lies lower, where the ground is flooded for most of the day. Both locations are characterized by a predominantly terrestrial and/or halophytic vegetation. The third location (III.) is permanently submerged, and underwater vegetation thrives on it.

At the time of sampling, the soils were completely flooded with water. The locations differed in water depth, with the first being 10 cm, the second 20 cm and the third 50 cm below sea level. They also differed in the vegetation. The first site is located within the predominant reed belt (*Phragmites sp.*) and is submerged daily for only a short time. The second site is under water most of the time, and various halophyte plants grow there (*Salicornia europaea, Arthrocnemum glaucum, Crithmummaritimum, Limonium angustifolium, Juncus maritimus*). The third was strongly dominated by seaweed (*Cymodocea nodosa*). As was later found out in the laboratory, the soils also differ in physical and chemical properties, in the stage of development and thus in the reference group.

Figure 2: View of the Bay of St. Bartholomew (zalivSv. Jerneja) (photo: A. Pristovšek).

We performed the field work and sampling twice (October 2010), using improvised equipment to take samples. During the work we used sewer pipes. The pipes containing samples were cut in the laboratory to obtain half of the content, observing the horizons, their thickness, and other morphological characteristics. The samples separated by horizons were dried, ground, and analysed in two laboratories of the University of Ljubljana (Faculty of Arts and Biotechnical Faculty). We carried out the standardized analyses (see Figure 3 and Tables 2 and 3).

Figure 3: Field and laboratory work (photo: B. Repe).

The data obtained on the site of the sampling, the soil forming factors were determined, the soil forming processes identified, the morphological characteristics observed, and the laboratory analyses made it possible to accurately identify the diagnostic horizons, properties and materials, the classification in the reference soil group, the main and supplementary qualifiers and thus the correct naming according to WRB.

3. Results

3.1. Factors and processes of soil formation in the Bay of St. Bartholomew

The parent material (p) refers to the source of the geological material from or in which the soil was formed. The study area is located in the Slovenia's littoral region, where the Eocene carbonate flysch predominates (Pleničar et al., 1973), from which material is deposited on the coastal bottom. In the bay of St. Bartholomew, it is mainly a coarse-grained, sandy remnant of the weathering of hinterland flysch material brought into the bay by watercourses and erosion processes (Natek et al., 2018; Repe, 2018b).

The influence of climate (cl) on subaqueous soils primarily covers the effects of temperature and solar radiation (Balduff, 2007). The climate is a typical sub-Mediterranean coastal climate in which the average temperature in January does not fall below 0°C (Ogrin, 1996).

The distribution of precipitation shows a transitional pattern between the Mediterranean and continental regimes, and generally does not meet the criteria for xeric (Vrščaj et al., 2017). Due to the continent, the sea water temperature in the Gulf of Trieste has a distinct annual cycle - the lowest is usually in February (8-9 °C) and the highest in August (about 24 °C). The average annual amplitude is 15-16 °C, and the average annual temperature is about 16 °C (Radinja, 1990).

On land, the relief determines the local hydrology, and in underwater environments the opposite can happen, so that the hydrological conditions (water balance) become a decisive factor in the formation of underwater relief forms. Altitude in underwater environments is replaced by the depth (B). This influences the development of subaqueous soil profiles and allows to explain the effects of internal/internal waves and wind induced waves (Demas and Rabenhorst, 2001). The hinterland is hilly, steeply sloping towards the sea. Where local watercourses flow into the sea, shallow coastal plains have formed (Ogrin and Plut, 2009; Repe, 2018b) with silty sediments from which the soils studied have developed. The bay has an accumulation type of coastline and its bottom is rather flat. About 50 meters from the shore there is a strip of land with occasional flooding. The depths in the bay reach 5 meters only 200 meters from the shore (Hidrografija, 2018; Natek et al., 2018).

The characteristics of the water flow (F) include the velocity of the water, its direction of movement and ripples (Balduff, 2007). As early as 1937, Krumbein (Krumbien, 1939; in: Balduff, 2007) found that in environments with high water energy, a coarser sediment texture was present, and in environments with low water energy, clay. In the Bay coarse material predominates.

Subaqueous soils receive organic matter from the macroflora, such as macroalgae. The activity of underwater plants can change the chemical structure of the soil. For example, seaweed releases oxygen into the soil, which oxidizes to compounds such as reduced iron and sulphides (Holmer et al., 2005). The macroflora can physically stabilize the surface. However, its effectiveness depends on the density of plants (Koch, 2001). We have observed that root and underwater wormholes allow the transfer of oxygen and organic matter to greater depths. A large number of shells helps to increase the amount of carbonates and basic cations and also raise the pH.

Most subaqueous soils are relatively young (t) and resemble to some extent young alluvial soils in flood plains (Demas and Rabenhorst, 2001). They have poorly developed profiles and an oxidized horizon on the surface (Stolt and Rabenhorst, 2010), which is also true for soils in the Bay of St. Bartholomew. Chemical properties of the water (W) include salinity, alkalinity, percentage of oxygen saturation and nitrate content. Despite its continental nature, waters of the Gulf of Trieste have a high average salinity (37-38 ‰).

The Slovenian Sea is characterized by a high turbidity, due to a muddy and fine sandy bottom, shallow depth and large quantities of nutrients and plankton (Kolbezen, 1998). Extremes (E) include events that occasionally affect the stability of the underwater surface (Demas and Rabenhorst, 2001), which was not observed in our case. We have also not observed a major human (H) influence, except for a smaller amount of artifacts (bricks, shards) dumped by bathers or passers-by.

The soil forming processes can be divided into four groups (Demas and Rabenhorst, 1999; Stolt and Rabenhorst, 2010; Turenne, 2010; Repe and Pristovšek, 2011). In the bay of St. Bartholomew, we discovered the following processes:

- Transformation: humification, formation of fine soil particles and sulphurisation.
- Vertical translocation: oxygen diffusion, bioturbation, vertical translocation of base cations.
- Inputs: mineral material from land and through waves and from shells; dead plant and animal organic material.
- Outputs: erosion of mainly mineral material by waves, during storms and stronger winds, and decomposition of organic material.

3.2. Classification of subaqueous soils the Bay of St. Bartholomew

Based on observations and measurements (Tables 2 and 3), we first determined diagnostic horizons, properties and materials in accordance with the WRB classification, all the qualifiers and final name (IUSS Working Group WRB 2015) (Figure 4).

Table 2: Results of the observations and analysis of samples/sites I., II., III. from St. Bartholomew Bay.

ID	HOR	depth	% Sa	% Si	% C	TEXT	pH (KCl)	ECe (dS/m)	OM	OC	% $CaCO_3$	colour (wet)
I/1	O	0 – 23	66,3	28,0	5,7	SaLo	7,43	22,53	10,84	6,30	66,67	N 3/
I/2	A	23 – 40	55,2	37,4	7,4	SaLo	7,40	28,80	7,39	4,30	50,00	2.5Y 4/2
I/3	AC	40 – 48	34,6	53,3	12,1	SiLo	7,39	55,30	2,97	1,73	65,00	2.5Y 5/8
I/4	C	48 –	26,4	58,7	14,9	SiLo	7,41	65,92	2,55	1,48	46,67	2.5Y 5/8
II/1	A	0 – 5	62,3	31,3	6,4	SaLo	7,81	22,46	4,21	2,45	50,00	5Y 3/1
II/2	AC	5 – 12	55,4	41,7	2,9	SaLo	7,70	24,45	3,11	1,81	55,00	5Y 3/2
II/3	C_1	12 – 32	42,7	51,5	5,8	SiLo	7,67	31,62	2,28	1,33	43,33	2.5Y 6/2
II/4	C_2	32 –	34,3	60,1	5,6	SiLo	7,70	40,19	1,59	0,92	36,67	2.5Y 6/3

III/1	AC_1	0 – 3	74,2	21,7	4,1	LoSa	7,79	19,71	1,31	0,76	40,00	2.5Y 2.5/1
III/2	AC_2	3 – 16	73,7	22,2	4,1	SaLo	7,63	21,95	2,07	1,20	60,00	2.5Y 4/1 2.5Y 6/4
III/3	C_1	16 – 44	73,3	22,6	4,1	SaLo	7,65	25,22	1,31	0,76	40,00	2.5Y 6/3
III/4	C_2	44 –	78,4	17,9	3,7	LoSa	7,99	57,28	1,24	0,72	33,33	2.5Y 7/6

ID – site and horizon identification; HOR – horizon name; depth – horizon depth; % Sa – sand percentage; % Si – silt percentage; % C – clay percentage; TEXT – texture class; pH (KCl) – pH in KCl; ECe (dS/m) – electric conductivity; OM – organic matter percentage; OC – organic carbon percentage; % $CaCO_3$ – calcium carbonate percentage; colour (wet) – soil colour in wet state.

Table 3: Results of the observations and analysis of samples/sites I., II., III. from St. Bartholomew Bay (continued).

ID	HOR	Ca	Mg	K	Na	H	S	CEC	V	% Ca	% Mg	% K	% Na (ESP)	% H
I/1	O	17,44	5,55	0,88	15,80	0,15	39,7	39,9	99,5	43,7	13,9	2,2	39,6	0,4
I/2	A	18,56	6,44	0,94	19,50	0,20	45,4	45,6	99,6	40,7	14,1	2,1	42,8	0,4
I/3	AC	22,25	12,87	1,61	39,84	0,55	76,6	77,1	99,4	28,9	16,7	2,1	51,7	0,7
I/4	C	24,15	17,47	2,21	49,30	2,10	93,1	95,2	97,8	25,4	18,4	2,3	51,8	2,2
II/1	A	17,21	4,97	0,88	15,30	0,10	38,4	38,5	99,7	44,7	12,9	2,3	39,7	0,3
II/2	AC	18,56	5,79	1,12	16,80	0,15	42,3	42,4	99,8	43,8	13,7	2,6	39,6	0,4
II/3	C_1	18,91	7,23	1,21	22,17	0,15	49,5	49,7	99,6	38,0	14,5	2,4	44,6	0,3
II/4	C_2	20,58	9,78	1,64	30,04	0,15	62,0	62,2	99,7	33,1	15,7	2,6	48,3	0,2
III/1	AC_1	16,51	4,37	0,81	12,41	0,05	34,1	34,2	99,7	48,3	12,8	2,4	36,3	0,1
III/2	AC_2	17,26	4,48	0,76	15,08	0,05	37,6	37,7	99,7	45,8	11,9	2,0	40,0	0,1
III/3	C_1	17,81	4,35	0,76	16,80	0,05	39,7	39,8	99,7	44,7	10,9	1,9	42,2	0,1
III/4	C_2	17,71	10,23	1,44	40,84	0,05	70,2	70,3	99,9	25,2	14,6	2,0	58,1	0,1

ID – site and horizon identification; HOR – horizon name; Ca –calcium content ($mmol_c$); Mg – magnesium content ($mmol_c$); K – potassium content ($mmol_c$); Na – sodium content ($mmol_c$); H – acid hydrogen content ($mmol_c$); S – sum of basic cations ($mmol_c$); CEC – cation exchange capacity ($mmol_c$/100g soil); V – percentage of base cations; % Ca – percentage of calcium; % Mg – percentage of magnesium; % K – percentage of potassium; % Na (ESP) – percentage of exchangeable sodium; % H – percentage of acid hydrogen.

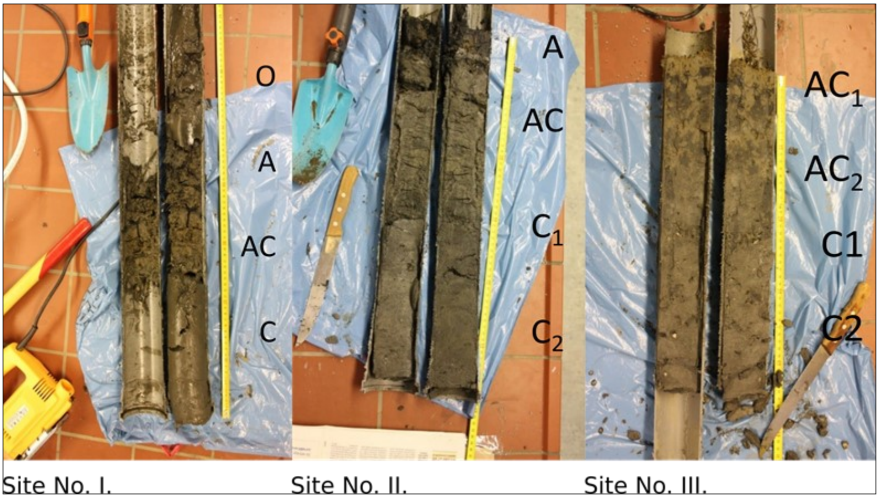

Figure 4: Profiles of the studied soils (photo: B. Repe).

Site No. I.
Diagnostic horizons: **mollic** (structure not massive or hard when dry, more than 0,6 % organic carbon and more than parent material, moist colour value is lower than 3, base saturation is higher than 50 %, it is more than 20 cm thick), **salic** (electric conductivity is higher than 15 dS/m, the product of ECe in thickness is higher than 450, it is more than 15 cm thick).

Diagnostic properties: **gleyic** (has reductimorphic colours (N),> 5 % of the oximorphic mottles around root channels), **reducing conditions** (presence of Fe^{2+}), **stagnic** (the profile is mottled, predominately around root channels, with appropriate moist colour values and chroma).

Diagnostic materials: **calcaric** (strong effervescence (more than 50 % of $CaCO_3$), structure is not disrupted, no concretions, nodules, coatings etc. present), **mineral** (soil properties are dominated by mineral components).

Reference soil group: **GLEYSOL** (a layer is more than 25 cm thick and starts less than 40 cm from surface, it has gleyic properties throughout, it has reducing conditions in every sublayer).

Principals qualifiers: **tidalic** (affected by tidal wate), **mollic** (has a mollic horizon), **amphistagnic** (has stagnic properties and reducing conditions more than 25 cm thick), **anocalcaric** (has a calcaric material throughout), hypereutric (because of **calcaric,** eutric is redundant).

Supplementary qualifiers: **anoloamic** (loamic texture within 50 cm from the surface), **humic** (more than 1 % of organic carbon), **hypersalic** (has a salic horizon and ECe more than 30 dS/m), **sodic** (does not have a natric horizon and has more than 15 % of Na), **uterquic** (has dominant gleyic and some parts with stagnic properties).

Complete name:
Anocalcaric Amphistagnic Mollic Tidalic GLEYSOL (Humic, Hypersalic, Anoloamic, Sodic, Uterquic)

Site No. II.
Diagnostic horizons: **mollic** (structure not massive or hard when dry, more than 0,6 % organic carbon and more than parent material, moist colour value is lower than 3, base saturation is higher than 50 %, it is more than 20 cm thick), **salic** (electric conductivity is higher than 15 dS/m, the product of ECe in thickness is higher than 450, it is more than 15 cm thick). Diagnostic properties: **gleyic** (has reductimorphic colours (N),> 5 % of the oximorphic mottles around root channels).

Diagnostic materials: **calcaric** (strong effervescence (more than 50 % of $CaCO_3$), structure is not disrupted, no concretions, nodules, coatings etc. present), **mineral** (soil properties are dominated by mineral components).

Reference soil group: **GLEYSOL** (a layer is more than 25 cm thick and starts less than 40 cm from surface, it has gleyic properties throughout, it has reducing conditions in every sublayer).

Principals qualifiers: **tidalic** (affected by tidal wate), **mollic** (has a mollic horizon), **reductigleyic** (does not have, more than 40 cm from the mineral soil surface, a layer that meets diagnostic criterion 2 of the gleyic properties), **anocalcaric** (has a calcaric material throughout), hypereutric (because of **calcaric,** eutric is redundant).

Supplementary qualifiers: **anoloamic** (loamic texture within 50 cm from the surface), **humic** (more than 1 % of organic carbon), **hypersalic** (has a salic horizon and ECe more than 30 dS/m), **sodic** (does not have a natric horizon and has more than 15 % of Na).

Complete name:
Anocalcaric Reductigleyic Mollic Tidalic GLEYSOL (Humic, Hypersalic, Anoloamic, Sodic)

Site No. III.
Diagnostic horizons: /
Diagnostic properties: /
Diagnostic materials: **calcaric** (strong effervescence (more than 50 % of $CaCO_3$), structure is not disrupted, no concretions, nodules, coatings, etc. present), **mineral** (soil properties are dominated by mineral components).

Reference soil group: **ARENOSOL** (texture class is loamy sand or coarser, it has less than 40 % of coarse fragments).

Principals qualifiers: **subaquatic** (being permanently under water not deeper than 200 cm),**epigleyic** (a layer, more than 25 cm thick, has gleyic properties throughout and reducing conditions in some parts, less than 50 cm from the surface), **sodic** (does not have a natric horizon and has more than 15 % of Na), **anocalcaric** (has a calcaric material throughout), hypereutric (because of **calcaric,** eutric is redundant).

Supplementary qualifiers: **ochric** (has more tha 0,2 % of organic carbon but does not meet the criteria for mollic or umbric), **nechic** (having uncoated mineral grains of silt or sand size in a darker matrix).

Complete name:
Anocalcaric Sodic Epigleyic Subaquatic ARENOSOL (Ochric, Nechic)

According to old classifications, all samples would be classified a gyttja (Mückenhausen, 1965).

4. Discussion and conclusion

The study of subaqueous soils is not a new field of research in pedology. However, research is rare for two reasons. Rarely do these studies have an application value (e.g., mapping and soil analysis of Dutch polders before dams are built) (Demas et al., 1996), and research is more demanding and expensive than average, which makes scientific investigation more problematic. In our work we encountered similar problems. Field work, especially underwater sampling, proved to be very time consuming, laborious, and demanding. Since no professional and expensive field equipment was available, we were forced to improvise, which made the work even more difficult. Nevertheless, we managed to get all the results, to name the floors successfully and thus to come to important conclusions. On the shores, with a very shallow and muddy bottom, different soil groups occur on sandy, carbonate material, although they have quite similar characteristics.

The depth of the soil before the impact with parent material varies between 40 and 65 cm, which means that there are medium-deep soils in the area under study. Skeletal particles are of mixed form and their percentage is between 20% and 30%, which decreases with increasing depth. Their size is between 2 and 6 mm. Many skeletons are of biogenic origin (shells of crustaceans and snail). In all soil horizons, the proportion of sand is high, and the proportion of clay is low, i.e., these are relatively young, poorly developed soils, which are exposed to soil forming factors and processes for short periods of time. Due to the flooding with seawater, the soils are slightly saturated with hydrogen and strongly saturated with sodium ions (more than 40%), the electrical conductivity is high (higher than 15dS / m).

The soils are salty (Brady and Weil, 1996), the sodium content and the salinity increase with depth as a result of vertical displacement of cations. The calcium carbonate content in the profiles is very high. In addition to the topsoil, the percentage is further increased by carbonate shells. As a result, the soils are almost 100% saturated with basic cations and slightly alkaline. On average, the proportion of organic matter increases with depth, as mineral material fills the soil surface and is displaced by bioturbation. The proportion of organic matter in the upper part decreases significantly away from the coast, due to the lower density of vegetation that contributes organic material (Figure 4).

We also noted that among all sites many soil forming factors (parent material, relief, water flow characteristics, chemical properties of water) and processes (run off: decomposition of organic matter; vertical translocation: bioturbation and oxygen diffusion; transformation: humidification, sulfidation) are very similar if not the same. However, some differences occur with the distance from the coastline towards the sea. The seawater gets deeper, but more than that, the main factor is the increasing time of flooding with seawater. This, in turn, initially has a decisive influence on the type and density of vegetation and the resulting amount of dead organic matter. This decreases in the direction mentioned above, while in the opposite direction the influx of mineral material to the surface increases with the waves. Also, in the same direction, seaward, the intensity and expression of stagnic and gleyic properties decreases. Slowly, however, the sandy fraction of the parent substrate dominates completely.

Therefore, the flat, muddy coast is zoned away from the coast (Figure 5). The same zonation has also been observed in other places (artificial Shell shore near Ankaran, Strunjan salt pans, lagoon Stjuža near Strunjan and Sečovlje salt pans). The first zone is a reed belt, which is only occasionally flooded with seawater. Gleysols are dominant and occur in the very narrow belt and together with Solonchaks (where flooding occurs only during extremely high tides). There are more fine particles (silt and clay), so that the gley properties are more pronounced.

This is followed by a zone of halophyte, terrestrial vegetation (*Salicornia europaea, Arthrocnemum glaucum, Crithmummaritimum, Limonium angustifolium, Juncus maritimus*), where the soil is saltier but gleyic properties are expressed to lesser extent. There are more sand and less clay fractions present. Where soils are completely flooded with water, underwater, marine vegetation (*Cymodocea nodosa*) is present. The gleying process are still present, but are not intense enough, therefore sandy fraction and Arenosols predominate in this zone.

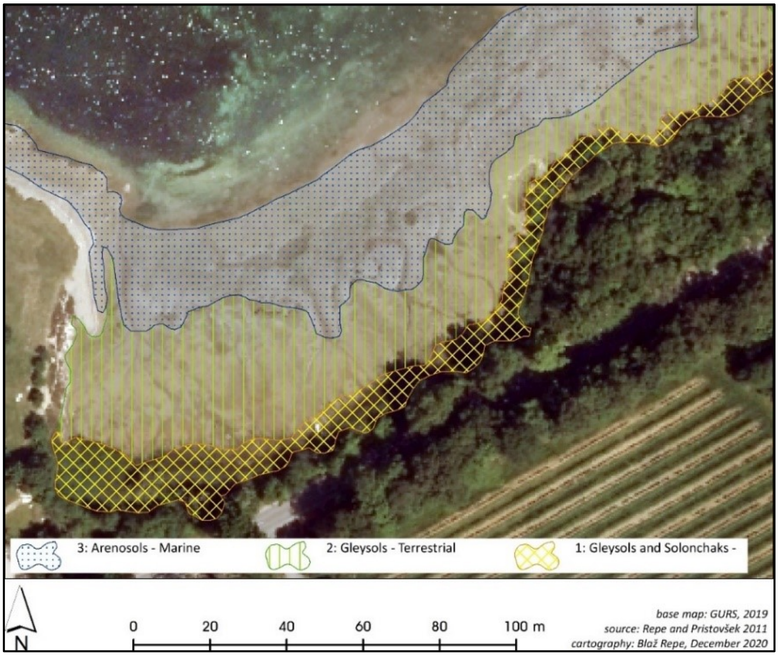

Figure 5: Zonation of the soils and vegetation of the Bay of St. Bartholomew

From field observations and laboratory analyses of selected soil examples on the Slovenian coast we can conclude that the soils were influenced by similar factors and processes and that the soils are also quite similar to each other, with similar properties. All soils are young, weakly developed soils with the basic structure of the A – Cprofile. All soils show signs of displacement (diffusion and bioturbation), gleying and oxidation of the surface horizons. The differences are more pronounced from the coast to the sea, which is due to the duration of flooding. These findings and regularities must be verified and further demonstrated by investigations at similar locations along the coast. In order to determine the overall picture of the soilsalong the coastal part of Slovenia, it will be necessary to examine also the soils under the cliffs, where there are considerably more skeletal fractions, or the parent material consists of hard, solid and poorly weathered rock.

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