ЗАГАЛЬНА ТА МОРСЬКА ГЕОЛОГІЯ

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MORPHODYNAMICS AND GEOLOGICAL LEGACY OF BERM SCARPS ALONG NON-TIDAL (UKRAINE) AND MICROTIDAL (THE BAHAMAS) COASTS

Berm scarps are erosional features characteristic of all coastal accumulation forms. Their profiles range from steep to overhanging ($\psi_{>90}$) and evolve through slope adjustment and burial by swash and aeolian accretion. Examples from the mixed siliciclastic-bioclastic beaches of the non-tidal Black Sea coast of Ukraine and the microtidal oolitic-bioclastic carbonate islands of the Bahama Archipelago demonstrate a wide range of scarp morphologies. Truncations of berm strata and density lag at the scarp base accentuate their recognition in the field and in geophysical (georadar) records. Although ephemeral as surface features, berm scarps may act as nucleation sites for aeolian aggradation, thereby generating continuous coast-parallel dune ridges. Accumulation of organic debris promotes colonization of incipient foredunes by plants and provides chronological control of erosional events. Therefore, paleo-berm scarps serve as important geological indicators of past storm activity and aid in constraining sea-level position.

Keywords: erosional scarp, truncation, heavy minerals, georadar

Introduction

Berm scarps are common erosional features along sedimentary coasts regardless of lithology or tidal range. Whereas gravel beaches may have multiple berms and scarps, sandy coastlines exhibit a single scarp within the berm (foreshore) region [2, 22, 23, 27]. This steep erosional feature may have variable longshore extent and is typically generated by wave erosion during storms, with subordinate mechanisms that include increased wave activity during spring high tides and seiches, ice scour, and tsunamis [12, 15, 22, 23, 27]. In contrast to dune scarps, these morphological elements receive less attention in the literature largely due to their ephemeral nature as surface features [3, 8, 20, 23]. However, unless they are eroded by subsequent storms, berm scarps may be responsible for nucleation of foredune ridges and have the potential to be preserved within coastal lithosomes. Therefore, understanding of scarp formation and preservation, as well as their geological legacy, are important first steps in assessing their paleoenvironmental value.

The aim of the study is the analysis of berm scarps, with emphasis on their morphology, preservation potential, and recognition in the geological record. An idealized conceptual model of scarp profiles is presented, with differentiation between designation of depositional and erosional elements.

Research subject – 1) recent erosional berm scarps and 2) buried paleo-scarps along a mixed siliciclastic-bioclastic shoreline of the Black Sea (Fig. 1) and various carbonate coastlines of the Bahamas (Fig. 2). The diversity of sediment composition and hydrodynamic conditions is designed to highlight the similarity of underlying mechanisms responsible for these erosional features.

Physical Setting

Recent berm scarps were investigated along the mixed siliciclastic-bioclastic shoreline of the Odessa Coast region, Ukraine (the Black Sea — Fig. 1A) and the ooid-dominated carbonate coasts of Little Exuma and Eleuthera Islands, Bahamas (Fig. 2A). The northwest Black Sea coast is non-tidal, with fair-weather waves dominating accumulation of berm/beachface successions. Intense storms produce a variety of erosional features such as dune and berm scarps, as well as breaches (prorvas) of thin barriers fronting coastal bays (limans) [6, 7, 21, 26]. Aeolian action dominates the upper dry portion of the berm, producing both deflation lag (shell fragments, heavy-mineral concentrations [2, 3, 5, 18]) and depositional features (incipient coppice dunes, wind-ripple lamination and aeolian ramps extending onto foredune ridges).

The Bahamian study sites are microtidal (mean tidal range ~0.3-0.5 m) and are impacted by Atlantic hurricanes of variable strength [9, 10, 16, 17, 24]. Intense storms that extend to the foredune result in a prominent dune scarp, whereas moderate storm conditions or beach segments with wide berms typically exhibit berm scarping.Well-developed berm scarps are formed by high-energy waves and are exposed to subaerial conditions during intervening fairweather periods or low-tide phases [8, 9, 19, 20].

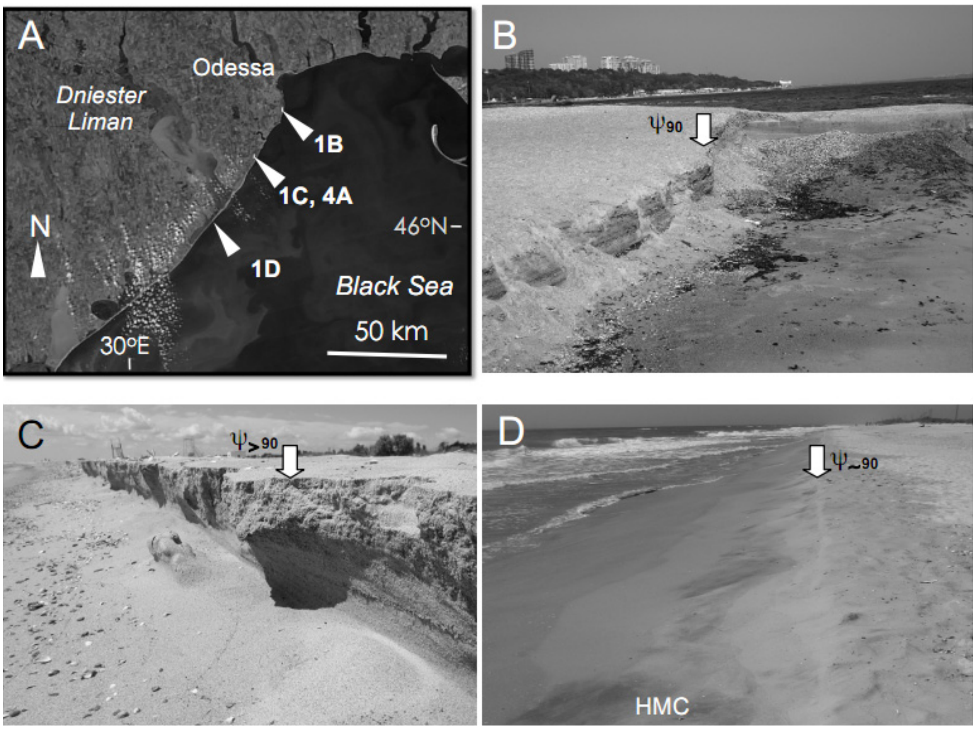

Fig. 1. A) Locations of study sites along the northwest coast of the Black Sea, Ukraine. B) Vertical berm scarp (arrow) exposing a sequence of shell-rich and siliciclastic horizons, Delphin Beach, Odessa. Note basal talus accumulations and patches of seaweed. C) Vertical to oversteepened scarp with overhang and basal swash accumulation, Albatross Beach. D) Near-vertical scarp with erosional re-entrants largely covered by swash accretion, with patches of heavy-mineral concentration (HMC), Zatoka Beach.

Scientific Information and Methods of Researching

Field investigations of recent berm scarps were conducted during June 2012 (Ukraine), January 2013 (Little Exuma, Bahamas), and May 2013 (Eleuthera, Bahamas). All scarps were identified, measured and photographed. Because it is often impossible to recognize buried scarps in point-source sediment cores and trenches, the identification and mapping of buried analogs (paleo-scarps) was conducted using ground-penetrating radar (GPR or georadar). Georadar uses electromagnetic impulses to provide rapid continuous imaging of the shallow subsurface [1, 2, 4, 11, 13, 14, 25]. The surveys were collected across the landward sections of selected study sites with a digital MALÅ Geoscience system. A monostatic 800 MHz antenna provided vertical resolution of 4-5-cm in unsaturated sand (signal velocity ~12cm/ns) within the upper 1.5-2.0 m of the coastal lithosomes. Field data were post-processed using the RadExplorer v1.41 software package and rendered as two-dimensional sections

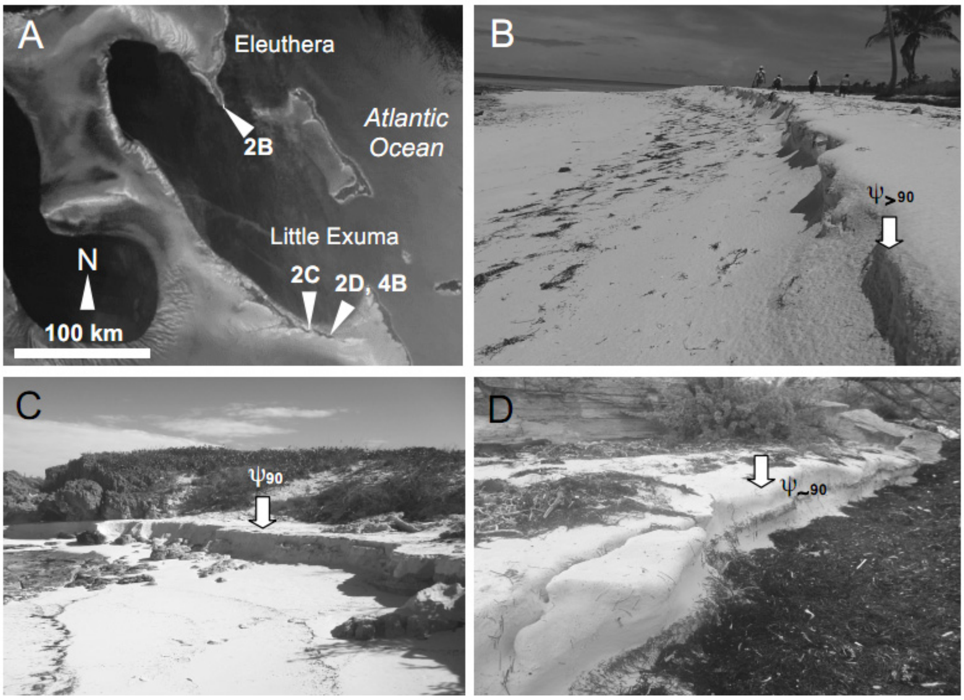

Fig. 2. A) Locations of study sites in the Bahamas. B) Oversteepened berm scarp (arrow) with extensive collapse features smoothed out by the swash, Lighthouse Beach, Eleuthera. Note patches of seaweed along the upper beachface. C) Vertical scarp exposing laminae of compact and semi-porous sand, La Shante Beach, Little Exuma. D) Near-vertical scarp with a partially detached block (left) and vegetation mats at the base, on the berm, and exposed along the scarp face (paleo-berm surface), Moriah Harbor Cay, Little Exuma.

(2D radargrams). Due to the protected nature of some field areas or lithification of carbonates, ground-truthing through trenching was limited, further emphasizing the need for non-invasive visualization and mapping tools [8].

Results and Discussion

Recent scarps. In this study, the seaward slopes of erosional morphotypes (i.e., scarp faces) are designated by ψ, in order to contrast them with the gradients of depositional features commonly represented by *b* (positive *b* – beachface slope; negative *b* – landward-dipping berm surface; Fig. 3). All slopes were measured relative to the berm crest or scarp top (brink). Scarp faces range from 10-20 cm to >1 m in height and exhibit a variety of morphologies from steep ($\psi_{>30}$) to vertical (ψ_{90}), and over-steepened ($\psi_{>90}$), with occasional overhangs (Figs. 1 and 2). Sub-horizontal and often landward-dipping layers (b_{-5}) can be seen outcropping along some scarp faces (Figs. 1B and 2C). Partial collapse due to swash undercutting results in listric-type faults, grainflow, and scarp-base talus accumulations, which may resemble aeolian ramps

(Figs. 1B, 2D, and 3). Similar to partially healed dune scarps, the upper part of a berm scarp may remain visible until subsequent slope decay or aeolian accumulation mask but not remove its diagnostic erosional nature.

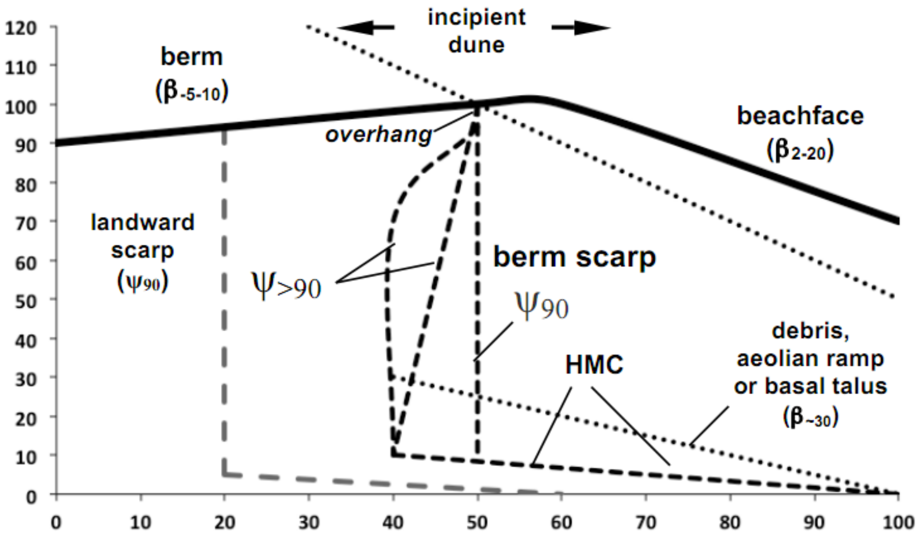

Fig. 3. Idealized berm scarp morphotypes (thick dashed lines) relative to the original beach profile (solid line; scale on both axes is arbitrary). Dotted lines represent depositional features of various origin (talus, aeolian ramp) and sites of lag formation (HMC: heavy-mineral concentration) and debris accumulation. Sediments deposited by aeolian ramp aggradation may completely cover the scarp and proceed as incipient foredune deposits accumulating immediately landward of the brink or seaward (atop buried wrackline). The long-dashed line represents the subsequent landward position in a net erosional regime or a paleo-scarp (net progradation regime).

Along the Black Sea coast and other siliciclastic shorelines, heavy-mineral concentrations occur as a density lag along the scarp base immediately following the storm event or result from subsequent swash action (Fig. 1D) and aeolian deflation [3]. Flotsam and vegetation remains (seagrass macroalgae, driftwood) may produce substantial accumulations along the scarp base. Heavy-mineral accumulations at Bahamian sites are absent, but shell lag and abundant decaying vegetation were often observed along scarp bases (Figs. 1B, 2B, 2D).

Paleo-scarps. Once formed, berm scarps may be: 1) eroded entirely (resulting in dune scarps, overwash, or breaching); 2) translated landward, resulting in a new berm scarp; 3) buried by swash and aeolian deposits, or 4) lithified. Because of these varied morphological responses, it may be possible to identify and map paleo-scarps using morphological analysis, trenching, or subsurface imaging techniques.

In high-resolution geophysical records, berm scarps are recognized as truncations of berm and upper beachface sequences (Fig. 4) [3, 5, 8]. The gradient of the truncating reflection is typically in the 10-20° range, which is higher than beachface slopes ($\beta_{<10}$). In many instances, the bedding gradient landward and seaward of the truncating reflection is substantially lower. Berm scarps were identified in seaward sections of late Holocene beach/dune ridges at both sites. In siliciclastic settings, heavy-mineral concentrations accentuate the scarp base, enhancing their visual recognition in trenches and GPR records (Fig. 4A). Such lithological anomalies may have sufficiently high concentrations of accessory minerals to serve as economically viable coastal placers.

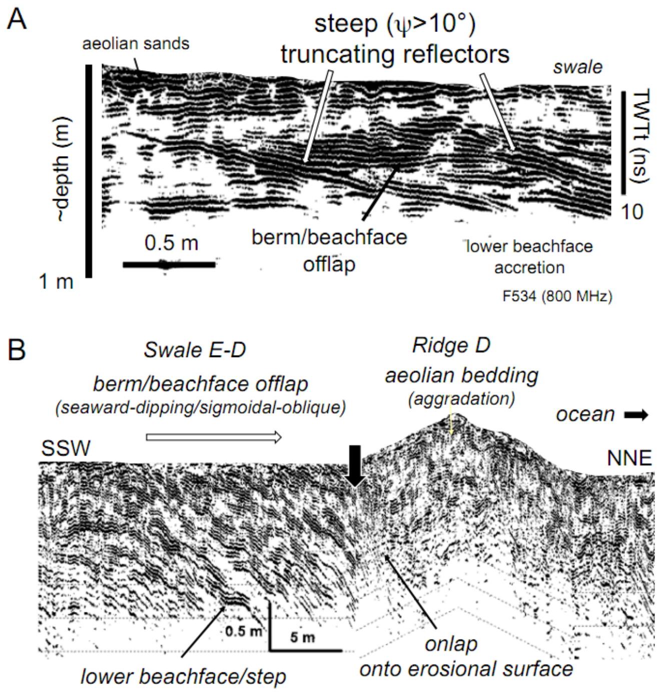

Fig. 4. Georadar images of paleo-berm scarps (frequerncy: 800 MHz; TwTt – two-way travel time in nanoseconds). Note difference in scale between the two profiles. A) Prominent seaward-dipping steep reflections (thick arrows) truncate older berm accretion horizons and are then overlain by subsequent depositional sequences, Albatross beach-ridge plain, Ukraine (Black Sea is to the right; see Fig. 1A for location). B) Truncated berm/beachface offlap sequence (large black arrow) is followed by wave-swash deposition and aeolian accretion (dune ridge) that was likely initiated and promoted by the scarp, Moriah Harbour Cay, Bahamas (See Fig. 2A for location).

As vertical or sub-vertical features (i.e., cross-shore sediment transport barriers), berm scarps induce deposition by fairweather wave swash and onshore wind, thereby serving as nucleation sites for incipient foredunes [8, 20]. This may explain alongshore continuity of some beach/dune ridges on coastal strandplains in many parts of the world [23]. Decaying organics (e.g., seagrass and shell fragments) at the scarp base (Figs. 1B, 2D) serve as fertilizer for colonizing plants, promoting dune stabilizaton. As materials suitable for radiocarbon dating, organic debris also provide general chronological control, complementing the optical chronology of overlying sediments [3, 12, 14, 15].

The potential role of berm scarps as high-energy indicators highlights the need for their utilization in paleotempestological research. In coastal accumulation forms that are too wide or high to prevent overwash into backbarrier wetlands, these erosional features may provide the only geological evidence of past storm impact [2, 3, 7, 8, 14, 19]. Although they represent the minimum number of events due to the potential for episodes of net erosion [3, 23], paleo-scarps act as mappable anomalies in prograded depositional systems. In addition to serving as storm indicators, the relatively limited vertical range of berm scarps can be utilized to constrain past sea-level positions [19, 20, 23].

Conclusions

1. Berm scarps serve as important diagnostic indicators of erosion by moderate storms that do not extend to the foredune.

2. Scarp morphology begins with $\psi_{\geq 90}$ and decreases with subaerial exposure, unless reactivation maintains the steep gradient in a more landward position.

3. Functioning as accumulation barrier makes berm scarps potential regions of nucleation of new beach/dune ridges. The cross-shore locus and alongshore continuity of these features explains the repetitive nature of many beach/dune ridge complexes (ridge sets). Organic matter associated with these features promotes colonization by plants and provides datable materials.

4. Given freshwater or unsaturated conditions, georadar serves as an ideal tool for identifying and mapping paleo-scarps, with prograded coastal complexes archiving a long-term record (>1,000 years) of erosion.

5. The limited vertical range and alongshore continuity make berm scarps reliable geoindicators of storms and can help to constrain past sea-level positions.

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МОРФОДИНАМИКА И ГЕОЛОГИЧЕСКОЕ ЗНАЧЕНИЕ ПЛЯЖЕВЫХ УСТУПОВ РАЗМЫВА НА БЕСПРИЛИВНЫХ (УКРАИНА) И МИКРОПРИЛИВНЫХ (БАГАМСКИЕ ОСТРОВА) БЕРЕГАХ

Резюме

Эрозионные пляжевые уступы в целом нехарактерны на крупных береговых аккумулятивных формах (барах, косах, террасах и др.). В подавляющем большинстве случаев они встречаются на песчаных пляжах, после очередных сильных ветровых волнений, характеризуются крутыми или даже обратно падающими уклонами (≥ 90°). Под влиянием высушивания подверхаются осыпанию или сползанию песка к подножью. Становятся захороненными под влиянием эолового занесения или разрушению под влиянием прибойного потока. Исследования пляжевых уступов выполнялись на песчаных кварцево-карбонатных берегах неприливного Черного моря в пределах Украины и на малоприливных (≤ 0,3–0,5 м) песчано-оолитовых пляжах на островах Багамского архипелага. Указанные берега несут на себе определенное разнообразие пляжевых уступов. Подрезание слоев бермы и накопления темноцветного шлиха вдоль подножья уступа могут быть индикаторами для обнаржения геофизическими методами (георадаром или радиозондом). Несмотря на их весьма кратковременное существование на поверхности, пляжевые уступы могут быть очагами, хотя и небольшой, но все же аккумуляции эоловых наносов. Тем самым они формируют вдольбереговые гряды в весьма специфических природных условиях. Накопление органических остатков порождает колонизацию растительности на эмбриональных авандюнах и может выступать материалом для абсолютного датирования проявлений волно-эрозионных процессов. Таким образом бывает шанс для сохранения песчаных пляжевых уступов. Следовательно, захороненные пляжевые уступы могут быть важными показателями прошедшей штормовой активности и помогают определить (или уточнить) положение среднего уровня моря в прошлом.

Ключевые слова: абразионный уступ, трункация, шлих, георадар

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МОРФОДИНАМІКА ТА ГЕОЛОГІЧНЕ ЗНАЧЕННЯ ЕРОЗІЙНИХ ПЛЯЖОВИХ УСТУПІВ НА БЕЗПРИПЛИВНИХ (УКРАЇНА) ТА МІКРОПРИПЛИВНИХ (БАГАМИ) БЕРЕГАХ

Резюме

Ерозійні пляжові уступи в цілому не є характериними на берегових акумулятивних формах. Вони бувають в левовій більшості випадків на піщаних формах, мають круті або навіть нависаючі (ψ>90) пересіки і піддаються осиповим процесам і похованню у стадії заплеску і еолової акумуляції. Приклади зі змішаних кварцево-карбонатних пляжів безприпливного Чорного моря в межах України і мікроприпливних піщано-оолітових пляжів на островах Багамського архіпелагу демонструють певний спектр морфометрії уступу. Зріз (трункація) шарів берми і накопичення шліху біля підсхилку уступу можуть сприяти їх виявленню геофізичними (георадарними) методами. Незважаючи на їх недовгий прояв на поверхні, пляжові уступи можуть виступати центрами, хоча невеликого, але накопичення еолової акумуляції, тим самим формуючи уздовжберегові гряди в суто специфічних умовах. Накопичення органічних залишків сприяє колонізації рослинності на ембріональних авандюнах і можуть виступати матеріалом для абсолютного датування ерозійних процесів. Таким чином, поховані пляжеві уступи можуть бути важливими показниками минулої штормової активності і допомагають в уточненні положення рівня моря.

Ключові слова: абразійний уступ, трункація, шліх, георадар.