Records of long-term coastal evolution in the southern Laptev Sea:

An interdisciplinary study of the Makhchar lagoon/beach-ridge system

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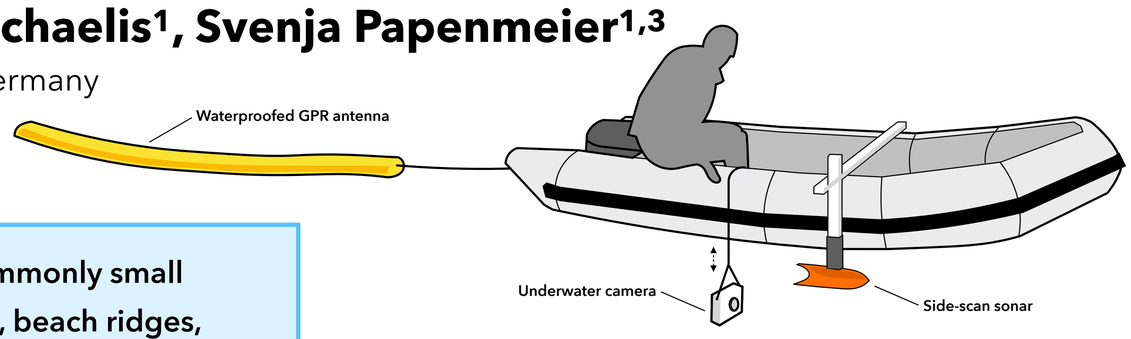
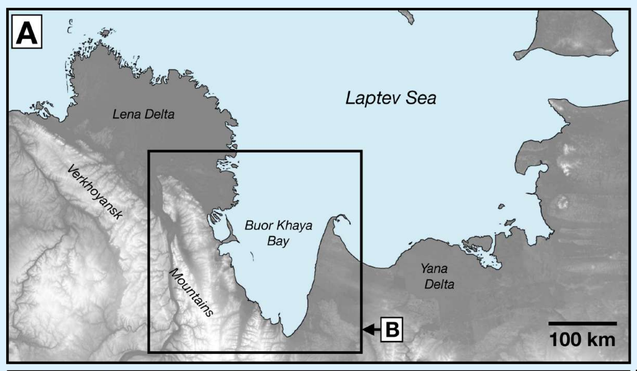


INTRODUCTION



The geomorphology and sedimentary record of commonly small coastal depositional environments, such as lagoons, beach ridges, barriers and spits, provide important insight into the spatio-temporal evolution of landforms and the drivers of their formation. In Arctic environments, the delivery of wave energy and sediment is intimately linked with the duration and extend of sea-ice-free conditions. The timing of local coastal evolution thus conceptually allows inferences on long-term changes in climate with validity for larger regions.

The investigated field site is a coupled lagoon/beach-ridge system that formed in a valley located within the hummocky topography of the Verkhoyansk Mountains. The area was transgressed c. 6000 years ago and marine landforms have developed since under stable relative sea-level conditions [1].

The presented study aims at (1) providing a full appraisal of the modern spatial properties of the Makhchar site, and at (2) establishing the value of studying similar coastal systems as a landscape archives of importance for the east Siberian Arctic.

Figure 1: Buor Khaya Bay is a shallow embayment of the Laptev Sea (Arctic Ocean, A). The eastern shoreline is dominated by the ice- and carbon-rich sediments of the east Siberian yedoma region (Buor Khaya Peninsula), while the western shoreline is composed of consolidated sedimentary bedrock (B). Here, a chain of lagoons, barriers, prograded spits and beach ridges formed over Holocene time scales. This study focusses of the Makhchar lagoon/beach-ridge system (C).

Methods

Fieldwork was conducted in August 2018. Data on the surface properties of lagoon sediments was collected using a Triton Starfish 990F side-scan sonar (1 MHz, hull mounted) and was combined with information on the properties of the water column and the subsurface obtained using ground-penetrating radar unshielded dipole antennas (GPR, 50 and 100 MHz, towed). An underwater camera setup, based on a waterproof action camera and a diving torch, was used to collect ground truth.

On land, GPS-RTK elevation profiles were recorded across the beach ridge system and combined with elevation data from the ArcticDEM. Data on beach morphology and the surface properties of the elevated marine deposits (grain size, vegetation, debris) were collected in the field. Age control on beach ridge progradation was obtained by the ^{14}C-dating of buried drift wood[1]. Sentinel and SPOT satellite imagery were used to obtain data on land surface characteristics and to support the interpretation of field data.

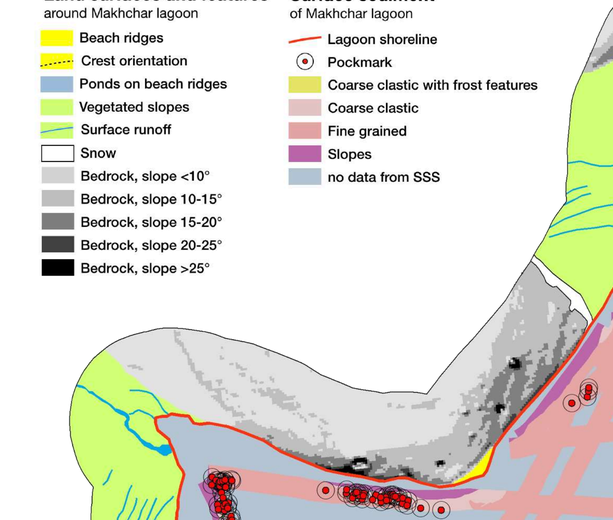


Figure 2: Data examples. (A) SSS sonogram of a pockmark field in c. 7 m water depth, (B-C) Frost sorting of coarse clastic sediment in shallow water (<2 m), (D) GPR data transect across the lagoon.

Holocene coastal evolution of the Makhchar system

The first preserved beach ridge at Makhchar formed c. 5950 cal BP (marked 1 in Fig. 3). The system prograded until 3400 cal BP (2), at a rate of 0.32 m/yr. Until 1250 cal BP (3), the rate then dropped to <0.04 m/yr, before slightly increasing again to c. 0.12 m/yr until 600 cal BP (4). No younger coarse-clastic beach deposits are preserved. The timing of progradation is consistent with data from a nearby system [1] and provides further indication that progradation primarily during warmer periods of the Holocene – probably driven by a longer duration of the open water season. Two drowned spits (* in Fig. 3) are found in the lagoon, suggesting a period with an open connection with Bour Khaya Bay prior to beach-ridge formation. The depth of the lagoon and the absence of a thick sedimentary infill however suggest that the closure of the lagoon must have occurred rapidly after the establishment of relative sea level stability 6200 cal BP [1].

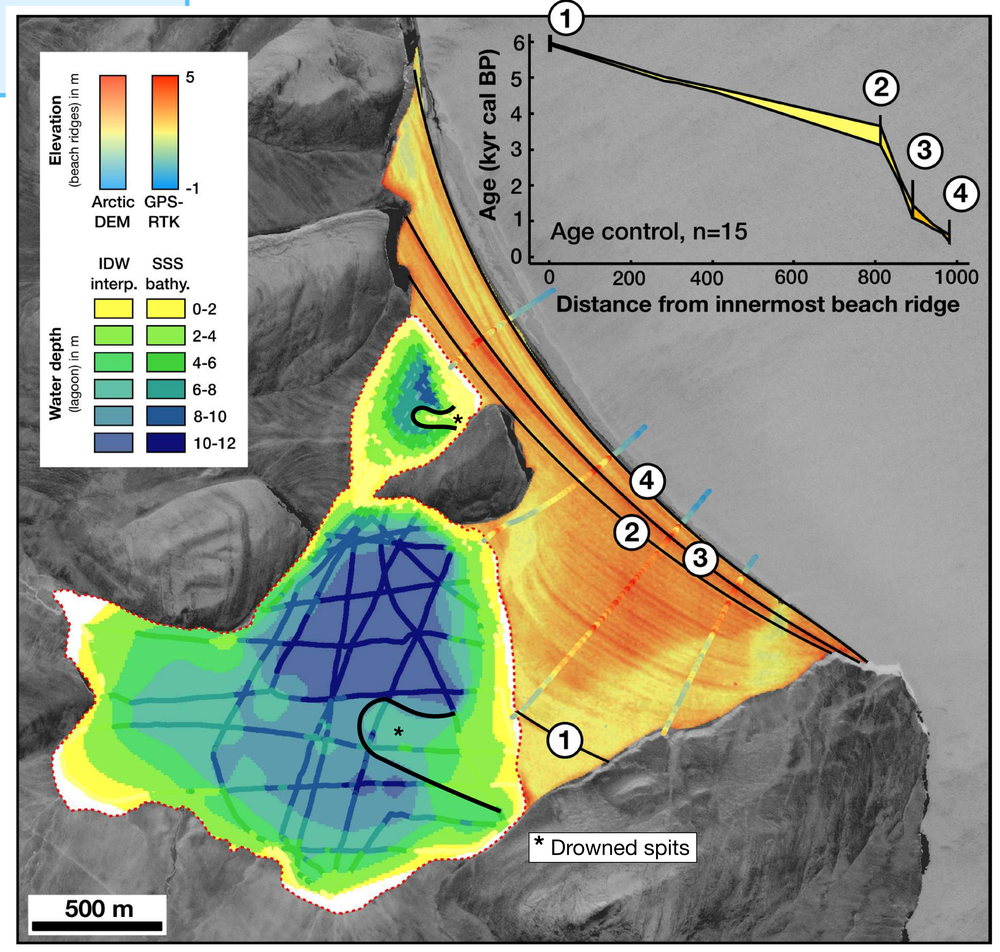


Figure 3: (Main map) Bathymetry of the Makhchar lagoon and the elevation of the beach ridge system. *Abbreviations in the legend: SSS bathy. – Bathymetry obtained from the bottom track of the side-scan sonar data, IDW interp. – Inverse distance weighted interpolation of the SSS bathy.* **(Top right)** Age-distance model along the the central GPS transect based the ^{14}C dating of 15 samples from the outermost tree rings of buried driftwood. Numbers mark the modelled ages the main transitions in the beach-ridge system.

Figure 4: Thematic map of the surface properties of the Makhchar lagoon and the adjacent land surface areas (200 m around lagoon shoreline).

The modern lagoon

The surface sediments of the lagoon floor reflect the long-term development of the field site to a large degree. The eastern boundary is composed of coarse clastic material of marine origin (beach clasts). The coarse and unconsolidated material is in shallow water (<2 m) arranged in round to polygonal frost patterns (sorting, bedding), while the degree of coverage by algae, biological turf and fine sediment increases toward deeper water depth. The deep and flat parts ('basins') of the lagoon are covered by a thin bed of fine sediment. On the gently dipping surfaces of the lagoon slopes, pockmarks are regularly observed in water depth between 4 – 8 m. This depth coincides with the maximum depth of the thermocline visible in the GPR data. This suggest that the warming of the surface water probably delimits the lower boundary for the occurrence of pockmarks.

Conclusions

This study provides evidence for the timing of the evolution of a coupled lagoon/beach-ridge system. The properties of the lagoon are primarily controlled by the antecedent topography as well as the dynamics during an early stage of formation. The beach ridges prograded roughly since the establishment of relative sea-level stability and were in their rates of progradation controlled by periods of warmer climate conditions. The results stress the value and importance of coastal sedimentary systems as paleoenvironmental archives. These are traditionally much less studied than thermokarst, permafrost, lake systems on land or marine archives from the Laptev and East Siberian Sea.

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