From field data to model: integration of onshore and offshore research to create a Digital Terrain Model of the Belgian coast around 6 ka BP for geoarchaeological research

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Highlights: Understanding coastal evolution requires a transdisciplinary approach, Connecting onshore and offshore findings, Creating a DTM enables testing long-standing geomorphological hypotheses.

Keywords: coastal landscape evolution, transdisciplinarity, palaeogeographical mapping, Belgian coastal archaeology, morphodynamical modelling

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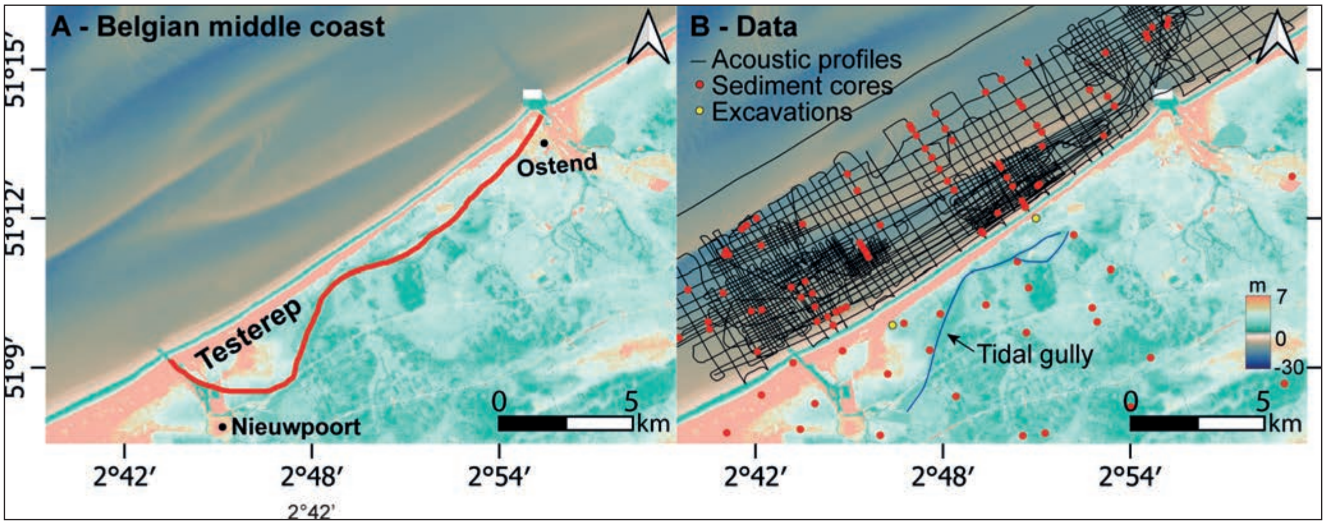

Figure 1: Location of the study area.

A) The Belgian middle coast with the onshore limit of the Testerep island. B) Data collected and analysed for the reconstruction, indicating the location of the silted-up tidal gully that marks the onshore limit of the Testerep island.

Introduction

In recent decades, research in geology, palaeoecology, archaeology, and history has provided valuable insights in the evolution of the Belgian coastal plain throughout the Holocene (Baeteman, 2018). The region was once a dynamic natural landscape with tidal channels, mudflats, dunes and salt marshes that turned into a highly urbanised and developed area. This transformation was shaped by the interplay between the environment, natural forces and human interference, ultimately resulting in the straight and static coastline that exists today.

During the Middle and Late Holocene, a large island known as Testerep stretched across the Belgian middle coast between the present-day cities of Nieuwpoort and Ostend (Fig. 1A). It was separated from the mainland by a large tidal gully. In medieval times, the embankment and drainage of the gully and much of the intertidal area turned the island's landward side into polders, while its seaward side witnessed a gradual demise due to severe storms according to historical sources (Tys, 2013). To gain a more in-depth understanding of the island's evolution since the Middle to Late Holocene and the drivers behind the landscape change, a better-founded reconstruction of its palaeogeography across the land-sea boundary was required. A major challenge is that large-scale coastal erosion and reworking hinders accurate reconstructions. Existing archaeological and geological data were combined with newly collected data at key onshore and offshore sites, to create palaeogeographical maps representing different time periods spanning the Middle to Late Holocene. These maps served as the foundation for constructing a digital terrain model of the Testerep island using a modern analogue. The digital model will be used as the basis for morphological and hydrodynamic modelling to test hypotheses, such as the effects of increased storm activity, of peat compaction and extraction, and the impact of embankments on coastal hydrodynamics.

Methodology and Results

To investigate the evolution of the former Testerep landscape, archaeologists collaborated with marine geologists and hydrodynamic modelers to gain a comprehensive understanding of Testerep's transformation since the Middle Holocene. New research on land involved the re-examination of existing sediment cores of the Belgian Geological Survey, collected in the Testerep palaeo-channel (Fig. 1B). This was complemented by electromagnetic induction surveys in the vicinity of the silted-up channel, and the excavation of Roman and medieval embankment structures (Fig. 1B). At sea, new high-resolution acoustic profiles (Innomar SES-2000 Quattro parametric echosounder, ca. 15 cm vertical resolution) and vibrocores (Fig. 1B) were collected to explore various palaeo-landscape features, such as tidal inlets, sandbanks, and peat deposits. Specific sediment layers were then dated using optically stimulated luminescence and radiocarbon dating methods to establish the chronological sequence of

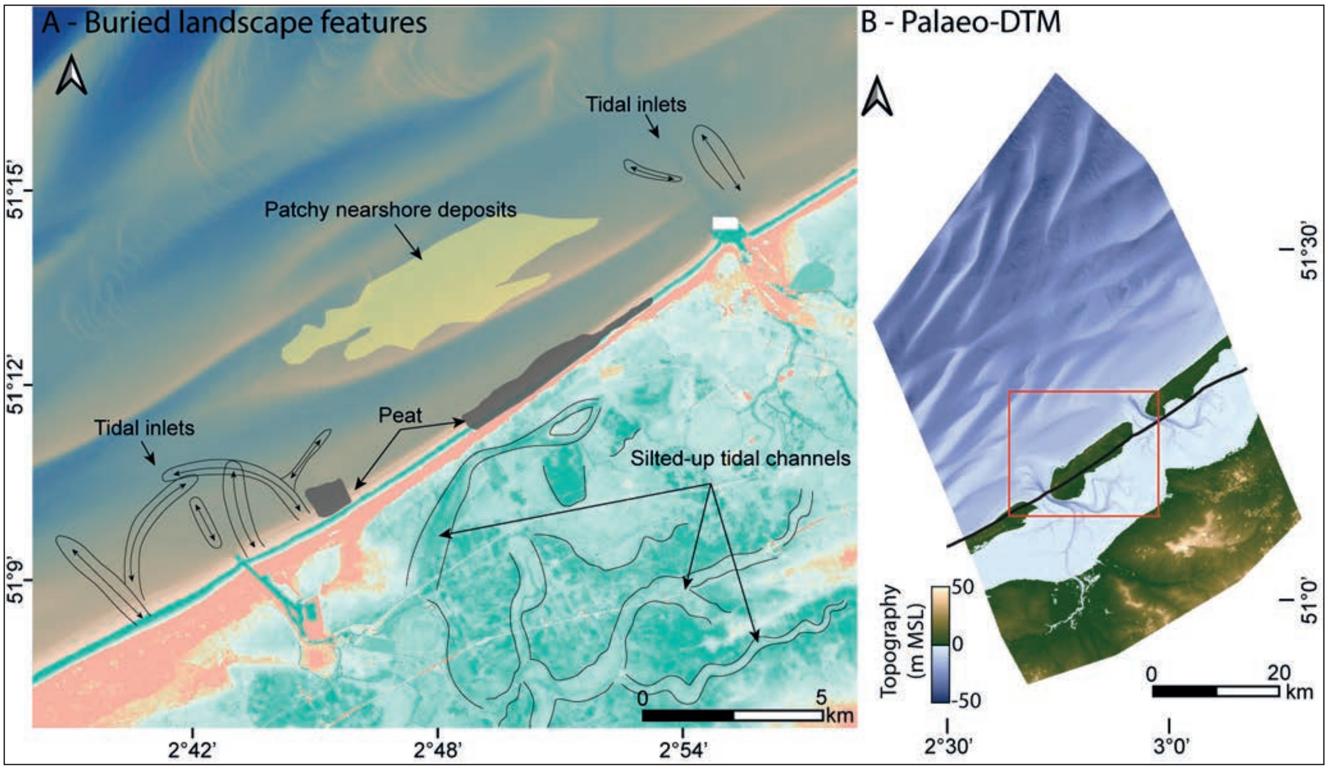

Figure 2: A) Landscape features identified in the study area, with remains of a barrier system with large tidal inlets and an extensive back-barrier area. B) Palaeo-Digital Terrain Model of the Belgian coastal plain created using the Wadden Islands as a modern analogue. The red square corresponds to the area shown in A.

these features and to link them to shifting coastal processes over time. These data were integrated in a Geographical Information System, which facilitated the creation of palaeogeographical maps representing different time periods.

The new data reveal complex palaeo-landscapes buried offshore (Fig. 2A). Several incised and filled features are identified to the east and west of the former island. Their sedimentary architecture and morphological characteristics represent tidal systems, pointing to the location of relict tidal inlets. These inlets display multiple phases of cut and fill but show limited lateral migration, with radiocarbon ages ranging from 8 ka BP to the present. Extensive sand deposits are associated with the tidal inlets, representing old tidal deltas and remains of linear sand barriers. Several peat deposits cut by small tidal creeks have been identified in the present-day intertidal and subtidal areas, representing former land surfaces subsequently drowned by the sea. These peat deposits correspond to low-energy environments commonly found in protected tidal settings. Coastal deposits indicative of intertidal and shallow subtidal environments with a luminescence age of 5-4 ka BP are also preserved further offshore underneath the Stroombank sandbank, a shoreface-connected ridge parallel to the present-day coastline. The formation of this sandbank started ca. 1.3 ka BP (based on luminescence dating) and is related to large-scale erosive processes affecting the former coastal plain. New dating of the channel systems onshore has allowed us to gain a better insight into the phases of incision and fill during the Late Holocene, and the depth of the underlying Pleistocene deposits to improve the landscape reconstruction. All this evidence points to the Testerep area once being a barrier system, however, due to erosion, much of the data about the former elevation is lost.

To create a Digital Terrain Model (DTM) of Testerep, a method was developed using the natural barrier-island system of the Dutch Wadden Islands as a modern analogue (specifically Ameland, Schiermonnikoog, and Terschelling). This modern analogue was selected because of the similarity between the Wadden Islands and the palaeolandscape reconstructed based on field data (Fig. 2A). A DTM of the Wadden Islands was created by integrating Lidar data (AHN.nl) and submerged bathymetry (EMODNet Bathymetry, emodnet.ec.europa.eu). The same approach was applied to the Belgian coastal plain and shelf, by integrating Lidar data (www.vlaandere.be/digitaal-vlaanderen) and multibeam bathymetry (www.agentschapmdk.be). All datasets were standardised to a common reference level (the local mean sea level, MSL).

A georeferencing project was created to adapt the shape and location of the Wadden Islands to the Belgian middle Coast by adjusting the coastline of Ameland to follow the location of the reconstructed tidal inlets for Testerep around 6000 BP. To account for differences in the tidal range between the Wadden Sea and the Belgian Continental Shelf, the topography was exaggerated by a factor of 1.5 and an offset of 1 m was added to guarantee that supratidal areas would remain emerged at high tide. This new dataset was used to replace the coastal area in the present-day DTM of the Belgian coastal plain, between the contour lines of -13 and 3 m MSL. The two DTMs were merged using triangulation with linear interpolation (Fig. 2B). Large sandbanks offshore which are located too close to the reconstructed coastline at 6000 BP, were removed before interpolation. The DTM was further improved using image editing software (Adobe Photoshop v.25.12), after translating it into a greyscale GeoTIFF file, limiting the depth ranges from -50 to +50 m MSL. This allowed the manual rectification of the model: on the one hand, unwanted features such as artificial structures (modern harbours, dikes, canals ...) and deformations generated by the georeferencing were removed, while on the other hand, landscape elements evidenced by the palaeo-geographic reconstructions such as tidal channels and the palaeo-Yser river system were added.

Discussion and Conclusion

The identification and characterisation of the different sedimentary environments across the land-sea boundary allowed us to interpret and reconstruct Testerep as a barrier system, harmonising the scattered evidence onshore and offshore. Owing to large-scale erosive processes during the Late Holocene, most of the former island has been washed away, which hinders a quantitative reconstruction of the landscape. These reconstructions are needed to perform morphodynamic simulations to test long-standing hypotheses about landscape development and the impact of human activities. The Wadden Islands were selected as a modern analogue to fill the gaps and produce a palaeo-DTM, although we acknowledge that the origin of this Dutch barrier-island system is different to the case of the Belgian middle coast. However, the distribution of sedimentary environments and landscape features in our reconstructions are similar enough to consider the Wadden Islands as an adequate modern analogue. The reconstructed topography has been corrected to include the palaeo-topography from field data, such as the depth and width of the tidal inlets, and the location of the barrier and tidal channels. The generated DTM represents the idealised reconstruction of the Belgian coast of 6000 years ago and will be used as the base for the morphological and hydrodynamic modelling of the coastal evolution and the investigation of the erosional and depositional patterns that drove the coastline retreat to its present-day position.

References

Baeteman, C., 2018. The Coastal Plain of Belgium, Joint Product of Natural Processes and Human Activities. *In* A. Demoulin (ed.). *Landscapes and Landforms of Belgium and Luxembourg. World Geomorphological Landscapes*. Springer International Publishing, Cham. DOI: 10.1007/978-3-319-58239-9_19.

Tys, D., 2013. The medieval embankment of coastal Flanders in context. *In* E. Thoen *et al.* (eds.). *Landscapes or seascapes? The history of coastal environment in the North Sea area reconsidered*. CORN Publication Series 13. Brepols Publishers, Turnhout, 199-239.