Seismic imaging of medieval dike remains in the Wadden Sea (North Frisia, Germany)

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Abstract
Dikes protected cultural lands along the Wadden Sea coast in medieval North Frisia. Remains of dikes must be found to reconstruct the drowned and lost landscapes. Certain imprints in sediment layers due to former load can be linked to eroded dikes. Sediment echosounding provides sections of these imprints and reveals dike courses. Medieval dikes have been traced at Hallig Südfall and south of Sylt.

Keywords
dike; Middle Ages; sediment echosounder; tidal flats; Wadden Sea

Introduction

In the study area (Fig. 1) of the North Frisian Wadden Sea (Germany), we investigated the remains of medieval dike systems in the tidal flats sediments using marine reflection seismics (sediment echosounder, SES).

Dikes and terp settlements were built in North Frisia from the 12th century onwards to protect newly colonized marshland from the North Sea (Meier 2004). Severe storm floods of the 14th century led to breakage of dikes. Large parts of the cultural landscape were inundated and turned into tidal flats (Hadler et al. 2021). Research of the 1920s discovered occasionally exposed remains of a dike with tidal gates, drainage systems and terps in the area of Hallig Südfall (Busch 1923). An initial study (Wilken et al. 2022) revisited this site to test geophysical prospection methods in the tidal flats. Although the dike remains recorded in 1921 were eroded thereafter, it was possible to trace the dike by magnetic gradiometry and image its characteristic imprint in the underlying sediments through marine reflection seismics. This imprint represents a known phenomenon already visible on the original dike remains (Busch 1936).

In the study presented, we probed SES data collected primarily for geological investigations in the same area for similar imprints to identify the further course of the dike and possibly other, unknown dike systems in the larger North Frisian tidal flats.

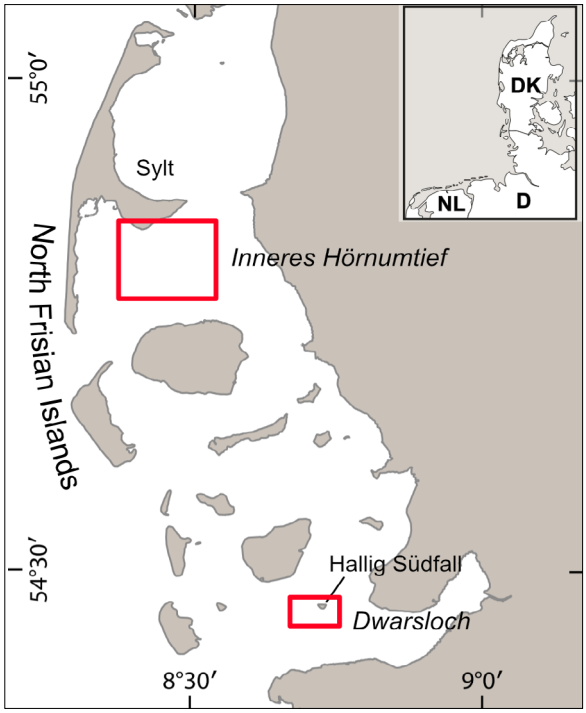

Fig. 1: Map of the North Frisian Islands (Germany) with outline of the two case study areas of the Dwarsloch tidal channel near Hallig Südfall and the Inneres Hörnumtief tidal channel near the island of Sylt.

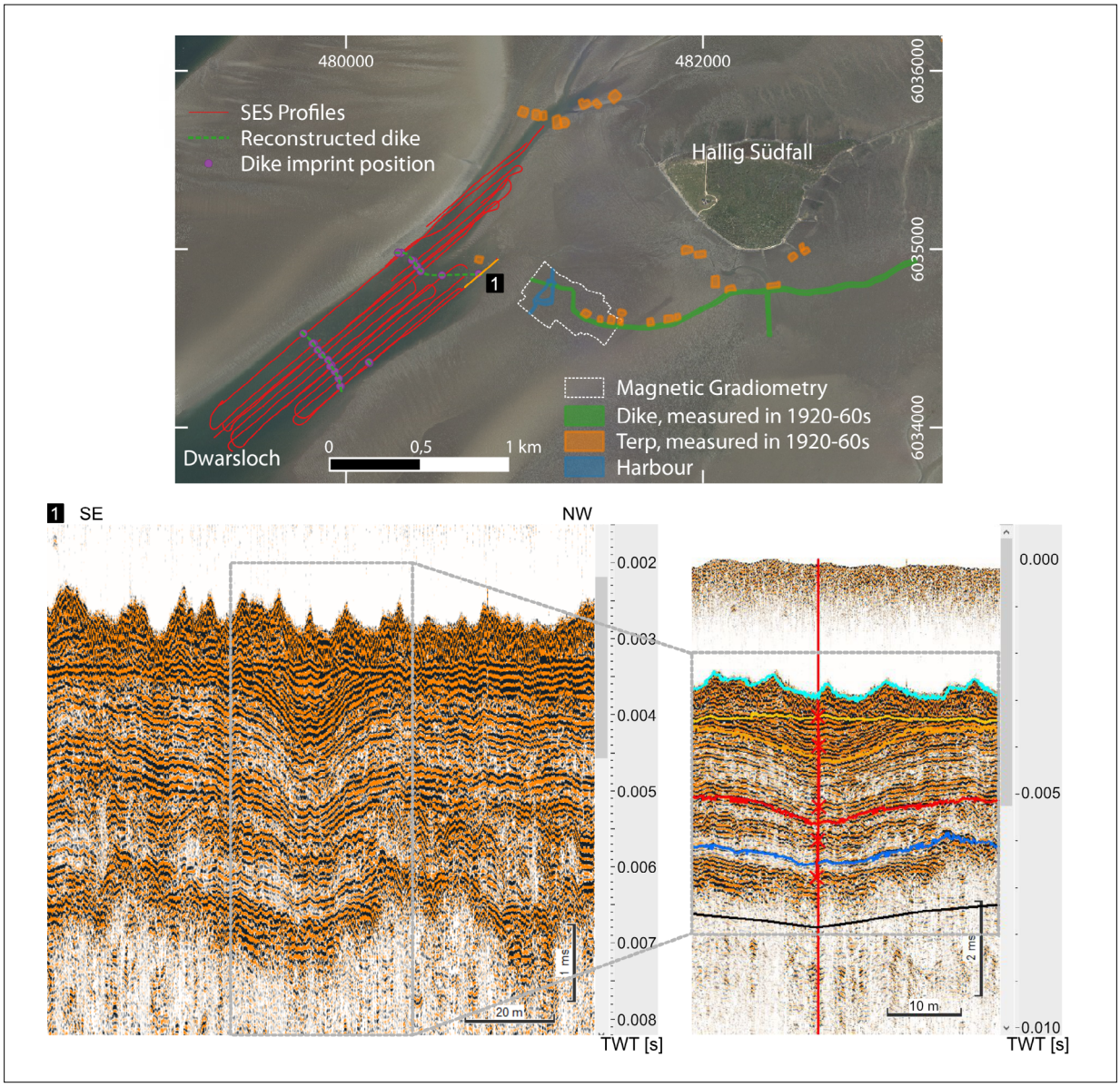

Fig. 2: Above: Aerial picture of Hallig Südfall (district of North Frisia, Germany) with drawing of dikes and terps as seen and measured in the 1920-60s and in magnetic gradiometry data (from Wilken et al. 2022), as well as sediment echosounder profiles in the Dwarsloch tidal channel with markings for dike imprints in the profiles and dashed outline of the newfound dikes. Aerial picture: LKN Schleswig-Holstein, 2018. Below: Seismic profile measured in the Dwarsloch with characteristic dike imprint. To the right, the profile section with the dike imprint is enlarged with reduced vertical exaggeration and drawing of discernible reflecting horizons.

Materials and methods

In the initial study, we used a high resolution two-channel SES with a center frequency of 4 kHz and a theoretical vertical resolution of about 0.1 m, positioned by RTK-DGNSS (Wilken et al. 2022). The SES data collected by K. Ricklefs in 2018-2021 in the tidal channels Dwarsloch southwest of Hallig Südfall and Inneres Hörnumtief southeast of Sylt used an INNOMAR2000 SES with a secondary frequency of 6 kHz and RTK-DGNSS positioning. The raw data was converted to the 16 bit SEGY data format and analyzed with Kingdom2018. The theoretical vertical resolution is 0.05 m, a maximum depth penetration of 15-20 m was reached in the Dwarsloch and 10-15 m at Hörnumtief. Both tidal channels were covered with long parallel profiles with a spacing of 50-100 m.

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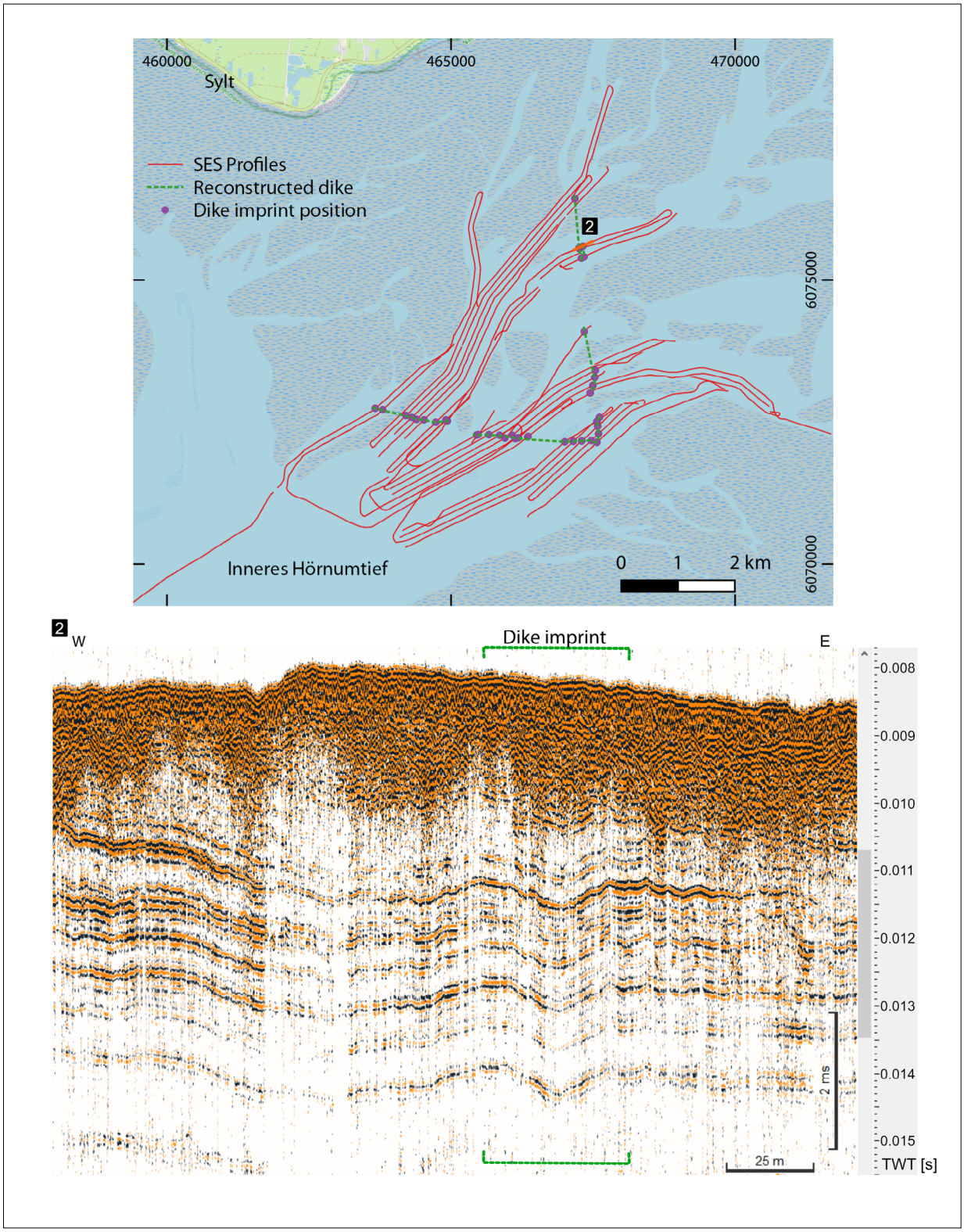

Fig. 3: Above: Map of the Inneres Hörnumtief tidal channel south of the island of Sylt (district of North Frisia, Germany) with drawing of sediment echosounder profiles, markings for dike imprints in the profiles and dashed outline of the newfound dikes. Map data: OpenStreetMap. Below: Seismic profile measured in the Inneres Hörnumtief with characteristic dike imprint.

The characteristic dike imprints derive from the pressure distribution underneath the original dike, leading to compression and deformation of the underlying sediment. The width of the imprint increases from shallow to deeper layers, while the imprints' height (of the deformation in regard to the overall course of the reflecting layer) decreases, therefore the dike imprints are only detectable in the upper 10 m of the stratigraphic sequence. This pattern distinguishes the dike imprints from geological features such as backfilled tideways. Dike imprints can only be found in pre-medieval, not redeposited layers, which can be clearly distinguished from younger tidal flat sediments. The SES profiles are screened visually for these characteristic structures. To gain a confident interpretation, possible dike imprints have to be aligned and found in at least five parallel profiles.

Results

The SES profiles measured in the tidal channel Dwarsloch lie parallel in extension to the measurements of the initial study (Fig. 2) and show a stratigraphy that can be matched with corings from the adjacent area (Wilken et al. 2022). The transition between young tidal flat sediments and pre-medieval, laminar strata is distinctive. In extension to the course of the previously recorded dike, all SES profiles show equally comparable dike imprints, describing a course towards the west with a bend to the northwest. In the upper layers, the maximum dimensions of the symmetrical, rounded imprint are 37 m in width with a depth of 27 cm, which is comparable to the initial study (Wilken et al. 2022).

A second row of dike imprints was found approximately 730 m further to the southwest. This previously unknown dike course ran roughly parallel to the south of the late medieval dike line in a northwestern-southeastern direction, indicating the existence of a younger polder seaward.

In SES profiles along the branches of the tidal channel Inneres Hörnumtief (Fig. 3), a number of structures have been found with striking resemblance to the dike imprints found in the Dwarsloch, albeit the conditions are not ideal with less visible original laminar layers and more redistributed sediment. Fewer parallel profiles were measured and higher boat speed und waves caused some noise. Possible dike imprints are found at 32 positions, but only few are clearly distinctive. Nonetheless, the confident imprints do align to an angled dike course. Best results are obtained in the northeastern, shallow parts channel branches with evidence of a north-south running dike. The dimensions of the imprints are comparable to the medieval dikes measured in the Dwarsloch.

Discussion

Seismic sounding on the confirmed archaeological site of a late medieval dike has shown that dike imprints can be measured in the subsurface. Starting from there, it was possible to find similar structures in further SES data. The known dike course could thus be extended, providing new evidence for the reconstruction of the medieval cultural landscape. But when screening further SES data, it is very hard to find confident imprints: the data quality is often poor due to noise from deeper waters or stronger engine thrust against the tide; many natural depressions appear as dike imprints; possible imprints do not recur in parallel profiles. Nonetheless, screening for possible dike imprints without a presumption based on archaeological data resulted in the case of the Inneres Hörnumtief. Upon further research, the newfound possible dike course fits well to existing medieval dike remains on Sylt and might resemble the unknown course of the Stinum-dike, which is believed to have been destroyed in 1362 (Kühn 1989).

Conclusion

The application of SES in the tidal flats and channels of North Frisia provides a useful method to track eroded medieval dikes along their imprints. The necessary preconditions are a suitable, undisturbed stratigraphy without deep erosion, a high resolution, several parallel profiles and calm conditions for measurements. Tracking dike courses from a known structure as a starting point is helpful to gain a high confidence for an interpretation as an anthropogenic structure in contrast to backfilled channels. In the cases of Dwarsloch and Inneres Hörnumtief, it was possible to track medieval dikes, which were previously only known in general, but not in their exact course and extent.

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