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A submerged Stone Age hunting architecture from the Western Baltic Sea

Jacob Geersen[a,b,1], Marcel Bradtmöller[c,d], Jens Schneider von Deimling[a], Peter Feldens[b], Jens Auer[e], Philipp Held[a], Arne Lohrberg[a], Ruth Supka[a], Jasper Justus Lutz Hoffmann[f,g], Berit Valentin Eriksen[h], Wolfgang Rabbel[a], Hans-Jörg Karlsen[c], Sebastian Krastel[a], David Brandt[i], David Heuskin[i], and Harald Lübke[h,2]

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The Baltic Sea basins, some of which only submerged in the mid-Holocene, preserve Stone Age structures that did not survive on land. Yet, the discovery of these features is challenging and requires cross-disciplinary approaches between archeology and marine geosciences. Here, we combine shipborne and autonomousunderwater vehicle hydroacoustic data with up to a centimeter range resolution, sedimentological samples, and optical images to explore a Stone Age megastructure located in 21 m water depth in the Bay of Mecklenburg, Germany. The structure is made of 1,673 individual stones which are usually less than 1 m in height, placed side by side over a distance of 971 m in a way that argues against a natural origin by glacial transport or ice push ridges. Running adjacent to the sunken shoreline of a paleolake (or bog), whose youngest phase was dated to 9,143 ±36 ka B.P., the stonewall was likely used for hunting the Eurasian reindeer (Rangifer tarandus) during the Younger Dryas or early Pre-Boreal. It was built by hunter–gatherer groups that roamed the region after the retreat of the Weichselian Ice Sheet. Comparable Stone Age megastructures have become known worldwide in recent times but are almost unknown in Europe. The site represents one of the oldest documented man-made hunting structures on Earth, and ranges among the largest known Stone Age structure in Europe. It will become important for understanding subsistence strategies, mobility patterns, and inspire discussions concerning the territorial development in the Western Baltic Sea region.

Stone Age | hunter–gatherer | Baltic Sea | marine geophysics | submarine geomorphology

Significance

Structures from the Stone Age can provide unique insights into Late Glacial and Mesolithic cultures around the Baltic Sea. Such structures, however, usually did not survive within the densely populated Central European subcontinent. Here, we explore a Stone Age megastructure, that has preserved under water in the Western Baltic Sea. It was likely constructed by hunter–gatherer groups more than 10000 y ago and ultimately drowned during the Littorina transgression at 8500 y B.P. Since then, it remained hidden at the seafloor, leading to a pristine preservation that will inspire research on the lifestyle and territorial development in the larger area.

The seafloor is shaped by geologic, biologic, and anthropogenic processes. The resulting morphologies are manifold, and their description and quantification can teach us about the underlying processes (1, 2). Yet the seafloor is veiled from our eyes, and we rely on geophysical and underwater visual studies. For many decades, it has been possible to resolve seafloor features on a scale of meters to tens of meters (depending on water depth) using ship-borne multibeam echosounder systems. Many smaller structures have, however, simply not been discovered to date. We applied state-of-the-art hydrographic and geophysical instruments and processing, as well as archaeological diving techniques to investigate a remarkable morphologic feature consisting of thousands of aligned stones that we discovered in the Baltic Sea at a water depth of about 21 m. The structure is located in the Bay of Mecklenburg, about 10 km northwest off Rerik, in Germany (Fig. 1).

The Bay of Mecklenburg is located in the southwestern part of the Baltic Sea (Fig. 1*A*) and was mainly shaped by the Weichselian glaciation (4). The sea level in this region since the Weichselian glaciation was governed by glacio-isostatic rebound and climatically controlled by ice coverage. Transgression and regression phases have led to at least four evolutionary stages of the Baltic Sea during the Holocene where alternating fresh, brackish, and marine water conditions occurred due to the opening and closure of drainage channels to the North Sea. As a result, rapid sea-level fluctuations occurred along the present-day coast of the Baltic Sea (5). Stattegger and Leszczyńska (6) provide evidence that the sea level in the Western Baltic Sea rose from −28 to −10 m below the mean relative sea level during the Littorina transgression between 8.57 and 8.0 ka B.P. Schwarzer et al. (7) report on a sea-level rise from −40 to −20 m between 13.3 and 12.7 ka B.P. The Bay of Mecklenburg has a maximum water depth of about 28 m. Shallow sedimentary strata are characterized by Holocene sandy mud that gets progressively sandier toward the coast. The surficial sediments are deposited on a basal till which is occasionally exposed on the seafloor.

The region is well known for its high density of submerged archeological sites, most of them documented by Lübke (8) and during the following SINCOS project between 2002 and 2009 (9–11). With a scientific focus on the post-Littorina transgression period, 23

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[1]To whom correspondence may be addressed. Email: Jacob.geersen@io-warnemuende.de.

[2]Present address: Leibniz Centre for Archaeology (LEIZA), Centre for Baltic and Scandinavian Archaeology, Schleswig 24837, Germany.

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submerged sites were uncovered in water depths of eleven to two meters, dating from 8500 to 5000 y B.P., shedding light on the continued settlement activities and the resilience of these societies. While older submerged sites are known from Scandinavia and the Eastern Baltic (12–14), older sites in Northern Germany are currently only known from the hinterland. Examples are the late glacial hunting spots at the Saaler Bodden (15) or the Ahrensburger Tunneltal (16), as well as the early Holocene camp sites at Hohen Viecheln at Lake Schwerin (17, 18) or ancient Lake Duvensee (19–21). Located in a water depth of about 21 m, the newly discovered stonewall likely predates the Littorina transgression, representing possibly the first known submerged Paleolithic archeological site in the German section of the Baltic Sea. With frequent outcrops of basal till in water depths ranging from the present coastline to more than 20 m (22) and given the abovementioned advances in resolution of shallow water hydroacoustic data, it seems likely, however, that similar yet undiscovered sites can be found elsewhere.

Results

The seafloor structure and basin-wide morphology in the Bay of Mecklenburg have been investigated by means of hydroacoustic data during numerous research campaigns over the last decades. However, it was only in September 2021, that we detected a spatially continuous, almost 1-km long, and usually <1 m high morphologic feature in high-resolution shipborne multibeam echosounder data. This elongated structure, that we hereafter refer to as the Blinkerwall, is located on the southern (landward) facing site of a northeast–southwest trending bathymetric ridge (Figs. 1 and 2). On its northeastern site, the ridge is connected to a concentric mound that elevates to a water depth of 13.5 m (Fig. 2*A*). The Blinkerwall extends over a longitudinal distance of 971 m between water depth of 21 m in the east and 21.5 m in the west. Toward the southeast (i.e., toward the present-day coastline), the two topographic elevations connect to shallower waters via a 300-m-wide ridge located in a water depth of about 19 m (Fig. 1).

The Blinkerwall is typically less than 1 m high (Figs. 2 and 3). Video observations from different sections along the wall, recorded by scientific divers, verified that the Blinkerwall is formed by a succession of individual stones (Fig. 4). The vast majority of the stones are also well resolved in the multibeam bathymetric data collected with the AUV (autonomousunderwater vehicle) at a range of about 2 m (Fig. 3). We used the high-resolution near-range AUV multibeam data to semiautomatically map the individual stones in order to evaluate their sizes and quantities. From the semiautomatic mapping approach, we counted 1,673 stones with a cumulative volume of 52.75 m^3 and a cumulated weight of 142,437 kg. The latter has been calculated by multiplying the volume with the density of granite of about 2,700 kg/m^2. While most stones weigh clearly below 100 kg, we also identified 288 heavier stones as part of the structure. The largest stone, located in the central section of the wall, has a calculated weight of 11,389 kg (Figs. 2*B* and 3*C*). Interestingly, it marks a sharp change from an east–west trending course of the stonewall to the west to a southwest–northeast trending course farther east. The second, third, and fourth largest stones, with weights of 2,083, 2,506, and 5,792 kg, are located at the western end of the wall, with the latter marking the termination of the wall (Figs. 2*B* and 3*A*).

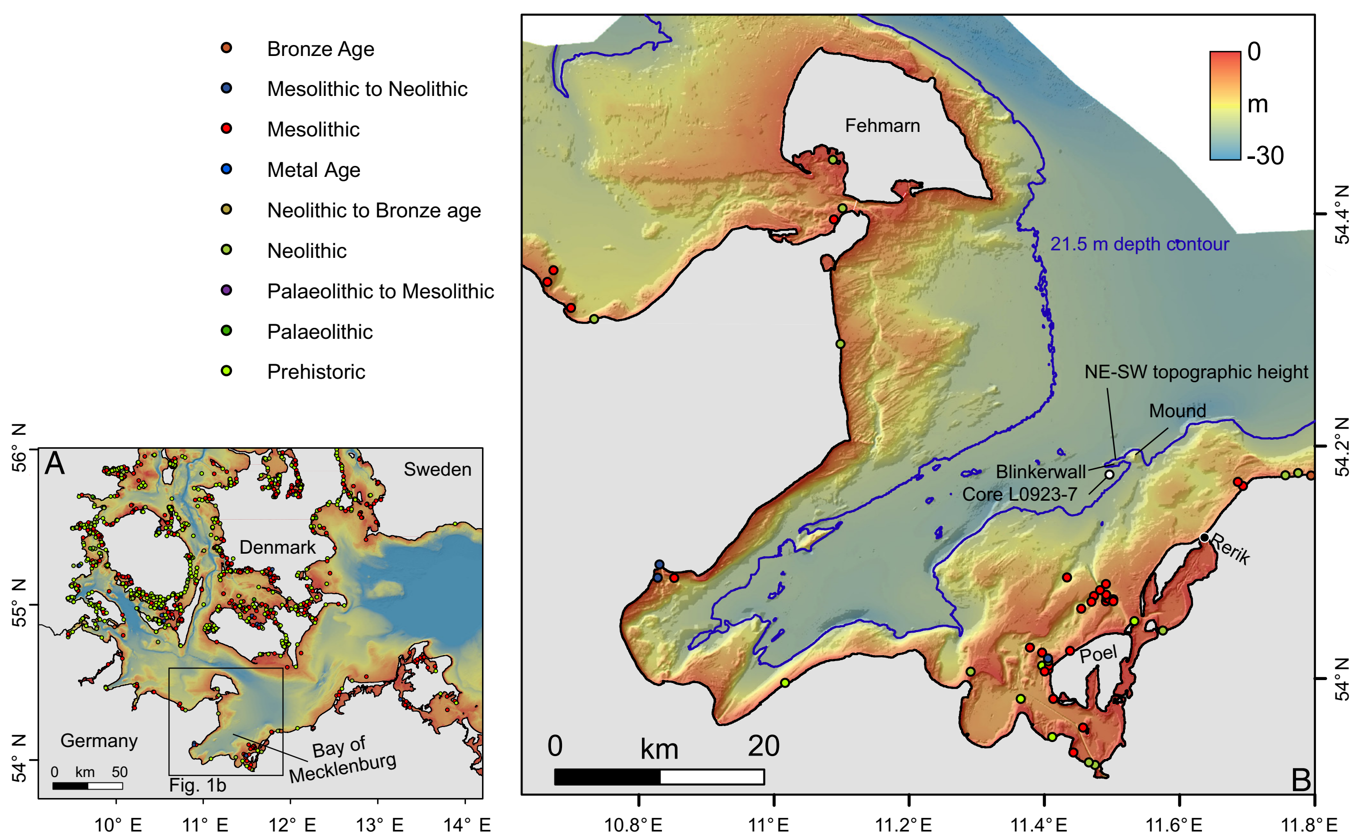

Fig. 1. The study area in the Baltic Sea. Location and relative ages of submerged archeological sites are taken from http://www.splashcos.org. (*A*) Overview map of the Western Baltic Sea. Bathymetric data were taken from the Global Multi-Resolution Topography (GMRT) synthesis (3). (*B*) Detailed structure of the Bay of Mecklenburg including the location of the Blinkerwall. Bathymetric data from The Federal Maritime and Hydrographic Agency Bundesamt für Seeschifffahrt und Hydrographie (BSH).

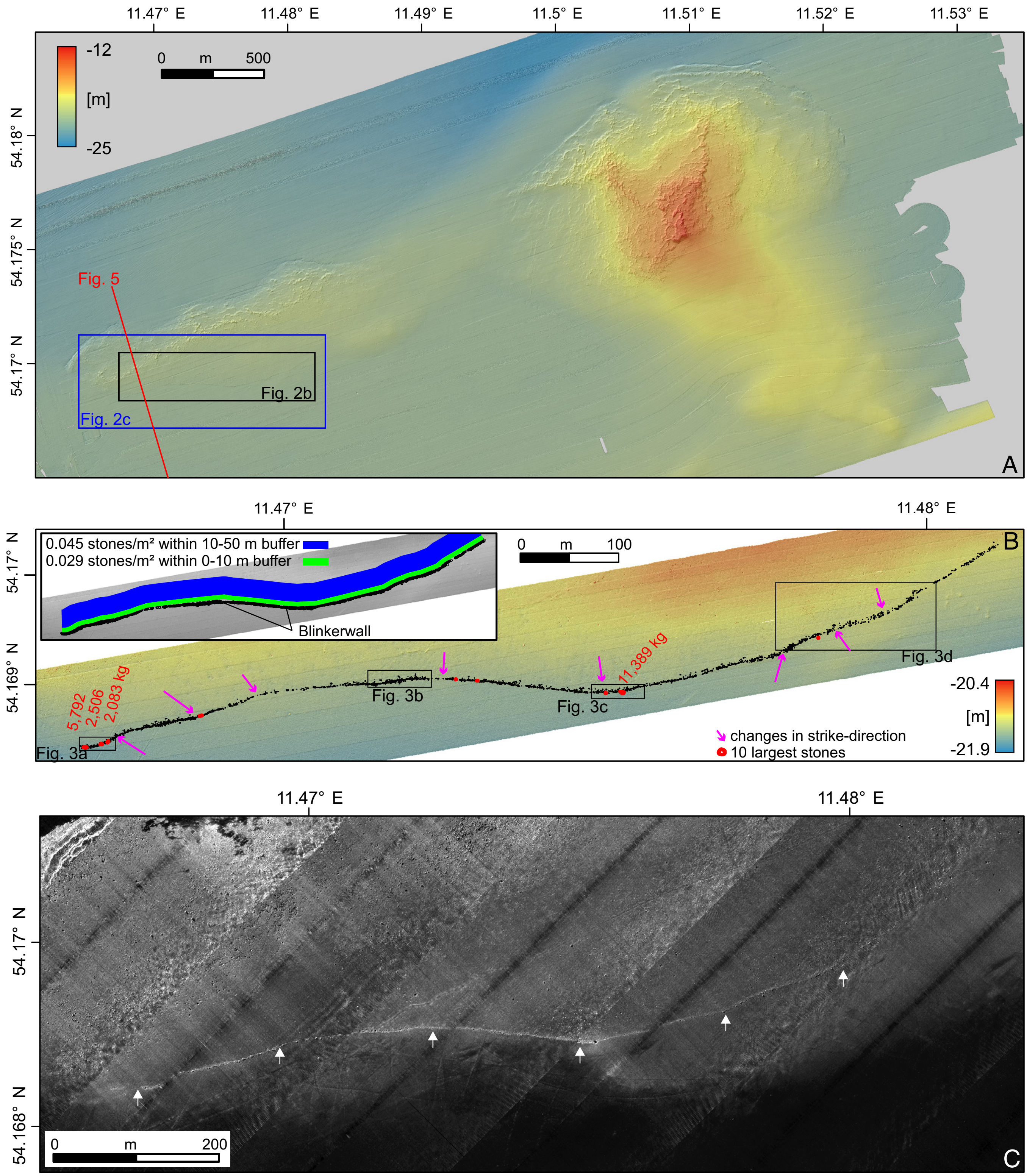

Fig. 2. Morphology of the southwest–northeast trending ridge that hosts the Blinkerwall and the adjacent mound. (*A*) Multibeam bathymetry collected with RV ALKOR (2021) and FK Littorina (2023). (*B*) Multibeam bathymetry collected with the AUV. (*C*) Side-scan image (bright colors = high backscatter) collected with RV Elisabeth Mann Borgese in 2020. White arrows point at the Blinkerwall.

Overall, the ten heaviest stones are all located within regions where the stonewall changes its strike direction (Fig. 2*B*).

Most stones are also well resolved in the side-scan sonar data collected on a regional basis (Fig. 2*C*). The measured heights of the individual stones from the side-scan data match with the semiautomatically determined heights from the AUV multibeam data, indicating consistency between the individual datasets. The side-scan data also indicate that elsewhere along the ridge, i.e., northward of the Blinkerwall, the seafloor is characterized by a high backscatter indicative of a rough topography (Fig. 2*B*). The high backscatter results from similar stones to the ones within the wall, which are widely distributed but randomly scattered farther

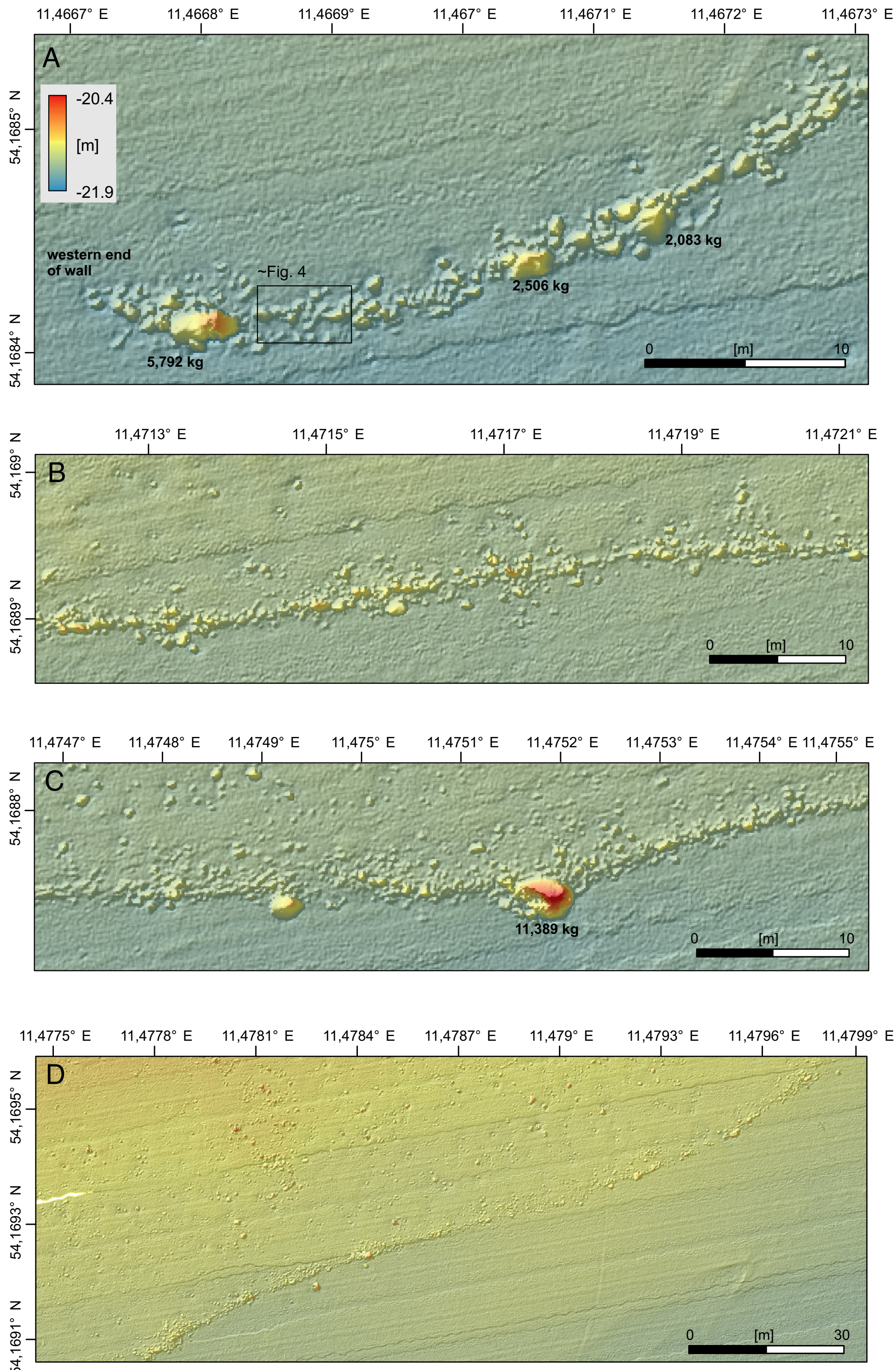

Fig. 3. AUV multibeam data from sections along the Blinkerwall. Please consider (Fig. 2*B*) for the locations of the different maps.

upslope on the southwest–northeast trending bathymetric ridge and the adjacent mound. Directly northward of the wall, the stone density decreases from 0.045 stones/m^2 at distances of 10 to 50 m from the wall to 0.029 stones/m^2 at 0 to 10 m distance (Fig. 2*B*). Especially along the western section of the wall, there are almost no stones within the first 10 m northward of the wall. Toward the south, no similar stones are found, and the high backscatter character changes 5 to 25 m southward of the wall. Here, a homogenously low backscatter suggests the presence of Holocene sediments (mud) deposited on the underlying basal till.

To investigate the regional geological setting and to reconstruct the paleolandscape adjacent to the Blinkerwall, we compiled

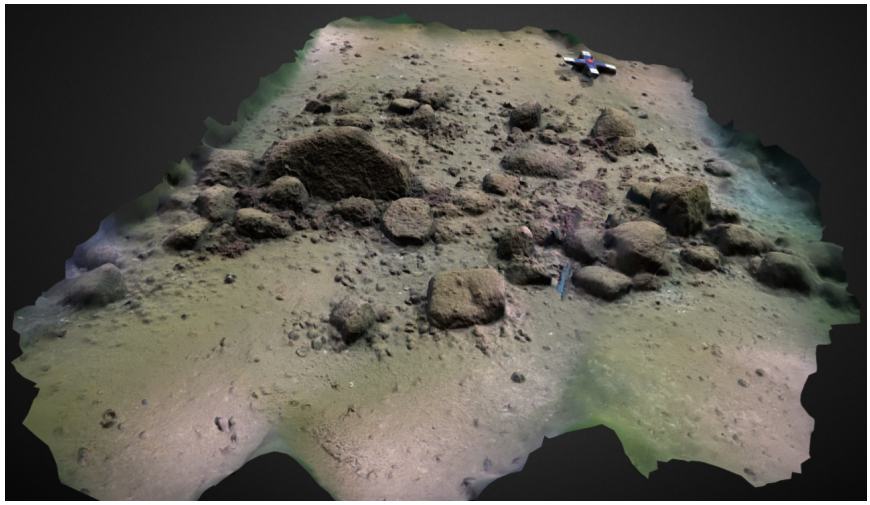

Fig. 4. 3D model of a section of the Blinkerwall adjacent to the large boulder at the western end of the wall. Photographs were taken by Philipp Hoy, Rostock University. The model was created using Agisoft Metashape by J. Auer, LAKD M-V. The scale bar at the *Top-Right* edge of the image is 50 cm.

various sediment echosounder lines. These data resolve the structure of the southwest–northeast trending bathymetric ridge that hosts the Blinkerwall, as well as the adjacent sedimentary basins toward the north and south (Fig. 5). The bathymetric ridge is described by a high amplitude seafloor reflection that hinders the imaging of deeper strata. The high reflection character matches the high backscatter signal observed in the side-scan sonar data. Toward the south, the seafloor loses its high-amplitude reflection character in the sediment echosounder and the side-scan sonar data. This is due to the presence of a shallow sedimentary basin. Within the basin, a high-amplitude erosional unconformity reflector divides an upper unit of well-stratified sediments from a lower unit of less-stratified sediments with lower reflectivity. Along the sediment echosounder line shown in Fig. 5, the upper unit reaches a thickness of 2.5 m while the lower unit is up to 3.5 m thick. The sediments in the upper unit show a parallel to subparallel relationship with the erosional unconformity.

Sediment core L0923-07, located about 890 m southward of the wall (Fig. 1) within the shallow sedimentary basin, recovered mainly Holocene mud before terminating at 1.8 m below the seafloor. Penetration at this depth was hindered by a peat layer that shows reduced reflectivity in the sediment echosounder data (Fig. 5). This layer overlies the erosional unconformity and wood samples from it preserved in the core catcher terminating the gravity core liner were dated to 10,578 ±84 cal B.P. (Beta Analytic, Beta - 673904). The age of the wood samples suggests that the underlying erosional unconformity corresponds in time to the Yoldia to early Ancylus Lake lowstand around 11.7 cal ka B.P. (4, 5). A corresponding unconformity has been observed elsewhere in the region (23, 24). Another wood sample taken from the upper layer of the sediment

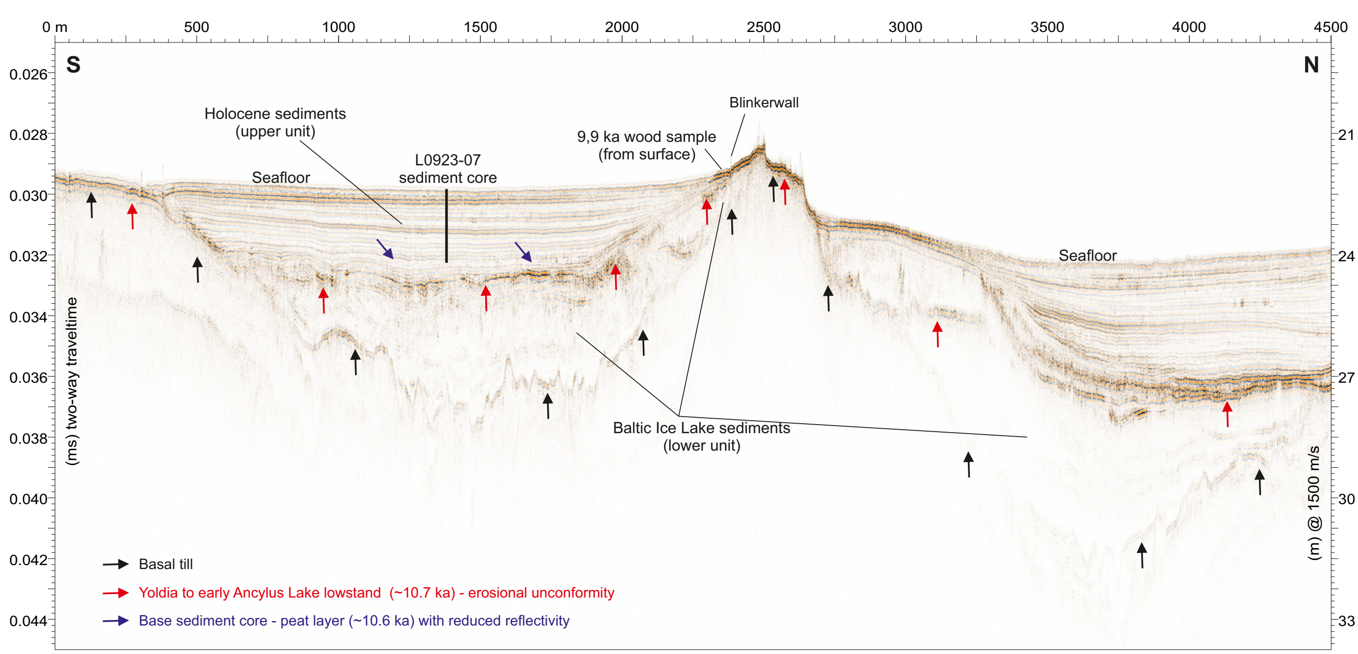

Fig. 5. North-south-oriented sediment echosounder profile (see Fig. 2*A* for location) across the east–west trending ridge that hosts the Blinkerwall and the sedimentary basin to the south. The erosional unconformity of the Yoldia to early Ancylus Lake lowstand land surface (compare Fig. 6) is located at 1 to 3 m depth in the basin and crops out slightly south of the Blinkerwall. The peat layer (10662 to 10494 cal B.P.) that hindered a deeper penetration of gravity core is visible as a layer with low reflectivity located above the erosional unconformity. The latter is underlain by the sediments of the Baltic Ice Lake.

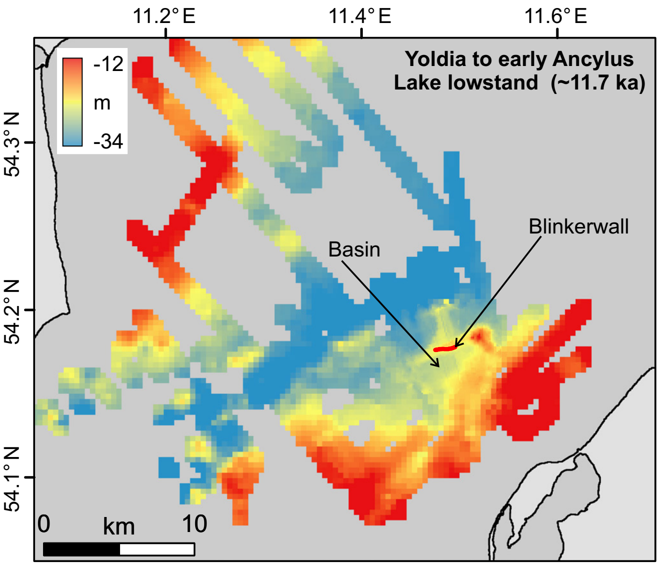

Fig. 6. The Yoldia to early Ancylus Lake lowstand land surface reconstructed from dozens of sediment echosounder lines retrieved from seismic archives of Kiel University (CAU) and the Leibniz Institute for Baltic Sea Research Warnemünde (IOW).

in the low backscatter area about 10 m southward of the wall was dated to 9,886 ±36 cal B.P. (Vilnius radiocarbon, FTMC-TR12-4). We therefore refer to the upper unit as Holocene sediments whereas we interpret the lower unit as Baltic Ice Lake sediments (Fig. 5).

The erosional unconformity reflector crops out at the surface slightly south of the Blinkerwall, forming the seafloor of the bathymetric ridge as well as the adjacent mound. On the southern flank of the bathymetric ridge, the surface of the reworked till deposits is not imaged continuously below the overlying sediment. The patchy character is, however, likely an artifact caused by the steep slope of the reflector along the flank of the basin. The southern boundary of the sedimentary basin is also defined by the outcropping of reworked till deposits, forming the seafloor toward Rerik and the islands of Wustrow and Poel.

Combining dozens of sediment echosounder lines, we traced the erosional unconformity, which we interpret to correspond in time to the 11.7 ka Yoldia to early Ancylus Lake lowstand, within the Bay of Mecklenburg (Fig. 6). At this time, the Blinkerwall (if it existed already) was located on an east–west trending topographic height that was linked to the hinterland in the southeast. South of the wall, located a 5-km-wide basin with a maximum paleodepth of 25 m, which is ~3 to 3.5 m below the ancient landscape adjacent to the Blinkerwall. Today, the basin contains up to 2.5 m of sediment on top of the Yoldia to early Ancylus Lake lowstand unconformity and up to 3.5 m of Baltic Ice Lake sediment below the unconformity.

Discussion

The Blinkerwall represents an exceptional morphologic feature, which has not yet been documented elsewhere in the Baltic Sea. The sediment echosounder data indicate that the structure is located on the reworked basal till deposits of the Weichselian glaciation (Fig. 5; also compare ref. 24). This was confirmed by diver observations during underwater surveys at the site. After the retreat of the Weichselian ice at around 17 cal ka B.P. (25), the basal till formed the land surface until it was repeatedly flooded during the following transgressions and regression of the Holocene Baltic Sea development (26). Considering the water depths of around 21 m, the seafloor surrounding the Blinkerwall was exposed above sea level during the lowstand of the Baltic Ice Lake (around 12.8 ka) and the Yoldia Sea (around 11.7 ka), both within the period of the Younger Dryas. It was also a terrestrial landscape during the lowstand following the Ancylus Lake regression (around 9.5 ka) in the Holocene (5). It was ultimately flooded during the Littorina transgression between 8.6 and 8.0 ka B.P., that followed on the Ancylus lowstand (6, 7).

Holocene sedimentation in the Bay of Mecklenburg and elsewhere in the Baltic Sea has resulted in a thick sediment cover of Holocene mud, which also defines the shallow strata in the sedimentary basin southward of the wall (Fig. 5). The Blinkerwall is located slightly upslope from where the reworked till deposits are buried beneath the stratified Holocene sediments and less well resolved sediments with a lower reflectivity located below the Yoldia to early Ancylus Lake lowstand unconformity. These older sediments were probably deposited during the existence of the Baltic Ice Lake [compare unit 3 in ref. 24 and Baltic Ice Lake II deposits described by Endler et al. (23)]. The transition from the sediments to the outcropping till deposits is resolved in the side-scan data due to the higher backscatter of the latter (Fig. 2*C*). The side-scan mosaic and the multibeam echosounder data show that stones are common features on the partially eroded till deposits (Figs. 2 and 3). This is a result of the subaerial exposure and shallow water environment the till was exposed to, leading to erosion and subsequent accumulation of formerly buried stones on its surface (27). Farther downslope within the basins, similar stones likely also exist in the basal till. However, already ~25 m southward of the wall, they are blanketed by more than 1 m of overlying sediment, the majority of which likely corresponding to the Baltic Ice Lake as indicated by the 9.9 cal ka B.P. wood sample from the surface sediments about 10 m south of the wall (Fig. 5). The existence of stones on the reworked till deposits on its own, however, does not shed light on the process that placed some of these stones side by side to create a 971-m-long feature.

There is no doubt that sufficient stones for the construction of the Blinkerwall were available in the immediate vicinity (tens to hundreds of meters) north of the wall where the basal till is exposed at the seafloor. Southward of the wall, the basal till is covered by the Holocene sediments and the underlying Baltic Ice Lake sediments. Here, the basal till may only have acted as source for a sufficient number of stones before the deposition of the Baltic Ice Lake sediments. In the following sections, we discuss natural and anthropogenic processes that are known to shape the land and seascape and evaluate whether they might be responsible for the genetic origin of the wall.

Natural Processes as Origin of the Blinkerwall. Natural processes capable of transporting stones exist, but they are rare and tied to specific geological settings. Huge tsunami waves, for example, can transport meter-scale stones and deposit them into large boulder fields (28). There are prominent examples of stones that have been moved by this process over kilometers within ocean basins or along continental slopes and volcanic islands [e.g., the Fogo tsunami boulder on Santiago Island (29)]. We are, however, not aware of a case where a tsunami wave has placed stones side by side along a 1-km-long line. The rare occurrence of tsunami in the Baltic Sea reported from Swedish and Polish coasts (30) combined with the location of the wall on the landward side of the bathymetric ridge, that would have buffered the wave energy on the seaward side, does not support a tsunami or storm-wave transport and deposition of stones along this paleoshoreline.

Moving ice is also able to transport stones. After the retreat of the Weichselian glaciers around 17 cal ka B.P. (25), different types of moraines remained in Northern Europe, that shape the landscape and seascape until today. From the different types, ground moraines are composed of till and not linked to linear ridges of stones. Lateral, medial, and terminal moraines, however, relate to ridges of unconsolidated debris. A lateral moraine as genetic origin of the wall seems implausible as there is no glacial valley in the area. This also rules out the presence of a medial moraine, which would require the presence of a glacial valley and corresponding lateral moraines. The region of the Blinkerwall, in contrast, was likely located in the center of a glacier stream at the time of the last glacial maximum based on the ice-marginal positions compiled by Stroeven et al. (25). The wall itself is oriented in SW-NE direction, and thus perpendicular to the expected direction of a terminal moraine in the area. Overall, the geographic position of the Blinkerwall makes it unlikely that it represents the remnants of a moraine from the Weichselian glaciation. Furthermore, the lack of a gravel fraction also argues against a moraine.

Subglacial meltwater tunnels (eskers) are found near former ice marginal lines, where they also form ridges composed of sand and gravel that can also include stones (31). In the Baltic Sea, reworked, branched, and stone-rich eskers up to 7 m high and a few hundred meters in length have been observed (32). In general, the height and width of eskers vary, but can reach several meters up to 50 m in height and up to 150 m in width (33). Esker lengths can exceed tens of kilometers, although they are often fragmented into shorter ridges measuring a few kilometers in length (31). The low height and small width of the Blinkerwall, along with the lack of a gravel fraction, are inconsistent with a glaciofluvial origin.

From Estonia and elsewhere in Scandinavia, beach ridges made of gravel have been reported to result from sediment-laden ice mases that drift to the shoreline, possibly wind-driven, thereby depositing their load (34). This process requires a coastline at −21 m (i.e., at the water depth of the Blinkerwall) and the availability of stones from outcropping basal till at the seafloor (or lake floor) in the adjacent basin to the south. Considering the late Pleistocene and Holocene Baltic Sea development, a coastline at 21 m was likely present repeatedly, but only over decadal to centennial periods during the transgressions and regressions in between the highstands and lowstands of the Baltic Ice Lake, the Yoldia Sea, and the Ancylus Lake (5–7). The Littorina transgression between 8.6 and 8.0 ka B.P., that followed on the Ancylus lowstand, represents the ultimate period when the Baltic Sea level was reduced by 21 m. During this time, however, the Baltic Ice Lake sediments and the overlying sediments from the Yoldia Sea and possibly the Ancylus Lake had already blanketed the basal till within the basin. The same holds true for the transgressions and regressions related to the Yoldia Sea and the Ancylus Lake.

The most plausible timing, for ice thrusting along a paleoshoreline as genetic origin of the wall, therefore falls into the period of the Baltic Ice Lake. Here, the paleolake-level variations are less well resolved compared to the later stages of the Baltic Sea (5). However, it appears likely that there have been periods when the lake shore was around −21 m and when the basal till was not significantly covered by sediments. Being built at this time would, however, imply that the Blinkerwall formed more than 13 ka ago and since then had withstand several of the later transgressions and regressions of the Baltic Sea, where it would have been in the swash zone for decades. Considering the well-confined width of the wall of generally less than 2 m, it is questionable whether such a pristine preservation is possible when the wall has been repeatedly located in a high-energetic near coastal environment.

Another doubt, whether the Blinkerwall may originate from ice thrusting along a paleoshoreline relates to the morphology of known ridges. The ridges usually extend over some meters up to tens of meters and also include a fine (gravel) fraction (34). The Blinkerwall, however, lacks such a gravel fraction and also shows a width limited to 2 m. Furthermore, the eastern end of the Blinkerwall is located in 21 m water depth, whereas the western end is located about half a meter deeper at 21.5 m. If the Blinkerwall is related to an ice push ridge, the elevation of the respective paleoshoreline would have to vary by 0.5 m. For a shoreline, such a variation over a distance of less than 1 km seems unlikely.

Taken together, the aspects discussed above do not ultimately rule out a natural process as the genetic origin of the Blinkerwall. However, for each of the different processes, several unresolved questions remain. We consider a shoreline influenced by drifting ice as least unlikely, whereas eskers, moraines, and tsunami deposits appear highly implausible. Finally, there is one observation that cannot be explained by natural processes at all, and which pointed us toward a possible anthropogenic origin of the structure. This is the preferential location of the largest and heaviest stones at knickpoints along the 971-m-long Blinkerwall (Fig. 2*B*).

Anthropogenic Construction of the Blinkerwall in the Modern Age. In the absence of basal complexes and basement rocks in Northern Germany, glacially derived stones were used for construction purposes in this area toward the end of the last millennium. The demand for stones resulted in the birth of stone fishing as a profession. Stone fishing represents an anthropogenic effort to move and conquer boulders from the marine environment using stone pincers and ropes. Stone fishing along the shorelines of the Western Baltic Sea dates back to (at least) the end of the 18th century (35). For Mecklenburg–West Pomerania, a recent investigation identified 55 locations along the shoreline, where stone fishing was conducted (35). All sites are located in shallow water environments at no more than 6 m water depth and the vast majority of sites concentrates to the east of the Island of Rügen. After 1906, stone fishing was prohibited, and the stones were left in place being identified as important habitat and also useful for coastal protection. Because stone fishing concentrated on the near-coastal waters and was not done in the central basins, we consider an anthropogenic movement of the stones for the purpose of stone fishing an unlikely candidate to explain the construction of the Blinkerwall. Furthermore, it seems unlikely that within the 18th and 19th century, stone fishers would have been able to place the stones next to each other over a distance of about 1 km given the water depth of about 21 m. Let alone the fact that their intention was to remove the stones rather than place them elsewhere on the seafloor.

Stone accumulation at the seafloor could also occur as a result of stone excavation during cable or pipeline construction. However, the nearest infrastructure of this kind, the "Baltic Cable" connecting the German and Swedish power networks (36), is situated more than 3 km toward the north and was placed into the fine-grained deposits of the central Bay of Mecklenburg (37). Therefore, it is unlikely that this infrastructure is responsible for the observed accumulation of adjacent stones. It also fails in explaining the change in strike direction of the wall at the position of the largest stone.

Anthropogenic Construction of the Blinkerwall in Prehistoric Times. With a natural origin and modern activities unlikely, the Blinkerwall was most probably built in prehistoric times. Located in a water depth of 21 m, submergence occurred latest between 8.57 and 8.0 ka B.P, considering the sea-level reconstructions for the Bay of Mecklenburg (6). This timespan directly serves as a terminus ante quem for the construction. Additionally, the wood sample recovered from the uppermost peat level of the adjacent paleolake can serve

Table 1. Stone-walled hunting structures found elsewhere around the globe with a comparable morphology

Location	Length	Construction type	Proposed function	Literature
JGHD02/Jibal al-Gadiwiyt, Jordan	>100 m	2 stone walls + enclosure	Drive lane and corral	58
Drop 45 Drive Lane, United States	>30 m	2 stone walls	Drive lane	59
Barnett site (EeOp-56), Canada	64 m	2 stone walls	Drive lane	60
Olson site (5BL147), United States	>1,300 m	Several stone walls	Game drive	61
AB547 and AB549, Saudi Arabia	1,549 m and 2,623 m	2 stone walls + enclosure	Drive lane and corral	53
I1/ Aasivissuit, Greenland	70 m	1 stone wall	Drive lane	55
Inussuk system/ Aasivissuit, Greenland	3,900 m	Row of regular and irregular cairns	Drive lane	55

as a post quem for the submerging of this landscape after 9.1 ka B.P. This timeframe is highly remarkable, as it excludes agrarian societies as founders. Instead, the regional chronology model (38) recommends ownership to the regional hunter–gatherer societies. Several archaeological traces from the ninth millennia B.P. are documented in the region of the southern Baltic Sea (10, 39). But while these societies are generally known for small-scale camps and nonpermanent features, the feature at hand clearly classifies as a stationary structure. It encompasses around 1,385 stones that weigh less than 100 kg and that should be movable by a small group of people. These movable stones were used to connect about 288 larger stones, with some of them clearly nonmovable by hand. All stones locate at the southern flank of a ridge made of glacial till, indicating that the raw material outcrop for the stones was directly accessible. This implies a short and downslope-directed transport of the stones. This hypothesis is supported by the 10-m-wide stripe just north of the Blinkerwall that shows a reduced stone density. With an estimated number of 1,281 of persons living contemporaneously in Northern Germany and Poland during the latest glacial (40), and a group size of 40-45 persons during the course of a year (group size 2, cf. ref. 41), the construction of an about 1-km-long stonewall would imply the high relevance of this structure for the group subsistence. It further raises the question of whether the entire structure was built at once or over multiple stages.

Similar-sized man-made constructions are completely unknown from the region, making a functional interpretation challenging. Late and End Mesolithic coastal cultures are known for intensive use of the newly emerging marine resources (42, 43), and fishing with stationary wooden fish weirs was of great importance (43–45). Theses constructions, however, usually do not exceed a few hundreds of meters in length, while the Blinkerwall is almost one km long. From other parts of the world, fish weirs made of stone have also been documented (46, 47). It seems, however, unlikely that the Blinkerwall has served as a stone fish weir, as these installations require an appropriate water flow for sufficient functionality. They are therefore usually constructed in rivers or on coastal sections with a strong tidal range. Neither is the case at the location of the Blinkerwall.

Also, several other functions seem unlikely due to the morphology and setting of the structure. This encompasses the use as an early groin for sea defense, which has been documented for a Neolithic site in the near East (48). With a width of usually less than 2 m, the Blinkerwall appears too small to function as base for such a coastal protection wall. Moreover, the function of the Blinkerwall as an early harbor construction is unlikely as the presumed age corresponds to a time for which boats have not yet been documented so far. Even if there would have been boats, they would not have been very sophisticated but may have been able to land on the beach (49, 50). Moreover, it is a period where we most likely are dealing with highly mobile hunter–gatherer groups with questionable territorial claims. Without fixed territories, both, a groin as well as a harbor construction appear implausible. Instead, it appears more likely that the late Paleolithic or early Mesolithic hunter–gatherers erected a structure that would need no mending throughout the year and would be rather immediately useable when needed.

The Hunting Hypothesis. Based on the information at hand, the most plausible functional interpretation for the Blinkerwall is that it was constructed and used as a hunting architecture for driving herds of large ungulates. While the terms "hunter–gatherers" and "architecture" are not the most natural couple, recent research at sites like Göbekli Tepe, Turkey (51), offers a more complex picture. Hunting architecture is thereby defined as a human-made modification to the natural landscape or any built stationary structure with the primary goal of procuring animal resources (52). In recent years, megascale stone-walled enclosures have been documented especially in arid regions, where the preservation potential is high due to the lack of fluvial erosion and sedimentation (53, 54, cf. https://www.globalkites.fr/). But also, in low-populated areas like west Greenland (55, 56), or submerged within the Great Lakes of North America (52, 57), similar structures have survived. These documented structures often encompass different elements including one or more drive lanes for manipulating the movement direction of the animals, corrals for trapping, and hunting blinds for killing the animals. Table 1 lists several stonewalls of different sizes, that were used as driving lanes or corrals in the drive hunt for ungulates living in herds. In warmer regions, these ungulates usually encompass gazelles or antelopes, whereas in colder regions like in the Western Baltic Sea, they are represented mainly by reindeer or bison (57).

For a long time, the dating of such megastructures was problematic, but in the meantime, it has been possible to prove that individual structures are of prehistoric age (58, 61, 62). Due to comparable environmental conditions in the Late Glacial/Early Holocene transition, stone-walled drive lanes that were used for reindeer hunting are of particular relevance for the interpretation of the Blinkerwall. The submerged "Drop 45" site located on the Alpena-Amberley Ridge in Lake Huron, United States, shares several characteristics with the Blinkerwall, including

- a location near the top of the slope, but below the crest,
- a subparallel trending marsh/lakeshore on one side,
- the construction on bedrock,
- the good preservation in a submerged context of 20 to 30 m water depth, and
- solid and continuous construction

The functionality of Drop 45 is thereby assumed to be a drive lane for hunting large ungulates. This interpretation is supported by lithic artifacts, which were documented during multiple diving surveys. These artifacts culminated in certain constructions along the Drop 45 structure, which were interpreted as hunting blinds (52, 59). Along the Blinkerwall, the large erratic blocks could have served as similar hunting blinds. This, however, needs to be tested by further archaeological surveys.

Both features differ, nevertheless, in scale. With a length of only 30 m and a total diameter of 100 m, Drop 45 is much shorter compared to the Blinkerwall. Furthermore, Drop 45 encompasses two stone lanes that narrow down to a small channel toward their ends, which is not the case for the site in the Bay of Mecklenburg. However, at the Blinkerwall, two opportunities for a cul-de-sac are evident. This could be either a second, parallel trending, row of stones to the south, which are now buried under the Holocene sediments. Or, it could be a small land bridge between the wall and an adjacent lake. Although reindeer are generally happy to swim, the water would have slowed down the animals allowing effective hunting from nearby boats (55).

Like many other drive lanes, the topographic orientation of Drop 45 suggests biannual migration routes of large ungulates, most likely caribou (Rangifer tarandus) (52). Interpreting the Blinkerwall as a driving lane for panicked large ungulates on biannual migration routes raises the question of the prey. The most obvious target of hunters in the region would be the Eurasian reindeer (Rangifer tarandus). Specialized hunting of reindeer herds using distinct topographies is documented since the Middle Paleolithic (63) and well known for the Baltic region (56, 64, 65). Thereby, hunters within these localities used the behavior of reindeers to be attracted to linearity, which is also used for the drive lanes (57). Furthermore, new studies (66) suggest east–west oriented migration routes for these herds which possibly explains, why the existing topography of the east–west oriented glacial ridge was chosen.

However, the expanding Holocene forest likely modified the seasonal patterns (67) and led to an emigration of reindeer northward. It was only until 9,8 ka B.P., that these animals were regularly and predictably present in the area (16). Consequently, if the Blinkerwall served as a driving lane for the reindeer hunt, the terminus ante quem for its construction is the Pre-Boreal or late glacial period. This puts the Blinkerwall into range of the oldest known examples of hunting architecture in the world (58, 62, 68) and potentially makes it the oldest man-made megastructure in Europe. However, exact dating of such hunting structures is generally challenging as artifacts and carcasses are often missing in these settings due to ancient cleaning (57). The oldest known drive lane, a so-called desert kite, could only be dated by luminescence dating (10000 B.P., 58). Dating will also be a challenge for the Blinkerwall.

Conclusion

Combining marine geophysical, sedimentological, and archeological data and considerations, we suggest that the Blinkerwall is of late-Pleistocene/earliest Holocene age. The wide absence of similar-sized Stone Age megastructures in Europe is likely due to preservation issues on the densely populated subcontinent, while difficulties of identification or even recognition could play another role (69, 70). Offshore, their recognition is mainly hindered by the required centimeter to decimeter scale resolution of hydroacoustic data, which was usually not achieved in legacy studies conducted over the last decades. Furthermore, the Holocene sediment cover has already blanketed similar-sized structures within the Baltic Sea basins, so that they only remain along structural heights where basal till crops out at the seafloor. In the Bay of Mecklenburg, there are, however, a certain number of sites where ground moraines from the Weichselian glaciation crop out at the seafloor in water depth around 20 m and beyond. These mounds and ridges (Fig. 1), which are largely starved off Holocene sediments, may provide crucial but yet missing information on the development of the Late Glacial and Mesolithic cultures during phases of rapid advance of the Baltic Sea.

The suggested date and functional interpretation of the Blinkerwall makes the feature a thrilling discovery, not only because of its age but also because of the potential for understanding subsistence patterns of the early hunter–gatherer communities. As stated by A. Lemke, "[..] permanent hunting structures anchor [the foragers] to certain places on the landscape and create sociopolitical and economic tensions concerning ownership, territoriality, leadership, labor aggregation, group size, and other social dynamics" (52). The discovery of this kind of structure shed light on many aspects of the regional hunter–gatherers, especially regarding their socioeconomic complexity. This encompasses first the question and search for the associated aggregation sites during building and hunting season (20, 39). Second, we need to ask whether the comprehensive stationary fish weirs from the post-Littorina Mesolithic can be possibly interpreted in the tradition of the stationary driving lanes from the Late Paleolithic/pre-Littorina Mesolithic? And finally, it is interesting to mention that the ethnographic comparisons for continuous and massive built driving lanes like the one at hand suggest the use of spear or lance (52). While bow and arrow was regularly used these days (71, 72), it could help to explain the high variability in projectile dimensions (16) and the suggested weapons documented, e.g., for the late glacial tanged points (73).

Materials and Methods

Multibeam Echosounder. Multibeam echosounder data were collected in 2021 during RV ALKOR Cruise AL565 (74) and in 2023 during FK Littorina cruise L0123 (75). In both cases, a NORBIT Multibeam iWBMS system was used. The roll offset of the system was calibrated through collecting data along the same profile in opposite directions. Sound velocity information from five Conductivity Temperature Depth casts was derived for refraction of the soundings. For overlapping soundings that showed a systematic offset, we applied a refraction correction algorithm to minimize the SD (76). The corrected soundings were spline filtered excluding the area of the wall. Here, we applied a point cloud-based filter and manual editing in order to account for the exceptional and complex seafloor morphology induced by the wall including the multitude of stones. Motion and navigation data were left unprocessed except for Real Time Kinematic height editing and interpolation in one file. The processed soundings were gridded with a spacing of 0.5 m and ultimately reinterpolated in order to remove small data gaps within the area. The final grid is projected in UTM32N and tidally reduced to GCG2016 with mean sea level as vertical reference.

Using the same multibeam system, we also collected bathymetric data using an AUV from the German Aerospace Centre Deutsches Zentrum für Luft- und Raumfahrt (DLR). The AUV was deployed during FK Littorina cruise L0123 (75). The AUV is equipped with a Doppler velocity log for measuring velocity over ground, a pressure sensor for measuring depth, a sound velocity sensor, and a GNSS system for positioning at the sea surface. For underwater positioning, the AUV uses a highly accurate inertial navigation system (INS, IXBLUE PHINS). The integrated INS enables the AUV to reach a high positioning accuracy. Its state-of-the-art positioning sensors enable the AUV to determine its current position, speed, and orientation at any time with a horizontal uncertainty of 0.1% of the covered distance. With this information in conjunction with a scanning sonar for obstacle detection, the AUV can independently react to unforeseen environmental conditions and disturbances such as currents (up to 3 kn), rising or falling seabed and unknown objects or structures on the seafloor. Processing of the AUV data was conducted in a similar manner compared to the ship-based data, with a final grid spacing of 0.1 m, accounting for the shorter range.

Semiautomated mapping of the stones in the AUV multibeam data was conducted through a combination of multiple hydrogeology tools in ArcMap. It mainly followed workflows used for mapping of seabed pockmarks (77). Using the inverse grid of the AUV multibeam data, all depressions (resulting from the inversion of the stones), were filled up to their pour point. The newly created grid was then subtracted from the original grid and areas that had changed by more than 4 cm were classified and outlined with polygons. The outlines of the stones were then smoothed and their surface areas and volumes were calculated for each feature. Polygons with a surface area of less than 0.03 m^2 were deleted as this was close to the resolution of the underlying bathymetric grid. Subsequently, the polygons were manually inspected and those that did not encircle stones were removed.

Scientific Diving. The site was visited and inspected by a team of scientific divers from Rostock University and the State Authority for Culture and Monuments in Mecklenburg Western Pomerania on one occasion. The dive primarily aimed at assessing the nature of the stonewall and to survey the surrounding seabed for the presence of possible archaeological artifacts. Additionally, a series of photographs were taken in order to create a measured photogrammetric model of the site (Fig. 4). The photographs were processed in the software Agisoft Metashape for three-dimensional (3D) reconstruction. The dives concentrated on two locations, namely the western end of the structure and a large stone in the center where the Blinkerwall changes direction (Fig. 3*C*).

While neither artifacts or dateable organic material was found in the immediate vicinity of the two dive locations, a small timber sample was retrieved from the Holocene sediments about 10 m to the south of the structure. The sample was used for radiocarbon dating by Vilnius radiocarbon, resulting in a conventional radiocarbon age of 9,143 ±36 B.P. Conversion to calendar years was based on the INTCAL20 database (78), resulting in an age of 9,886 ±36 cal B.P. (95.4% certainty).

Gravity Coring and Radiocarbon Dating. Sediment core L0923-07 was collected in 2023 during FK Littorina cruise L0923 at 54.1609°N and 11.4728°E. It was recovered with a 3-m-long gravity corer attached to a weight of about 600 kg. After recovery, the core was transported to the IOW. It was split and visually described. A wood fragment from the peat layer below 1.83 m core depth was preserved in the core catcher. It was extracted and used for radiocarbon dating by Beta Analytics. The radiocarbon dating resulted in a conventional radiocarbon age of 9,350 ± 30 B.P. Conversion to calendar years was based on the INTCAL20 database (78), resulting in an age of 10662 to 10494 cal B.P. (92.1% certainty).

Sediment Echosounder. Data on the structure of the subseafloor were retrieved from seismic archives of Kiel University (CAU) and the Leibniz Institute for Baltic Sea Research Warnemünde (IOW). The data were recorded with the parametric subbottom profilers Innomar SES-2000® medium and SES96 standard. Innomar SES-2000® medium systems are permanently installed on RV ALKOR and RV ELISABETH MANN BORGESE with a hull-mounted transducer, while the mobile system SES96 standard was used onboard RV PROFESSOR ALBRECHT PENCK. Data were recorded between 2002 and 2022. The Innomar systems are connected with a motion sensor for roll and pitch stabilization of the sound beam. It produces two high frequencies, symmetrically placed around 100 kHz, to generate a focused low frequency soundbeam of low frequency. The resulting secondary frequency corresponds to the difference between the two high frequencies and can be set between 4 and 15 kHz. The systems have a vertical resolution of about 6 cm while the accuracy depends on the frequency and water depth, e.g., 100/10 kHz: 2/4 cm + 0.02% of the water depth (79). The secondary frequency for data used in this study was set between 6 and 12 kHz. For interpretation in this study, raw data were converted to the sgy format with the Innomar software tool SESconvert and loaded into HIS Kingdom for further interpretation.

Side-Scan. Backscatter data were acquired using the dual frequency (100/400 kHz) Klein Marine Systems, Series 4000 side-scan sonar. Data were recorded onboard the research vessel Elisabeth Mann Borgese on September 20 and 21, 2020 (80), and processed with SonarWiz 7 (Chesapeake) to a mosaic resolution of 0.25 m. The high-frequency backscatter mosaics are shown in this study. Processing included slant range correction, empirical gain normalization, nadir filtering, and layback corrections. The backscatter mosaic is projected in UTM32N.

Data, Materials, and Software Availability. All data are archived in https://www.io-warnemuende.de/data-portal.html. AUV based multibeam data (http://doi.io-warnemuende.de/10.12754/DATA-2024-0001) (81). Ship based multibeam data (http://doi.io-warnemuende.de/10.12754/DATA-2024-0002) (82). Sediment echosounder data (http://doi.io-warnemuende.de/10.12754/DATA-2024-0003) (83). Side scan data (http://doi.io-warnemuende.de/10.12754/DATA-2024-0004) (84). Yoldia lowstand land surface data (http://doi.io-warnemuende.de/10.12754/DATA-2024-0005) (85).

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Author affiliations: [a]Institute of Geosciences, Faculty of Mathematics and Natural Sciences, Kiel University, Kiel 24118, Germany; [b]Leibniz Institute for Baltic Sea Research Warnemünde (IOW), Rostock 18119, Germany; [c]Heinrich Schliemann-Institute of Ancient Studies, Rostock University, Rostock 18051, Germany; [d]Interdisciplinary Faculty, Department WKT, Rostock University, Rostock 18059, Germany; [e]Landesamt für Kultur und Denkmalpflege Mecklenburg-Vorpommern, Schwerin 19055, Germany; [f]Department of Coastal Geology, Helmholtz Centre for Polar and Marine Research, Alfred-Wegener-Institute, List 25992, Germany; [g]Department of Geosciences, Marine Geology and Seafloor Surveying Group, University of Malta, Msida MSD 2080, Malta; [h]Schleswig-Holstein State Museums Foundation Schloss Gottorf, Centre for Baltic and Scandinavian Archaeology, Schleswig 24837, Germany; and [i]German Aerospace Center, Institute for the Protection of Maritime Infrastructures, Bremerhaven 27572, Germany

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