Autonomous remote detection of submarine archaeological sites in the Kiel Bight / Baltic Sea using AUV and ROV

A field report

Philipp Grassel, Fritz Jürgens, Marco Berger, David Brandt, Jonas Enzmann, David Heuskin, Lea Meyer

Authors:

- Dr. Philipp Grassel, German Maritime Museum - Leibniz Institute for Maritime History
- Dr. Fritz Jürgens, Institute of Pre- and Protohistoric Archaeology of Kiel University
- Marco Berger, now ATLAS Elektronik
- David Brandt and Dr. David Heuskin, research group System Integration and Verification of the German Aerospace Centre (DLR) - Institute for the Protection of Maritime Infrastructures in Bremerhaven
- Jonas Enzmann, workgroup for maritime and limnic archaeology (AMLA), Institute of Pre- and Protohistoric Archaeology of Kiel University
- Lea Meyer, now Heerema Marine Contractors

Abstract: Through a collaboration between experts from the research group System Integration and Verification of the German Aerospace Centre - Institute for the Protection of Maritime Infrastructures in Bremerhaven, the German Maritime Museum - Leibniz Institute for Maritime History and the Institute of Pre- and Protohistoric Archaeology of the Kiel University, it was possible to investigate several underwater areas within the Kiel Bight in the Baltic Sea. In two campaigns in 2020 and 2021 some large scale surveys could carried out by using an autonomous underwater vehicle (AUV) and a remotely operated underwater vehicle (ROV). The article presents some of the objects investigated during these surveys and categorises them scientifically.

Zusammenfassung: Durch die Zusammenarbeit von Expert:innen der Forschungsgruppe Systemintegration und Verifikation des Deutschen Zentrum für Luft- und Raumfahrt - Institut für den Schutz maritimer Infrastrukturen in Bremerhaven, des Deutschen Schifffahrtsmuseum - Leibniz-Institut für Maritime Geschichte und des Instituts für Ur- und Frühgeschichte der Christian-Albrechts-Universität zu Kiel war es möglich, mehrere submarine Areale innerhalb der Kieler Bucht in der Ostsee zu untersuchen. In zwei Kampagnen, in den Jahren 2020 und 2021, konnten mit einem autonomen Unterwasserfahrzeug (AUV) und einem ferngesteuerten Unterwasserfahrzeug (ROV) großflächig Surveys vorgenommen werden. Der Artikel stellt einige der bei diesen Surveys untersuchten Objekte vor und ordnet sie wissenschaftlich ein.

Introduction

The Kiel Bight is a highly interesting area for underwater archaeological research. Due to several thousand years of settlement and shipping history, this area offers a multitude of underwater finds ranging from remains of the Stone Age to finds from contemporary times. These conditions predestine the Kiel Bight for a scientific cooperation between the research group System Integration and Verification of the German Aerospace Centre (DLR) - Institute for the Protection of Maritime Infrastructures in Bremerhaven, the German Maritime Museum - Leibniz Institute for Maritime History (DSM) and the Institute of Pre- and Protohistoric Archaeology of the Kiel University (UFG - Kiel University). Within this cooperation, DLR specialists were able to test an autonomous underwater vehicle (AUV) of the type SeaCat as well as a remotely operated vehicle (ROV), model BlueROV2 Heavy Duty.[1] (fig. 1) The SeaCat AUV was developed by Atlas Elektronik and features an Edgetech 2205 Sidescan sonar (230/850 kHz), a High-Resolution Norbit WBMS Multibeam Echo sounder (400 kHz) and a parametric Subbottom profiler (Tritech Seaking SBP). Furthermore, interchangeable payload areas enable the relatively uncomplicated installation of additional sensors in the device. The ROV have

[1] members of the DLR team at this time: Marco Berger, David Brandt, David Heuskin and Lea Meyer

a Low-Light HD Video camera with 2 MP 1080p, 1920 x 1080 pixel, video compression, 1/2.9" Sony Exmor IMX322 / IMX323 sensor and a focal length of 2.9 mm. Furthermore, a forward-facing Multibeam sonar (BlueView p900-130) is installed and the maximum possible diving depth is 100 m.
The AUV and ROV tests were carried out on various underwater objects. They were organised and scientifically accompanied by scientists from the DSM and the UFG - Kiel University. The research vessel FK LITTORINA served as base for the investigations. In two campaigns, which took place in July 2020 and April 2021, a Mesolithic site, some potentially Iron Age wreck remains, two wreck remains with brick cargoes, an already known wooden wreck with fax-lime cargo, a previously unknown and potentially flat-bottomed wooden wreck, the wreck of guard ship (Wachschiff) no. 11 / VOITJA, two downed British bombers from the Second World War and a pile of possible sea mines dumped after the Second World War were explored by means of large-scale, high-resolution Sidescan and Multibeam images. The specialists from the DSM and the UFG - Kiel University than were able to evaluate and classify these finds and, in some cases, examine them directly through diving. The following article will present an overview of the results for some of the examined objects. The focus will be on those finds that date to the 20th century. (fig. 2) However, the analyses of the research data have not yet been completed and the potential for further finds or new data on known objects is very high.

MALIK. A wreck with a brick cargo at the Kiel Fjord

In 2015 and 2016, two unknown wrecks were found by divers during their training as certified scientific divers by the scientific diving centre at the Kiel University (FTZ – CAU Kiel) within the Kiel Fjord. As the names of both ships remain unclear the wrecks were named MALIK and 2-ANKER WRACK. Both sites were reported to the Schleswig-Holstein State Archaeological Office (ALSH) and officially labelled as *Ostseegebiet 1527 LA 13* as well as *Ostseegebiet 1527 LA 16*. The sites were archaeologically investigated by short dive surveys in 2015, 2016 and 2018. A dendrochronological sample was only taken during the surveys at the 2-ANKER WRACK. Unfortunately, it did not yield any usable data and further sampling has not yet been carried out on neither the MALIK nor the 2-ANKER WRACK. The most noticeable feature of both wreck sites is a large amount of bricks covering the further remains. A description and critical evaluation of both sites based in the results of the short dive surveys in 2015 to 2018 was published in 2021 by Philipp Grassel.[2] Due to the limited length of this article only the wreck MALIK will be roughly described in the following; including the new measurements obtained from the AUV surveys.
The wreck site lies on a sandy bottom about 2.4 km off the coast near Bülk Lighthouse at the western entrance to the Kiel Fjord in a depth of about 10 m. It is orientated in a north-south direction, ca. 12 m long, approx. 1.80 m high at its highest point and around 6 m wide. The mound covering the wreck remains consists entirely of bricks and has a rather elliptical basic shape. The bricks are completely overgrown with marine fauna. About 3.5 m beside the find a smaller accumulation can be found, also made of bricks, about 2 m wide, ca. 6 m long and 0.3 m high. (fig. 3) In the northern area of the wreck site, about 2 m away from the larger accumulation of bricks, an anchor is visible. This heavily overgrown anchor is about 2 m long. It is corroded, but the shape and individual parts are still clearly recognisable. The two preserved arms are each approx. 80 cm long. The arms extending from the cross of the anchor, including the flukes, each have a length of around 50 cm. (see fig. 4) Other metal objects of different shapes and sizes can be found scattered around the wreck, but have not yet been assigned a proper function. However, following the reports from the early dive surveys two wooden plank remains are clearly recognisable. The exposed part of one of the planks measures 2.26 m in length and 32 cm in width and is located on the western part of the larger brick feature. The wood does not show any definable processing marks. It also appears that a much larger part is still hidden in the sediment. The second plank measures ca. 1.60 m in length and also 32 cm in width. It is located in the southern area of the find and has rectangular perforations of approx. 7 cm in length at regular intervals. It is likely that these are so-called scuppers. This would make the plank a remnant of the former bulwark.[3] Further structural parts of the ship are overlaid by bricks and sediment. So far no detailed investigations of the areas underneath the bricks have been carried out. This is the same with an area at the western site of the find. Here a lot of different objects can be seen in the Sidescan sonar. Some long and thin objects

[2] Grassel 2021, 25-38
[3] Grassel 2021, 28f.

are visible which can be assumed as possible parts of a former rigging. To clarify this, further dive surveys in this area would be worthwhile in the future.
Some of the bricks are still stacked and preserved in situ. (fig. 4) However, there are also many individual pieces of bricks scattered around the wreck site. They have slightly different measurements which range from 21.8 x 9.9 x 5.1 cm to 22 x 10.5 x 6.5 cm. It should be noted here that only a handful of bricks were investigated in 2015 and 2018 and more extensive measurements of several bricks from different areas of the wreck site have not yet been carried out. Based on the different dimensions, a standardised format cannot be assumed for the bricks on the wreck for now. Special moulded bricks or other optically different formats have also not yet been identified. The colouring of the bricks is described as "reddish-yellow" and in some cases they show impurities from smaller and medium-sized stones. The investigated pieces also show no markings of brickworks or other elements that would allow an assignment of the origin or a dating. However, it is relatively clear that the sheer quantity of bricks characterises them as cargo or partial cargo.
As no dendrochronological dating is available and the bricks are not yet suitable for a chronological classification, the find can only be dated very roughly on the basis of the anchor and the general features of the wreck site. The shape of the anchor gives an indication of a *terminus post quem*. Based on shape and construction, it is probably a version of an admiralty anchor. Variations of this type of anchor can be found since the 1830s.[4] The anchor show that a dating of the wreck before 1830 is very unlikely. Since the wreck find is rather small, no remains of a propulsion engine are detectable so far, only wooden planks can be assumed as construction material – as no remains of a metal hull were found – and possible rigging remains can be found in the western area of the wreck site an interpretation of the find as the wreck of a small, wooden coastal sailing ship is quite likely so far. In Germany, smaller shipyards can still be found after 1900, which continued to build wooden or composite ships and mainly produced smaller types of rigged ships for coastal shipping. Nevertheless, until shortly before the beginning of the First World War, the main use of steel as building material and the main use of auxiliary engines for propulsion can be assumed for almost all shipping, including the small costal shipping, on the German coasts.[5] Based on the described finds, a time frame from the 1830s to the first decade of the 20th century can be narrowed down, in which the wreck can very probably dated. As this is a quite rough dating based solely on indications, further scientific verification for example by means of usable dendrochronological samples is necessary. Also the wreck site must be examined in detail during a comprehensive archaeological excavation to research possible construction features underneath the bricks and sediments and within the possible area with the potential remains of the rigging.

VOITJA. A shipwreck from the Second World War

As in many other waters, the majority of the wrecks in the Kiel Fjord are probably from the 20th century, primarily from the Second World War.[6] During the 2020 and 2021 surveys, one of these wrecks - BSH no. 336[7] - was surveyed in detail with the AUV. The wreck lies in the outer fjord at a depth of 20 m and its location is proving problematic for exploration. It is located in the centre of the ship traffic separation area, south of Kiel Lighthouse and the shipping lane must not be obstructed there. In this case, the use of the AUV proves to be ideal, as it can autonomously navigate to the wreck under water while the research vessel can wait outside the shipping lane. Large-scale remote sensing of the wreck also proves to be indispensable, as the wreck is no longer intact and the debris around the wreck site is quite confusing. The detailed mapping of the wreck, which was achieved using a Multibeam sonar, enables the scientific divers to carry out targeted investigations later. This was important due to the limited diving time at the wreck site and the greater depth. (fig. 5) During the dives, we followed the German regulations for scientific diving. The German regulation mandatory requires valid certificates when using for example mixed gases.[8] The divers would therefore have to present an additional training

[4] Schmidt 1983, 67 f.; Lehmann 2014, 35-38.
[5] Spethmann 2002, 17 f.; Detlefsen 2007, 11-47.
[6] Huber 2015, 94.
[7] BSH is the german abbreviation for German Federal Hydrographic Agency (**B**undesamt für **S**eeschifffahrt und **H**ydrographie)
[8] German regulations for scientific diving, see BGR/GUV-R-2112, 2011.

certificate for mixed gas diving. Furthermore, the regulations of the Kiel University did not allow diving with e.g. rebreather. For these and other organisational reasons, we decided to dive with compressed air. The investigated wreck was the VOITJA, also known as VÕITJA or WÕITJA (translated: winner). This ship was built in 1907 by J. Poopu on the Estonian island of Saaremaa. The originally wooden three-masted barque had a length of 36.80 m, a width of 9.20 m and a displacement of 320 GRT.[9] In February 1929 the ship was bought by Peeter Jüriska and the Lloyd's Register 1933/34 lists her under the official number 60; call sign HBEK. Its home port was Käsmu in Estonia, where it sailed for the shipping company P. Jüriska & J. Aberg and was mainly used to transport timber. Until 1939 the owner Peeter Jüriska himself was the captain. (fig. 6) The ship was nationalised in 1940, than captured by the Germans in 1941 and transferred to Germany. Here it was converted into a guard ship (Wachschiff). The masts were removed and anti-aircraft guns installed. A more precise description of the conversion activities and further construction details of the ship after it was brought to Germany have not yet been found. On February 7th 1945, the VOITJA was subordinated to the 1st Securing Division (1. Sicherungsdivision) as guard ship nr. 11 and, like other converted sailing ships, served to protect waters which were threatened by aircraft mines. The Kiel Fjord, as entrance to the important war harbour, was such a particularly endangered area and at the beginning of 1945, the VOITJA was sunk by an aerial bomb. It is not clear whether there were any casualties among the crew.[10] In March and April 1945, the city of Kiel was bombed in at least six air raids (11.03., 21.03., 22.03., 03.04, 04.04. and 09.04.). The sinking or loss of ships is mentioned for at least four of these air raids on March 11th, April 3rd, April 4th and April 9th.[11] But, whether and if so at which of these attacks the VOITJA was possibly sunk, remains unclear so far.
The wreck was surveyed by AUV on April 13th 2021, with Sidescan and Multibeam images being taken. It lies in a position of about 130°, with the hull listing 30° to starboard. The Multibeam image clearly shows the severe state of destruction of the wreck. (see fig. 5) While the stern and the portside are badly damaged, the bow is still largely intact. It is possible that the damage, or at least parts of it, was caused by the bomb that sank the ship. However, some of the damage may also have been caused by fishing nets, as observed by divers on the wreck. One outstanding feature is a twin anti-aircraft gun, which is still on the foredeck and was used for the guard ship's air defence. It is presumably the common 2 cm or 3.7 cm calibre.[12]

Two Royal Air Force bomber in the Kiel Bight

In recent years, relics of aviation history have also increasingly become a focus of archaeological research. The majority of these are certainly aircraft wrecks from fighting planes and bombers from the Second World War. In contrast to the other types of findings, aviation archaeology is often only indirectly concerned with the object, in this case the aircraft, but rather with the fate associated with it. The aim is to identify and recover the aircraft and the crew that crashed with it. Due to this fact, often not traditional archaeological organisations, but missing persons search organisations are involved in the search and excavation of crashed aircrafts. There are two known sites were airplanes crashed in the Kiel Fjord which were part of our surveys. The first site is located in shallow water near Bülk Lighthouse at a depth of 6 m. It is very poorly preserved due to its exposed location and the “visits” of souvenir hunters. In the Sidescan image, the site is only visible in the form of a tyre with a few smaller pieces of the wreck in its immediate vicinity. (fig. 7) In 2020, this site was investigated due to a dive survey.
As visible in the scan, a tyre of the main undercarriage is the largest remaining component. The rubber of the tyre remains intact for a long time even in salt water. Surrounding numerous smaller objects that can be assigned to the engines, including a crankshaft, piston, oil pump and radiator are preserved. The crankshaft shows that it was an in-line engine, a V-engine to be precise. Alongside the frequently used radial engines, this is the typical engine type on propeller aircrafts. When the wreck was discovered by sport and professional divers, several engines and the iron propeller hubs of the three-bladed propellers were still present. A single-engine fighting aircraft can therefore be ruled out. Using the engines and

[9] Schmelzkopf 1996, 241.
[10] Gröner 1993, 456.
[11] A contemporary source which lists a lot of air raids in Germany from January to April 1945 can be found in the Federal Archive (Bundesarchiv - BArch) in Berlin. Title: „Einsatz einzelner Sparten der Ordnungspolizei.- Lagemeldungen Nr. 1377-1381, 1389, 1391-1396, 1402-1407, 1410-1421.“ BArch, R 19/341.
[12] Jürgens 2023, 102.

details on the frame construction, the bomber can be identified as a Halifax II (Mk. 2) of the Handley Page Aircraft Company and thus as a four-engined bomber of the Royal Air Force (RAF). (fig. 8)
Over 6.000 machines of this aircraft type were produced in various versions between 1940 and 1946. In addition to its use as a normal bomber, this type of aircraft was also used for numerous special tasks such as mining of shipping lanes and harbour entrances. The bomber lying near Bülk Lighthouse was probably also used for this purpose, as shown by two sea mines found at the site. They were removed and detonated by the explosive ordnance clearance service several years ago due to their potential danger. The five machine guns present at the time of discovery have since disappeared from the wreck site. However, parts of their ammunition are still scattered around the wreckage. Human remains in the form of bone fragments could also be observed at the crash site over several years. Accordingly, it is therefore a war grave. Despite a surviving frame number, the aircraft has still not been unequivocally identified, meaning that the names of the crew who died there are not yet known. Whether it is actually the Halifax II with the identification number LW 287 that was shot down over Kiel on October 2nd 1943, is not yet certain. Other sources report that this aircraft was probably shot down by an anti-aircraft gun in Rönne / Bornholm, where it exploded over water.[13] However, it is certain that the remaining parts of the wreck will have completely disappeared within a few years due to the salt water and wave action. Also identifying the site purely by means of Sidescan images is already associated with major problems in its current state. However, as the majority of aircraft wrecks in shallow European coastal waters are probably in a similar state of preservation, the limits of remote identification of such objects alone due to scan images are clearly evident, even though the objects are comparatively young in archaeological terms.
Due to its location several nautical miles off the coast of Schönberg, at a depth of 15 m, the second known aircraft wreck is much better preserved and is therefore an exception. It was discovered in 2004 by the BSH. Divers found debris scattered over an area of 35 x 17 m, including an engine and a propeller. The latter was retrieved for closer examination by the ALSH. It was also a V-engine, precisely a Merlin from the British manufacturer Rolls-Royce, which also clarified the nationality of the aircraft. However, this engine model was built very frequently and was used in numerous aircraft models. Due to the size of the wreck parts the examined specimen can only be a bomber, which limits the selection to five models. In addition to a Handley Page Halifax, as identified for the other described wreck site, it could be a Fairey Battle, a Vickers Wellington, an Avro Lancaster or an Armstrong Whitworth Whitley. A Sidescan image from 2020 shows a wing and parts of the fuselage, as well as parts that can be assigned to the engine nacelle in the wing. (see fig. 7) The engine and propeller were also recovered at this point. Based on the current data, it appears to be a twin-engine Whitley bomber from the Armstrong Whitworth Aircraft Company. (fig. 9) This was also used as a maritime reconnaissance aircraft for the airspace over Kiel. However, this can only be determined with certainty after further research and diving investigations at the wreck site. As part of the project, this site was scanned using AUV over an area of 150 x 150 m. In addition to the already known finds – parts of the fuselage, a wing and the engine nacelle – further wreck parts were identified in the surrounding area. A wheel of the main landing gear can be found 30 m to the south, and further finds, such as another engine with a propeller, were verified by divers in May 2021. This scattering of parts over a larger area, visible in the Sidescan image, can be explained by the fact that the bomber broke apart as it hit the water surface. The wreckage fragments than probably drifted apart and sank. Otherwise, the scattering could also be explained by the effect of trawls, but this seems rather unlikely due to the good preservation of the individual fragments.
To summarise, aircraft wrecks under water often lie on the surface due to the slowing effect of the water, in contrast to such wrecks on land. However, this makes the lightweight materials used, such as aluminium, particularly susceptible to erosion, which is why only the cast steel engines or rubber tyres usually remain as recognisable objects in the area under investigation. This makes remote sensing very difficult, with a few exceptions such as the last site presented here. A doubtless categorisation based solely on scan data is therefore only possible in a few individual cases.

[13] Jürgens/Huber 2021, 94-101.

Possible sea mines at the ammunition dump site Kolberger Heide

During the project, it was also possible to survey a small area of the so called Kolberger Heide ammunition dump site with the AUV. The Kolberger Heide is an area of approx. 15 km², located near the eastern entrance to the Kiel Fjord, a couple of nautical miles off the coast. It was used as dumping area for ammunition after the Second World War and a wide variety of ammunition e.g. different types of sea mines, artillery grenades and depth charges but also torpedo heads, cartridges for pistols and rifles as well as lumps of loose explosive without any metal shell can be found here.[14] (fig. 10)
The area is prohibited for any activity and a licence is necessary to work here. The Sidescan image shows an accumulation of spherical objects (probably moored sea mines) over an area of ca. 24 x 10 m in ca. 10 m depth.[15] There is a smaller accumulation about 4.5 m away and other individual spherical objects can be found nearby. (see fig. 11) Each of the objects has a diameter of approx. 1 m. Some of them are still well preserved, whereas others already show clear signs of corrosion or the casings appear to be almost gone. There are other small finds in the vicinity which could presumably also be ammunition remnants. Another Sidescan image shows a roundish sediment structure in 12 m depth, which is probably a blast crater. (fig. 11) The potential crater itself is again about 1 m deep in the ground. Some of the mines dumped at the Kolberger Heide were intentionally blown up between 2009 and 2012 by the explosive ordnance clearance service, which potentially led to such sediment structures.[16]
The Kolberger Heide is just one of 15 designated ammunitions dumping areas in German waters and the German Exclusive Economic Zone (EEZ) in the North Sea and Baltic Sea.[17] Other areas contaminated by ammunitions and so-called suspected ammunitions sites are also known and have been partially mapped.[18] The problem of ammunition in the sea and the potential dangers pose by ammunition to the marine environment have long been a research topic, and a number of research projects have already been carried out; particularly in the Baltic Sea but lately also in the North Sea.[19]

Conclusion

As shown in this article by using several examples, the collaboration between the DLR engineers and the specialists for maritime archaeological-historical research from the DSM as well as UFG - Kiel University has been extremely fruitful. Some previously little known or even unknown sites in the Kiel Bight have been investigated with an AUV and ROV. The Sidescan and Mulitbeam images form an extremely important and very comprehensive basis for further archaeological research and for the planning of diver-assisted surveys. The detailed scans also made it possible to analyse individual objects precisely but also show, as in the case of the remains of the bomber lost near Bülk Lighthouse, the limits of such scan methods. However, remote sensing is clearly an invaluable advantage for archaeological surveys due to the sometimes poor visibility conditions in the Baltic Sea. It was also possible to use the scans to directly visualise decaying processes, for example at the wrecks of the bombers or the possible ammunition at the Kolberger Heide. In future such data could, for example, make it possible to avoid diver-supported investigations for signs of decay at potentially dangerous objects.
In a similar way, regular sensor based investigations using AUV and ROV of underwater archaeological sites, such as the wreck sites of the MALIK, the VOITJA and the bombers, could carried out in the future. So, scientific divers could focus directly on underwater archaeological excavations, which could be planned using the scans. The scan data also makes it possible to create detailed, digital 3D-models of the underwater finds and features in the future, which in turn can be used for scientific analyses, cultural heritage reports and public relations work for research projects. The transdisciplinary collaboration presented here has therefore an enormous scientific potential, both for archaeological-historical research in the marine environment and for the use as well as evaluation of state-of-the-art imaging scanning techniques for submarine areas.

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[14] Kampmeier u.a. 2020, 3f.
[15] Very similar objects and structures in the same area are described as moored mines. Maser/Strehse 2020, 1943f.
[16] Maser/Strehse 2020, 1941-1953.
[17] Jenisch 2020, 493.
[18] For more information about ammunition in the sea, see https://legacy.amucad.org/ (15.11. 2023). For more information about ammunition dump sites in German waters, see: https://legacy.amucad.org/map (15.11. 2023)
[19] See for example Appel u.a. 2018, 1072-1078; Schuster u.a. 2021; Grassel 2022, 89-100; Maser u.a. 2023.