RESULTS FROM THE JOINT BALTIC SURVEY, PERFORMED AS PART OF THE ALLIED MUNITIONS DETECTION UNDERWATER PROJECT BETWEEN THE UNITED STATES AND GERMANY

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Abstract: *There is a significant worldwide capability shortfall in deploying reliable techniques for remotely detecting and mapping underwater munitions for unexploded ordinance (UXO) remediation in complex environments. As part of the Department of Defense's (DoD) Coalition Warfare Program (CWP), the Naval Surface Warfare Center, Panama City Division (NSWCPCD) from the United States and the Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD71) from Germany are partnering to enhance their joint capability to detect, classify, localize (DCL) and map underwater munitions and mines in challenging and harsh environments with an emphasis on utilizing unmanned underwater vehicles (UUVs) to detect and localize buried objects.*

This will be accomplished by developing, testing and evaluating novel survey concepts utilizing innovative and emerging technologies and techniques from mine countermeasures (MCM) science & technology (S&T) programs during joint international sea trials for data collection and analysis. The first joint sea trial occurred in September 2016 in the Baltic Sea north of Germany over various known and suspected UXO dumping sites dating back to the Second World War. Over the span of two weeks, organizations from both countries deployed and operated advanced prototype sensing technologies, primarily acoustic and magnetic, in these areas with high success. Results from the 2016 Joint Baltic Survey (JBS) will be discussed along with a short discourse on upcoming future work within this program.

Keywords: *acoustics, magnetics, UXO, data fusion, survey, MCM, UUV*

1. PROJECT OVERVIEW

There is a significant worldwide capability shortfall in deploying reliable techniques for remotely detecting and mapping underwater munitions for UXO remediation and for hunting buried and stealthy sea mines in complex environments. Therefore the Allied Munitions Detection Underwater Initiative (ALMOND-U) project was formed as a cooperative research and development project by the US and German Navies to enhance the ability to utilize UUVs to DCL and map underwater munitions in challenging and harsh environments with an emphasis on buried objects. This project will be focused on developing, testing and evaluating novel unmanned underwater survey concepts, utilizing advanced, innovative and emerging acoustic, magnetic and electro-optic technologies and techniques (including concepts of deployment, sensor fusion, data fusion for automated detection, classification, identification and mapping) from MCM S&T programs.

ALMOND-U will develop innovative technological underwater munitions survey concepts utilizing UUVs and then test these concepts during sea trials conducted in Germany and in the US. Based on the sea trials and joint technical workshops, a mature engineering system design shall be developed for an automated, unmanned, and autonomous underwater munitions survey system to DCL and map underwater bottom and buried munitions.

The coalition effort will focus on the joint sea trials to collect invaluable real-world data in US and German waters; the analysis of which will facilitate each nation to expand its underwater UXO survey capability as well as to independently advance their own mine hunting programs.

2. SURVEY OVERVIEW

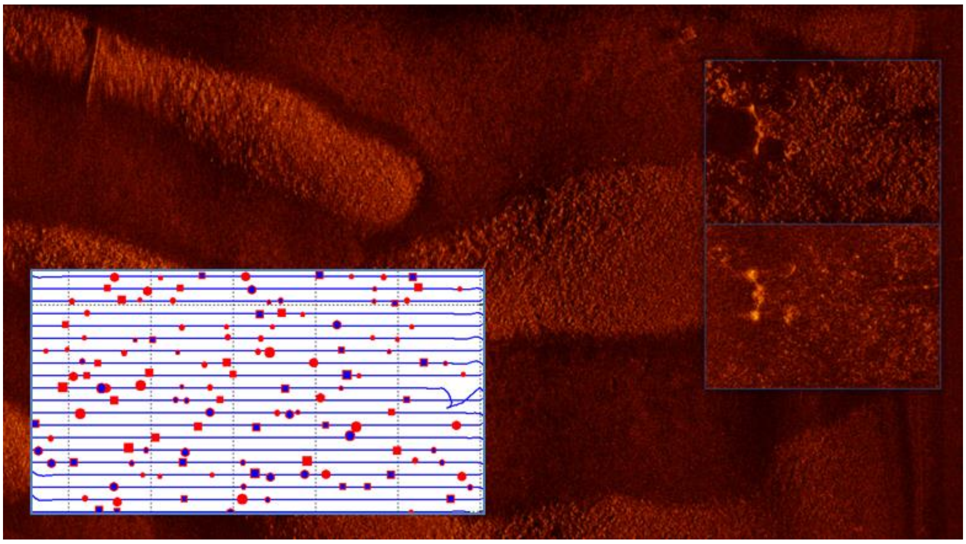

Fig.1: Example SAS data showing high resolution bottom imagery clearly composed of two different sediments. The right inset shows an anchor from two different frequencies while the left inset shows magnetic contacts displayed based on size (size of the dot), burial (red for proud, blue for buried) and cylindrical nature (circle for cylinders, square for other).

The US Navy is investigating synthetic aperture sonars (SAS) capable of generating high resolution imagery of the bottom and, using lower frequencies, penetrating a small amount into certain sediments to image some buried targets in addition to magnetic gradiometers. Since many UXO are smaller than typical mines and a high percentage are believed to be buried, these two primary technologies serve as an excellent starting point in hunting UXO. The US provided two UUVs, one integrated with a SAS system and the other integrated with both a magnetic gradiometer and a dual sidescan sonar and subbottom profiler (MAG-SBP). Similarly, Germany provided a UUV mounted SAS system, a towed magnetic gradiometer, and, at a later time, a pole mounted subbottom profiler. Data sharing agreements in place allows for data from all of the systems to be shared between countries, enabling system comparisons and testing of algorithms and procedures on new data (e.g., testing US magnetic algorithms on German gradiometric data). See Fig. 1 for an example of what these sorts of systems are capable of.

All systems spent time at known WTD71 sites (see Fig. 2) containing known and unknown UXO (Schönhagen and Neustadt) as well as several quality check targets (an acoustic resolution target and a pair of strings of known magnetic dipoles). Additionally, all systems also ran at two sites (Falshöft and Olpenitz) known to be contaminated with UXO, but to an unknown extent. In 2015 a NATO exercise known as “North Coast” identified what they believed to be six World War 2 era mines and torpedoes, which were not thought to be present at these sites. Thus it was deemed worthwhile to survey these areas to find any additional UXO that might be of interest.

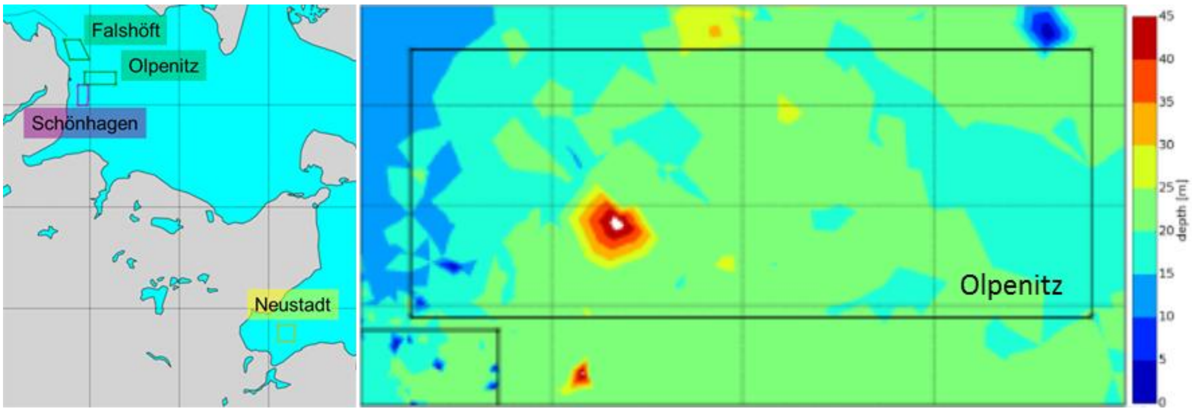

Fig.2: JBS operational areas of interest within the Baltic Sea named for nearby towns (right) and example bathymetry common to the region (left).

3. PRELIMINARY DATA ANALYSIS

The US SAS system experienced several hardware malfunctions that needed to be diagnosed and repaired during the survey, both US vehicles experienced significant navigation issues due to an inability to access Wide Area Augmentation System GPS (WAAS GPS) and both teams had problems with their ship based GPS antennas. However, all of these issues were dealt with by the vehicle operators, so the quality of this data collection should be seen as a huge success. The US SAS system spent two days down while a ground fault was tracked down. Both German systems operated within standard parameters and only had a small number of easily rectifiable issues. The remainder of the survey was accomplished without significant hardware issues.

The US MAG-SBP system was run at varying altitudes to explore the functionality of the SBP sonar. While the gradiometer is usually run around 2-3m for better magnetic detections, the SBP was operated up to 6m in order to see how well it functions at higher altitudes. Additionally, the MAG-SBP system was run over several buried items previously identified by the SAS systems, using a tight track spacing, to help better understand the fusion of magnetic data with bottom penetrating sonar data. Finally, given the proliferation of items in this area, the gradiometer was able to collect a substantial amount of data over relevant UXO targets, helping to improve detection and classification algorithms.

Alongside the US gradiometer, IPHT Jena operated their superconducting quantum interference device (SQUID) based gradiometer over similar areas, including several items previously identified by acoustic, which allows for the comparison of a more sensitive gradiometer being operated at a higher altitude from a quieter tow-body. Additional data was collected with both gradiometers running over calibrated magnetic dipole strings consisting of permanent magnets of variable magnetic moment embedded in concrete disks. Since magnetic sensors are highly sensitive to both platform noise, target moment, and range to target, it will be greatly interesting to explore the trade-off between the two systems against the calibrated dipole strings as well as targets of opportunity that were observed in the various survey sites. See Fig. 3 for example magnetic data collected over the dipole string.

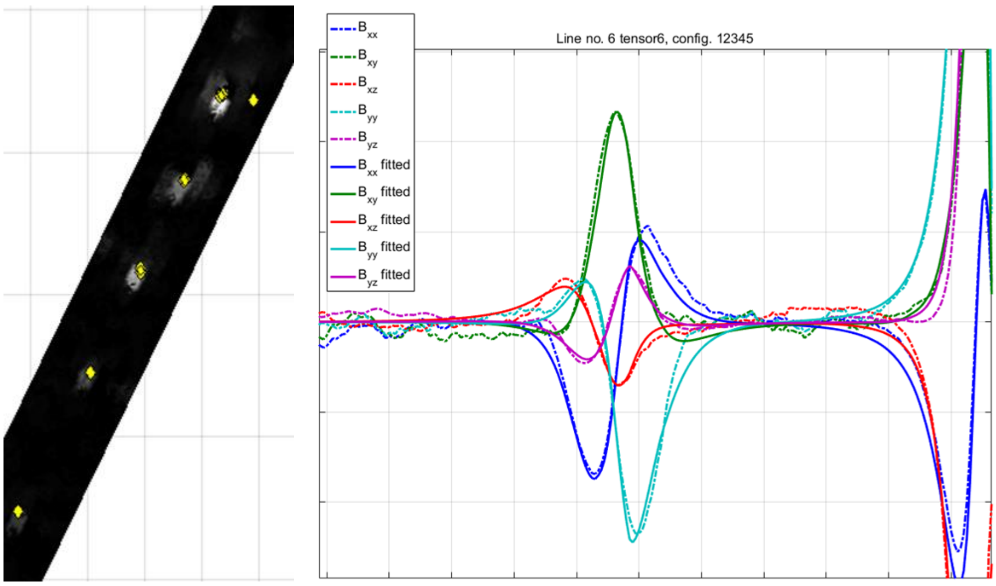

Fig.3: Magnetic gradiometer data over the calibrated dipole strings, showing a heat map from the US system (left) and a time series representation from the German system (right).

The US SAS covered more than 2,000 acres (with the German SAS covering even more based on its larger swath width) over highly interesting UXO contaminated bottom, passing a bevy of targets over to the gradiometers for further interrogation. The US and German SAS systems ran very similar missions, using similar mission parameters for comparing hardware differences and using their standard parameters for comparing procedures. The US SAS identified several buried targets and passed that information along to both the German SAS and the gradiometers so that the other systems had a definite subsurface item to test their sensors against. The US SAS ran various circular missions over a fair number of targets, identifying several as clutter, collecting valuable information over identified targets, and collected data that will allow experimenting with imaging below the surface and within targets. See Fig. 4 to Fig. 9 for examples of acoustic data collected during the JBS.

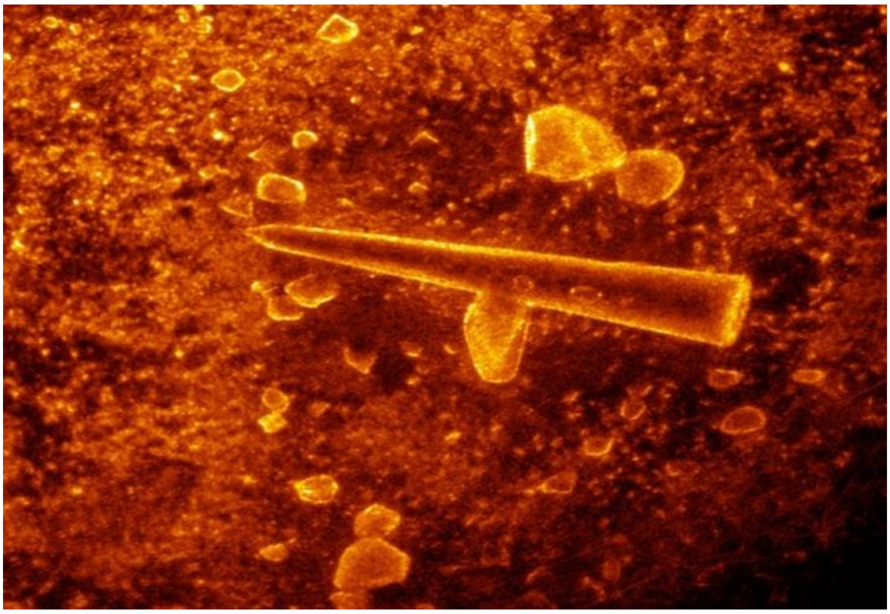

Fig.4: Circular SAS (CSAS) image(by US SAS) of item identified by the German SAS, originally believed to be a torpedo shaped item (See Fig. 4).

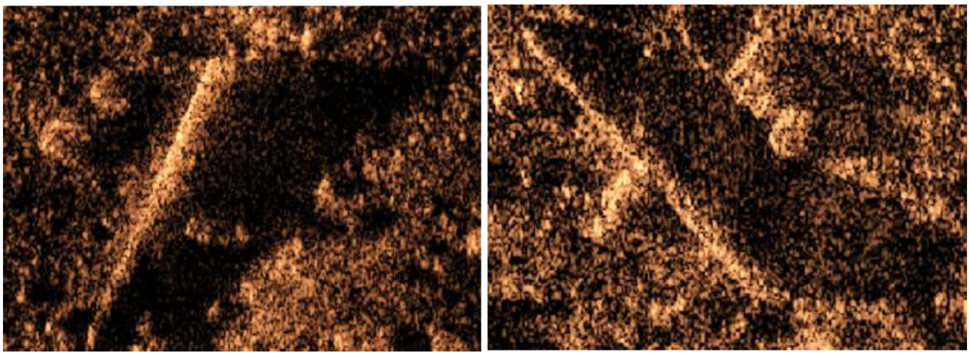

Fig.5: Linear SAS image of suspected torpedo identified by German SAS.

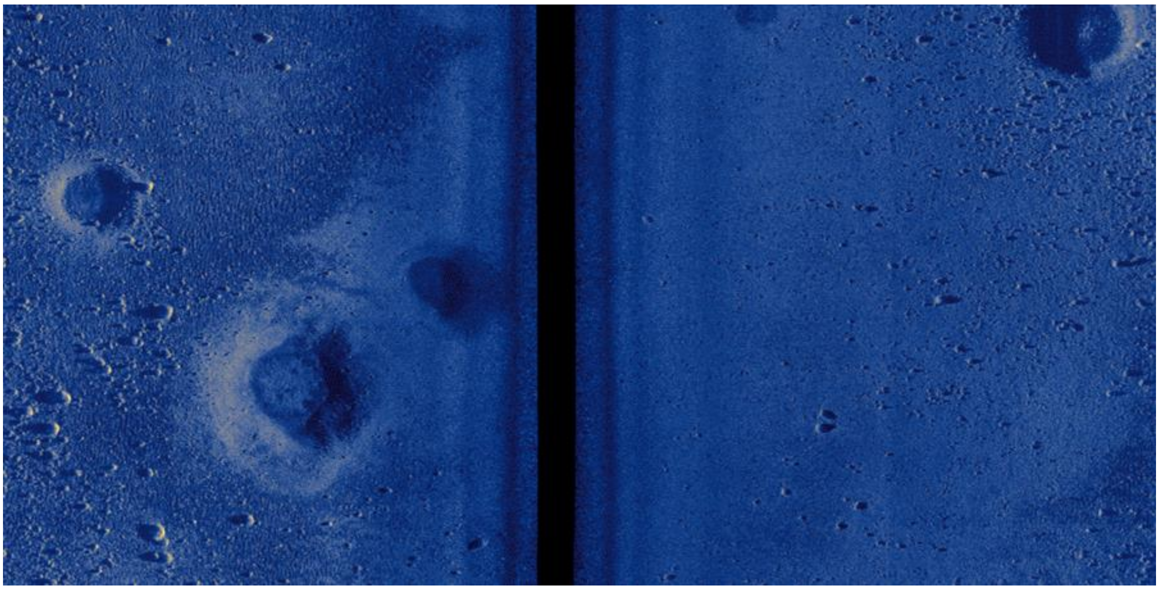

Fig. 6: Alongside evidence of trawling, there is clear evidence of cratering from explosive detonations in these areas, most likely during planned high order events.

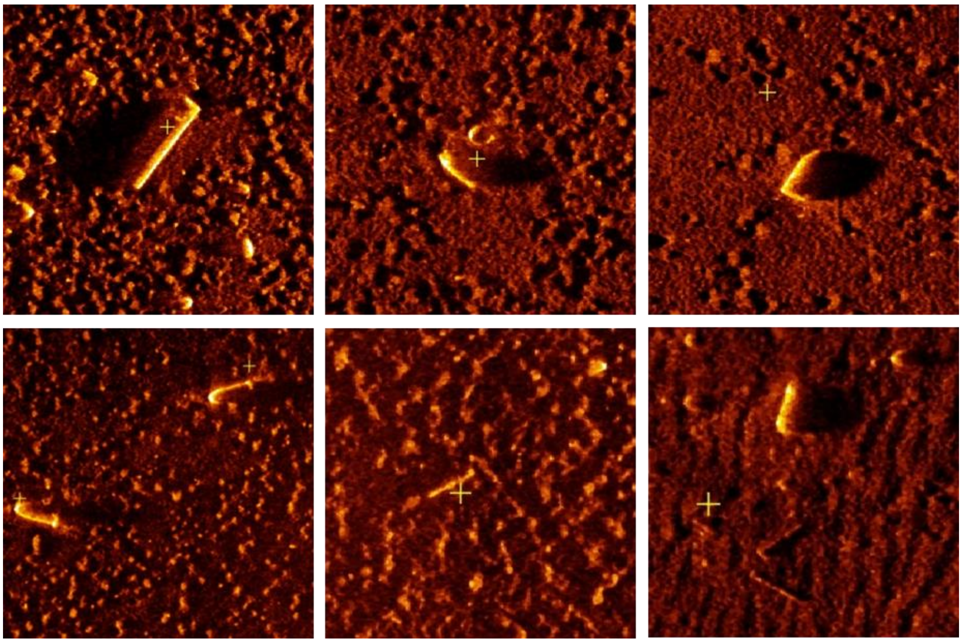

Fig. 7: Representative UXO shapes of all sizes discovered at Falshöft.

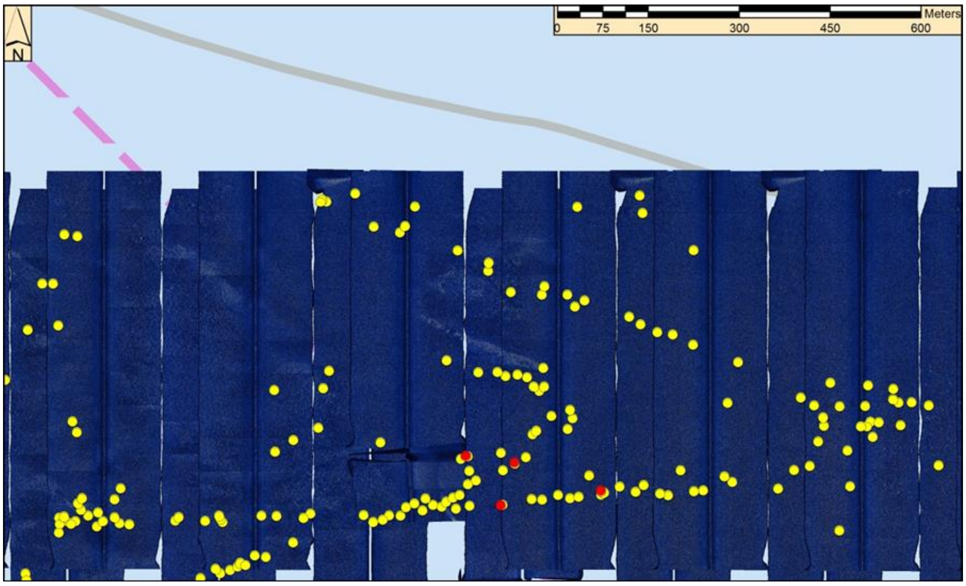

Fig. 8: Four items identified at Falshöft during the NATO exercise "North Coast" (red) and 223 items identified by the US SAS (yellow). Note what appears to be two separate lines of targets running through the imagery. The current hypothesis is that at the end of World War 2, at least two separate ships were transiting through the area, dumping their munitions over the side. A survey along the direction of each of these paths was cancelled due to weather in the final days but will be considered by the German team at a later date.

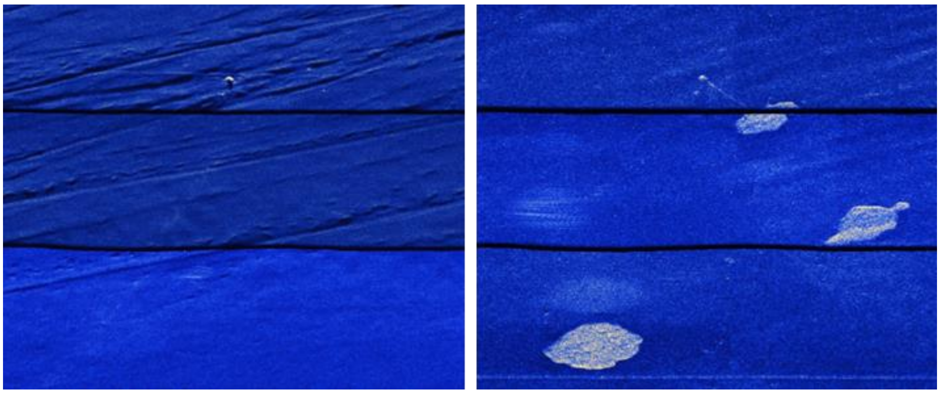

Fig. 9: Oddly shaped targets identified in lower frequency SAS data (right). Since these objects aren't visible in the higher frequency data (left) they are believed to be buried.

4. FUTURE WORK

With the JBS occurring in the final days of 2016, primary analysis of the survey data has been occurring in 2017. An additional survey is currently scheduled for October 2017 in San Diego, California. Lessons learned from the JBS will be applied to allow data relevant to several research thrusts be collected.

The format of the Joint Pacific Survey (JPS) will be similar to the JBS, pairing multiple systems with each other and operating over the same environments. It is expected that newer versions of the US SAS and magnetic systems will be used for this survey. Additionally, it is expected that NSWCPCD's 1m eBOSS (Edgetech Buried Object Scanning Sonar) will be joined by WTD71's 4m eBOSS, focusing the data collection on acoustic burial penetration rather than magnetics. A final technical workshop will follow several months after the JPS, providing time for collaboration, wrapping up the final report and closing out the project.

The research thrusts currently being investigated include but are not limited to:

- Low frequency CSAS to image buried targets and to peer within other structures (e.g., inside wooden crates)
- Low frequency structural acoustic phenomenon to aid in classification and visualization of targets not readily viewable by standard SAS techniques.
- Advanced CSAS processing techniques to image partial circles
- Bathymetry based on interferometric SAS data, both to create bathymetric data products and to improve SAS imagery by removing the flat earth assumption
- In-depth comparison of gradiometric technologies and techniques, including
    - UUV vs. tow-body integration, trading altitude for reduced platform noise
    - 3 channels vs. 5 channels of the magnetic tensor
    - Optically pumped Helium cell vs. SQUID technology
- UXO ATR maturation using target rich data sets
- Removing nearby acoustic signals (e.g., acoustic communications or sonar data from a nearby SAS system) from SAS imagery
- Sediment characterization using lower frequency acoustics
- In-depth comparison of different eBOSS arrays (i.e., 1m vs. 4m array)

5. SUMMARY

The CWP ALMOND-U project has brought together the US and German Navies and their MCM/UXO detection development tracks, allowing both organizations to share hardware developments, concepts of operation, algorithms, procedures and lessons learned. Both teams (see Fig. 10 and Fig 11) gathered excellent, relevant data over a variety of exciting UXO sites and have already generated a preliminary set of lessons learned that will help inform future collaborative surveys. Initial planning for the JPS has already begun and promises to be a successful, valuable data collection.

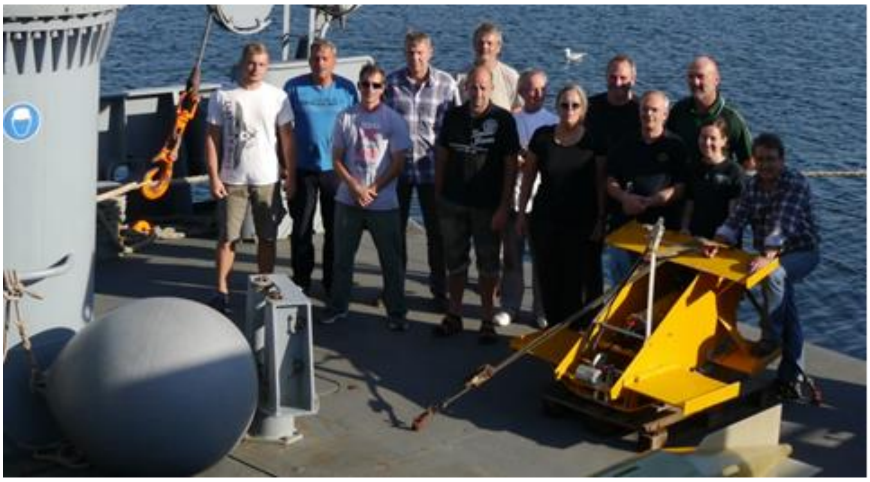

Fig.10: Magnetics team onboard the MzB Mittelgrund from left to right; (back row) Michael Mueller, Berndhard Rapp, Achim Pawel, Kay Behrmann, Steffen Brocke, Bernd Hilgenfeld, Frank Richter and (front row) Neil Claussen, Daniel Bunge, Ana Ziegler, Andreas Chwala, Amanda Bobe, Manfred Dommasch.

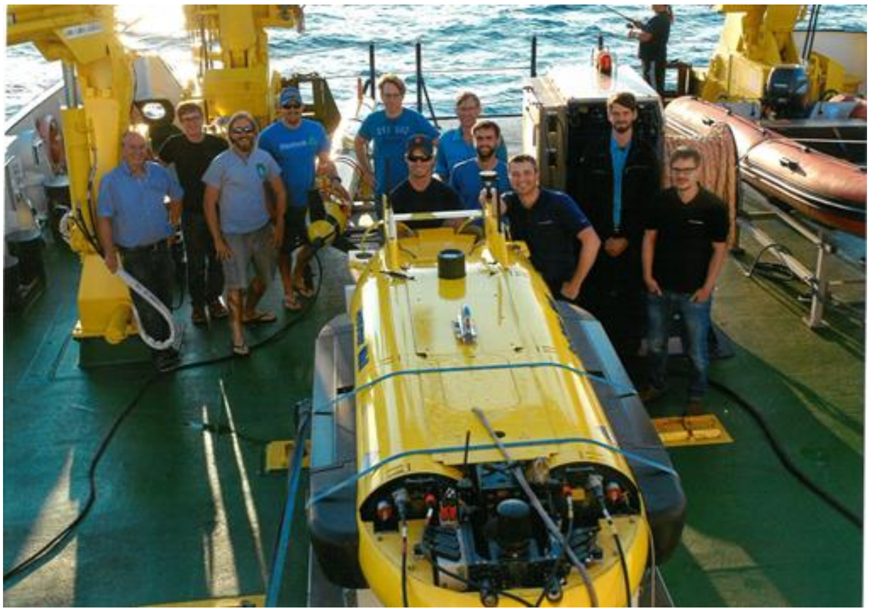

Fig.11: SAS team onboard the EMB from left to right; Hans-Joachim Soost, Jim Prater, Jesse Angle, Andrew Boe, Holger Schmaljohann, Thomas Dill, Jan-Peter Babst, Sven Osburg, Thomas Keller, Julian Klinner, and Stefan Leier.

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