Imaging Australia's first naval loss

THE 2018 PHOTOGRAMMETRIC SURVEY OF SUBMARINE HMAS *AE1*

In December 2017, the wreck of Australia's first submarine, HMAS *AE1*, was found off Papua New Guinea, 103 years after disappearing without trace. A second expedition, in April 2018, captured high-resolution images that shed light on the possible causes of the submarine's loss and have also been used to create a detailed digital 3D reconstruction of the wreck site. By **Dr James Hunter** and **Dr Andrew Woods**.

IN APRIL 2018, a remotely-operated vehicle (ROV) examined the wreck site of HMAS *AE1* in waters off the Duke of York Islands in Papua New Guinea. *AE1*, Australia's first submarine, participated in the capture of German New Guinea by Allied forces in the opening months of the First World War. It disappeared with all hands off the Duke of York Islands on 14 September 1914 while on patrol with the Australian destroyer HMAS *Parramatta* (I). The submarine's fate and whereabouts remained a mystery until December 2017, when it was found during a collaborative search expedition that included the Australian National Maritime Museum, the Silentworld Foundation, the Royal Australian Navy, Find AE1 Ltd, the Submarine Institute of Australia and Fugro NV (see *Signals* No 122, March–May 2018).

Just four months later, in April 2018, an opportunity arose to conduct a detailed ROV examination of *AE1*. This follow-up expedition was conducted gratis from RV *Petrel*, a research vessel owned by Microsoft co-founder Paul G Allen and operated by Vulcan, Inc, the company that oversees Mr Allen's network of philanthropic organisations and initiatives. *Petrel*'s crew was accompanied by a collaborative team from Australia that comprised researchers from Find AE1 Ltd, ANMM and Curtin University's HIVE (Hub for Immersive Visualisation and eResearch). Because *AE1* is located in more than 300 metres of water, the site was examined via *Petrel*'s Bathysaurus XL, a Work-Class ROV built by Norwegian firm Argus that can operate to a depth of 6,000 metres. It is outfitted with manipulator arms and an array of standard- and high-definition video cameras. These were augmented with a specially designed deep-water digital still camera provided by Curtin University and the Western Australian Museum so that a photogrammetric 3D reconstruction of the wreck site could be developed.

01 Pages 2–3 Port side view of the interim 3D photogrammetric model of HMAS *AE1*. A high-resolution 3D model is currently being generated from the 8,000-plus still images at Curtin University's HIVE (Hub for Immersive Visualisation and eResearch). 3D model by Curtin University from images courtesy of Paul G Allen, Find *AE1* Ltd, ANMM and Curtin University. © Curtin University

02 A Remotely-Operated Vehicle (ROV) deployed from RV *Petrel* uses a camera mounted on its manipulator arm to inspect the interior of *AE1*'s stern torpedo tube. Image Paul G Allen, Find *AE1* Ltd, ANMM and Curtin University. © Navigea Ltd

03 Implosion of *AE1*'s forward hull has caused the fin to collapse into the remains of the submarine's control room. Image Paul G Allen, Find *AE1* Ltd, ANMM and Curtin University. © Navigea Ltd

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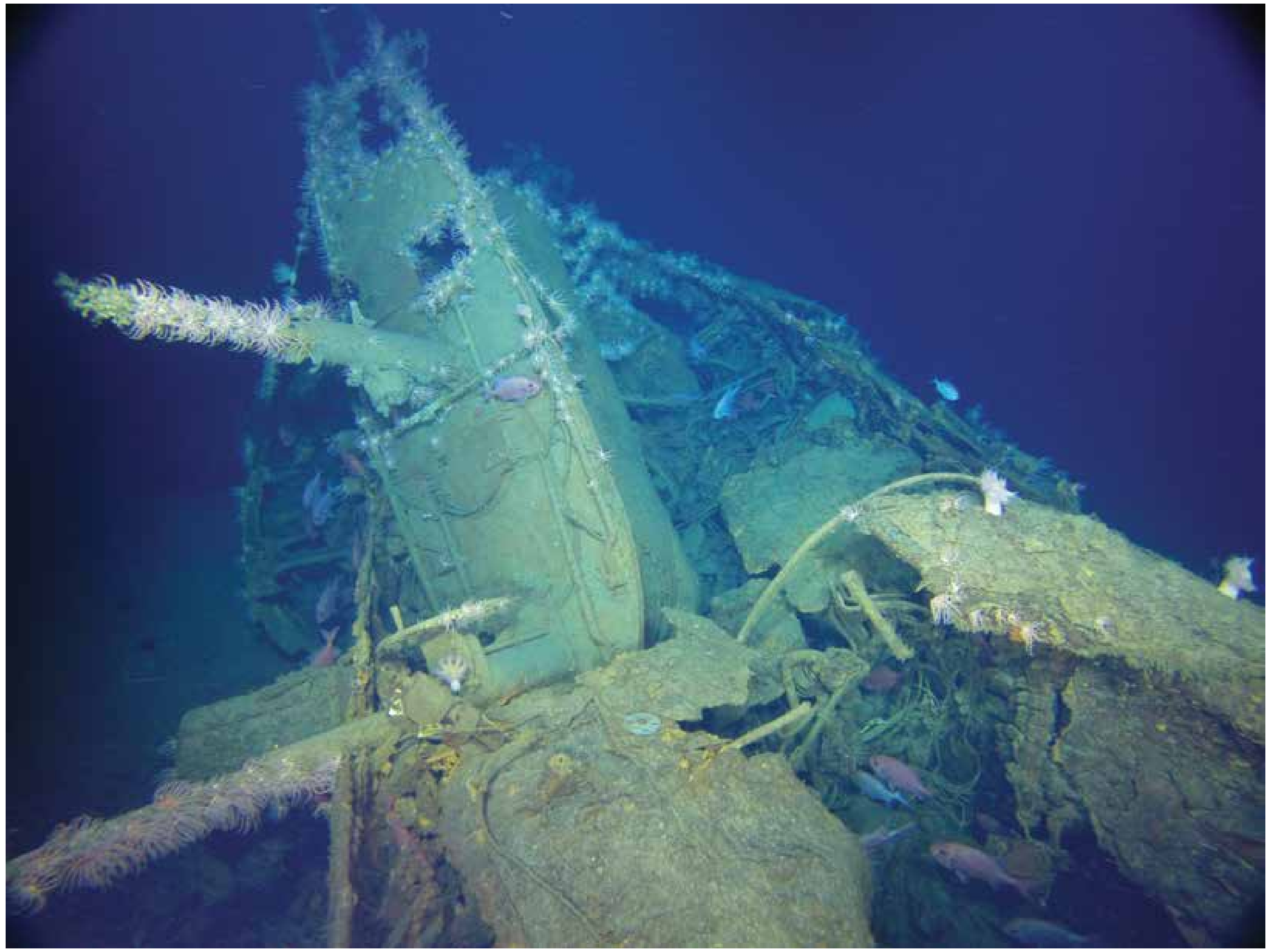

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The same camera was among the equipment that captured photogrammetric imagery of the Second World War shipwrecks HMAS *Sydney* (II) and HSK *Kormoran* in 2015.

Photogrammetric 3D reconstruction

Photogrammetric 3D Reconstruction (P3DR) is a cutting-edge algorithmic process in which highly detailed and visually accurate digital 3D models or digital reproductions of real-world objects can be generated from multiple digital still images. The technique is also known as 'Structure from Motion', 'photogrammetry' or '3D Reconstruction'. The term 'photogrammetry' is widely used within the discipline of maritime archaeology to refer to P3DR; however, photogrammetry traditionally refers to the science of obtaining measurements from photographs, and although this occurs at very high density in P3DR, the later stages of digital 3D model development are beyond the scope of traditional photogrammetry.

> *AE1* is resting upright on a largely flat, featureless rocky seabed and is almost completely exposed

Photogrammetric 3D reconstruction is a multi-stage process. First, each image is individually processed to identify its visually unique features (known as 'feature points'). These might be edges or textures in the image that are mathematically unique. Computer algorithms, such as the Scale Invariant Feature Transform (SIFT), allow features to be described and matched regardless of their size or orientation. The feature identification stage may identify as many as 20,000 unique features within a given image. Identification of image features is followed by 'feature matching', in which all images in the dataset are compared with one another to identify common matching features. This is followed by 'bundle adjustment', an algorithm that calculates the relative location, orientation and lens parameters of the camera(s) used to capture each image. In addition, the bundle adjustment calculates the 3D coordinates of the image dataset's respective feature match points, which generates a sparse point cloud.

Once the camera locations are known and a sparse point cloud exists, further parts of each image can be matched in finer detail to produce a dense point cloud. The point cloud is then converted into a mesh of individual triangular-shaped surfaces that are laid across the surface of the point cloud to generate an un-textured 3D model of the object. Finally, the original digital images are projected onto the mesh to generate a textured 3D model. The result, if the process is successful, is a photorealistic digital 3D model of the original object. The mesh and texture can be produced at various resolutions depending on the complexity of the object and the planned use for the 3D model, and the accuracy depends on a range of factors.

Typically, images that will be used for 3D reconstruction are acquired in a methodical manner that captures objects from different angles, shows all occluded surfaces and ensures all areas are imaged by at least two camera angles, if not more. P3DR can produce digital 3D models of areas and objects that are not flat, and generate relatively accurate site measurements. The 3D reconstruction process allows more detailed and realistic three-dimensional rendering of an area than can be generated with conventional 2D photomosaic techniques, but requires a higher number of images to do so.

The 2018 photogrammetric survey of *AE1*

Archaeological examination and documentation of *AE1* took place over two days and involved five separate dives by *Petrel*'s ROV. The first dive confirmed the submarine's location and identity, and allowed the ROV operators to familiarise themselves with the wreck site and its environmental conditions and to identify potential hazards (such as protruding structures that could foul the ROV's tether). It provided the research team with its first detailed glimpse of *AE1*, which proved useful in identifying features of interest and refining the survey strategy for subsequent dives. The first dive also allowed *Petrel*'s crew to ensure that the ROV was operating properly, and to check and colour-correct the video camera array. At the end of this dive, the photogrammetric still camera was installed on the ROV's pan-and-tilt mechanism. This camera was chosen because it was relatively simple to install and operate – a necessity due to the limited timeframe within which the *AE1* survey was organised and undertaken – and was pre-programmed to capture 12-megapixel resolution images every five seconds.

Once on site, the ROV ran multiple longitudinal transects along *AE1*'s hull at a relatively slow (approximately 0.10-knot) pace to allow for the required image overlap. Close-order survey was conducted around complex hull features, such as *AE1*'s fin. During a handful of transects, particular emphasis was placed on capturing images along the submarine's lower hull where it meets the seabed. This was done to acquire greater detail in these areas, and contribute to the accuracy and completeness of the overall 3D model. To document the fragmented remnants of *AE1*'s side-mounted 'saddle' ballast tanks (which now lie in linear piles immediately beneath both sides of the hull), a 'zig-zag' pattern was adopted whereby the ROV would approach the hull, then pull away, to thoroughly document the extent of the adjacent debris. A standard-definition camera was attached to one of the ROV's manipulator arms and used to image and closely inspect specific areas of interest, such as the submarine's open bow and stern torpedo tube caps, the face of the bridge telegraph, and small openings in the pressure hull that could not be adequately imaged with the regular ROV camera array.

> Imagery and data collected during the survey have refined and contributed to an understanding of the sequence of events that led to *AE1*'s loss

Once the second ROV dive concluded and image data became available, data processing commenced aboard *Petrel* to confirm that the camera and modelling software were working properly and to generate test models of specific site features. These interim models were in turn employed to find gaps in the image data and to guide the subsequent imaging strategy and ROV operations. By the end of the survey, interim low-resolution models had been generated for *AE1*'s stern and bow sections, starboard ballast tanks and fin. A total of 8,367 images and approximately 25 hours of full high-definition video were collected during the expedition.

Preliminary survey results

The ROV examination of *AE1* confirmed some preliminary observations made during the December 2017 expedition, but also offered new revelations. Detailed still and video imagery and the generation of a comprehensive 3D photogrammetric model of the submarine have also resulted in refinement of some conclusions made in 2017.

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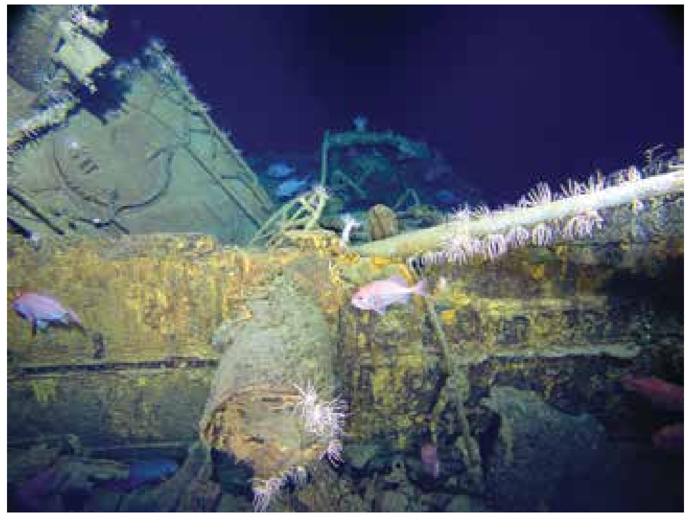
Unlike many historic shipwreck sites in shallow water and/or more developed areas, *AE1* appears to be relatively free of modern rubbish and debris

01 *AE1*'s disarticulated skeg and rudder lie on the seabed beneath the submarine's port propeller.
02 Since *AE1*'s discovery in December 2017, the fin has collapsed further into the remnants of the control room. This is evidenced by the forward periscope, which now rests directly atop the surviving starboard pressure hull plating.
03 Natural forces such as corrosion have caused most of *AE1*'s 'saddle' ballast tanks to disintegrate and collapse to the seabed. The opening for the submarine's port side amidships torpedo tube is visible at far right.
Images Paul G Allen, Find *AE1* Ltd, ANMM and Curtin University. © Navigea Ltd



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AE1 is resting upright on a largely flat, featureless rocky seabed and is almost completely exposed, with only the keel and the tip of a blade from each propeller buried in the surrounding silt. While the approximate aft half of the submarine is largely intact, hull sections forward of the fin have collapsed inwards due to catastrophic implosion. Specific areas within *AE1* devastated by implosion damage include the control room and forward torpedo compartment. Structural failure of the forward pressure hull has caused the fin to collapse and topple forward into the remnants of the control room.

Damage to *AE1*'s forward pressure hull from implosion is clearly evident in the 2018 ROV footage, still imagery and interim 3D model. Sections of hull plating have been folded over and collapsed, and the pressure hull completely opened from the forward torpedo room to the control room. Two copper-alloy hand wheels in the forward torpedo compartment have been bent and warped in a shallow 'U' shape – attesting to the power of the violent inrush of water as the pressure hull failed. Due to either the implosion or *AE1* striking the seabed (or both), the hull plating at Frame 70 failed, and effectively broke the submarine's back. This damage is evident in individual images, but the extent of the hull's failure is best captured by the 3D photogrammetric model, which shows the forward section misaligned and collapsing downwards relative to the rest of the hull.

AE1's aft torpedo tube cap was fully open – the necessary first step to launch a torpedo. However, the torpedo is protected from sea pressure by a sluice valve, which is shut. This indicates that the tube was not fully prepared for firing. The stern cap was opened via a manually operated hand-wheel, and the effort necessary to do this clearly indicates it was intentional. Why the cap is open remains unclear; it may have been opened as part of a training exercise, but could also have been in preparation for a speedy torpedo launch should *AE1* come under attack. The cap for the forward torpedo tube is slightly ajar, but not fully open. The worm gear used to open the forward cap does not appear to be damaged, which suggests it was either partially open – or in the process of being intentionally opened or closed – when the loss of *AE1* occurred. The doors for both amidships torpedo tubes – which were positioned athwartships across *AE1*'s central pressure hull and ballast tanks – are closed.

While still largely intact, the submarine's hull has been detrimentally affected by differential corrosion of its various metallic components. This is perhaps most evident in the destruction of most of *AE1*'s saddle ballast tanks, which were constructed of lighter-grade steel than the pressure hull and appear to have preferentially corroded, fragmented and collapsed to the seabed. Other disarticulated hull elements observed during the survey include *AE1*'s hydroplane guards, rudder and skeg. All four guards are lying flat on the seabed, just beneath their respective hydroplanes. While natural processes such as corrosion could have caused them to fall away from the hull, it is more likely that they snapped off as *AE1* fell onto its keel after initially striking the seabed stern first and pitching forward. The 2018 survey confirmed that both fore and aft sets of hydroplanes were in the 'hard-to-rise' position, which indicates that the crew desperately attempted to recover from a dive and return to the surface. *AE1*'s rudder and skeg were found lying beneath the port side propeller. Both appear to have been broken off by the submarine striking the seabed stern first; however, the angle of the impact was shallow enough that it did not damage *AE1*'s propellers.

Specific hull components may also have deteriorated and disarticulated due to seismic and tectonic activity in the area. The fin, for example, has collapsed further into the control room since *AE1*'s discovery in December 2017 (and in the wake of large earthquakes and accompanying aftershocks in New Britain in March 2018). While there is clear damage to the submarine from natural processes, no evidence of human-manifested change (such as anchor or trawl damage) was noted. Indeed, unlike many historic shipwreck sites in shallow water and/or more developed areas, *AE1* appears to be relatively free of modern rubbish and debris.

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Conclusion

The 2018 ROV examination and photogrammetric survey of *AE1* proved immensely successful. It acquired detailed still and video imagery, and an interim 3D digital model of the entire shipwreck site has already been produced. This in turn has aided archaeological examination of *AE1* on a macro scale, and led to the identification of large-scale features – such as the slump in the submarine's hull resulting from the break near Frame 70 – that otherwise might have gone unnoticed. A significantly more detailed high-resolution photogrammetric model of *AE1* is currently being generated at the Curtin HIVE, and is expected to offer even greater opportunities for analysis, interpretation and – eventually – exhibition. Lessons learned during the 2015 photogrammetric survey of *Sydney* and *Kormoran* were put to good use during the *AE1* expedition, with the result that the latter shipwreck received effective, comprehensive photographic coverage in a short time. The survey also revealed – through the use of only one uncomplicated and inexpensive camera for photogrammetric capture – that much can be accomplished with relatively little.

Imagery and data collected during the survey have also refined and contributed to an understanding of the sequence of events that led to *AE1*'s loss. For example, the submarine's bow and stern torpedo tube caps were either partially or fully open, and this appears to have been an intentional act carried out on the surface. Why the caps were open, and whether they contributed in some manner to the loss, will probably never be known. *AE1* then entered into a dive, and despite efforts by the crew – as evidenced by the positions of the hydroplanes – was unable to resurface. At an unknown depth, the forward pressure hull partially imploded, killing the crew instantly. The submarine continued its fatal dive until it struck the seabed stern first at a shallow angle, breaking off the skeg and rudder. The hull then pitched forward, breaking *AE1*'s back and possibly snapping off all four hydroplane guards. This violent movement also affected the fin, which – probably already weakened structurally during the implosion – began to topple forward into the control room.

In the future, the imagery and 3D model generated from the 2018 investigations will prove critical in *AE1*'s ongoing interpretation, exhibition and management. Among other things, the survey revealed that the shipwreck site is in a state of rapid natural decline, as differential corrosion, and contributing factors such as local seismic activity, take their toll on the submarine's constituent parts. The interim photogrammetric 3D model already generated now serves as an accurate representation of *AE1*'s state of preservation when discovered, and can be the benchmark to which future surveys of the site may be compared. It can also serve as the foundation upon which a variety of innovative interpretive and exhibition options may be explored and developed to share *AE1*'s story for years to come.

This article is an edited version of a presentation by Dr James Hunter of the Australian National Maritime Museum and Dr Andrew Woods of Curtin University HIVE (Hub for Immersive Visualisation and eResearch) at the Archaeology of War conference at the museum on 23 June 2018.

For more information, see the following press releases:

news.navy.gov.au/en/Apr2018/Events/4577/Expedition-provides-detailed-new-look-at-HMAS-AE1.htm

news.curtin.edu.au/media-releases/photographic-processing-unlocks-secrets-hmas-ae1-shipwreck/