Research Vessel *Petrel* Baseline Survey of HMAS *AE1*

April 2018

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Front cover: RV *Petrel* control room during the survey.
Image courtesy of Vulcan Inc, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Back cover: *AE1* bow torpedo tube.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

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Examining the engine room hatch opening using the ROV's manipulator arm camera.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Executive summary

The Research Vessel (RV) *Petrel* survey in April 2018 has delivered a comprehensive photographic survey of the wreck. Thanks are due to Paul Allen for his generosity in diverting *Petrel*, along with her highly capable remotely operated vehicle (ROV) and very professional survey team.

We wish to recognise the support provided by the Papua New Guinea Government and PNG National Museum and Art Gallery (NMAG) in authorising the survey.

The survey was coordinated by Find AE1 Ltd, in collaboration with the Australian National Maritime Museum (ANMM), WA Museum and Curtin University. The Submarine Institute of Australia funded Find AE1's participation.

The survey has provided an excellent baseline survey that will be utilised by the ANMM to develop a wreck management plan in collaboration with the PNG NMAG.

It has also facilitated a better understanding of what may have caused the loss of the submarine. The original analysis from the Fugro survey which led to the location of the wreck on 20 December 2017 – a diving accident – has been confirmed and refined with some facts and much informed speculation that flows from the new clues. There are a number of unresolved puzzles presented by the new detail available from the high-definition video and still images.

Many of these assessments must be qualified – our knowledge remains incomplete and they represent judgements from an analysis team of experienced submariners, engineers and naval architects who have reached a consensus on the cause of the loss. Mr John Jeremy AM[1] and Mr Peter Holt[2] have provided an independent review of the report. The Defence Science and Technology Group has reviewed the report and considers the hypothesis to be reasonable based on the information available.[3]

The ship's ventilation hull valve has been found 60% open; this may have initiated a sequence that led to the flooding of the after end of the submarine, causing it to sink, out of control, past its crush depth, leading to an implosion that would have killed the crew instantaneously. The submarine then appears to have sunk stern first to the bottom. We don't know why the valve was not shut prior to diving.

The stern and bow caps – the outer openings on the after and forward torpedo tubes – are open. We don't know why. We believe *AE1* diverted from the ordered patrol off Cape Gazelle to try to locate a German steamer sighted the night before off the Duke of York Islands. The simplest explanation is that both torpedo tubes were prepared as a precautionary step, against the eventuality of encountering this steamer.

The analysis underpinning both judgements is discussed further in Annex C (see page 59).

If so, *AE1* was lost seeking out the foe!

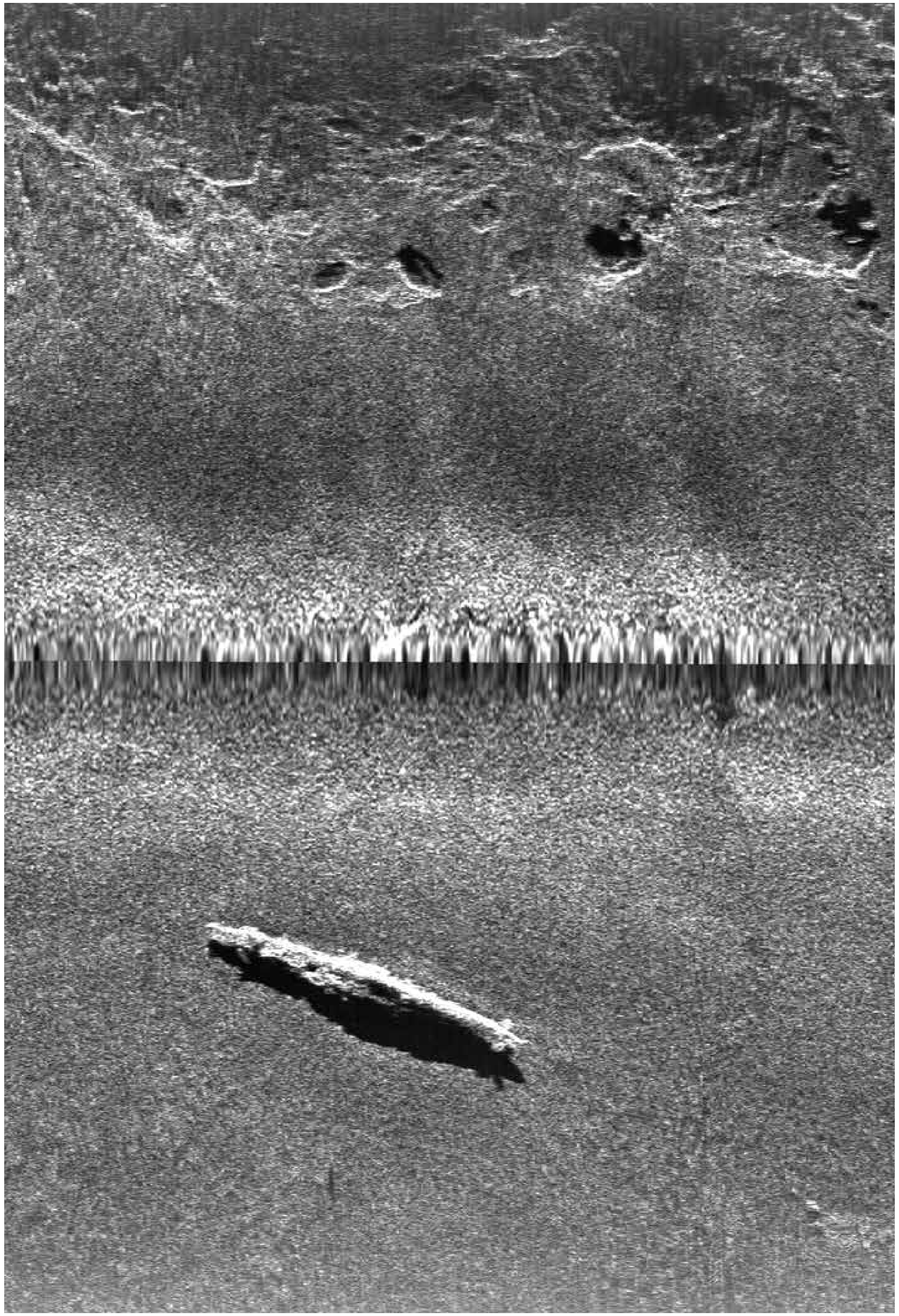
The wreck lies in an area exposed to strong ocean currents and is suffering active corrosion; it is noticeably weakened in a number of areas. Lacking a protective layer of concretion, the hull is actively rusting, with galvanic corrosion from the manganese bronze conning tower. Most of the lighter-weight steel plating has disappeared; it is predicted that the wreck will undergo major structural collapse in the next 5–12 years. Further, it is estimated that in 80 years only the conning tower, propellers, propeller shafts and engine bed plates will remain. Additional oceanographic data from the wreck site is required to enable these predictions to be refined. These issues are discussed in detail in this report and its Annexes B (see page 47) and E (see page 122).

While the survey has added significantly to our knowledge, it also raises a number of questions for follow-up investigation by future surveys. Given the predicted longevity of the wreck, these should take place as soon as possible.

A full set of oceanographic data to contribute to our understanding of what happened to *AE1* and a wreck management plan should also be undertaken.

This report recommends urgent PNG and Australian action to jointly declare the wreck a protected area and establish effective monitoring of the site.

The wreck management plan should be jointly developed by the ANMM and PNG NMAG and is a priority, given its role in protecting the wreck.



1 Introduction

1.1 Finding *AE1*

HMAS *AE1* was identified on 20 December 2017, two days after being located by an autonomous underwater vehicle (AUV) launched from the *Fugro Equator*. A full report on this expedition has been issued.[4]

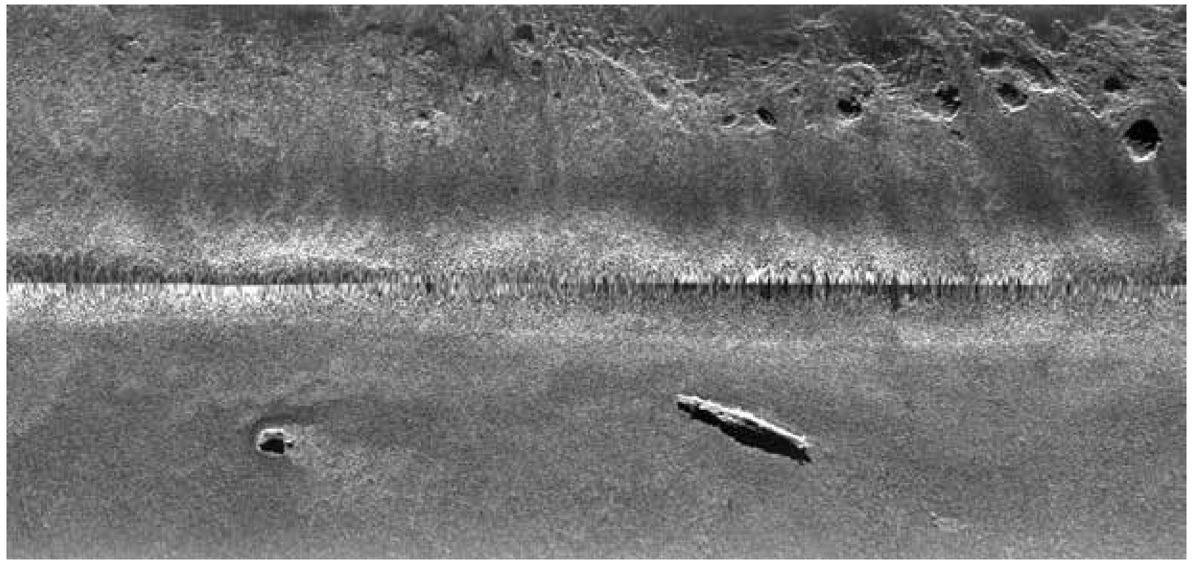


Figure 1 – Sonar mosaic of *AE1*. Image courtesy of Fugro

Images of the wreck were obtained using a drop camera fitted with a video and a stills camera and still images from the AUV. Both are limited to an overhead aspect, from several metres above the wreck. While these provide a good overview of the wreck, the vertical aspect limits their utility in analysing the details of the wreck and identifying the cause of the loss.

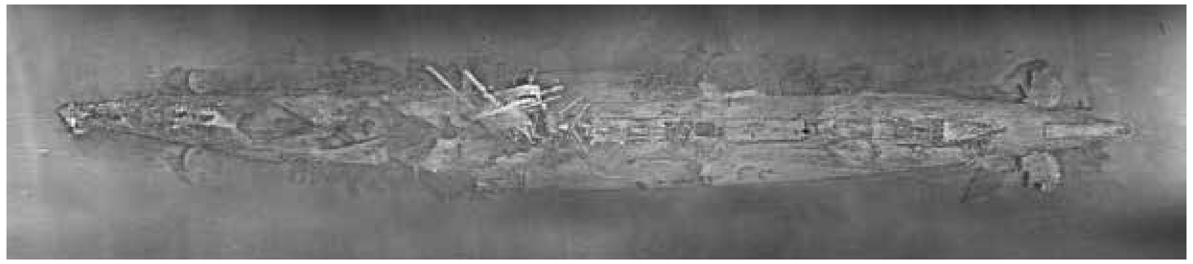


Figure 2 – *AE1* overhead mosaic from AUV camera. Image courtesy of Fugro

The report concluded that *AE1* had most likely been lost due to a diving accident that caused her to exceed crush depth, leading to hull implosions over the control room and forward torpedo compartment. The report recommended a follow-up examination to provide a baseline survey, add to the understanding of the cause of her loss and reduce the attraction of an illicit examination.

Opposite: Sonar mosaic of *AE1* (detail of Figure 1). Image courtesy of Fugro

1.2 Requirements for a follow-up examination

The Find AE1 team began planning for the follow-up examination shortly after locating the wreck. The objectives identified were to:

(a) establish a baseline for the 'as-found' condition of the wreck site of HMAS *AE1*, to enable an assessment of its archaeological integrity, inform the development of a shipwreck management plan and enhance understanding of HMAS *AE1* and its history;

(b) allow Find AE1 and ANMM to investigate specific technical issues to achieve a better understanding of what led to the loss of HMAS *AE1*;

(c) provide Find AE1 and ANMM with a foundation for future management of HMAS *AE1* in the wake of a successful search to locate and identify the wreck site.

The use of three-dimensional (3D) modelling to convey the story of a shipwreck is an emerging technique, discussed further in Annex E (see page 44). The ANMM has recently embarked on a collaborative program with the WA Museum and Curtin University to develop this technique.

Figure 3 – Interim 3D model HMAS *AE1* port side.
3D model by Curtin University from images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Curtin University.

1.3 The search for options

The initial plan – to utilise a laser scanner to provide an accurate model of the wreck's layout on which to overlay photographic images – was overtaken by the reality of the cost and difficulty of providing a large, 'work class' remotely operated vehicle (ROV) capable of deploying the laser scanner.

An offer utilising a ship already deployed in the area indicated a project cost in the region of $2m. A major fund-raising effort and significant delay seemed inevitable prerequisites to achieve this option.

In mid-2016 Find AE1 had approached the agent supporting Paul Allen's spectacular Motor Yacht *Octopus* regarding the possibility of becoming involved in the search for *AE1*. On this occasion the stars did not align and no search resulted.

1.4 RV *Petrel* survey – An opportunity too good to be missed?

However, in late November 2017 the director of Subsea Operations for Vulcan Inc, the operator of RV *Petrel*, also owned by Paul Allen, contacted Find AE1, flagging plans for the vessel to be in the area early in 2018 and enquiring about the status of the project to find *AE1*.

Figure 4 – RV *Petrel*. Courtesy of Navigea Ltd

Vulcan Inc were advised in early December of the intended search by *Fugro Equator* in mid-December and a discussion about the possibility of a follow-up examination ensued. Vulcan Inc very generously offered to undertake the survey free of charge and to accommodate observers from the Find AE1 project team and the ANMM. The key outstanding issues included resolving an acceptable licensing arrangement, given Vulcan's ownership of all the data generated onboard RV *Petrel* and the availability of time in her busy schedule, prior to a refit in Singapore in mid-April. It was agreed to remain in touch, leaving the ownership of the data as an unresolved point of difference.

Following the analysis of the imagery collected by *Fugro Equator* and realisation of the limitations of the purely overhead shots obtained during this search, the focus shifted to a follow-up examination. A working group led by Find AE1, with Find AE1 team members, offshore industry specialists and representatives from the ANMM, WA Museum and Curtin University worked through the options and issues (see Annex A List of Volunteers and Sponsors of Find AE1 Ltd, page 44).

The working group benefitted greatly from the WA Museum and Curtin University's experience in undertaking a 3D survey of the wrecks of HMAS *Sydney II* and HSK *Kormoran*.[5] A workshop held at the ANMM on 12 March concluded that:

- The capability demonstrated by *Petrel* during the USS *Lexington* survey should be sufficient to complete a baseline survey of *AE1*.
- A laser survey capability could pose technical/integration and financial issues in the short time remaining and should not be pursued.
- A 3D image capability could probably be achieved if the WA Museum digital underwater still camera could be fitted to the *Petrel* ROV to provide stills images for Curtin University HIVE[6] processing.

See Attachment 1 – Notes on *AE1* workshop discussions at ANMM (page 142).

Find AE1 brokered an agreement between Vulcan Inc and the ANMM on satisfactory licensing for use of the images/footage and arrangements to conduct the survey, including the requirement to undertake it discreetly, to avoid compromising negotiations for a joint PNG–Australia protection zone around *AE1*. These were incorporated into a three-party memorandum of understanding (MOU) between Vulcan Inc, the ANMM and Find AE1 that was agreed on 26 March after several iterations. The RAN was consulted in finalising the MOU. (See Attachment 2, page 145.)

On 18 March Find AE1 submitted an application to the PNG National Museum and Art Gallery for a permit to undertake the survey (see Attachment 3, page 168). This was promptly approved on 19 March (see Attachment 4, page 171), greatly facilitating negotiations with Vulcan Inc to undertake the survey.

In the meantime, RV *Petrel* was busy undertaking successful searches for the World War II shipwrecks USS *Juneau* and USS *Helena* and transiting to Alotau to rendezvous with the MY *Octopus*. On 29 March, having completed these searches, discussion regarding a possible schedule for a survey during April quickly resulted in a plan for the Find AE1 expedition team to join *Petrel* by boat transfer off Kokopo. This was promptly approved by *Petrel*'s owner, Paul Allen, and the ship headed north for the rendezvous off Kokopo as the Find AE1 expedition team hastily finalised travel arrangements.

1.5 Recognition of funding and support

Paul Allen's generous agreement to extend RV *Petrel*'s highly successful cruise and divert the ship to Kokopo, where the Find AE1 expedition team embarked, made the survey possible. The survey crew's willingness to extend their cruise and the professional manner in which they undertook the survey delivered on this generous gesture.

The PNG Government and National Museum and Art Gallery provided a prompt approval of the permit request, facilitating a favourable decision against very tight timescales.

The ANMM and RAN have provided ongoing support for the Find AE1 project and supported the permit application.

The WA Museum provided the high-definition underwater digital still cameras used to obtain the images for development of a 3D model of *AE1*.

Curtin University provided the expertise of its Hub for Immersive Visualisation and eResearch (HIVE) facility to supervise the collection of still images and process these into digital 3D models.

The Find AE1 board and team of experts (see Annex A, page 44), working as volunteers, coordinated and led the survey and the post-survey analysis.

The Submarine Institute of Australia funded Find AE1's participation.

Darren Brown has undertaken much of the initial research upon which the successful search was based and has provided generously from his collection of images, historical records and memorabilia in support of the project.

2 The survey

2.1 Preparations

The April 2018 Find AE1 expedition team consisted of:

Roger Turner Find AE1, submarine engineering analysis and logistics

Dr James Hunter ANMM observer, maritime archaeology adviser

Dr Andrew Woods Curtin University stills photography

Peter Briggs Find AE1 expedition team leader

Team members signed an Individual Agreement, signifying their acceptance of the ground rules for participating (see Attachment 5, page 172) and a copy of the Vulcan Non-Disclosure Agreement.

Efforts to include a cameraman were unsuccessful due to the need to avoid a conflict in rights held by a camera crew already embarked in RV *Petrel*. In the event, the Find AE1 expedition team members were able to collect supporting video and still images and had full access to all images collected by the various cameras fitted to RV *Petrel*'s ROV.

Figure 5 – Triton 6000 remotely operated vehicle. Image courtesy of Paul Mayer

The expedition team flew to Kokopo in New Britain Province to join the ship by boat transfer using the ship's rigid inflatable boat. The transfer was conducted in marginal conditions in a heavy tropical downpour.

The team were quickly briefed and settled into the very comfortable single cabin accommodation provided. The ship was positioned over *AE1* overnight and maintained position without difficulty using its dynamic positioning system.

2.2 Day 1

The first serial commenced at 0630 and at 0730 the strong sonar contact from the ROV's sonar was converted into an amazing visual contact as *AE1*'s stern emerged into the field of view of the ROV's well-lit cameras.

Figure 6 – First sighting of *AE1*'s stern.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Serial 1 was intended as a familiarisation with the site for the team and opened with an exciting moment as the first ROV sighting of *AE1* was obtained. It was also an opportunity to commence working our way through the Queries and Desired Shot List (see Attachment 6, page 175).

The ROV surfaced at ~1100 to enable a digital still camera to be fitted, having completed a circumnavigation of the wreck. This was ably accomplished by the ship's technicians, working with Dr Andrew Woods. The camera was programmed to take a shot every five seconds and provided a live feed of its shots in a low resolution. The high-resolution images were stored on an internal memory card in the camera and recovered after each ROV serial.

The modified ROV began the task of collecting a thorough coverage of still shots shortly after 1600. Serial 2 was deliberately kept short and the ROV recovered by 1800 to allow an early assessment of the images being produced by the still camera. These proved most satisfactory.

Serial 3 began at 1940, continued the collection of still shots and included some close-up inspection of features using the standard-definition video camera fitted to the ROV's manipulator arm. The serial completed at 2130 after a very satisfying day and a tiring one for the ROV pilot and his assistant.

Figure 7 – Examining the after torpedo tube sluice valve.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

2.3 Day 2

Serial 4 commenced at 0830. On this occasion the current over the wreck was less than on the day before and visibility was excellent. Some time was spent examining the rudder, which has been displaced and is lying under the port propeller, along with its supporting skeg, which has broken off.

Figure 8 – Displaced rudder and supporting skeg lying under port propeller.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

The serial was completed at 1145 for a lunch break before resuming in the early afternoon for Serial 5. By 1315 we had completed the stills coverage and shortly afterwards recovered the ROV to prepare for the laying of the three commemorative flags representing the crew members of *AE1*. Prior to the last serial a brief commemorative service was held in front of the ROV.

Figure 9 – RV *Petrel* survey crew and expedition team in front of the ROV. From left: Peter Briggs, James Hunter, Andrew Woods, Rob Kraft, Patrick Travis, Richard Seabrook, Paul Mayer, Rudi Schlepp, Roger Turner.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Serial 6 completed at 1800 after laying the flags and completing several photographic passes to fill in gaps in the coverage to achieve the first complete, non-invasive photographic survey of *AE1*. An operations complete message was sent at 8.04 pm to the ANMM, RAN and Find AE1 principals (see Attachment 7, page 177).

Overnight the ship transited to an anchorage off Kokopo.

2.4 The return to Australia

The expedition team made good use of the excellent internet connectivity onboard to send updates on the survey and departed RV *Petrel* on the afternoon after completion of the survey. After staying overnight at the Kokopo Bungalow Beach Resort, the expedition team departed by an early morning flight to Port Moresby for connections to Australia.

The virtual Find AE1 team formed to analyse the search images, supplemented by the experts involved in planning the follow-up examination, immediately began assessing the images to try to understand what may have happened to *AE1* (team members are listed in Annex A, page 44). The results of this process are discussed in the next section.

3 The survey results

3.2 The site

The wreck lies on what appears to be a hard, level bottom in over 300 metres of water, with minimal sediment. The area experiences strong ocean currents whose velocity is likely to be heavily influenced by the seasonal wind patterns and the nearby bottom topography. This also probably explains the low levels of sediment around and in the wreck. Attachment 8 (see page 179) is a series of surface current and wind observations provided by the bridge watch on RV *Petrel* on day 2 of the survey to illustrate the variable nature of the surface current. The current on the bottom was more consistent, coming from the south-southwest at speeds estimated to be ~0.5–1 knot. An accurate series of observations is required to provide a better understanding of the wreck's environment and the impact this may have on its future and, of course, the effectiveness of the ships searching immediately following the accident.

Given the site's location off the Duke of York islands it is anticipated that conditions may vary greatly between monsoon and wet seasons and the oceanography of the site may be complex as a consequence. The single sound velocity profile obtained during the *Fugro* search is insufficient to detail the environment; this can only be determined by collection over a much longer period. This information is critical to the future management of the wreck.

As one of the descendants remarked on viewing the footage, 'It is a beautiful gravesite'. It is indeed, with abundant fish life and some beautiful marine growth.

Figure 10 – Marine growth on the windlass.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

There are several patches where the concretion layer protecting the wreck has dropped away and fresh corrosion is apparent. It is speculated that local seismic activity may be a factor in this situation. Most of the lighter-weight steel plating has disappeared; it is predicted that the wreck will undergo major structural collapse in the next 5–12 years. Further, it is estimated that in 80 years only the conning tower, propellers and shafts and engine bed plates will remain. Additional oceanographic data from the wreck site is required to enable these predictions to be refined. These issues are discussed in detail in Annexes B (see page 47) and D (see page 102).

Figure 11 – Pressure hull near starboard after hydroplane, showing concretion delamination.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

3.2 Video footage

Two high-definition video cameras were fitted to the ROV; the 'Zeus' camera is mounted centrally on the front of the ROV and fitted with a pan and tilt mechanism. The second video camera, identified as the 'Argus', was sited above the Zeus camera, again with pan and tilt controls. It was surprising to note the impact the separation of these cameras had on their respective fields of view.

A standard-definition video camera and single light were fitted to the starboard manipulator on the ROV to provide a limited facility to inspect openings in front of the ROV.

All the data gathered is held by the ANMM.

3.3 Still images and 3D images telling the story

A high-definition digital still camera provided by WA Museum was fitted to the ROV on the Zeus mounting plate and set to take a photograph every five seconds.

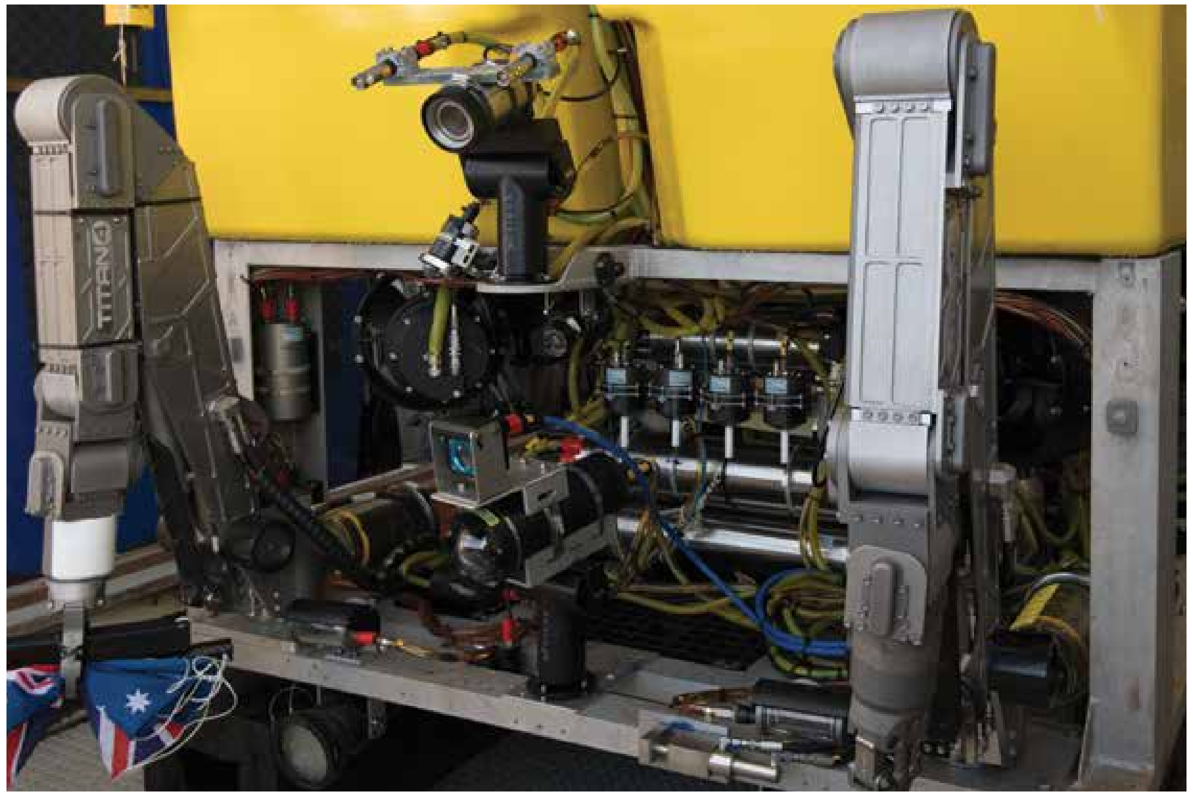


Figure 12 – Triton 6000 ROV showing camera arrangements. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

3.4 The balance of probabilities

The group mobilised by Find AE1 to undertake the assessment of the images gathered during the RV *Petrel* mission includes a wide range of experience and skillsets. The conclusions drawn by the group are opinions, drawn on the balance of probabilities, not certainties. Mr John Jeremy AM[7] and Mr Peter Holt[8] have provided an independent review of the report. The Defence Science and Technology Group kindly consented to act as a review body.[9]

There are a number of unusual or significant observations arising from the survey. These are summarised here and discussed in greater detail in Annex C (see page 59).

3.5 The open ship's ventilation hull valve

This is the most significant observation: the ship's ventilation system hull valve is ~60% open. The valve is a large, 6-inch (~152-millimetre) opening. It is one of five ventilation hull valves situated at the after end of the fin and now exposed to view by the displacement of the fin; the remaining four are associated with the battery ventilation system. The ship's ventilation system was designed to supply sufficient air to the engine room to allow the diesel engines to be run at reduced power while on the surface, presumably in a situation when the conning tower upper hatch had to be shut due to rough weather.[10]

The arrangement of the intake and hull valve inside the fin is shown below.

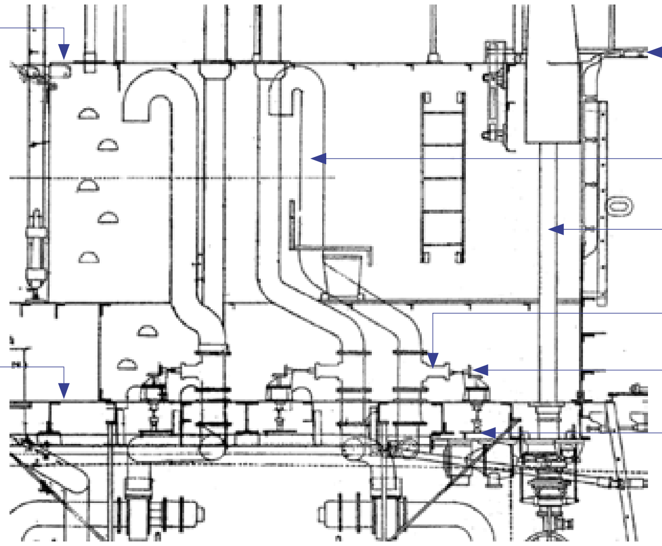


Figure 13 – Ship's ventilation arrangements inside the fin, from as built drawings. Image courtesy of National Archives of Australia

The valve is a sluice or gate valve construction, external to the hull and operated by a handwheel, driving through a rod gearing to turn a thread on the valve shaft, in order to drive the sluice across the opening. The thread actuator remains intact and attached to the pressure hull and therefore we think it most unlikely that the valve has been pulled open by the force of the implosion. In the image below, the curved leading edge of the sluice valve is clearly visible beneath some light debris – it is ~60% open.

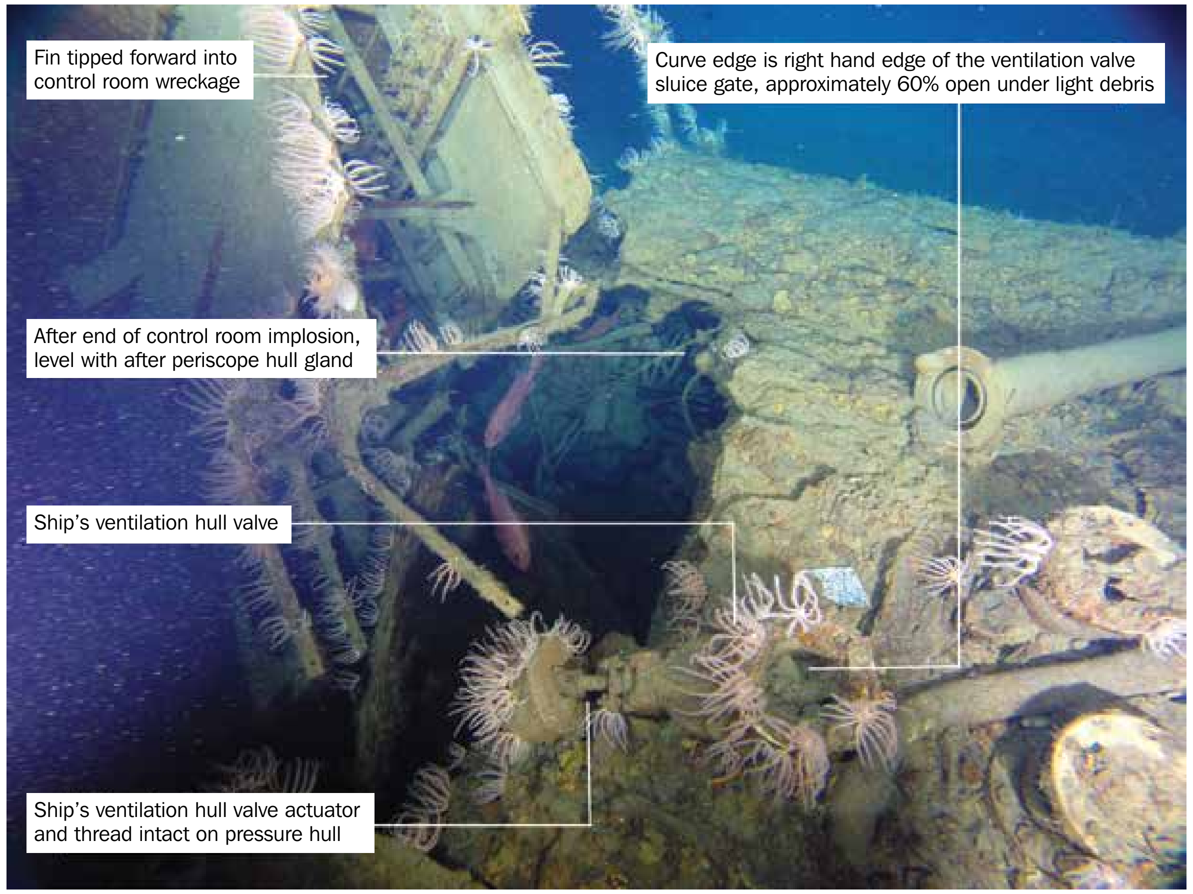


Figure 14 – The open ship's ventilation hull valve.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

This would have allowed water to enter the ship's ventilation system as soon as the ventilation trunking in the fin was under water. The specification we believe was used for constructing *AE1* calls for a quick-acting valve to be fitted as a back-up to the hull valve and the associated pipework to be pressure tested to 50 pounds per square inch (344.74 kilopascals, equivalent to 30 metres of seawater). The 'as built' drawing package held by the National Archive of Australia includes drawings covering the ventilation system but we have been unable to locate a quick-acting valve on any of these drawings. It may or may not have been fitted.

It is considered likely that the normal state of the quick-acting valve when on the surface (that is, prior to diving) would be open. In this case, with the quick-acting valve open (or not fitted), or if the trunking failed to hold the pressure build-up, then water could have entered the after end of the submarine immediately on diving. The water could quickly make its way to the lower section of the after end of the submarine containing the after main battery and vital systems supplying power, lighting and the port main propulsion motor. The additional water would also cause a loss of buoyancy, causing *AE1* to sink faster. As it sank deeper the volume of water entering the submarine would increase dramatically.[11] The combined effect would be a rapid loss of control and the depth excursion that caused the fatal implosion.

We do not know the precise circumstances which led to the hull valve being open. It appears that the four battery ventilation hull valves are shut – there is a layer of light debris in each valve, presumably resting on the shut sluice. The ship's ventilation hull valve is partially shut. It may be that the individual shutting it was simply overtaken by the process of diving as it would have required a significant number of turns to shut, or the valve may have jammed with an obstruction or a gearing malfunction – we don't know.

We believe that once the water started to enter the submarine, the situation would have very quickly got out of control; issuing the orders and undertaking the actions necessary to arrest the situation and recover would have been extremely difficult against the noise and confusion arising from the inrush of water into a rapidly sinking submarine, probably compounded by the loss of lighting and propulsion.

This situation sets the scene for discussion for a number of issues arising from the images provided by the survey.

3.6 Stern cap open

The stern cap on the after torpedo tube is open. This was unexpected. Some technical details follow:

- The stern cap is the outer opening on the after torpedo tube.
- It is backed up by a sluice valve in the tube positioned about 2 metres forward of the stern cap.
- The torpedo is stowed forward of this, with a rear door giving access to the tube inside the after torpedo compartment.
- The stern cap is opened by a handwheel operated from the after torpedo compartment, driving through a rod gearing to an external worm gearing arrangement to open the stern cap.
- The whole arrangement is shielded by a casing external to the pressure hull.
    - This casing is intact.
    - The gearing arrangement would have been very resistant to opening caused by the sinking process.

Figure 15 – Protective casing over stern cap operating rod.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

It is therefore considered highly likely that the stern cap was opened as a result of deliberate action by the crew. Why would this step be taken?

- Possibly a precautionary step to prepare the tube for action in anticipation of locating the German steamer, which we believe caused the commanding officer to divert to the Duke of York Islands.
- The after torpedo tube's sluice valve has been sighted shut using the ROV manipulator camera.
  - We assume the torpedo remains unfired in the torpedo tube on the other side of the sluice valve.
- Why start to prepare the after torpedo tube?
  - This initial step does not expose the torpedo to seawater and could be simply executed as the bow and stern caps were at the waterline and partially under water on the surface.
  - The after tube would have been less vulnerable to damage from flotsam or the wash compared to the bow tube, enabling the stern cap to be fully opened with little risk of damage.
- Alternatively, it could have been opened as a training drill.

We do not know why.

Figure 16 – Examining the after torpedo tube using the ROV manipulator arm camera.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Given the flooding scenario set out above there would have been no time to open the stern cap after diving. It is therefore considered most likely that the stern cap was opened prior to the dive, possibly some time earlier in the day, and that it played no part in the accident sequence.

3.7 The forward torpedo tube

The bow cap on the forward torpedo tube is partially opened, say 20–25 degrees of the 90 degrees necessary to be fully opened.

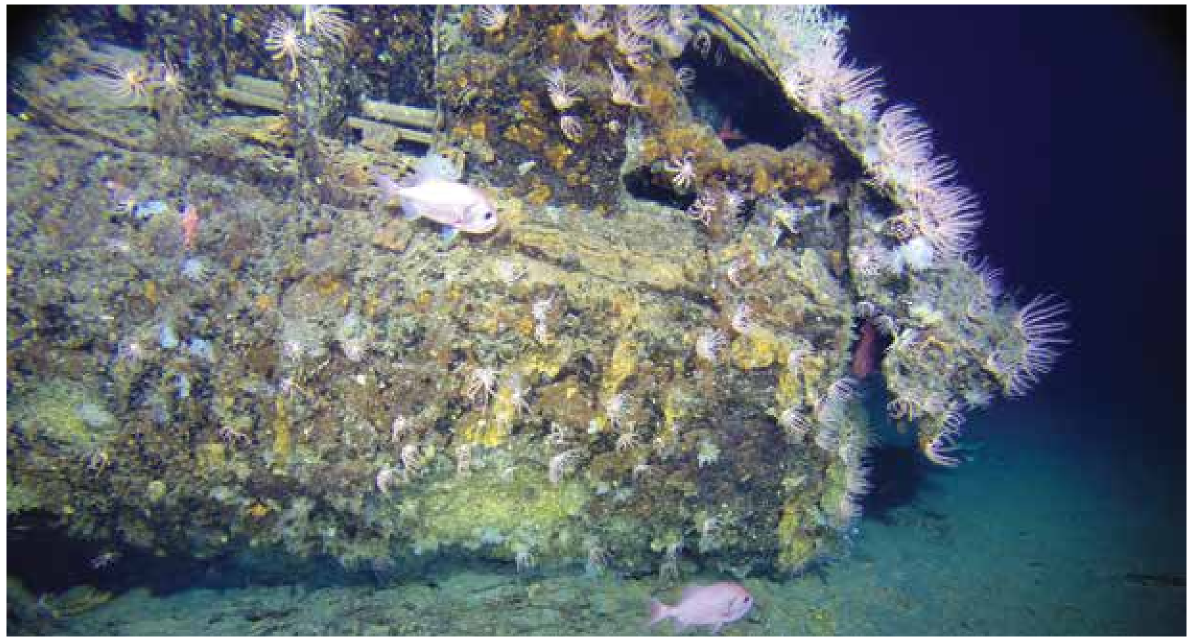


Figure 17 – Partially open bow cap.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

We were unable to inspect the forward torpedo tube sluice valve due to the bow cap obstructing access.

Figure 18 – Failed attempt to inspect bow torpedo tube.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Three of the four butterfly nuts securing the rear door in the forward torpedo compartment are dislodged; the fourth butterfly nut is out of sight behind debris. We believe the nuts probably dropped open when the implosion shock wave compressed the rear door onto its seal. The door would then be held shut (its current position) by the pressure of seawater admitted to the compartment after the implosion. The jolting of the sinking process may have also played a part in causing the unloaded butterfly nuts to drop off.

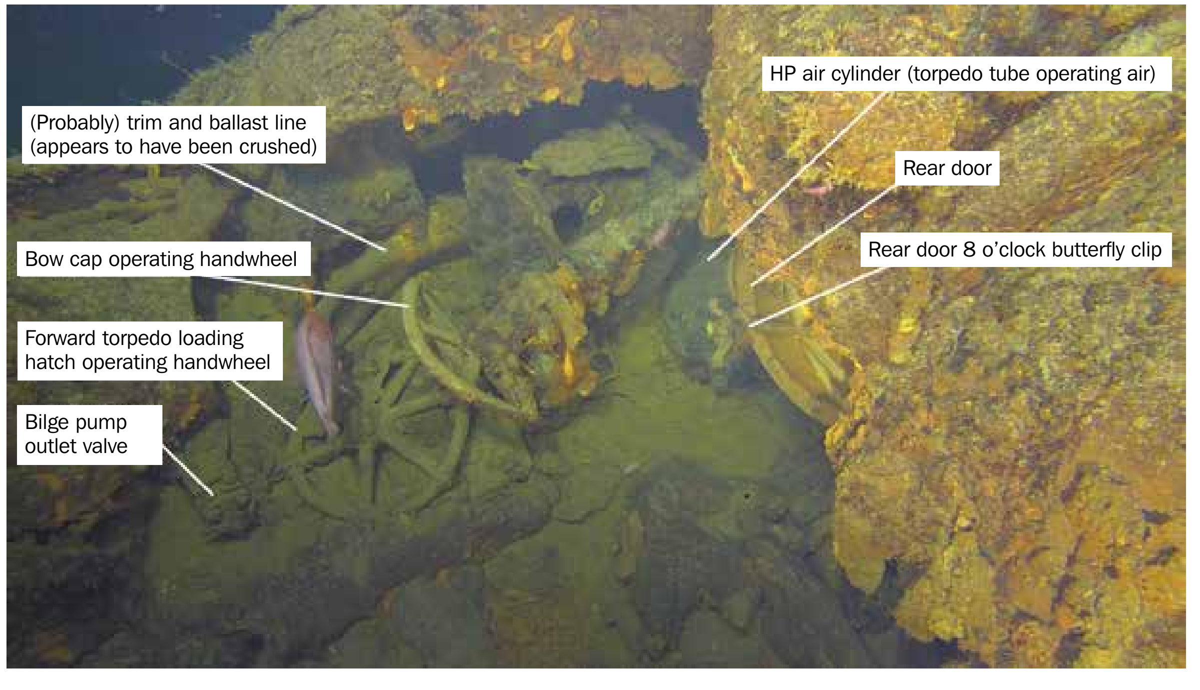


Figure 19 – Forward torpedo tube rear door butterfly clip, open view from starboard.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

We do not think this was part of the accident sequence; the rear door remains shut, indicating that it was not the source of any flooding. This is corroborated by the implosion over this compartment as flooding would have tended to equalise the external water pressure, making implosion less likely if the compartment had flooded through the forward torpedo tube.

It is possible that the bow cap was also opened as a precaution, to reduce the time necessary to prepare the tube for firing at the same time and for the same reasons as the stern cap. In this case the bow cap was only partially opened to protect the bow cap operating arrangement from damage from the bow wave or flotsam as the submarine moved around on the surface. Alternatively, it could also have been opened as part of a training drill.

We have considered the possibility that the sinking process could have distorted the rod gearing and worm gearing opening arrangements sufficiently to partially open the bow cap, but on balance think the absence of significant impact damage to the bow militates against this explanation.

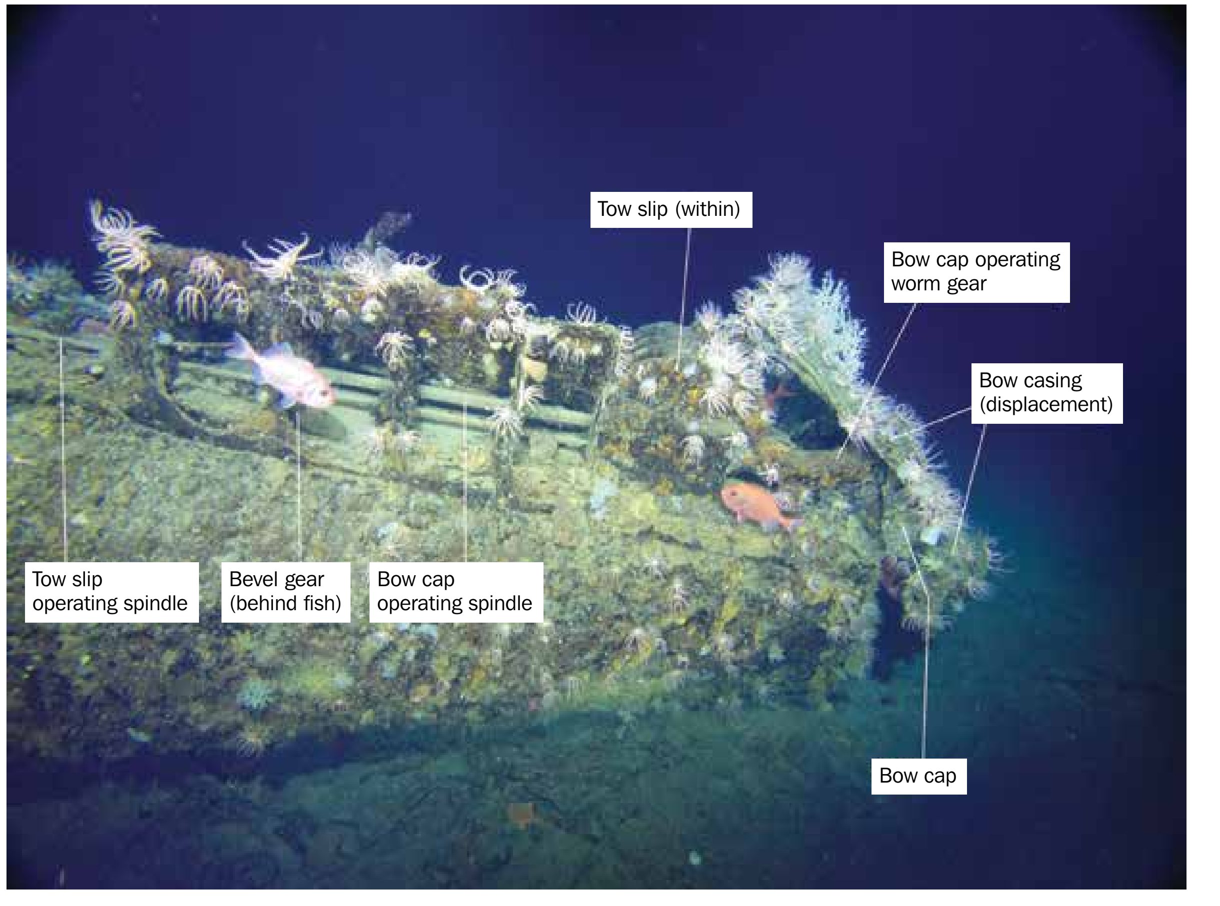


Figure 20 – Bow cap operating arrangements.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

In summary: we do not know why the bow cap is partially open. We think it was most likely done prior to diving and do not think it was part of the accident sequence leading to the loss of the submarine.

3.8 Forward main battery section visible

A portion of the forward main battery is visible. This was unexpected. The batteries were secured in a waterproof metal tank with a top cover made up of a double layer of teak boards in turn covered with two layers of painted canvas so as to be waterproof, and was tested to 3 psi (20.68 kilopascals) air pressure to check that it was sealed.[12] These arrangements have obviously broken down with the passage of time. Why only a portion of the battery is visible and there is no sign of the after section of the battery is not known.

Figure 21 – Battery cells visible in the control room.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

3.9 Broken keel

It would appear that the keel and pressure hull have broken in the vicinity of frame 70[13] and this could explain why one battery section is visible and one has dropped from sight. The apparent split in the pressure hull/keel will be considered further in discussing the sinking process below.

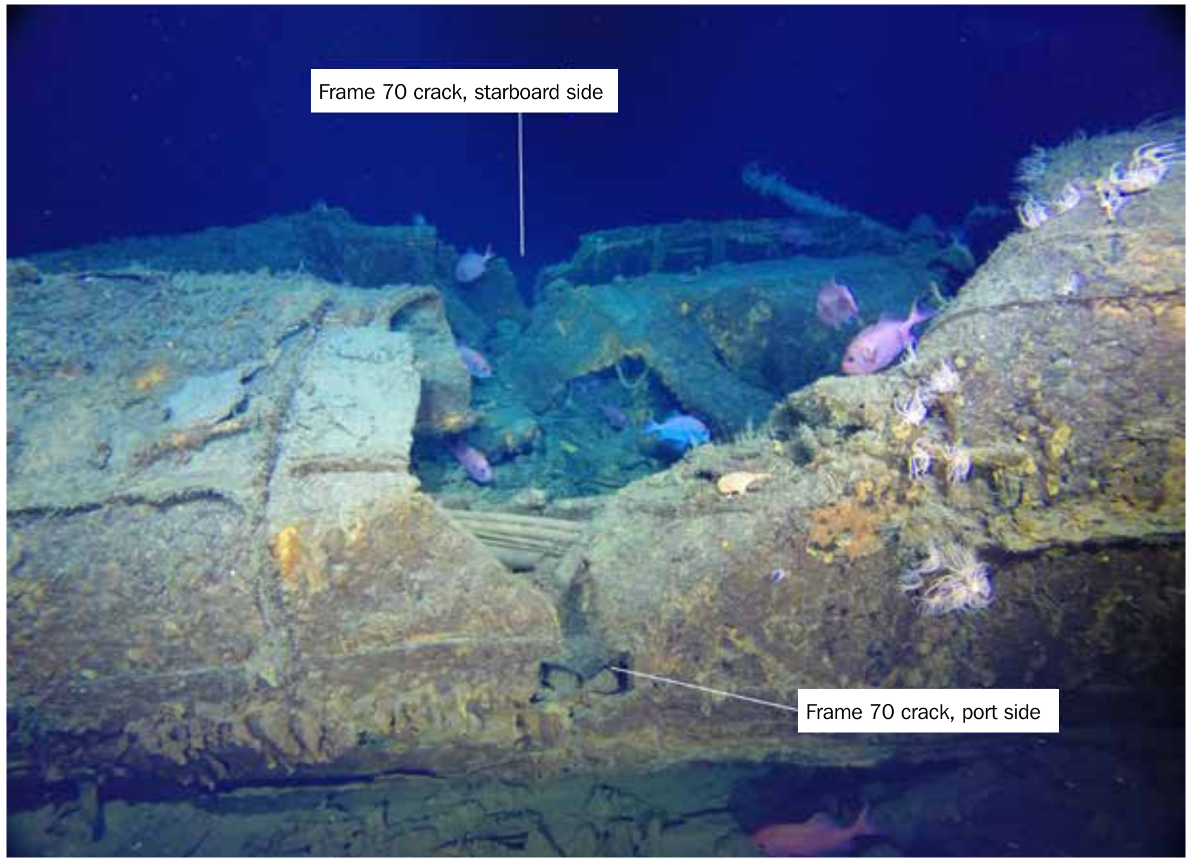


Figure 22 – Pressure hull split at frame 70.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

3.10 Rudder and skeg broken off

The submarine had a large, single rudder mounted aft of the two propellers, supported by a substantial skeg holding the lower bearing. The skeg protrudes below the line of the two propellers.

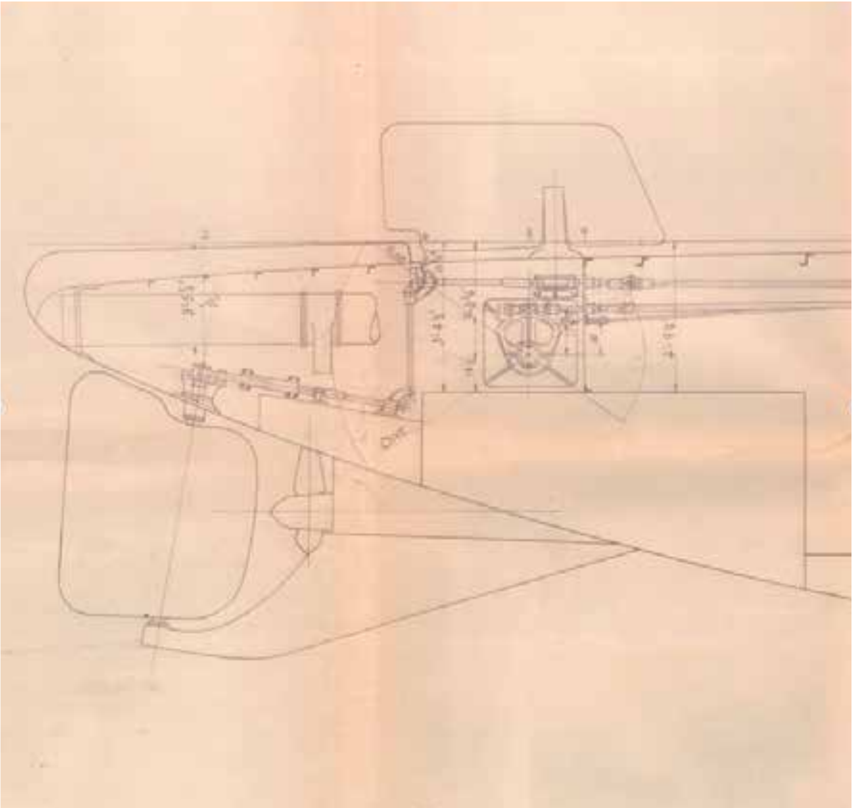


Figure 23 – Rudder and skeg arrangement, from as built drawings. Image courtesy of National Archives of Australia

The skeg has broken away from the pressure hull and the rudder has been displaced; both are lying on the sea floor in the vicinity of the port propeller.

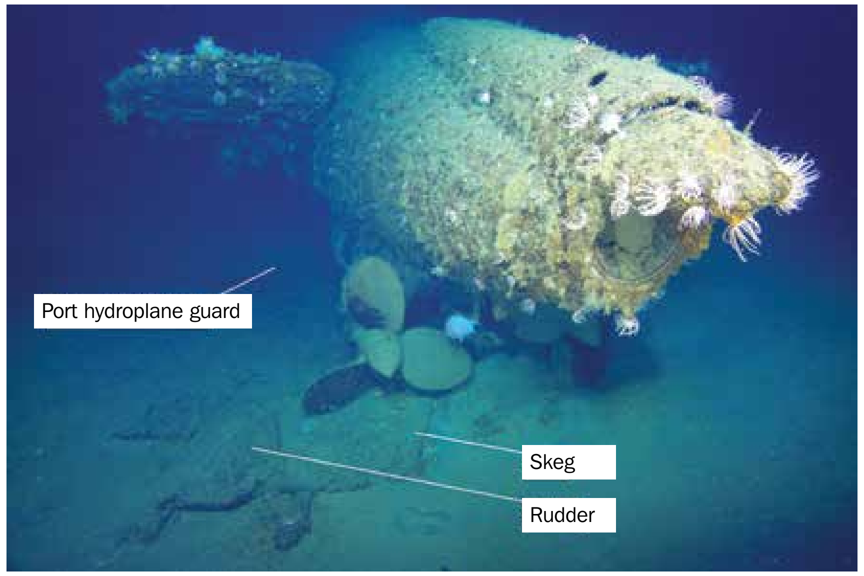


Figure 24 – Rudder and skeg lying on the sea floor.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Significant force would be required to break the skeg and displace the rudder. This damage is consistent with the initial and major impact of a stern-first grounding. This will be considered in greater detail in the section dealing with the sinking process.

3.11 Missing conning tower lower hatch and coaming

The opening in the pressure hull for the conning tower lower hatch has been identified because it is in a portion of the pressure hull on which the after periscope is mounted. The coaming and hatch are missing; just the opening remains. This is another unexplained puzzle and is discussed further in Annex C (see page 59).

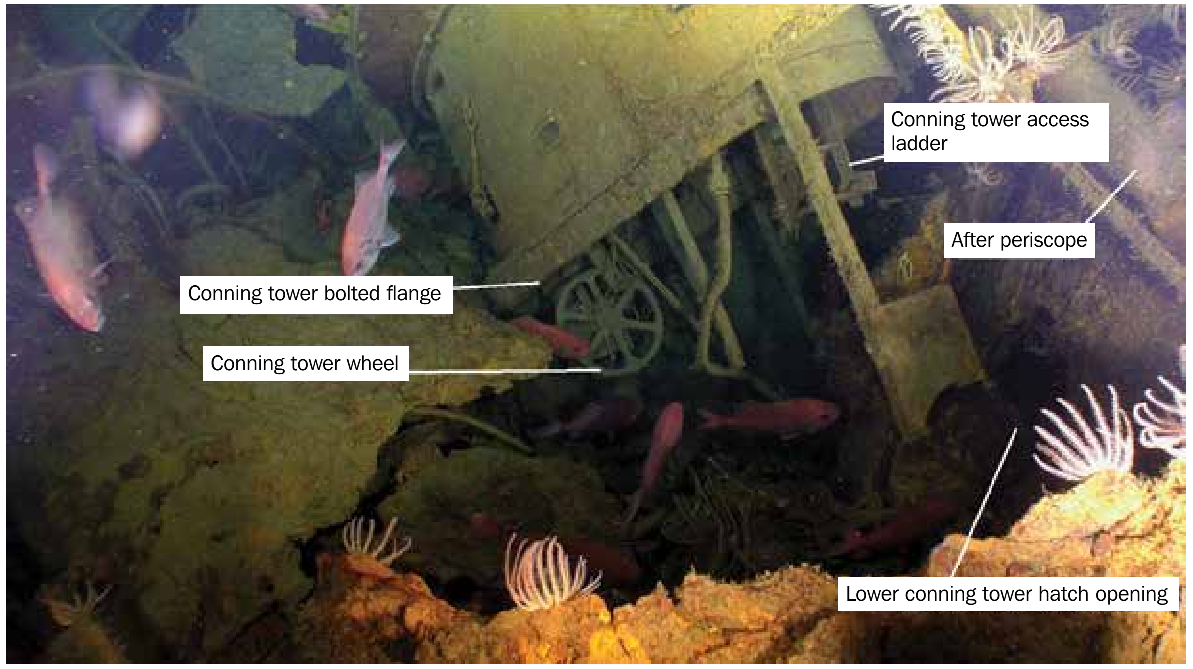


Figure 25 – Conning tower lower hatch opening.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

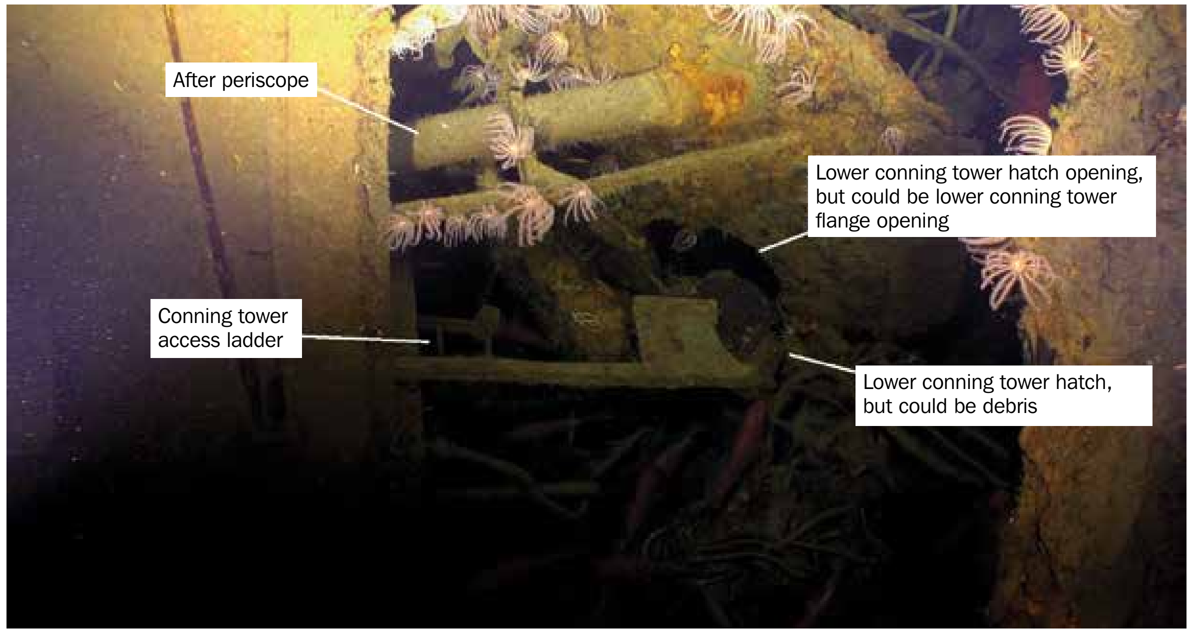


Figure 26 – Possibly the lower conning tower hatch.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

3.12 The sinking process

The clues provided by the partially opened ship's ventilation hull valve, lack of damage to the bow, relatively intact state of the after section of the pressure hull (that is, no implosion aft of the fin), split in the hull at frame 70 and damage to the rudder and skeg have caused a substantial rethink on the sinking process.

- From these clues we believe it is likely that the submarine began to flood through the ship's ventilation system shortly after diving.
- The ventilation system directed water into the after section of the hull, causing a loss of buoyancy aft (in submarine trim terminology, making the submarine heavy overall and heavy aft).
- The submarine began to sink stern first.
- As the flooding progressed the submarine became progressively more negatively buoyant (heavier).
- The influx increased dramatically as the submarine sank deeper.
- Propulsion would have been lost once the flood waters reached any or all of the after main battery, port propulsion motor or their associated power supply arrangements.
- Note, we believe that only the port main motor was available when the boat was dived, due to a defect on the starboard main engine clutch.[14]

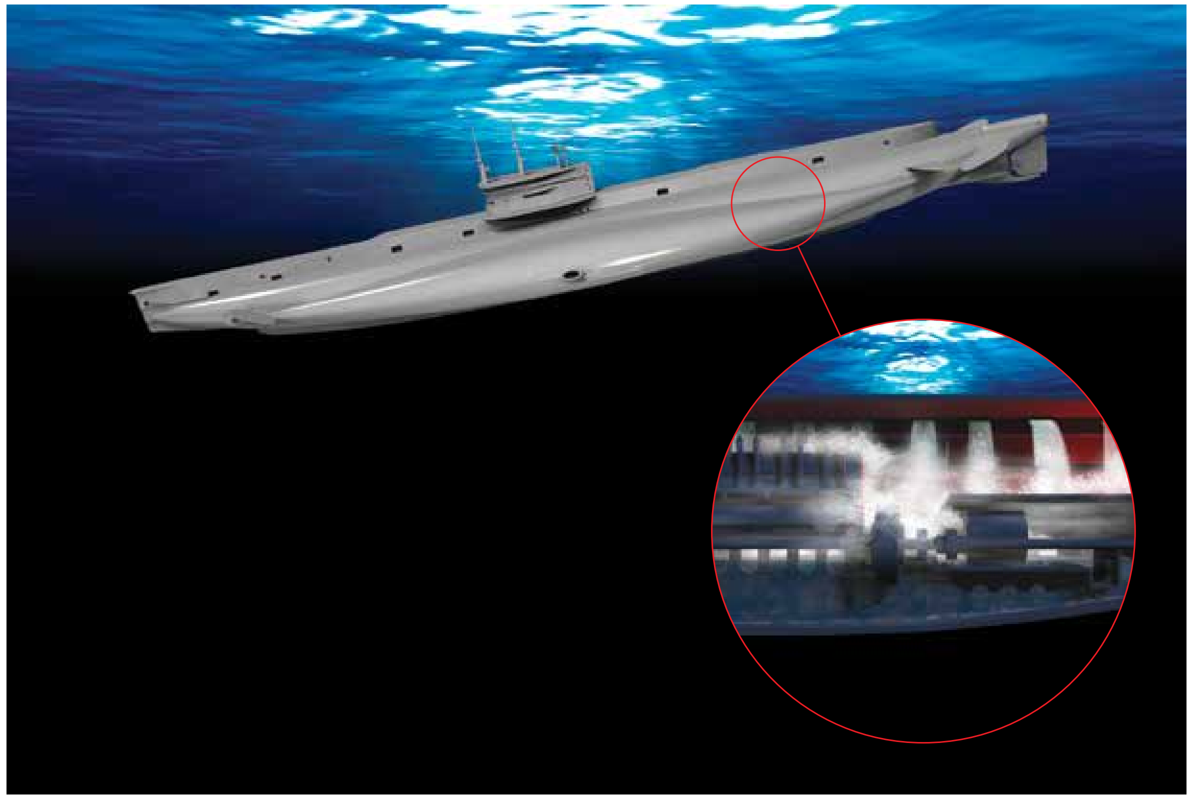


Figure 27 – Artist's impression of the situation on diving. Grant Gittus for Find AE1 Ltd

The submarine exceeded its crush depth (~90–120 metres) and the pressure hull imploded over the control room and forward torpedo compartment. The after end of the submarine, by then substantially flooded, did not implode; however, the shock wave from the implosion of the forward compartments blew off the engine room hatch.

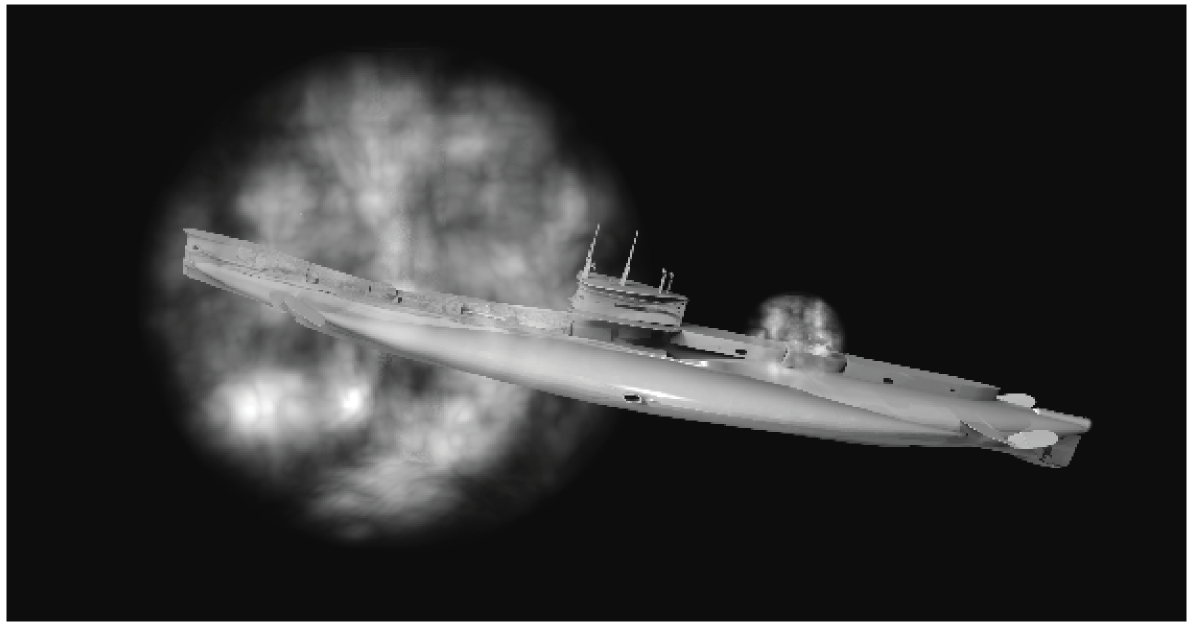


Figure 28 – Artist's impression of the implosion. Grant Gittus for Find AE1 Ltd

The rudder and skeg absorbed the main impact as the submarine struck the bottom with a slightly stern down angle and little or no headway, snapping off the skeg and displacing the rudder. The first impact may have caused the after hydroplane guards to break away and drop to the bottom, close to their normal positions on the hull.

Figure 29 – Artist's impression of the first impact on rudder and skeg. Grant Gittus for Find AE1 Ltd

The submarine then pitched forward to land on its keel. The second impact may have also contributed to unseating the fin, already weakened by the implosion damage to its footings, causing it to start its movement forward into the wreckage over the control room. The location of the toilet bowl shards in the fin suggest that the fin movement may have taken some time, slowly settling forward, as a higher-energy event could be expected to shatter the bowl and scatter the remnants.

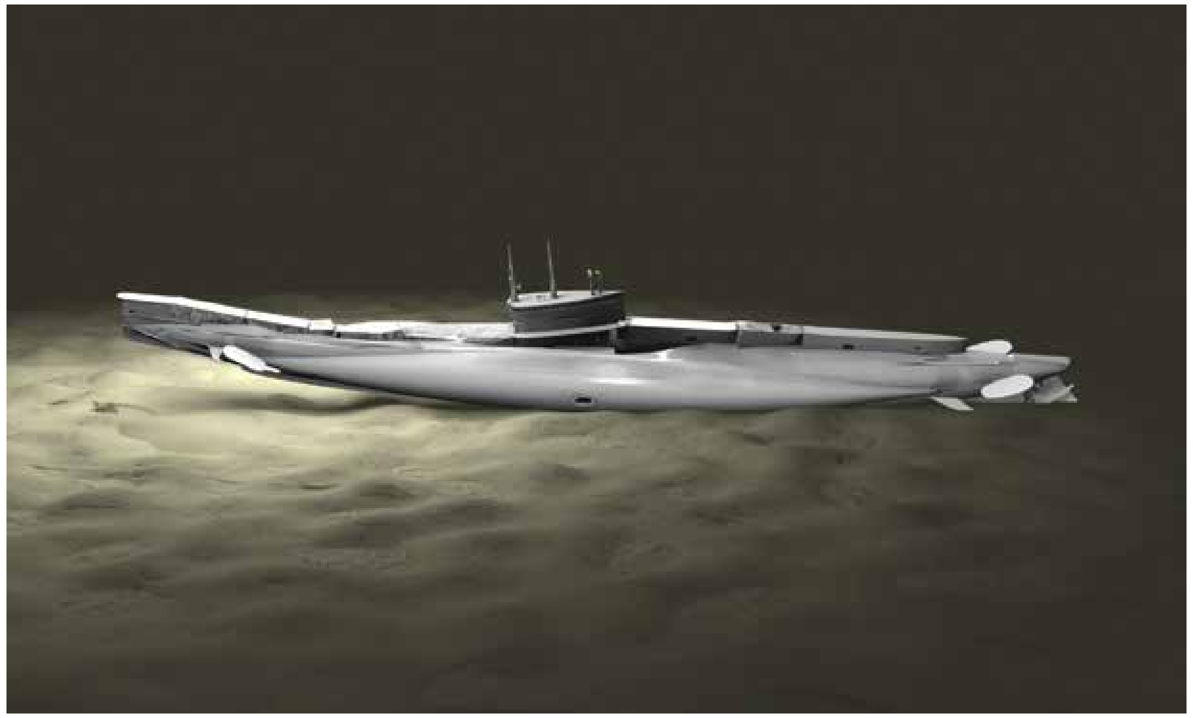


Figure 30 – Artist's impression of second impact: landing on the keel. Grant Gittus for Find AE1 Ltd

The whiplash effect from the second impact on the forward, unsupported length of the pressure hull in front of the keel appears to have split the pressure hull at frame 70 (see Figure 22, page 27).

The second impact appears to have been sufficient to cause the forward hydroplane guards to break off and fall to the bottom under their normal position on the hull.

Figure 31 – Artist's impression of final situation as submarine settled on the bottom. Grant Gittus for Find AE1 Ltd

4 Contributing factors

4.1 The embryonic state and rapid development of the Royal Navy submarine arm

From the commissioning of the RN's first submarine, *Holland 1*, in 1902 until 1910, the design rapidly evolved through A-, B- and C-Classes, each basically an evolution from the Holland design, each larger and safer than its predecessor, but essentially coastal submarines of limited endurance and capability.[15]

Figure 32 – *Holland 5* leaving Portsmouth. Image courtesy of Darren Brown

The D-class, launched in 1908, represented a departure in design. These submarines were designed for deployment off an enemy coastline. They were larger, with external ballast tanks in 'saddle tanks', a greater reserve of buoyancy, improved surfaced stability and diesel engines among the many improvements. The D-Class was twice the size of the C-Class and was the first British submarine to be fitted with a deck gun. When the eighth and last D-Class was launched in 1911, the RN had 75 submarines in service, spread across five classes of submarine.

The E-Class was an evolution of the D-Class, significantly larger, more stable and seaworthy and with new equipment and features such as a gyro compass and beam torpedo tubes. They became the workhorse for World War I, evolving to reflect lessons learnt; a total of 56 were built.

Submarine depot ships supported groups of similar classes of submarines and provided basic submarine training for personnel entering the submarine arm.

Submarines were in their infancy in the Royal Navy and the RAN. Training and operating procedures were embryonic or non-existent (for example, we have found no standing orders setting out the procedures for operating *AE1* or *AE2*).

An account of the loss of HMS *A7*[16] on 16 January 1914 records the short-term postings and low levels of experience of the commanding officer, first lieutenant and coxswain – at this embryonic stage of the Royal Navy's submarine service this situation appears to have been not unusual, with on-the-job training being typical, rather than any formal work-up, team training or evaluation.

The same account notes that between the launch of *Holland 1*, the Royal Navy's first submarine, in 1901 and August 1914, there were 68 serious accidents in submarines worldwide, including 13 (that is, 19% of losses) sunk due to improperly shut hull openings.[17]

4.2 State of training

It would appear that *AE1*'s crew had very little opportunity to practise dived operations.

- Diaries and records on *AE1* were lost with her, but *AE2* can be used as a yardstick since they followed very similar programs.[18]
- The dived trials post-build in January 1914 appear to be the only occasion that *AE1* and *AE2* dived under way at sea prior to arrival in Sydney.
- These trials were combined with the engine trials and conducted in one day.
- No operational work-up was conducted in the UK; the 10 days spent in Portsmouth were employed preparing for the delivery voyage.
- During this period, torpedoes were embarked, and the gyrocompasses and wireless telegraphy sets[19] were fitted.
- The forward hydroplanes were removed prior to sailing from Portsmouth for the voyage to Australia to prevent damage in bad weather, so diving was not possible.
- After arriving at Australia on 24 May 1914 *AE2* (and presumably *AE1*) conducted a number of dives alongside to check for leaks and at least one short voyage outside Sydney Heads is recorded in Petty Officer Kinder's diary,[20] presumably after the docking and refitting of the hydroplanes, where they dived for an hour.
- *AE1* and *AE2* underwent a docking in Fitzroy Dock, Cockatoo Island, on 3–24 June 1914 and were refitting in Sydney when war was declared.
- The refits were truncated; *AE1* and *AE2* were hastily readied, completing their refits on 8 and 10 August respectively.
- It is not known whether practice torpedoes were purchased for the submarines, but no record of torpedo practice firings has been found.
- *AE1* sailed for Rabaul on 28 August and *AE2* five days later.
- Petty Officer Kinder in *AE2* records that they made a slow passage northward in company with Upolu, arriving in Port Moresby on 5 and 6 September for fuel and provisions.
- They sailed on 7 September to rendezvous with the main Fleet at Rossel Island on 9 September, prior to their entry into Rabaul on 11 September.

It is worth noting that there would have been little opportunity to work up prior to sailing for PNG and little time for dived operations en route to induct the new members of the crew, including Lieutenant Scarlett, who joined *AE1* in Sydney as the third officer, probably on 10 August 1914, the day his submarine pay commenced.[21]

Besant was an experienced submarine commanding officer with over four years in command in smaller, single-shaft Holland, A- and C-Class – all coastal submarines.

The *AE1* command team (Besant, Moore and Scarlett) were all new to the E-Class. In Scarlett's case his first experience would be when he joined in Sydney in 10 August 1914, after having been invalided out of the Royal Navy in December 1912 and having qualified in submarines approximately two years earlier. Details of these officers' service in submarines is summarised in Annex F (see page 131) and available in Appendices IIIA and IIIB written by Barrie Downer[22] in Michael White's excellent account of the history of Australian submarines.

Figure 33 – Submarine A5, believed to be Lieutenant Besant on the fin. Image courtesy of Darren Brown

Figure 34 – Submarine *C30* on the Tay. By the National Maritime Museum and from the Oscar Parkes Collection, sold May 2011. Image courtesy of Darren Brown.

Figure 35 – Submarine *C12* leaving Portsmouth, as built, Lieutenant Besant on the fin. Photograph by Richard Perkins. Image courtesy of Darren Brown

4.3 State of the trim

It is considered quite likely that *AE1* conducted a trim dive shortly after parting company from HMAS *Parramatta* on the morning of 14 September. This would have been good submarine practice following a period in harbour.

The subsequent opening of the bow and stern cap – possibly as a precaution as *AE1* approached the Duke of York Islands on the surface in search of the German steamer sighted the night before by HMAS *Yarra* – could have affected the trim[23] (regardless of the earlier trim dive).

Opening the bow/stern caps on the surface, without compensating correctly, could leave the submarine up to 200 gallons (that is, 880 kilograms) negatively buoyant (heavy). (Each tube section between the sluice valve and bow/stern cap contains ~97 gallons or 367 litres.) This would have a noticeable impact on the trim, making the submarine negatively buoyant (heavy overall). Controlling the submarine while correcting this situation, particularly with only one shaft available, would compound the immediate problem caused by any flooding through the ship's ventilation system on diving.

4.4 The lack of success searching on the day

The failure of searchers to localise the wreck in the immediate aftermath of the accident is another puzzle. The precise position of the wreck remains confidential; however, it lies to the south of Mioko Island and would probably have been in a westerly-flowing current, reportedly flowing strongly at ~3 knots on the surface, under the influence of the southeasterly monsoon that was blowing in September 1914. Given the implosion damage and open engine room hatch, the wreck is essentially open and debris and oil slicks could be expected.

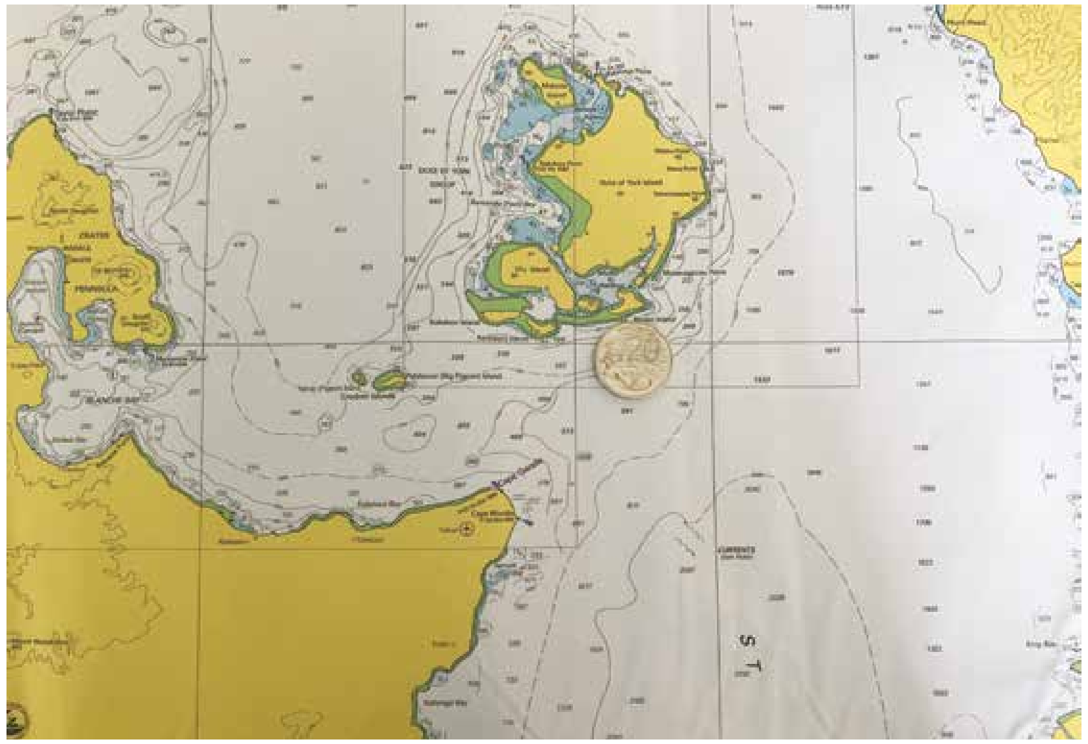


Figure 36 – General area of the wreck, marked by the coin

We believe the accident most likely occurred on diving, with the crew and all extraneous materials secured inside the pressure hull. Much of the lighter materials and many of the bodies could be expected to be contained under the implosion rubble or in the intact after end of the submarine; the implosion pressure wave would tend to move mobile material into that area. The material that did escape the pressure hull would have been carried to the west along the southern side of the Duke of York Island group and thence northwest between those islands and the Credner Islands.

Based on the analysis above, the accident probably occurred at ~1530–1600; the concentration of debris from the immediate sinking would have been carried 26–40 nautical miles (13 hours at 2–3 knots; 48–74 kilometres) from the site by sunrise the following morning and dispersed in the strong currents and moderate SE wind reported.

By contemporary standards, the immediate search was poorly coordinated. No datum was established, leading to some confusion over the last seen position and timing, nor were ships allocated search areas in a structured manner. This is discussed further in the Search Report (section 5.6 and Annex C).[24]

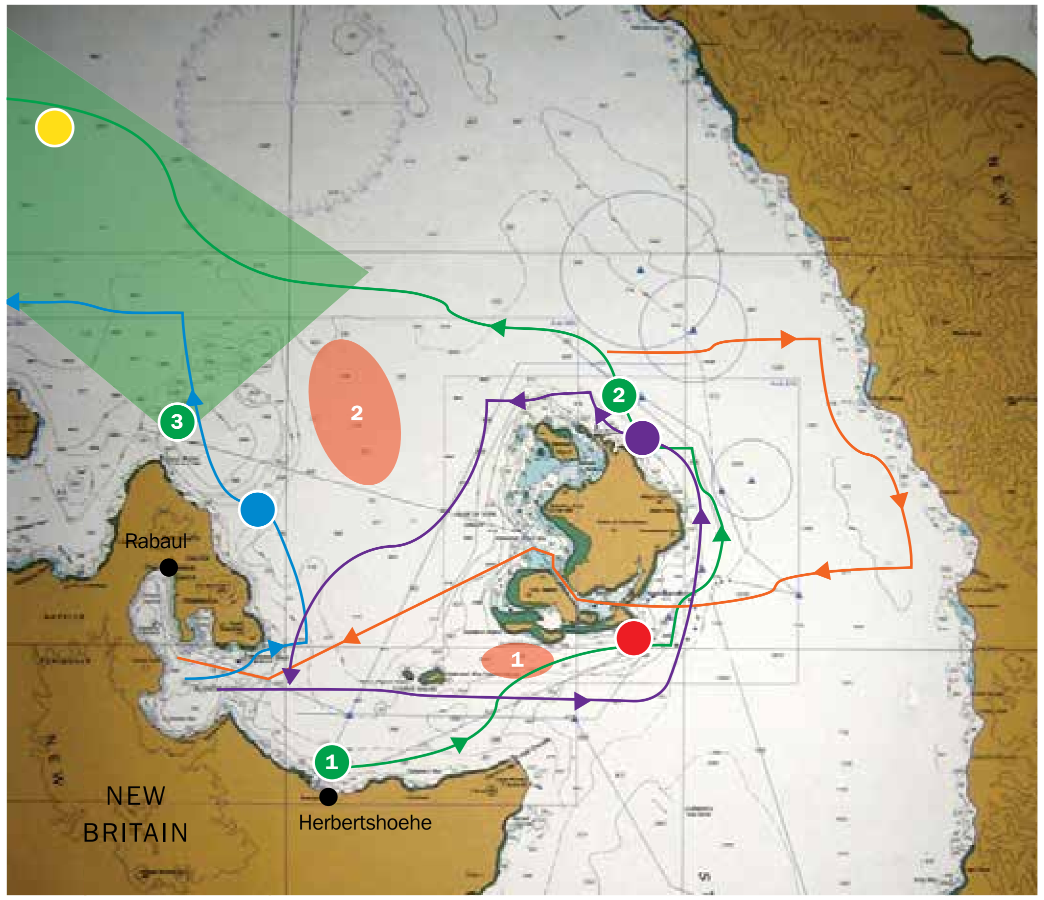


Figure 37 – Reconstruction of searching ships' tracks, 14–15 September 1914

Parramatta – Uncertain track 2320 14 – 1400 15 September (in company with *Yarra* from about 0001–0200 15 September)

Yarra – Uncertain track from approx 0200 15 September until off Mioko Harbour at 1300 15 September. Grounded at 1340 15 September

Sydney – Estimated track on 14 September

Encounter – Track on 15 September

Parramatta search box forenoon 15 September

1 *AE1* estimated debris at sunset on 14 September

2 *AE1* estimated debris at sunrise on 15 September

Possible areas of debris expanding with time and moving with current, W then NNW, initially at 2 knots and reducing as the channel widens to about 1 knot by 0700 on 15 September

1 *Parramatta* at anchor at 1900–2320 on 14 September

2 *Parramatta* and *Yarra* at 0150 on 15 Setember

3 *Parramatta* position at 1400 on 15 September

Warrego estimated position at 0730 on 15 September, enroute to Rabaul

Sydney estimated position at 2200 on 14 September

AE1 nominal position for wreck. Estimated sank at 1530–1600 on 14 September

Encounter position 0800 on 15 September. She left Rabaul at 0525 and returned to Rabaul by 1045 on 15 September

A reconstruction of the searching ships' tracks set out in Annex C of the Search Report indicates that HMAS *Parramatta* and *Yarra* would have crossed the likely path of any debris trail in the dark. By first light at 0525 the debris field would have been to the northwest of the area searched by *Parramatta* during the forenoon of 15 September. *Yarra* returned east about (or clockwise) around the Duke of York Island and would not have crossed the debris trail in daylight before a serious grounding removed her from the search effort. HMAS *Encounter* sailed from her anchorage off the Beehive Rocks in the entrance to Rabaul Harbour at first light at 0525 and proceeded counterclockwise around the Duke of York Islands. None of these ships passed through the initial, and arguably largest, sinking debris field generated immediately after the accident. *Encounter* would have crossed the path of any debris trail, albeit ~10 nautical miles downstream from the wreck, ~18–19 hours after the accident and sometime after the initial sinking debris field had been carried away to the northwest by the current. *Encounter* reported an oil slick. This may well have been from *AE1*, but we don't know, as *Encounter* attributed it to shipping operating in the area and the position was not recorded or logged.

4.5 Baseline survey and maritime archaeology aspects

The survey has provided a comprehensive video and stills photographic baseline of the wreck. Post-survey processing by Dr Andrew Woods at Curtin University HIVE Centre has provided a 3D model of the wreck developed from the high-resolution, digital still images (see Annex E, page 122). This will provide an excellent tool for ongoing analysis and revolutionise the public's ability to interact with the wreck.

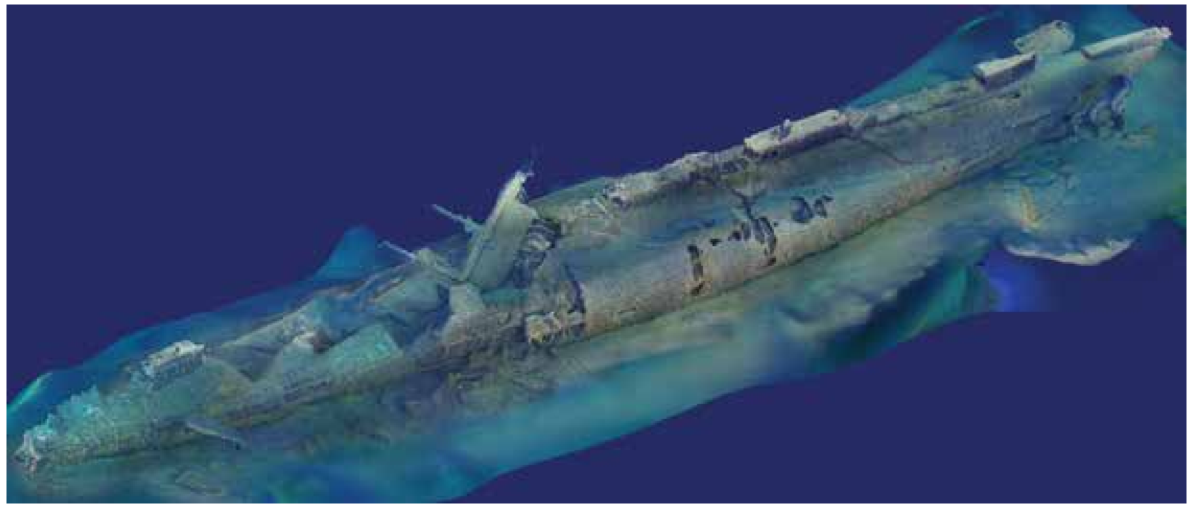


Figure 38 – Interim 3D model of *AE1* port side. 3D model by Curtin University from images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Curtin University

The maritime archaeology aspects of the baseline survey are discussed in detail in Annex B (see page 47).

5 Conclusions

The images collected by the highly skilled survey team on RV *Petrel* have provided an excellent baseline survey of *AE1*. Given the fragile state of the wreck, its ongoing corrosion, advancing age and the harsh environment it is lying in, the timing of Paul Allen's generous offer was very fortuitous.

The 3D image processing technique employed by Curtin University's Dr Andrew Wood, which uses the stills collected by the WA Museum digital still camera to generate a photogrammetric 3D model, has added significantly to the ability to understand the wreck and interact with the images, opening up new horizons for public displays and interaction.

The wreck will continue to corrode away; it is forecast that the conning tower and stronger members such as the propellers, propeller shafts and engine bedplates will be all that remain in 80 years' time.

The consensus reached by a team of submarine and engineering experts on the cause of the loss has been verified as a reasonable hypothesis by competent external experts and the Defence, Science and Technology (DST) group. Nonetheless it remains an informed judgement; those who know what happened perished in *AE1*.

The identification of the open ship's ventilation hull valve provides a credible explanation for the initiation of a sequence that turned an otherwise straightforward training dive into a fatal depth excursion. Given the size of this opening the volume of water entering the submarine would have quickly led to a complete loss of control. The crew's efforts to return to the surface would have been greatly hampered by the unavailability of the starboard main motor, due to a jammed engine clutch.

The resultant implosion at 90–120 metres depth would have been an extremely high–energy event, illustrated by the displacement of the engine room hatch. The pressure wave generated by the implosion would have killed the crew instantaneously and probably contributed to the displacement of the fin, it having lost its footings due to the implosion over the control room.

The breakage of the rudder skeg, displacement of the rudder and resistance of the after half of the submarine to implosion are clues consistent with a sinking process that would have followed such a flooding incident through this hull valve.

The survey reveals a number of unresolved puzzles that invite follow-up in any future surveys of the wreck, including the location of the lower conning tower hatch, possibly blown clear of the hull opening by the implosion, but more likely simply corroded away in the presence of the galvanic action arising from the manganese bronze conning tower.

There were a number of contributing factors to the loss, of which the low level of dived training for the *AE1* officers and crew is the most significant. It would appear that this was not an unusual situation given the embryonic and rapid state of development of submarines in the Royal Navy in 1913–14 and the Royal Australian Navy's complete unfamiliarity with these specialised, demanding and dangerous craft.

5.1 Recommendations

The physical protection of the wreck by jointly declaring it a protected area and establishing monitoring arrangements to alert authorities in PNG and Australia to any incursions is a pressing priority.

An agreement with the Mioko Islanders would appear to be the most effective and cheapest form of monitoring, and is recommended.

Given the potential complexity of the oceanographic environment at the site, situated at a junction for currents flowing under the influence of the seasonal winds and significant bottom topography, the collection of a full set of data over a 12-month period is recommended.

A series of follow-up visual surveys should be undertaken as the opportunity arises to follow up on outstanding issues and contribute to the development of a sound wreck management plan. This plan should be jointly developed by the ANMM and PNG NMAG.

Given the wreck management plan's role in preserving the wreck and the rapid pace of decay, this is also a matter of priority.

Endnotes

1 Mr John Jeremy AM BE FIEAust FRINA is a naval architect, the last Chief Executive Officer of Cockatoo Island Dockyard and is experienced in working on submarines. He is a past President of the Royal Institution of Naval Architects, Australian Division.

2 Peter Holt BEng CEng CMar Eng MIMarEST MCIfA MHydSoc, Director, 3H Consulting Ltd, an engineer who has worked in offshore subsea systems for 20 years, involved in maritime archaeology for 25 years, been a full-time archaeologist for six years and has a particular interest in the development of early submarines.

3 The Chief Defence Scientist, Dr Alex Zelinsky AO, provided support throughout the project, authorising the participation of the Chief of the Maritime Division of the Defence Science and Technology Group, Dr David Kershaw, Naval Architect Dr Stuart Cannon and Dr Roger Neill, who have all given freely of their time to critically review the findings.

4 *HMAS* AE1*: Finding the men of* AE1 *– 20 December 2017*, a report by Find AE1 Ltd, published by ANMM in January 2018.

5 https://en.wikipedia.org/wiki/Battle_between_HMAS_Sydney_and_German_auxiliary_cruiser_Kormoran.

6 https://humanities.curtin.edu.au/research/centres-institutes-groups/hive/.

7 see Note 1 above.

8 See Note 2 above.

9 See Note 3 above.

10 Specification for Building the Hull of a Twin Screw Submarine Boat, para 52.

11 A 6" (152 mm) opening at 1 metre depth would admit 8L/sec; at 50 metres this would increase to 550L/sec.

12 Specification for Building The Hull of a Twin Screw Submarine Boat, para 50.

13 Frames were numbered from aft, generally spaced at 21" (533 mm). The location of frame 70 can be identified on the general arrangement drawings.

14 *Subsunk: HMAS* AE1 *– Search area recommendation*, 10 February 2012, section 3.5; http://findAE1.org.au/reports/AE1-search-report-2012/, described as the Search Report.

15 Innes McCartney, *British submarines of World War I*, New Vanguard, 2008.

16 Peter Holt, *HM Submarine* A7*: An Archaeological Assessment*, published by The SHIPS Project, 2015. Section 8.

17 Ibid, section 6.3.

18 According to Petty Officer Kinder's diary, *AE2* had minimal dived experience.

19 An early, primitive wireless set using manually transmitted morse code to exchange signals.

20 https://www.awm.gov.au/index.php/collection/C396277.

21 Michael White, *Queensland History Journal; The Royal Historical Society of Queensland* (2016) vol. 23, no. 1, pp 19–31.

22 Michael White, *Australian Submarines: A History*, 2nd edition, ATOM, 2015.

23 A dived submarine that is neutrally buoyant and balanced fore and aft is said to be 'in trim'. The forward and after hydroplanes can then be most effective in controlling the depth and bow up/down angle on the submarine respectively.

24 *Subsunk: HMAS* AE1 *– Search area recommendation*, 10 February 2012, section 5.6 and see Annex C, page 59; http://findAE1.org.au/reports/AE1-search-report-2012/.

25 https://en.wikipedia.org/wiki/Lossy_compression.

26 https://en.wikipedia.org/wiki/List_of_submarine_classes_of_the_Royal_Navy.

27 Klaxon, *The story of our submarines*, William Blackwood & Sons, 1919, Chapter 1, pp 2, 3 and 4. ‘Klaxon’ was the pseudonym of Commander John Graham Bower – a Submarine Commanding Officer who was appointed to his first submarine command pre-WWI.

28 Nicholas Lambert (ed.), *The Submarine Service 1900–1918*, Navy Records Society, 2001, ISBN 0 7546 0294 X.

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Annex A
List of volunteers and sponsors of Find AE1 Ltd

Introduction

Since its inception on 20 December 2013 Find AE1 Ltd has been fuelled by the efforts and in-kind support of volunteers, including descendants of the crew, and associates, some professional, others passionate enthusiasts from a variety of backgrounds. Throughout the company's existence, the energy and passion of these groups have been outstanding. Funds have always been tight, hard-won and greatly appreciated.

Find AE1 Ltd board

The board of Find AE1 Ltd not only fulfilled its collective statutory responsibilities in the governance and operation of the company but also as individuals they provided their professional services in kind or *pro bono*, sought donations throughout the community and acted as ambassadors for the cause 'Find the men of *AE1*'. The board comprised:

Rear Admiral Peter Briggs AO CSC RAN Rtd, Chairman
Commodore Terence Roach AM RAN Rtd, Deputy Chairman
Mr Trevor Lloyd, Director
Mr Paul Wetherill, Director
Dr John White, Director
Dr Michael White OAM QC, Director
Captain Ken Greig OAM RAN Rtd, Company Secretary

AE1 Descendant Families Association

The crew of HMAS *AE1* were the fathers, sons, brothers and uncles of 35 families who never forgot them. They have lived with the unbearable pain of the loss of their loved one surrounded in unfathomable mystery. Submariners have long understood the importance of farewelling a family member and as such have a duty to find out what happened to *AE1* in order to provide some comfort to the families.

Descendants formed a group at the time of the research and searches by the late Commander J D Foster OAM RAN Rtd. Later, this group organised under the banner of the *AE1* Descendant Families Association with the triumvirate of Ms Robyn Rosenstrauss, Ms Vera Ryan and Mr Tom Tribe – descendants of Chief ERA Class 1 James Fettes, Chief ERA Class 3 John Messenger and Petty Officer William Tribe respectively – as the association's leadership. Their tireless efforts have been greatly supported by the other descendant families, including both the Wilson and Scarlett families – descendants of Chief ERA Class 2 Joseph Wilson and Lieutenant the Honourable Leopold Scarlett respectively – who donated their forebears' decorations to the Australian National Maritime Museum collection.

Submariners

Sir Winston Churchill, First Lord of the Admiralty in 1914, said 'Of all the branches of men in the forces there is none which shows more devotion and faces grimmer perils than the submariners'. The care submariners have for one another meant the loss of *AE1* was sorely felt and bestowed an obligation on those who followed to find the men of *AE1* and lay them to rest.

The Submarine Institute of Australia (SIA) has been foremost in supporting all the activities throughout both Find *AE1* and its predecessor, the *AE2* Commemorative Foundation's Project Silent ANZAC. The SIA has not only supported Find AE1 Ltd with funds but also in the technical aspects of planning the searches. The SIA president, Commodore Mark Sander RAN Rtd, the secretary, Commander Frank Owen OAM RAN Rtd and the executive director, Commander David Nichols RAN Rtd, are notable for their contribution to the project's success.

The Submarine Association of Australia (SAA) has been a stalwart supporter of Find AE1 Ltd. From turning out in force and parading the SAA banners at the unveiling of the *AE1* commemorative plaque at Garden Island, to the annual commemorative services held at Gordon in Sydney by the SAA Motorcycle Group and at the Shrine of Remembrance by the Victoria Branch, to the plaques in Canberra at the Australian War Memorial (AWM) and in Fremantle at the Western Australian Maritime Museum (WAMM), SAA support has been wholehearted and enduring.

The Submariners Association in the UK, in particular the Barrow in Furness branch, has long supported the efforts of Find AE1 Ltd with research and detailed information on the boats and their crews. The indomitable Mr Barrie Downer MBE (retired Lieutenant Commander RN) was instrumental in the installation of a commemorative plaque on behalf of AE1 Inc (the predecessor of Find AE1 Ltd) and the *AE1* Descendant Families Association at a prominent position in Barrow, close to where *AE1* was built.

Volunteers, associates and workshop participants

Dr Stuart Anstee
Dr Ross Bastiaan AM RFD
RADM Peter Briggs AO CSC RAN Rtd
Mr Darren Brown
Mr David Donohue
Dr Nigel Erskine
Dr Neil Gordon
Mr Ted Graham AM
Mr Peter Graham
Dr Jeremy Green
CAPT Ken Greig OAM RAN Rtd
Mr Kieran Hosty
Mr Paul Hundley
Dr James Hunter
Mr John Jeremy AM
Dr Elizabeth Johnstone
Dr Ian MacLeod
Ms Irini Malliaros
Mr Gus Mellon
Dr Garth Morgan
Mr John Mullen
Dr Roger Neill
CMDR David Nichols RAN Rtd
CAPT Ian Noble RAN Rtd
CMDR Frank Owen OAM RAN Rtd
Mr John Perryman
CDRE Kim Pitt AM RAN Rtd
Mr John Richardson
Mr Peter Richardson
Mr Michael Rikard-Bell
CDRE Terence Roach AM RAN Rtd
Mr Tim Smith OAM
CAPT Roger Turner RN
Dr Michael White OAM QC
CMDR John Young RAN Rtd

RV *Petrel* ROV survey review group

Mr Darren Brown
Mr Alec Coles, WA Museum
Mr Tim Eastwood, WA Museum
Dr Nigel Erskine, ANMM
CAPT Ken Greig OAM RAN Rtd
Mr Michael Harvey, ANMM
Dr James Hunter, ANMM
Mr John Jeremy AM
Dr Ian MacLeod
Mr Gus Mellon
Dr Roger Neill
CAPT Ian Noble RAN Rtd
CDRE Terence Roach AM RAN Rtd
Mr Tim Smith OAM
CAPT Roger Turner RN
Dr Andrew Woods, Curtin University

Sponsors

This survey was made possible by the generosity of Mr Paul Allen, who diverted his highly capable ship, the RV *Petrel*, and extended the expert survey team's cruise to undertake the survey, free of charge.

Throughout the four years of operations Find AE1 Ltd has enjoyed the generous sponsorship of:

ASC Pty Ltd

Australian National Maritime Museum

Arthur J Gallagher & Co

Defence Network Services

Defence Science and Technology Group

IJS Global

IX Blue [formerly IXSurvey Australia]

Land and Marine Services Pty Ltd

Mr Trevor Lloyd – legal practitioner

Lockheed Martin Australia

McTaggart Scott Australia

Mr Gus Mellon (retired Lieutenant RAN)

MetOcean Solutions Ltd

Naval Group [formerly DCNS]

PWA Accounting

RSL Queensland Branch

RSL Victoria Branch

SAAB Technologies

Sea and Land Technologies

Secora

SERCO

CAPT Peter Sinclair AM RAN Rtd

SONARTECH ATLAS

Submarine Institute of Australia

Taylored Offshore Services

ThyssenKrupp

Donors

Most recently, support was given to the Australian National Maritime Foundation to match funding from the Department of Defence and enable the successful search. Major donors were:

News Corp

Commonwealth Bank

Fugro

Goodman Group

John and Jacqueline Mullen

Arthur Tzaneros

Terry Tzaneros

Macquarie Group and Directors

Macquarie Group Foundation

Goldman Sachs Gives on behalf of Christian Johnston

Australian Capital Equity

Navantia Australia

Qantas Airways Limited

Malcolm Broomhead

Peter Dexter AM

Daniel and Helene Janes

Guy and Debbie Templeton

Rob Sindel

April 2018 RV *Petrel* ROV survey expedition sponsors

Australian National Maritime Museum

Curtin University

Submarine Institute of Australia

Vulcan Inc.

Western Australian Museum

April 2018 RV *Petrel* ROV survey expedition participants

Peter Briggs, Find AE1

James Hunter, Australian National Maritime Museum

Roger Turner, Find AE1

Andrew Woods, Curtin University

Annex B
Archaeological survey of *AE1*: Methodology and preliminary observations

Dr James Hunter, Curator, RAN Maritime Archaeology, Australian National Maritime Museum

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1 Introduction

In April 2018, the curator of RAN Maritime Archaeology at the Australian National Maritime Museum (ANMM) participated in a remotely operated vehicle (ROV) examination of the shipwreck site of HMAS *AE1* in waters off the Duke of York Islands in Papua New Guinea. *AE1* was Australia's first naval submarine and participated in the capture of what was the colony of German New Guinea by Allied forces in the opening months of World War I. 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 as part of a collaborative search effort that included ANMM, the Silentworld Foundation, the Royal Australian Navy, Find AE1 Ltd, the Submarine Institute of Australia and Fugro NV.

The ROV examination of *AE1* 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 included ANMM, Find AE1 Ltd, and Curtin University's Hub for Immersive Visualisation and eResearch (HIVE). Because *AE1* is located in over 300 metres (roughly 980 feet) of water, the site examination was conducted via *Petrel*'s work class ROV (a 'Bathysaurus XL' model built by Norwegian firm Argus and capable of operating to a depth of 6000 metres), which was outfitted with an array of standard- and high-definition video cameras (Figure 1). These cameras were augmented by a specially designed 12-megapixel deep-water digital still camera provided by the Western Australian Museum and Curtin University for the purpose of developing a 3D photogrammetric model of the shipwreck site (Figure 1, inset). The same camera was used by the Western Australian Museum and Curtin University to capture photogrammetric imagery of the World War II shipwrecks HMAS *Sydney II* and HSK *Kormoran* in 2015. Specific details relating to the photogrammetric capture and 3D digital modelling process can be found in Annex E (see page 122).

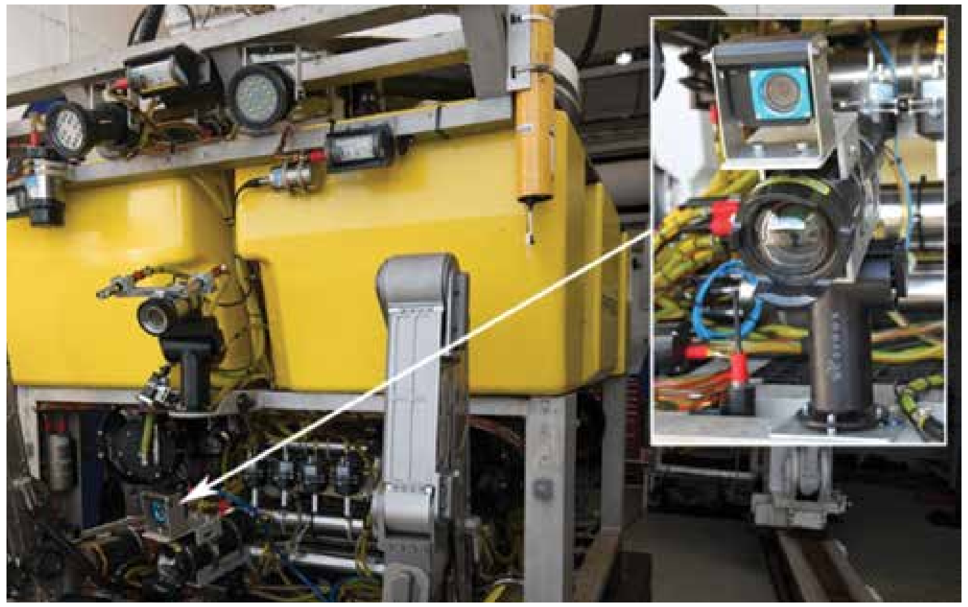

Figure 1 – The ROV and digital still camera (inset, top) used to conduct the archaeological and photogrammetric surveys of *AE1*. Images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

2 Survey methodology

Archaeological examination and documentation of *AE1* took place over the course of two days and involved five separate dives by *Petrel*'s ROV. The first dive (Serial 1; *Petrel* dive no. 88) confirmed the submarine's location and identity and served as an opportunity for the ROV operators to familiarise themselves with the wreck site and its environmental conditions and identify potential hazards (such as protruding structures that could foul the ROV's tether). It also 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 inaugural dive also allowed *Petrel*'s crew to ensure the ROV was operating properly, and to check and colour-correct (white-balance) the video camera array.

At the end of the first dive, the digital still camera was installed on the ROV's pan-and-tilt mechanism. Following a brief testing and troubleshooting regimen for the camera on the surface, Serial 2 (*Petrel* dive no. 89) commenced. Once on the bottom, the ROV was deployed to *AE1*'s bow, and proceeded along the starboard side of the hull at a relatively slow (~0.10-knot) pace to allow for required image overlap. Upon reaching the stern, the ROV operators deployed a small standard-definition camera attached to one of the manipulator arms and inserted it a short distance into the stern torpedo tube to determine the position of its sluice valve. Once this area was imaged, and the sluice valve was confirmed shut, the ROV's altitude above the wreck site was increased and a second transect executed along the hull's centreline, with the ROV moving from stern to bow.

The overhead pass allowed the team to see *AE1* from a new vantage point, and to pick out new features that had missed detection on prior passes. For example, a small handwheel was spotted on the port side of the hull within the control room, and structural elements associated with the fin and conning tower, including the ladder in the aft section of the fin and the upper conning tower hatch counterbalance, were observed and inspected. A final transect moving from bow to stern was executed along the port side of the hull. Upon completion of this transect, Serial 2 ended.

The first transect of Serial 3 (*Petrel* dive no. 90) began at the stern and moved along *AE1*'s starboard side, with particular emphasis placed on capturing still and video imagery of the submarine's lower hull where it meets the seabed. This was done for the explicit purpose of acquiring greater detail at the interface between the underside of *AE1*'s lower hull and seabed, which in turn would contribute to the accuracy and completeness of the 3D model. As the ROV approached the debris field, a 'zigzag' pattern was adopted whereby the ROV would approach the hull, then pull away to thoroughly document the extent of the adjacent debris field. As the ROV approached the midships area, the starboard side of the fin was imaged and the bridge telegraph was observed attached to the top of the fin just forward of the aft periscope. The manipulator arm camera was then deployed in an effort to obtain close-up imagery of the telegraph and determine the setting indicated by its dials. With the telegraph documented, the ROV continued along the starboard side of the hull towards the bow.

At the bow, the ROV's manipulator arm camera was once again employed in an attempt to determine whether the sluice valve in the forward torpedo tube was open or shut. Because the bow torpedo tube cap was only partially open, the manipulator arm could only be inserted a short distance inside the tube, and this ultimately proved insufficient to adequately illuminate its interior and observe the position of the sluice valve. The ROV then performed a second transect down the starboard side at the level where the submarine's surviving casing meets the pressure hull and surviving starboard ballast tanks. Serial 3 concluded at the engine room access port, and the manipulator arm camera was deployed to examine the interior of this space. A copper alloy handwheel was observed, but nothing else of note.

Serial 4 (*Petrel* dive no. 91) commenced with close-range imaging of *AE1*'s stern section. Particular emphasis was placed on capturing the underside of the aft hydroplanes and the broken skeg and rudder assembly that is now disarticulated and lying beneath the stern and propellers (these areas were imaged during the previous day's dive(s) but were partially obscured by one of the other cameras mounted on the ROV). Once these areas were imaged, the ROV proceeded towards the bow along the submarine's starboard side but was elevated to a slightly higher altitude than occurred during Serial 3 so that the photogrammetry camera could be tilted down to capture the starboard hull from overhead. During this transect, what appears to be the base of the wireless telegraphy mast was located just forward of the collapsed fin. In addition, further inspection of what remains of the forward end of the forward torpedo room revealed the presence of what appears to be the compressed air cylinder for the forward torpedo tube, and part of a third copper alloy handwheel that is just visible above the sediment. Additional fragments of a ceramic chamber-pot first observed during Serial 1 were noted as well; the entire ceramic assemblage comprises five visible sherds, two of which are quite large but mostly buried beneath sediment. Upon completion of the starboard transect, the ROV embarked on a second transect along *AE1*'s port side (moving from stern to bow), with occasional pauses to obtain close-order imagery of superstructure and other prominent features.

Close-order survey was conducted around *AE1*'s fin and resulted in the discovery and positive identification of the base of the submarine's wireless telegraphy antenna base. A long iron shaft located within the collapsed pressure hull forward of this area was subsequently identified as the wireless telegraphy antenna stump (Figure 2). Imaging of the area around the forward periscope revealed that the fin has shifted forward and downwards, either as a result of – or resulting in – fragmentation of hull plating lying immediately beneath the forward periscope. Comparison with drop-camera and AUV photomosaic imagery from December 2017 shows a clear difference in the orientation of the fin relative to the surrounding hull, and strongly suggests the fin has collapsed further into the remains of the pressure hull due to the latter's rate of corrosion/deterioration. While imaging this same area, the ROV conducted close inspection of the submarine's ventilation valve, as well as the four battery ventilation valves located immediately adjacent to it.

A third transect proceeded along the submarine's port side (moving from bow to stern) and imaged the interface between the lower pressure hull and seabed. The 'zigzag' pattern utilised during Serial 3 to image the adjacent debris field was employed again to good effect. Once this task was accomplished, the ROV made additional passes along the port and starboard sides of the hull with the goal of filling in gaps in the photographic record. Beginning with Serial 2, Andrew Woods of Curtin University's HIVE generated preliminary 3D digital models of the stern, port side torpedo tube and upper hull around the fin. These models were employed to find gaps in the image data and guided subsequent imaging strategy and ROV operations.

Towards the end of the survey, the project team requested that the manipulator arm camera inspect small openings in the pressure hull that could not be adequately imaged with the regular ROV camera array. Two holes in the aft pressure hull were inspected in this manner: a copper alloy handwheel was observed through the first hole, and imagery revealed that it is attached to the upper hull just inside the opening. The space viewed through the latter hull breach in the aft torpedo compartment contained indeterminate structure that may include one of *AE1*'s stowed spare torpedoes. Of particular interest was the relative lack of sediment deposition in either area, which suggests that the pressure hull where it remains intact and effectively sealed has prevented the ingress of sediment from outside. While it was difficult to image these areas because of the confined nature of the openings, the few artefacts or elements of hull structure/machinery/fittings observed appeared to be in a relatively good state of preservation and were not as heavily corroded as material in the sections of hull that were breached/open to the sea. Serial 4 ended upon completion of this task.

The project's final dive (Serial 5; *Petrel* dive no. 92) primarily comprised installation of a commemorative set of national flags on the shipwreck site near the port bow. Flags included those of the nations that lost crewmen aboard *AE1*: Australia, New Zealand and the United Kingdom. With this task accomplished, the ROV made a few transects over and around the aft end of *AE1*'s fin so that the scant framework structure remaining in this area could be imaged. Serial 5 concluded once this task was completed.

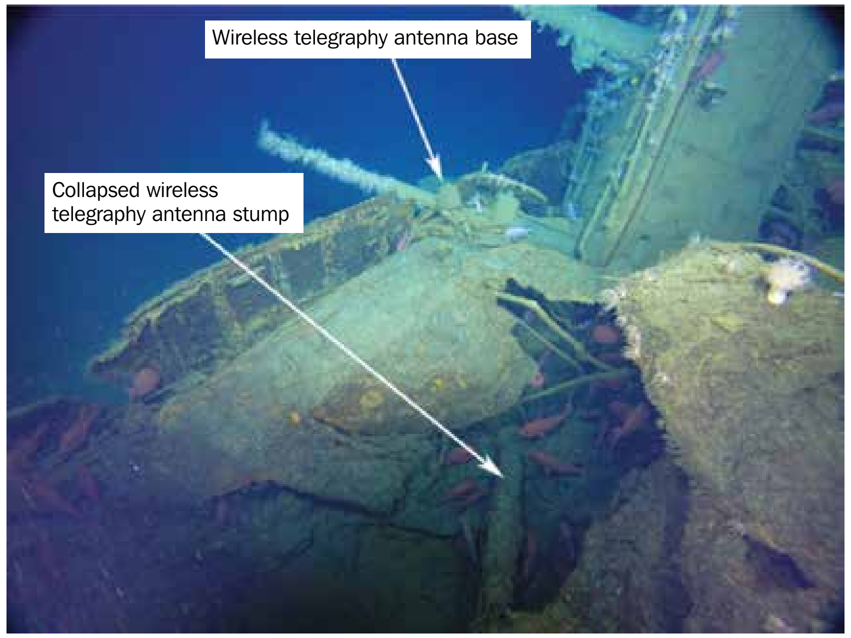

Figure 2 – Remnants of *AE1*'s devastated control room, showing the locations of the collapsed wireless telegraphy antenna and its base, which remains *in situ*. The collapsed fin is visible in the background. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

3 Site appearance and general condition

AE1's overall appearance is shown in the interim photogrammetric full 3D model developed by Curtin University's HIVE (Figure 3). *AE1* is resting upright on a largely flat, featureless sand/silt 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 as a consequence of a catastrophic implosion event. Specific activity areas within *AE1* devastated by implosion damage include the control room and forward torpedo compartment. Structural failure of the forward pressure hull has resulted in the fin collapsing and toppling forward into the remnants of the control room.

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 *AE1*'s side-mounted '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, a more likely explanation is that they snapped off as *AE1* fell onto its keel after initially striking the seabed stern first and pitching forward. *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.

Figure 3 – Interim 3D photogrammetric model of *AE1*. The submarine's port side is shown, and the bow is at image left. 3D models by Curtin University from images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Curtin University

It is worth noting that deterioration and disarticulation of specific hull components may also have been facilitated by tectonic activity around New Britain and the Duke of York Islands. 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). 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.

4 Survey results

The ROV examination of *AE1* confirmed some preliminary observations made during the December 2017 expedition, but also offered a number of 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. Observations gleaned from the 2018 survey that relate to *AE1*'s surviving ship's architecture and associated material culture are addressed below.

4.1 Torpedo tubes

AE1's aft torpedo tube stern cap was observed in the fully open position – the necessary first step to launch a torpedo. However, the torpedo is protected from sea pressure by a second sluice valve, which was confirmed shut. This indicates the tube was not fully prepared for firing. The stern cap was opened via a manually operated handwheel and the effort necessary to perform this function clearly indicates it was done intentionally. The reason why the cap is open remains unclear; it may have been opened as part of a training exercise but could also have been a preparatory step to increase the speed with which a torpedo could be launched if *AE1* came under attack.

The cap for the forward torpedo tube is slightly ajar, but not in the fully open position. 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 accident resulting in *AE1*'s loss occurred. The forward torpedo tube's rear door is visible in the forward torpedo compartment and appears to be manufactured from copper alloy. Three bolt-and-wingnut assemblies used to hold the rear door shut are visible but are not in position and tightened down. The reason for this is unclear, but there is no indication that the torpedo tube was in use when the accident occurred. Indeed, the more likely explanation is that the bolt-and-wingnut assemblies were dislodged either during the implosion event, or from the force of *AE1* striking the seabed (see detailed discussion in Annex C, page 59). The doors for both amidships torpedo tubes, which were positioned athwartships across *AE1*'s central pressure hull, and ballast tanks are in the closed position.

4.2 Rudder and skeg

AE1's rudder is unshipped, while the skeg (a tapering, sternward projection attached to the after end of the submarine's keel that served as a mounting for the rudder and helped stabilise and protect it) has been broken away near its attachment point with the hull. Both are lying flat on the seabed immediately beneath the port side stern (Figure 4). By contrast, neither of the submarine's propellers appears to be damaged apart from a nick in one of the blades in the starboard propeller. This flaw is understood to have pre-dated *AE1*'s loss. Taken together, these lines of evidence indicate *AE1* struck the seabed stern first, but at a shallow enough angle that the rudder and skeg were broken away while the propellers remained unaffected.

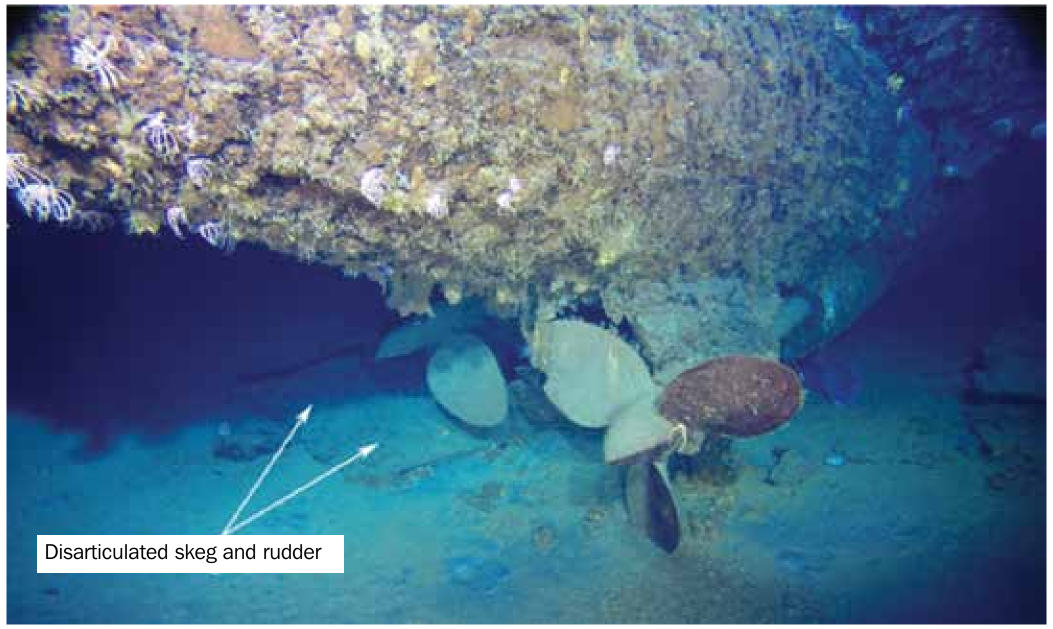

Figure 4 – *AE1*'s disarticulated skeg and rudder are lying flat on the seabed beneath the stern. Note the relatively undamaged condition of the propellers. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

4.3 Hydroplanes and hydroplane guards

AE1's hydroplanes were used to adjust the submarine's depth and trim angle (up and down orientation) while submerged. During the 2018 survey, the fore and aft hydroplanes were confirmed to be in the 'hard-to-rise' position, which indicates the crew desperately attempted to recover from a dive and return to the surface. Damage is present on the forward edges of the aft hydroplanes, but absent on the forward hydroplanes. The reason for this damage is presently unclear but is most likely a result of corrosion. Large rusticles were noted growing from the forward edges of the aft hydroplanes, as well as the iron 'A' brackets that attached each propeller shaft to the underside of the stern. The close proximity of rusticles to areas of significant damage along the forward edge of each aft hydroplane suggests the two may be directly associated. A thorough treatment of corrosion issues as they relate to *AE1* appears in Annex D (see page 102).

Each of *AE1*'s hydroplanes was equipped with a guard. These fin-shaped steel features were positioned immediately forward of their corresponding hydroplane and designed to deflect potential sources of fouling, such as line or seaweed, that could render it inoperable. All four of *AE1*'s guards are lying flat on the seabed, just beneath their respective hydroplanes. The attachment point for the aft port side hydroplane guard is the most clearly defined on the shipwreck site and exhibits a largely flat and straight break where the guard separated and fell away. Close inspection of its exposed interior surface revealed what appears to be iron-impregnated wood and suggests timber may have been used as a spacer between the hydroplane guard and pressure hull. The presence of wood spacers may have weakened the attachment point between the hydroplane guards and hull and could account for why each guard is located on the seabed immediately below its respective *in situ* position and appears to have broken away from the hull. The sudden downward movement of *AE1*'s hull falling to the seabed after striking stern first could have generated enough force to snap the hydroplane guards off at their attachment points and account for their locations relative to the hull.

4.4 Fin and conning tower

Damage to *AE1*'s fin and the pressure hull surrounding it is much more catastrophic than was originally evident from the drop-camera and AUV footage acquired in December 2017. The fin has collapsed forward, but is oriented almost 90 degrees from vertical, with the forward periscope resting on what remains of the intact forward pressure hull. The attachment points for the fin were probably partially dislodged by the implosion event. The submarine's impact with the seabed then caused the fin to begin 'toppling' into the implosion area. This process has since continued but at a slower pace, as corrosion of the surviving pressure hull caused structural failure that has allowed the fin to settle further into what remains of *AE1*'s control room. As mentioned previously, the fin has settled an additional 0.5 metres in the five-month period between *AE1*'s discovery in December 2017 and the ROV examination in April 2018.

The upper conning tower hatch is closed, and close inspection of the upper helm revealed it is manufactured from copper alloy and affixed to the periscope standard with a large copper alloy nut (presumably attached to a threaded bolt). The upper helm also has a copper alloy steering handle attached to it. Images of the helm within the conning tower revealed that it too is manufactured from copper alloy but affixed differently, either by a copper alloy bolt that has been peened over the hub of the wheel, or one that is held on with a nut (or some other means) within or on the other side of the periscope standard. Unlike the upper helm, it does not have a steering handle.

Close inspection of the submarine's ventilation valve – which was positioned in the after section of the fin and is currently exposed as a consequence of the fin toppling forward and dislodging the valve's associated ventilation trunking – revealed that the edge of its sluice plate is positioned across the valve so that it was ~60% open (Figure 5). Given that the ventilation valve was not completely shut, it would have served as a point of ingress for water while the submarine was submerged, and likely was the primary contributing factor to its loss. The ventilation valve's mechanism, and its hypothesised role in *AE1*'s loss, are discussed in greater detail in Annex C (see page 59).

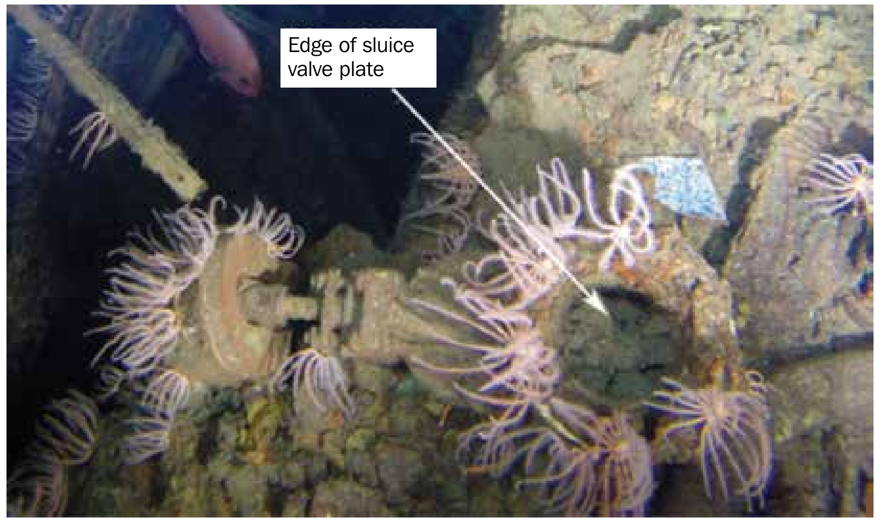

Figure 5 – *AE1*'s open ventilation valve; the arrow indicates the edge of the valve's sluice plate. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

4.5 Pressure hull, hull casing and ballast tanks

Damage to *AE1*'s forward pressure hull from implosion is clearly evident in the 2018 ROV footage, still imagery, and 3D model (see Figure 3). 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 handwheels 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 (Figure 6). Either as a consequence of the implosion or *AE1* striking the seabed (or both), the hull plating at Frame 70 has failed and effectively broken the submarine's back (Figure 7). 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.

A line of batteries within the forward battery bank are clearly evident and indicate the timber deck structure above them (as well as the control room and other activity spaces above it) was either completely destroyed in the implosion event or has subsequently succumbed to natural deterioration. An interesting counterpoint is a section of what appears to be part of the timber lining for the battery tank still *in situ* along the port side of the pressure hull in this area (Figure 8). Archival records indicate the tank lining was manufactured from teak, a wood that is durable, rot-resistant, and typically survives on historic shipwreck sites in preservative environments.

The forward hull casing immediately aft of the bow appears to have collapsed, and may obscure *AE1*'s anchor, which was not observed anywhere on the site. The aforementioned damage is located in the area where the anchor would have been stowed when not in use, which reinforces the theory. Similarly, sections of the aft casing have also completely collapsed and disappeared. The reason for its absence is unclear but is likely associated with corrosion of its metal fabric, which was manufactured of relatively lighter-grade steel. By contrast, both the forward and aft firing tanks (which held compressed air to fire the torpedo in the aft torpedo tube) are completely intact. The reason for this is also unclear but could be related to the retention of their respective charges of compressed air, which could have prevented them from imploding when the submarine reached crush depth.

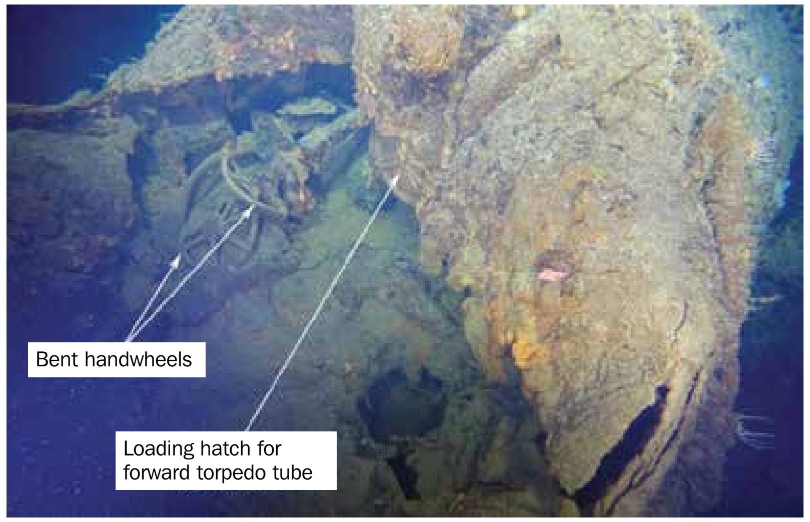

Figure 6 – *AE1*'s devastated forward torpedo compartment, showing folded hull plating and the damage to handwheels wrought by the implosion event. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

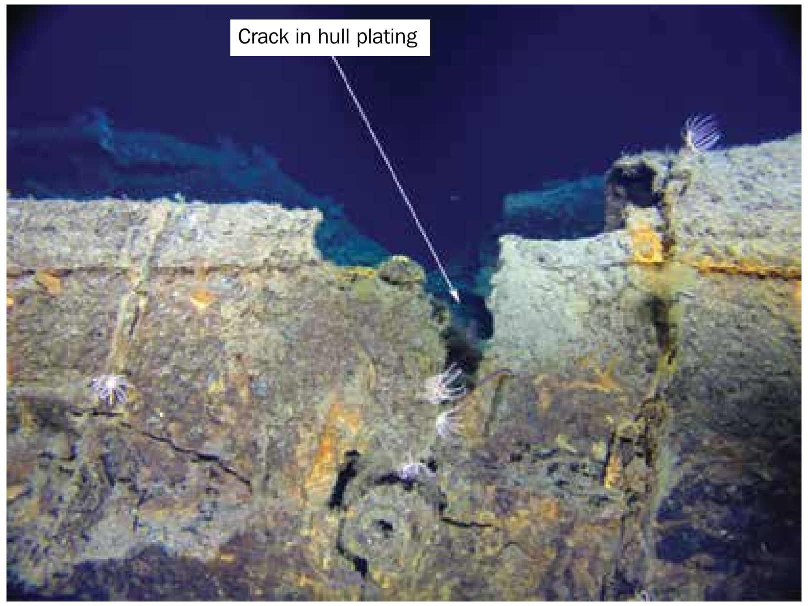

Figure 7 – Vertical fissure in *AE1*'s port side pressure hull at Frame 70. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Significant damage and collapse have occurred to the majority of *AE1*'s 'saddle' ballast tanks. As has been noted for the forward and after hull casing, this may be a consequence of the presence of lighter-grade iron/steel in these areas, differential corrosion, or a combination thereof. Circular holes in the port ballast tanks identified during the 2017 survey were thoroughly scrutinised during the ROV examination and have been ruled out as projectile damage. They instead appear to be the result of corrosion and natural deterioration.

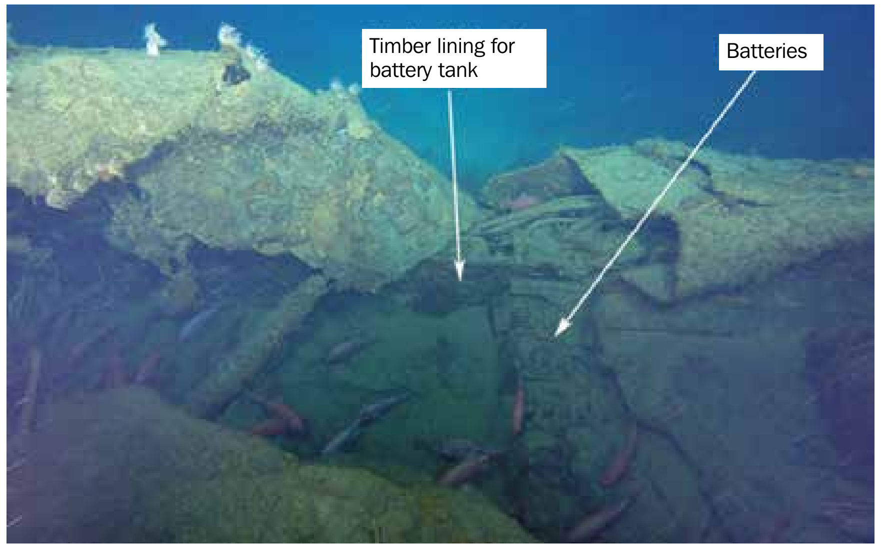

Figure 8 – Remnants of the timber lining for one of *AE1*'s battery tanks, located within the remains of the control room along the submarine's starboard interior hull.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

4.6 Small artefacts

Five fragments of a basin-shaped ceramic vessel were discovered in the approximate location of the aft end of *AE1*'s fin and appear to be remnants of either a porcelain chamber-pot or the basin from a purpose-made ship's head (Figure 9). One fragment clearly has a blue-and-white floral motif and appears to be transfer-printed whiteware. Efforts are ongoing to identify the specific transfer-printed pattern on these fragments and determine the date range, origin and purpose of the ceramic vessel. While it is possible the ceramic fragments could be intrusive, the fact that there are multiple examples relatively close to one another, and that at least one is pinned beneath hardware from the submarine, lends credence to its being associated directly with *AE1*. If this is the case, the presence of the fragments also strongly suggests the fin did not completely dislodge until the submarine struck the seabed, as relatively light artefacts of this type would almost certainly have been removed from context and dispersed into the water column.

The only other small finds observed during the 2018 survey were an intact glass bottle, the neck (with what appears to be an applied lip) and base of a broken glass bottle, and what appears to be the heel from a leather shoe or boot (Figure 10). All four artefacts are located within the remnants of *AE1*'s control room, lying atop a surviving bank of batteries in the approximate centre of the pressure hull. The intact bottle is manufactured from clear glass and is cylindrical in form, with a short shoulder and neck. An object that appears to be a stopper is visible in the bottle's mouth, and an opaque, white-coloured substance that may represent the bottle's original contents is pooled near the base. No markings indicative of contents or manufacturer are visible, although much of the bottle is covered in marine growth.

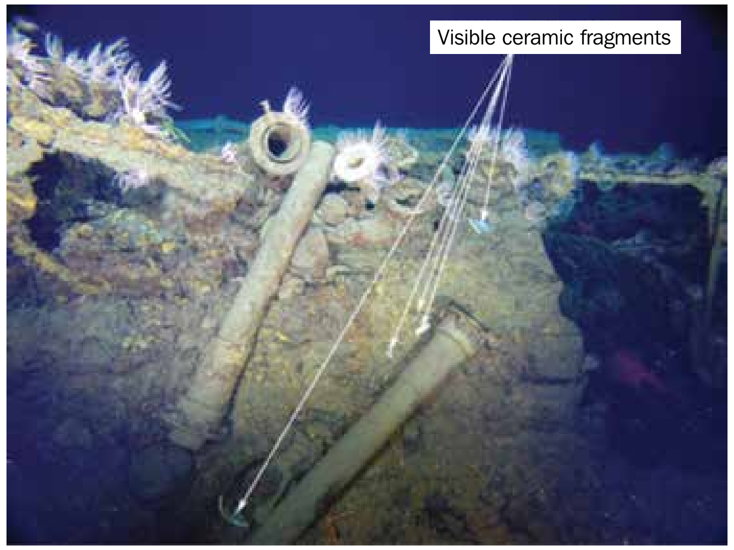

Figure 9 – Upper surface of *AE1*'s pressure hull at its junction with the after end of the fin, showing five ceramic fragments believed to have once comprised one of the submarine's heads. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

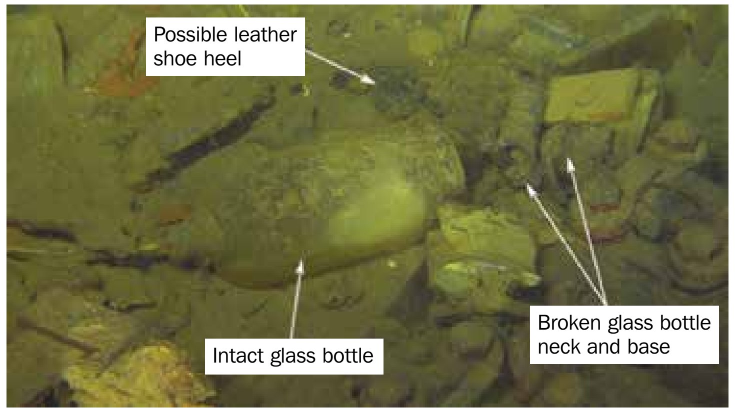

Figure 10 – Small finds located within *AE1*'s control room, including an intact glass bottle, two bottle fragments and what appears to be a leather shoe or boot heel. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Two fragments of another glass bottle are located immediately adjacent to the first and comprise a complete neck with rim and part of the base. In terms of appearance, the neck and rim most closely approximate a spirit (beer or wine) bottle. The glass does not appear to be transparent, although its colour is difficult to discern due to adhering marine growth and available image resolution (the bottle fragments and other artefacts were only captured by one of the ROV's standard-definition video cameras). As with the intact bottle, no diagnostic markings are visible on either fragment. What appears to be a leather shoe or boot heel is located a short distance forward of the bottle neck. It is roughly triangular in shape, brownish-black in colour, and appears to be positioned with its upper (interior) surface facing upwards. The glass artefacts and possible heel were located in the approximate location of the officers' wardroom lockers and may represent clothing and personal belongings that were stowed at the time of *AE1*'s loss.

4.7 Human remains

No human remains or personal effects (save for the glass bottles and leather shoe heel mentioned above) were noted, either within the exposed portions of the submarine's hull or the surrounding debris field. However, a small number of objects in the debris field warranted close inspection, as they had the outward appearance of skeletal material. ROV imagery of these objects ultimately revealed them to be either sections of wooden branches, or complete or partial coconut husks.

Although human remains were not observed during the 2018 survey, there is strong likelihood that skeletal remnants could – and indeed probably have – survived in areas of the submarine where there are substantial sediment deposits. This is evidenced by the presence of surviving organic material, such as the timber battery tank lining and possible leather shoe heel, within remnants of the forward torpedo room – an area devastated by implosion and completely open to the sea. Using this as a benchmark, it is safe to assume that *AE1*'s after section – which is enclosed, has largely retained its structural integrity, and was not as catastrophically affected by implosion as the forward section – may contain remains of crewmen who were stationed there and could have been overcome in the early stages of the sinking. If skeletal remains are still present in these areas, they are probably buried (in whole or in part) in accumulated sediment.

The vast majority of human remains in *AE1*'s forward section were likely destroyed by the implosion event, and/or subsequently washed away and dispersed by the associated inrush of water. Those remains not destroyed or removed by the implosion may well have been consumed by marine organisms, given that what remains of the forward section is largely open to the sea. However, some bodies (or more likely, parts thereof) could have become trapped among sections of the hull and/or machinery and may have been buried and preserved beneath subsequent accretions of sediment.

5 Conclusion

The 2018 ROV examination and photogrammetric survey of *AE1* proved immensely successful. In addition to acquiring detailed still and video imagery, the effort also resulted in production of an interim 3D digital model of the entire shipwreck site. This in turn has facilitated 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 that has resulted from the break near Frame 70 – that otherwise may have gone unnoticed. A significantly more detailed high-resolution photogrammetric model of *AE1* is currently being generated at HIVE and is expected to offer even greater opportunities for analysis, interpretation and – eventually – exhibition. Lessons learned during the 2015 photogrammetric survey of HMAS *Sydney II* and HSK *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 span of 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 our understanding of the sequence of events that led to *AE1*'s loss. For example, we now know that the submarine's bow and stern torpedo tube caps were either partially or fully open, and that this appears to have been an intentional act. Why the caps were open, and whether they contributed in some manner to the loss, will likely never be known. Similarly, the mystery of why the ventilation valve was partially open will probably never be solved, but it is fair to say that it was one of the root causes of the submarine's demise once it began to submerge on what would be its last dive. Despite efforts by the crew to recover – as evidenced by the positions of the hydroplanes – *AE1* was overwhelmed by the inflow of water through the ventilation valve and began to sink by the stern. 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 – likely already weakened structurally during the implosion – began to topple forward into the control room.

Going forward, the imagery and 3D model generated as a result of 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 natural decline, as differential corrosion – and contributing factors such as local seismic activity – takes its toll on the submarine's constituent parts. The photogrammetric model now serves as an accurate representation of *AE1*'s state of preservation when discovered and can be the benchmark by 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 outcomes may be explored and developed to share *AE1*'s story.

Annex C
Engineering observations and the most likely cause of the loss of HMAS *AE1*

Captain Roger Turner CEng FIMarEST RN

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1 Introduction

Australia's first submarine, HMAS *AE1*, was lost with all hands while on patrol to the east of the Duke of York Islands, PNG, on 14 September 1914. The wreck lay undiscovered for 103 years until it was successfully located and positively identified by an expedition conducted by MV *Fugro Equator* on 20 December 2017. Using AUV and drop camera technology a range of images was then obtained which allowed some initial observations, deductions and conclusions to be drawn regarding the condition of the wreck and the possible cause of its loss. Those findings have been published[1] in what here will be referred to as the Fugro Report (FR).

The Fugro expedition was 100% successful in meeting its aims; however, neither the quality of the images nor their extent was sufficient to allow a detailed analysis or to provide the important baseline survey to establish the current condition of the wreck. Seeking to improve on the knowledge gained of the wreck, a second expedition was conducted by the RV *Petrel* in April 2018. Using a state-of-the-art ROV operated by *Petrel*'s highly capable team, extensive and detailed imagery of stunning quality was obtained of the wreck from all aspects. That imagery has provided a lasting record of the condition of the wreck as at the date of the survey. It has also provided the opportunity for a more detailed analysis of the state of the submarine's systems at the time of its loss.

2 Aim

It is the aim of this paper to summarise the observations made of the wreck by the *Petrel* expedition and where possible draw conclusions as to what that evidence implies with regard to the circumstances under which the submarine was lost. For completeness of the evidence some of the Fugro Report will be repeated; however, to avoid unnecessary repetition, references will be made to that report. Inevitably the evidence is not always conclusive; hence conclusions are, where appropriate, caveated as being probable or possible. It is made clear where a suggested conclusion has required speculation.

3 E-Class characteristics

The E-Class operating depth was 30.5 metres (100 feet), though they were known to have gone to depths greater than 61 metres (200 feet). The build specification[2] for the submarines requires the depth-dependent systems (including the ventilation sluice valves) to be tested to 100 psi (61 metres depth). An exception to this was the bilge pump, which was tested to 200 psi. This would, theoretically, allow it to operate down to 120 metres. The high-pressure air and ballast blowing system operated at 2500 psi and the system was designed to achieve a pressure of not less than 5 psi above the external pressure when all the tanks were being blown at once.

Crush depth (sometimes called collapse depth) is the submerged depth at which a submarine's hull is expected to collapse due to the pressure applied externally by seawater. In later submarines the crush depth could be calculated with some accuracy. However, the E-Class had a riveted hull construction which, because of the inconsistent manner in which the rivets are fitted and hence would fail, makes it hard to estimate what the crush depth would be. A conservative band of expectation would be that the hull would begin to fail below 90–120 metres (300–400 feet).

4 HMAS *AE1*, 14 September 1914

AE1 sailed for her patrol on 14 September 1914, meeting her escort HMS *Parramatta*, separating from her and then rendezvousing off Duke of York Island in the early afternoon. They then parted a second time. *Parramatta*'s log essentially establishes the last known position of *AE1*. The details of these events (where known) are recorded in the Fugro Report.

On that day *AE1* had a defective starboard main engine clutch which prevented the clutch from disengaging. Under those circumstances the submarine could propel as normal on the surface (employing both diesel engines) but, being unable to disengage the clutch, would be unable to operate the starboard main (electric) motor. This would mean the starboard shaft could not be used when dived or for astern power on the surface. This would be significant in terms of provision of propulsive power in response to a dived emergency.

5 Observations made from the *Fugro* and *Petrel* search imagery

Examination of the wreck imagery (*Fugro* and *Petrel*) reveals the following points:

- The wreck is lying on a near-level rock seabed at a depth of over 300 metres.
- There is little sedimentation visible on the seabed – implying there was nothing to soften the impact of the grounding into which the wreck has settled.
- The bow and stern keel sections are visible where they rise clear of the seabed. The central keel section is not visible and may have been crushed or compressed.
- The forward section shows a list to starboard of 2–3 degrees. The stern section is near upright or slightly to port.
- Ship's head is at 235 degrees T (MBES – multibeam echo sounder – data from Fugro Report) – on course consistent with her return to Rabaul.
- The bow casing is dislodged with the 'forecastle' slumped partially over the bow cap and some plating apparently on the seabed to starboard.
- The bow cap is opened by ~25 degrees.
- The structure beneath the forward tube (bow, forefoot and supporting structure) is intact, with no sign of impact damage. This section appears to be clear of the seabed.
- The foreplanes are set hard (30 degrees) to rise.
- The forward planeguards are lying on the seabed close to below their mounted position.
- The forward planeguard securing points appear to have the same degree of corrosion/concretion/marine growth as the surrounding pressure hull.
- The forward torpedo compartment has suffered a complete implosion, with the pressure hull folded flat to the point of failure with sections of the hull now lying on what was the deck of the forward torpedo compartment.
- The implosion has exposed the forends (Frame 79 to 85) such that key features now visible are:
  - Forward tube rear door with 4, 8 and 11 o'clock butterfly clips released
  - Forward tube bow cap operating handwheel (collapsed) and sluice valve operating handwheel
  - The (badly deteriorated) forward reload torpedo
  - Foreplanes operating rod gearing

  - Forward tube firing HP air bottles
  - Forward torpedo loading hatch operating handwheel
  - Forward bilge pump outlet valve.
- The pressure hull implosion has not been so catastrophic in way of the forends bulkhead, though still badly 'crumpled'.
- The forward windlass is visible on top of the damaged pressure hull.
- The main implosion area extends between Frames 55 and 72.
- The capstan winch drum is exposed within the damage area at c. Frame 72.
- A section (Frames 62 to 72) is open, revealing the interior of the control room area (vacant).
- A section of the main battery is visible at c. Frame 70 – probably row 5 of the battery cells.
- One cell of row 6 – the outermost (starboard side) cell – is visible under the folded pressure hull.
- Some pieces of soft material are on that cell – possibly remains of the canvas deck cover.
- The control room teak deck and canvas cover are near entirely missing from this area.
- The teak lining of the port side of the battery tank is visible from Frames 65–70. The battery cells (rows 6 and aft) are not visible where they should be in this area.
- A crack is visible in the pressure hull at Frame 70 on both sides of the hull – the pressure hull from here forward has 'slumped' by 2–3 degrees.
- A broken glass bottle neck is visible lying on row 5 of the battery cells, together with a glass cylinder – probably a screw-top bottle containing a yellowish liquid which is heavier than seawater.
- Nearby is a well-preserved corner join of (probably) teak – probably a piece of the wardroom furniture.
- The upper part of the WT antenna stump is lying in the implosion area. Its internal insulation and cabling are visible in a broken section.
- The bottom of the WT antenna stump is in place on a (comparatively) undamaged section of pressure hull.
- The fin has toppled forward by ~70 degrees and to starboard by ~30 degrees.
- In toppling it has torn the conning tower securing flange to expose the conning tower wheel and access ladder.
- The angle of the fin has changed in the interim between the *Fugro* and the *Petrel* surveys, the forward edge of the fin being some 0.5 metres lower than it was in the first survey.
- The fin guardrails and stanchions are stowed for diving.
- The upper conning tower hatch is shut.
- The bridge wheel (which can be removed to the conning tower) is in place.
- The implosion area to port and aft of the fin is partially visible, revealing part of the after end of the control room and specifically:
  - Handwheels (probably 3 and 4 main ballast tank (MBT) Kingston valves)
  - Sections of small-bore pipework and fittings.
- There is much damage to 3 and 4 MB tanks, with the plating and frames lying on the seabed.
- Both periscopes are in the raised position, although the after periscope appears shorter than it should be – probably the consequence of the fin having tilted forward.
- The after sections of the fin plating are missing and cannot be located among the seabed debris. The remaining fin plating is in (seemingly) good condition, with features (navigation lights, viewing scuttles, etc) clearly visible.

- The inside of the fin (aft of the conning tower) is clearly visible, revealing:
    - The access ladder
    - Conning tower upper hatch operating lever and counterbalance and
    - Four-way junction box
    - Lower section of the after periscope
    - Steering rod gearing
    - Bridge telegraph operating rod gearing.
- The badly damaged pressure hull below the fin is visible, revealing a hole where the lower conning tower hatch should be. While the hole location and dimensions correspond with the hatch, the hatch coaming and the hatch itself are not visible.
- The conning tower lower section appears to be missing.
- The saddle tanks in way of the beam tubes are largely intact, with the beam tube outer doors clearly visible and shut.
- The damage has exposed the main ballast pump/blower outlets and the ballast tank Kingston valve operating rod gearing.
- The pressure hull is largely intact aft of Frame 55.
- Three of the five ventilation trunks have fallen from the fin and are lying adjacent to their original positions. The fourth and fifth have not been located.
- The ventilation trunks which terminated inside of the fin have been fitted with mushroom splash guards as opposed to the goosenecks shown in the drawings.
- There are three blue and white ceramic shards lying on the pressure hull consistent with being part of a china toilet pot.
- The sluice of the forward-most ventilation valve (ship's ventilation supply hull valve) is visible and ~60% open.
- Three of the four battery ventilation hull valves are visible and (probably) shut. The fourth is obscured by the ventilation trunking.
- There are no signs of a WT mast.
- The forward beam tube firing tank is largely intact.
- The after beam tube firing tank has collapsed.
- The pressure hull aft of the fin is largely intact.
- Nos 5 and 7 MBT have collapsed onto the seabed.
- Nos 6 and 8 MBT are largely in place, though badly corroded.
- The regularly shaped hole in No. 6 MBT (seen fleetingly in the *Fugro* footage) is clearly the consequence of corrosion.
- There is a hole in the starboard pressure hull at Frame 42 offering a view into the senior sailors' mess. This provides a view of No. 7 main vent operating handwheel whose indicator suggests it is either fully open or fully shut.
- The engine room hatch derrick 'mast' is missing but may be lying on the saddle tank to port of the ER hatch.
- The derrick boom is missing but its two principal fittings are lying on the casing aft of the ER hatch. Coloured yellowish, they are probably made of a non-ferrous nickel alloy.
- The engine room hatch and casing cover are missing. The hatch is probably lying to port of the ER hatch opening, having been flipped to reveal the second strongback.
- One (the furthest aft of two) ER hatch strongbacks is still in place in the ER hatch opening.

- The casing aft of the ER hatch and over the exhaust tank is largely intact.
- One guardrail stanchion (port side of the exhaust tank) is still in place and erect – curious when the remainder are all folded in preparation for diving.
- The casing aft of the exhaust tank is largely missing.
- The exhaust tank discharge pipework is in place (though damaged), as is the exhaust overboard discharge pipework.
- The stern firing tank is largely in place.
- There is a hole in the pressure hull on the port side abreast the stern firing tank which affords a limited view into the after ends, providing glimpses of what are probably the torpedo tube and its reload. The rudder operating rod gearing is visible.
- Both afterplane guards have collapsed onto the seabed near to being under their mounted positions.
    - The port afterplane guard appears to have sheared, leaving its mounting flange in place on the hull.
    - The starboard afterplane guard has sheared, taking the flange with it.
    - Both mountings show corrosion/concretion/marine growth consistent with that of the adjacent pressure hull.
- There is a small (~150 x 20 centimetre) oblong area of lesser corrosion under and aft of the port planeguard mount consistent with being the seat of a galvanic protection mount.
- The afterplanes are set hard (30 degrees) to rise.
- The leading edges of both the afterplanes are badly corroded/eroded.
- The stern glands, 'A' brackets, propeller shafts and propellers are near intact.
- There is a substantial nick out of one blade of the starboard propeller.
- The rudder has become detached from below where its stock enters the pressure hull. It is lying on the seabed to port of its mounted position.
- The rudder skeg is broken off and is lying on the seabed close to the rudder.
- The underside of the stern torpedo tube shows no sign of impact.
- The stern torpedo tube outer door (stern cap) is fully open.
- The stern torpedo tube sluice valve is shut.
- The number of 'mystery discs' identified in the Fugro Report has expanded to include:
    - MD1 – Frame 65 – 6-holed blue disc lying on the pressure hull by the WT stump
    - MD2 – Frame 56 – 6-holed pale blue disc lying on port pressure hull/saddle tank join
    - MD3 – Frame 54 – 6-holed blue disc lying on starboard saddle tank abeam vent trunk
    - MD4 – Frame 75 – 6-holed grey disc lying on starboard pressure hull by windlass
    - MD5 – Frame 25 – 6-holed grey disc on ballast tank, appears to have moved
    - MD6 – Frame 79 – spiral wound gasket – only the asbestos spiral remains. Located on the pressure hull inside No. 2 main ballast tank.
    - MD1–5 appear to be of lead antimony alloy and are consistent with being gaskets from a high-pressure (seawater or air) system.
- In a very thorough examination of the imagery, nothing was seen that could be interpreted as being human remains.

It has been sought to record the principal features of interest. The impressively comprehensive ROV footage reveals other features too numerous to list comprehensively here but which may become the subject of future study.

The points noted are illustrated by the following images:

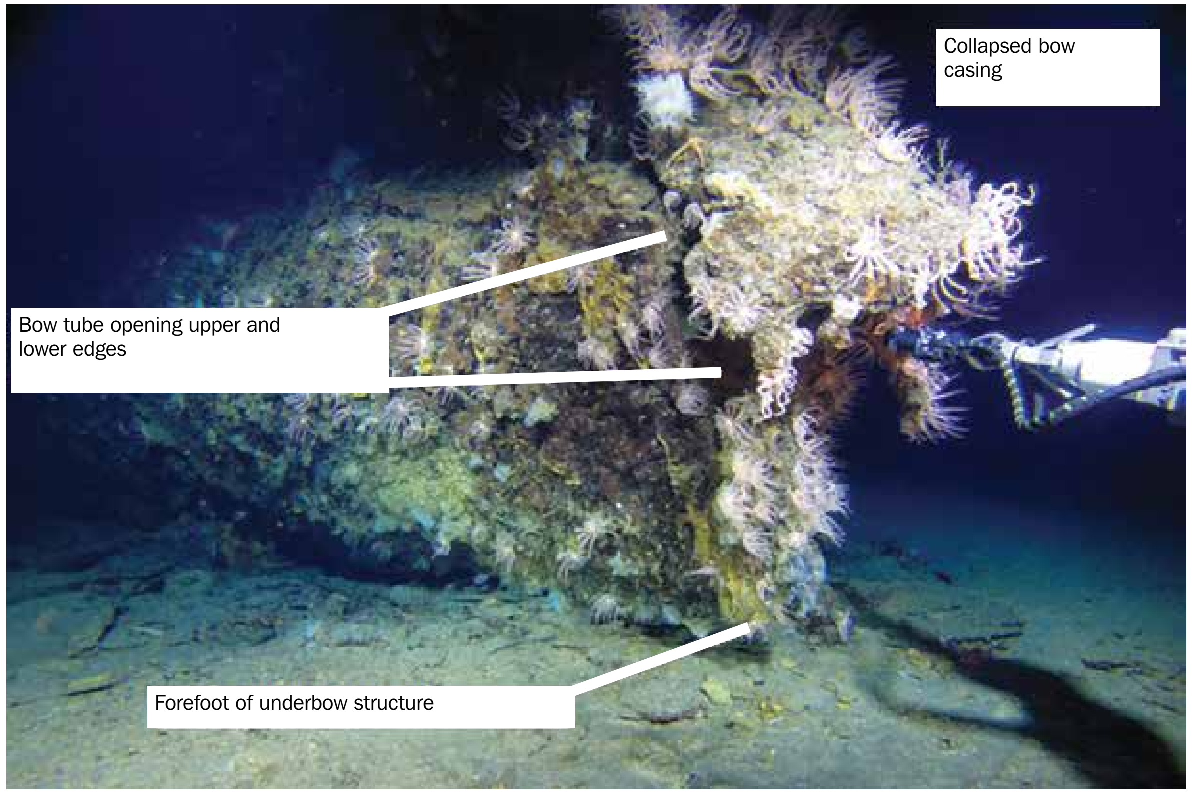

Figure 1 – Bow section.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

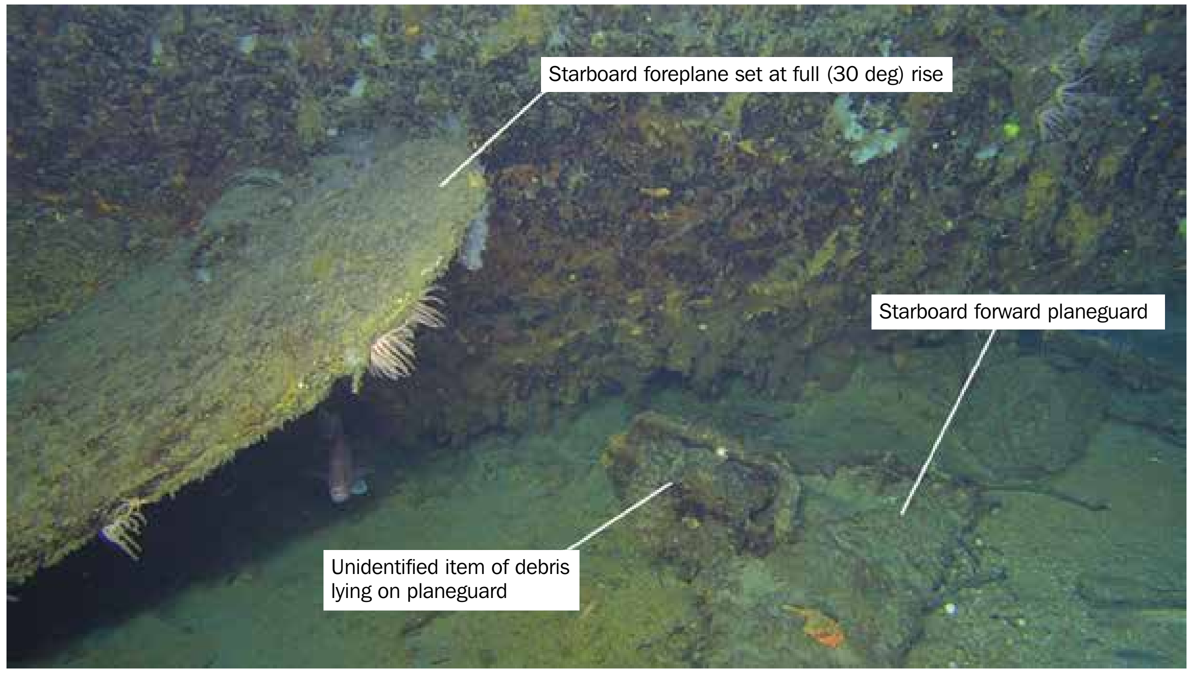

Figure 2 – Starboard foreplane and planeguard.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

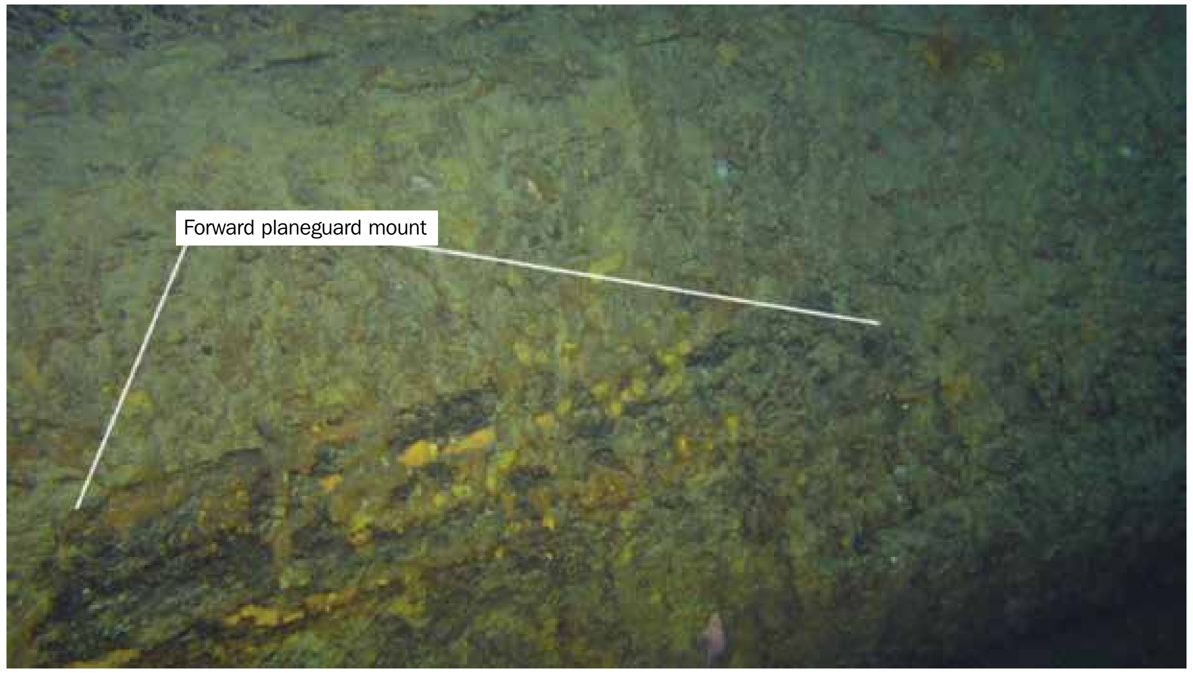

Figure 3 – Starboard forward planeguard mount.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

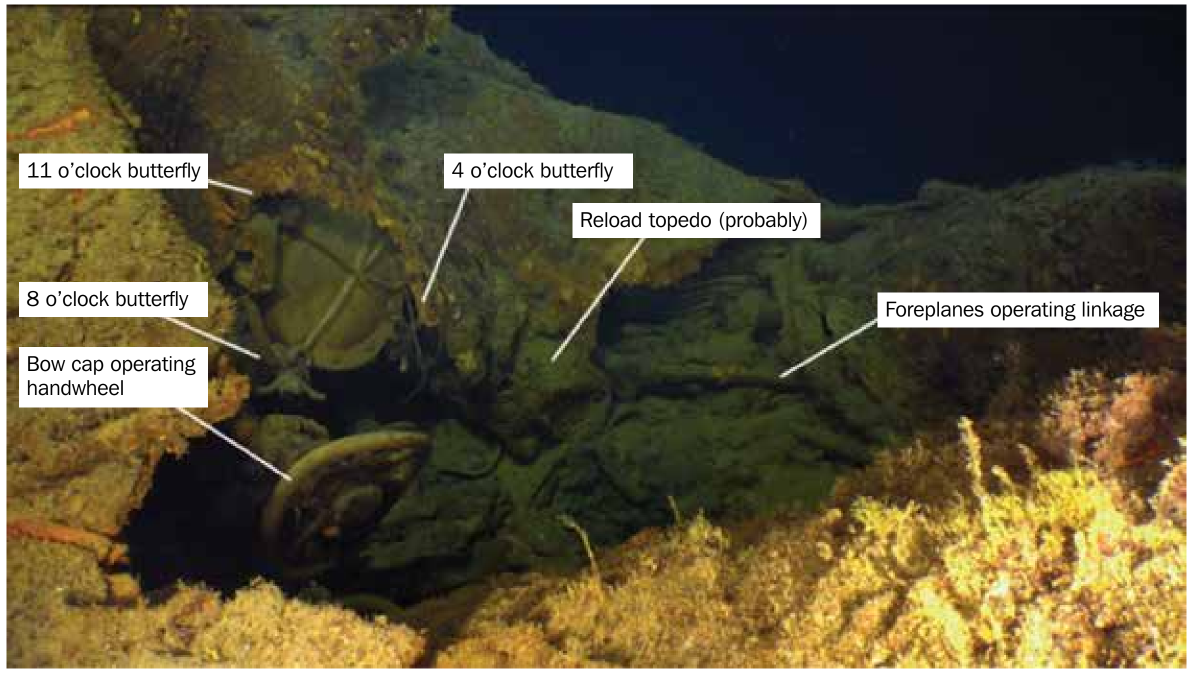

Figure 4 – Forward implosion area and forward tube rear door.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

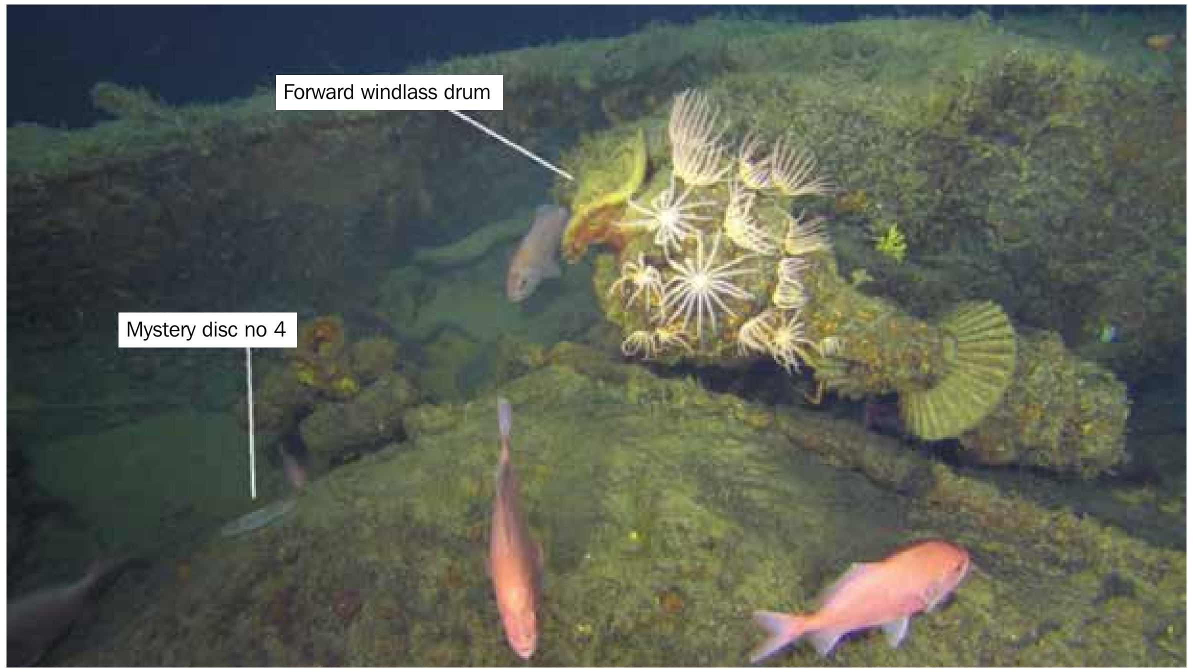

Figure 5 – Forward windlass.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

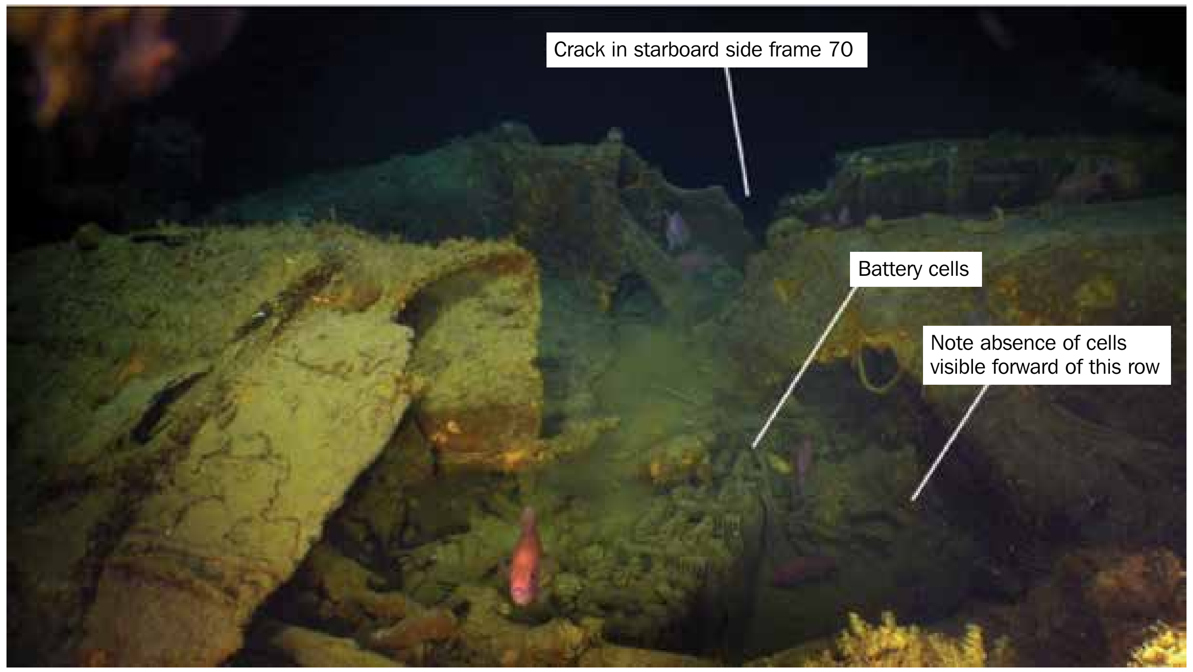

Figure 6 – Control room implosion area and Frame 70 crack in pressure hull.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

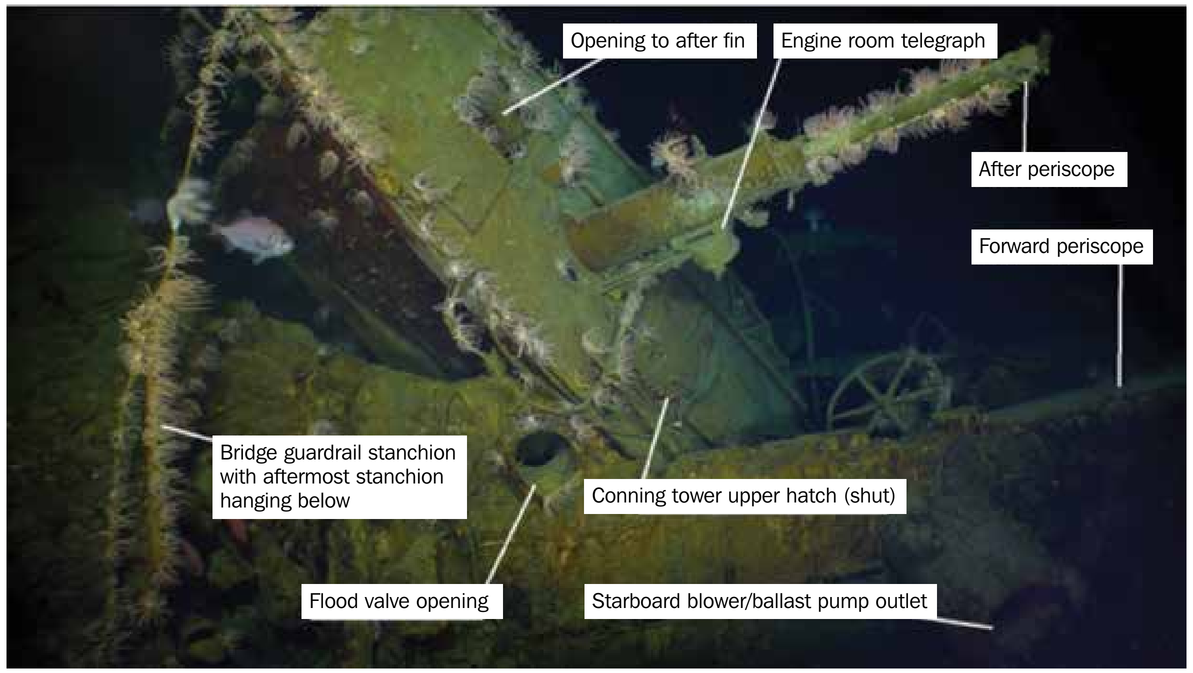

Figure 7 – Fin area from starboard.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

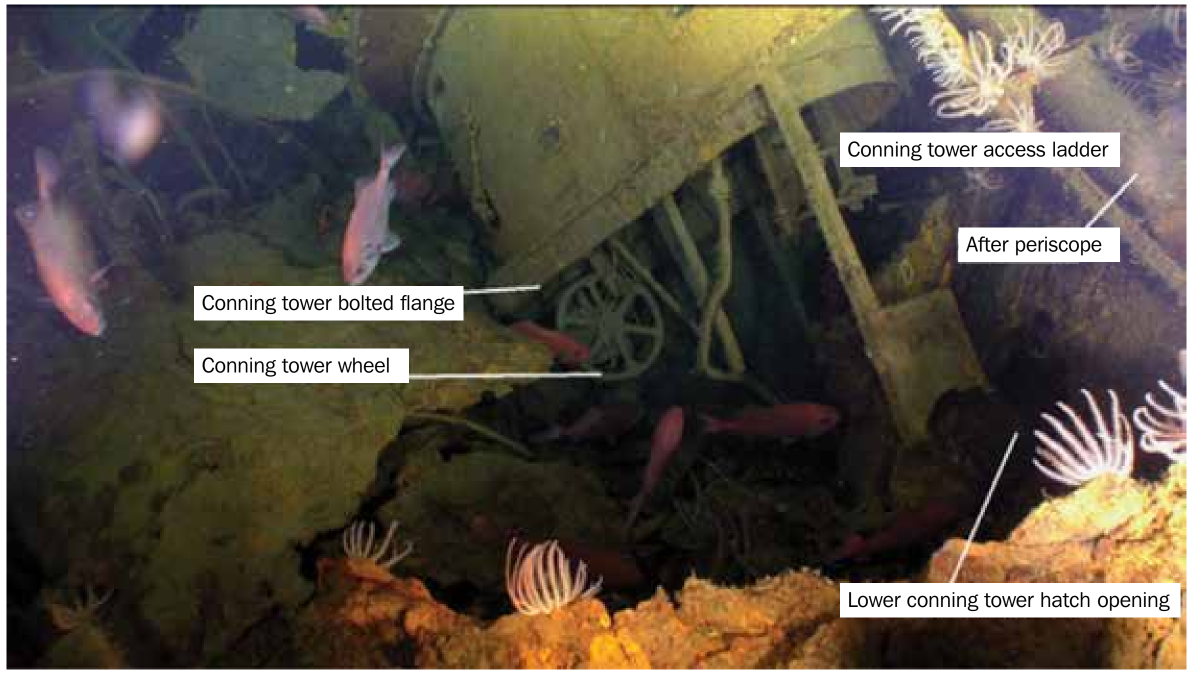

Figure 8 – Fin from port. Note absence of conning tower lower section.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Figure 9 – Starboard blower and No. 3 main ballast tank debris.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

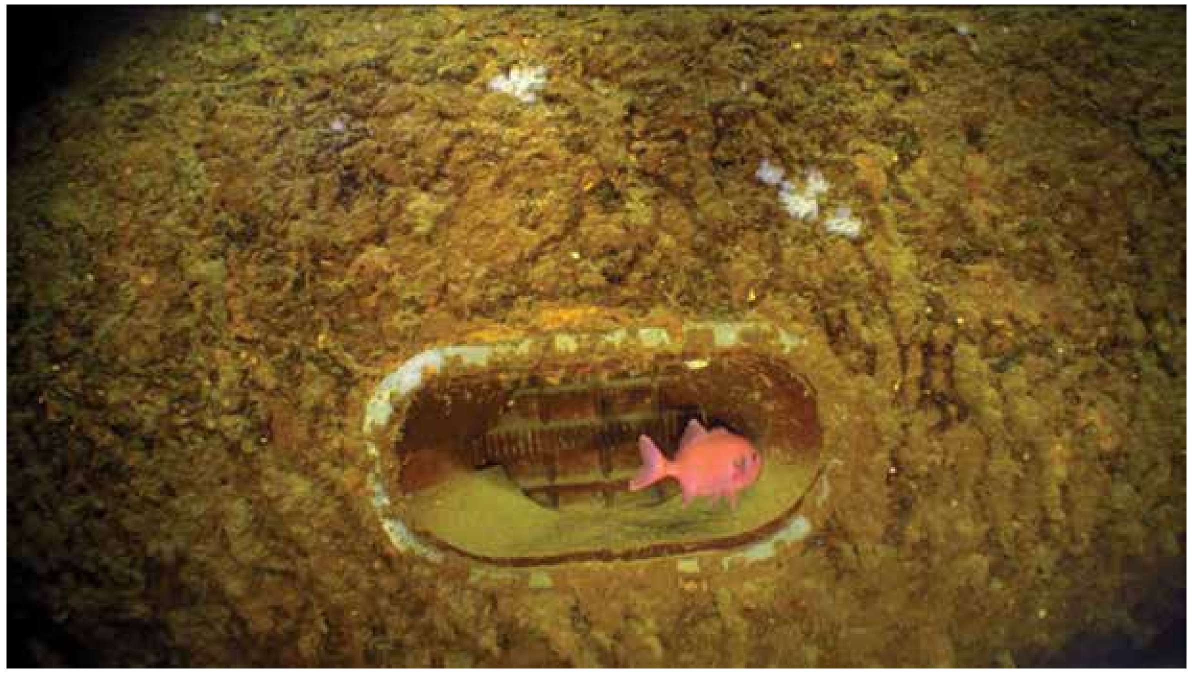

Figure 10 – Starboard beam tube outer door (shut).
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

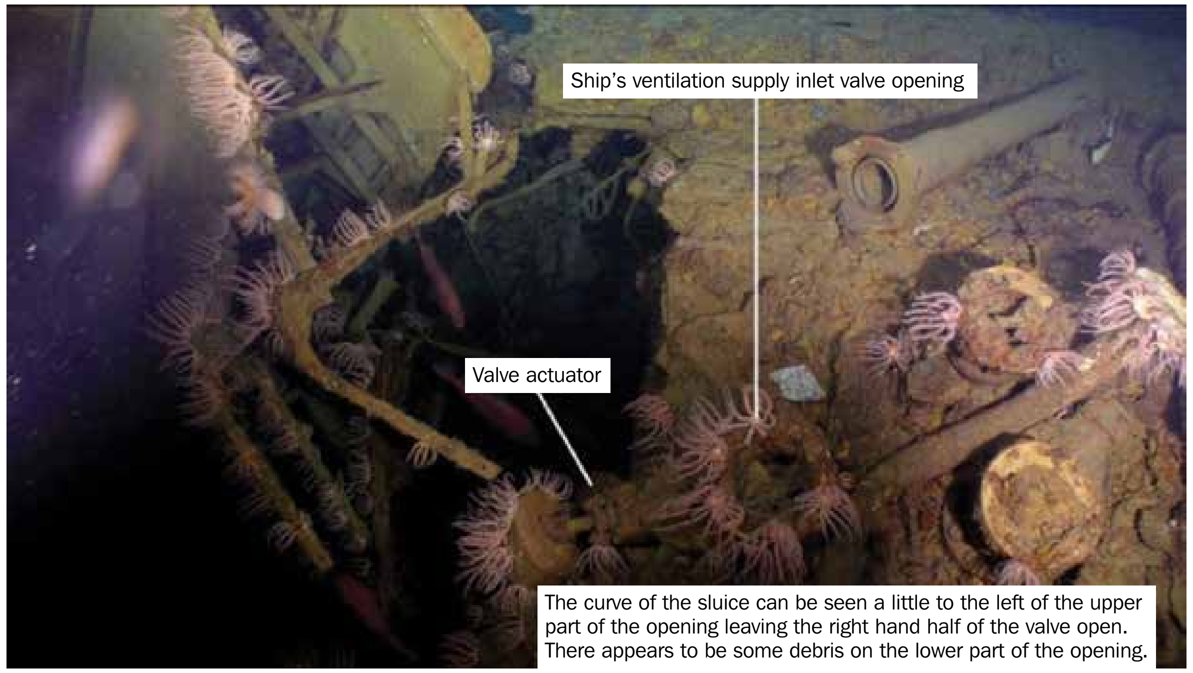

Figure 11 – Ventilation trunking and hull valves.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Figure 12 – Beam tube firing tanks.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Figure 13 – Hole over senior sailors' mess.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Figure 14 – No. 5 main vent valve handwheel.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

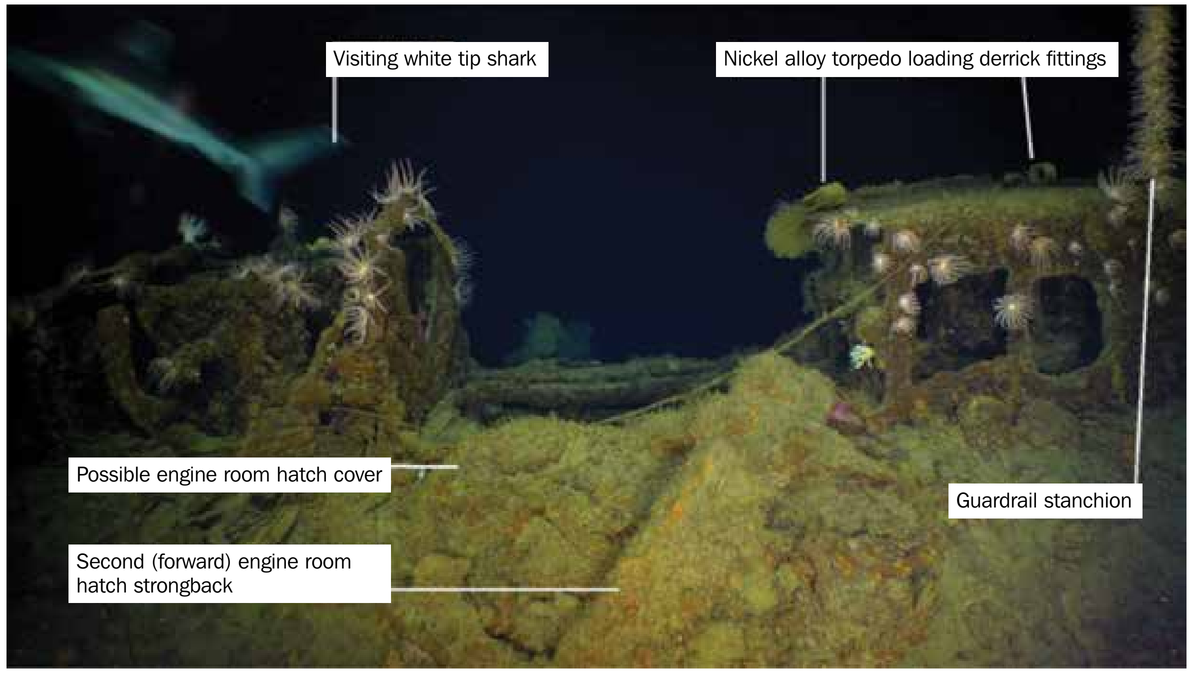

Figure 15 – Engine room hatch from port side.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

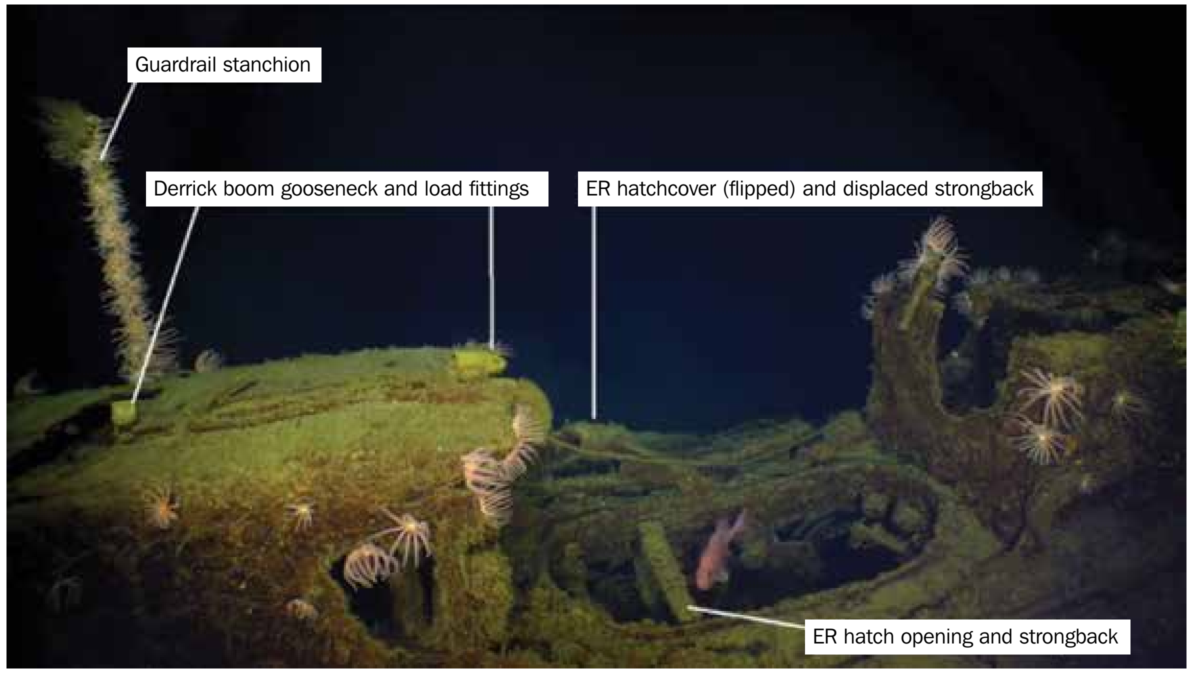

Figure 16 – Engine room hatch from starboard.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

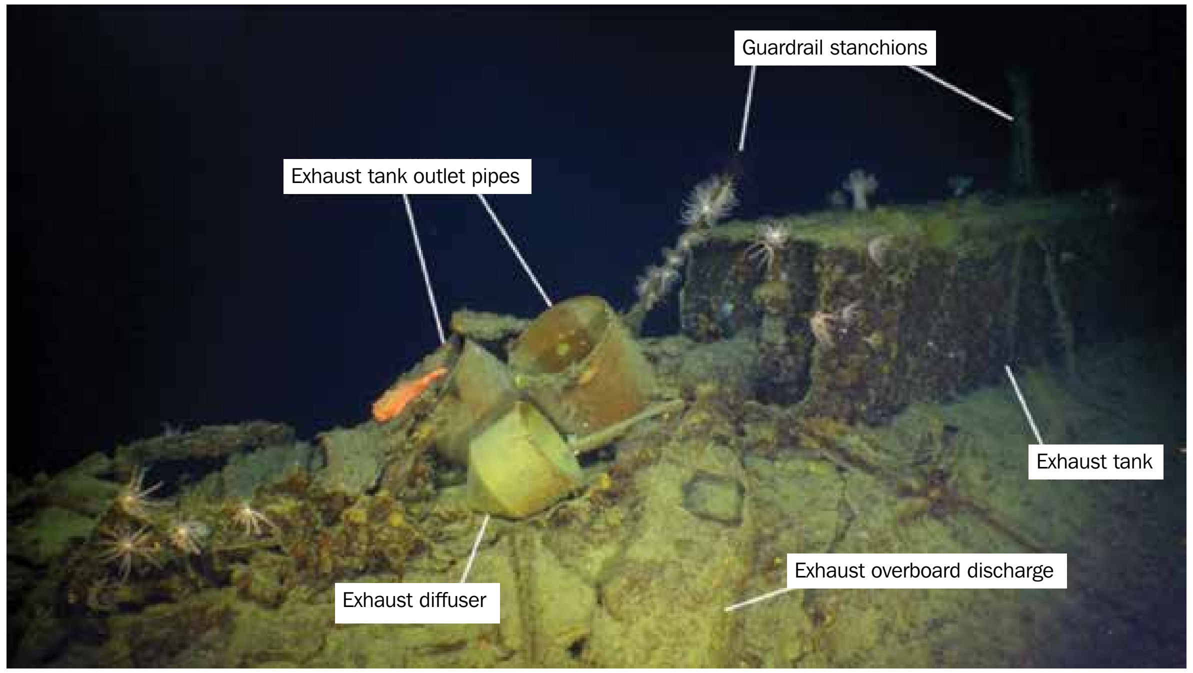

Figure 17 – Exhaust tank outlet pipework.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

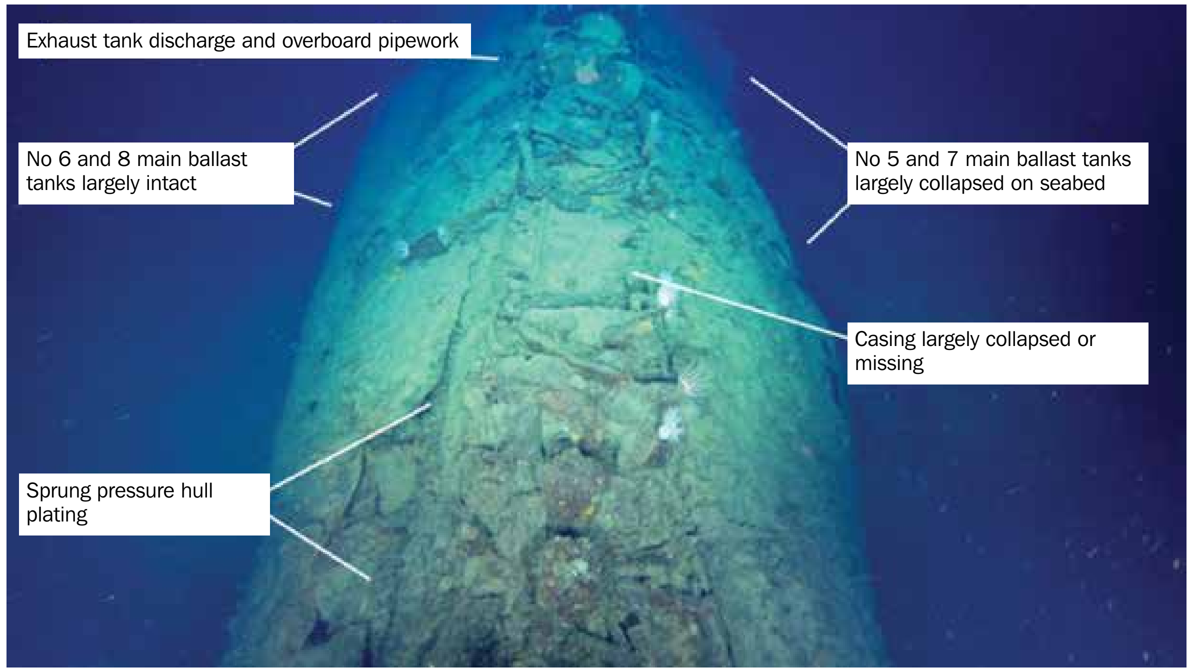

Figure 18 – After casing area. Note how little of the casing remains.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Figure 19 – Stern firing tank and hole over after ends (viewed from port).
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

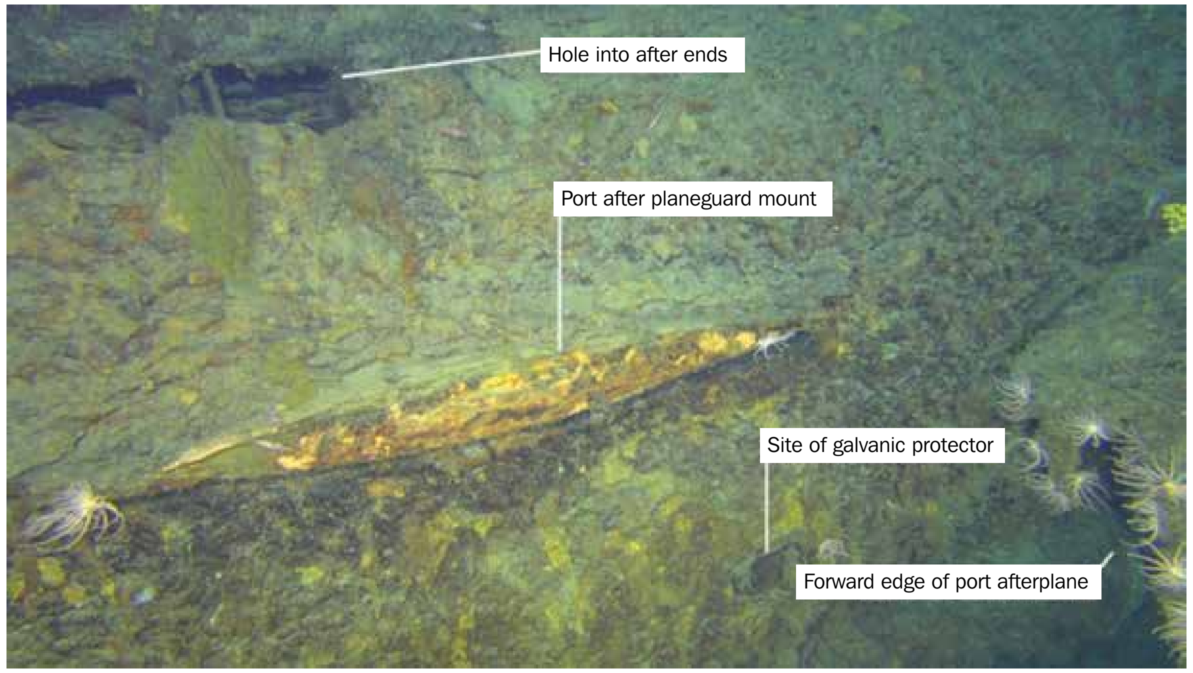

Figure 20 – Port after planeguard mount.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

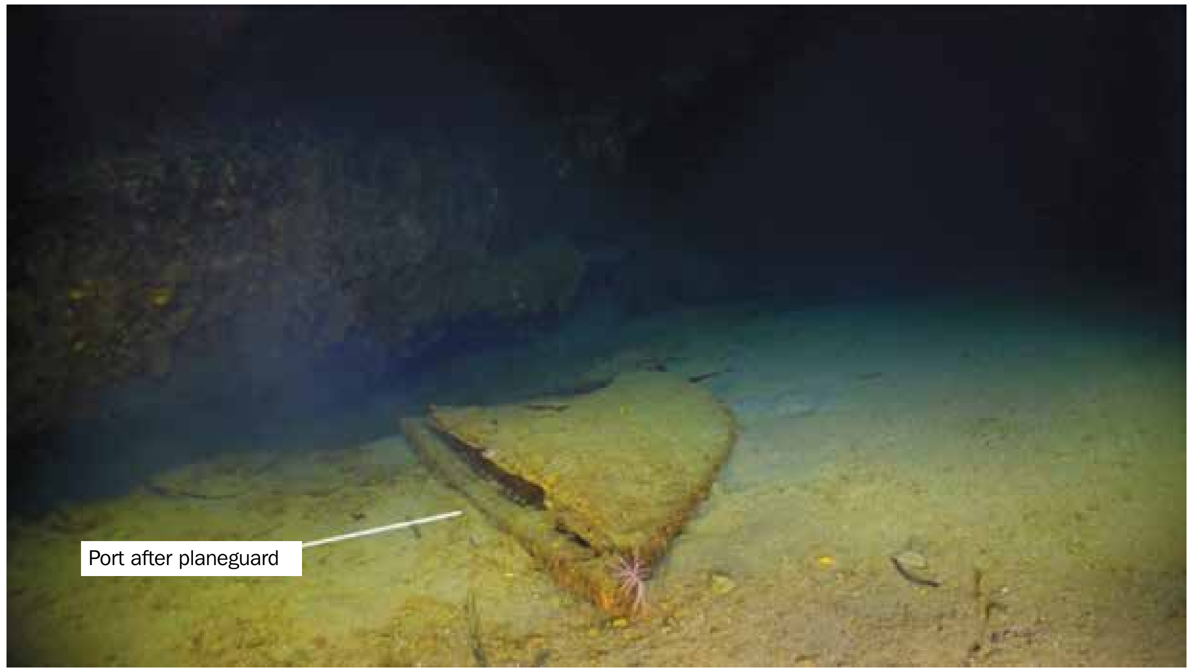

Figure 21 – Port after planeguard.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

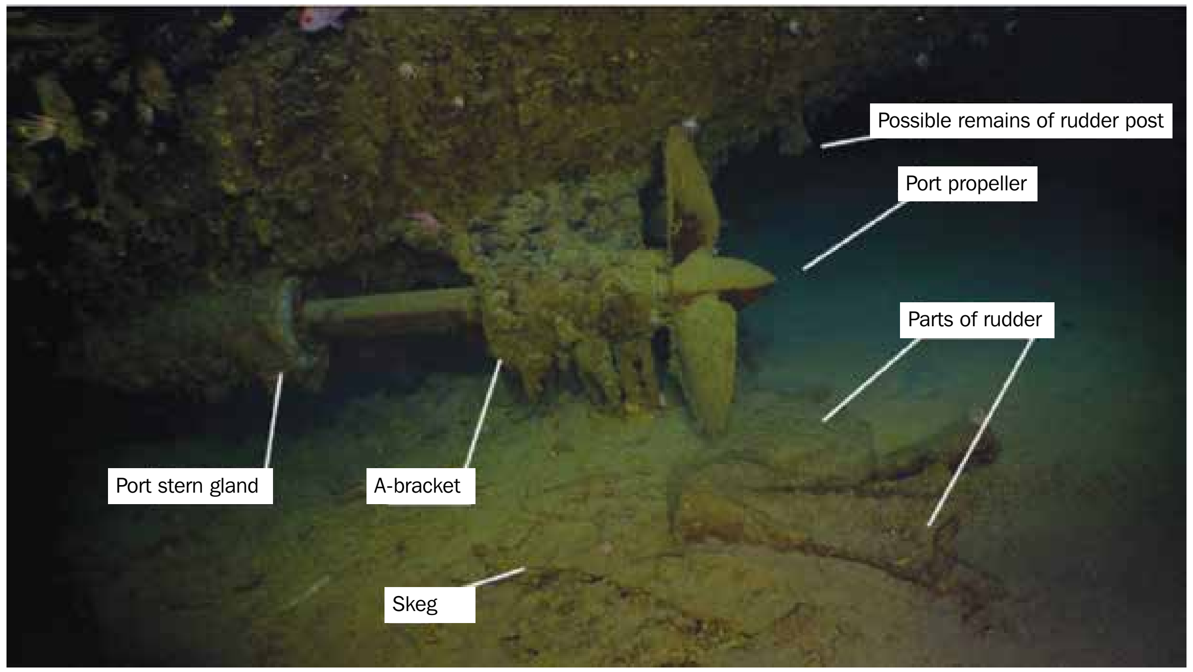

Figure 22 – Port propeller shaft, rudder and skeg.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

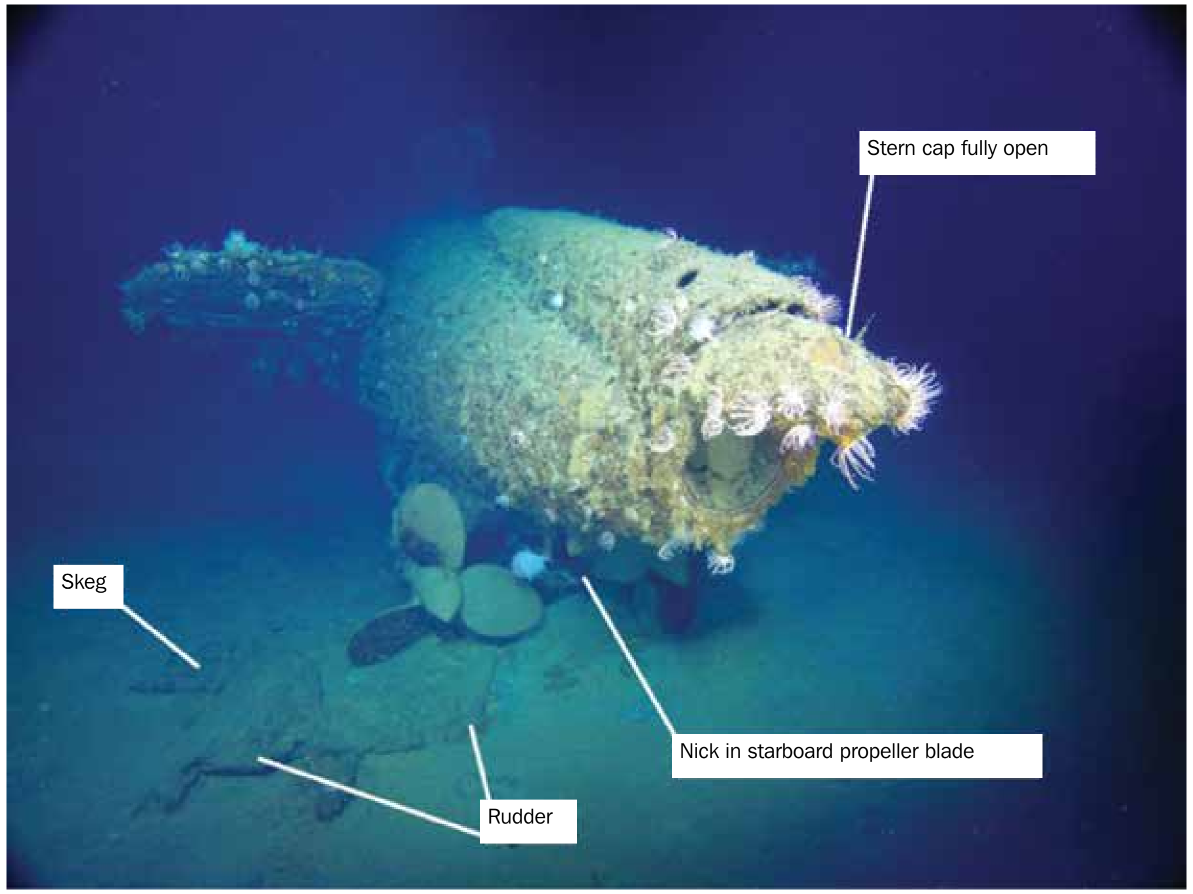

Figure 23 – Stern tube, rudder and skeg.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

6 Some particular features

6.1 The open ship's ventilation hull valve

The E-Class were fitted with a ship's ventilation system which allowed air to be induced into the engine room for the purpose of being able to run 'shut down'. In that condition the main engines could be operated with the conning tower upper lid shut. The induced air was then distributed throughout the after ends. The inlet to the system was a 6-inch (15-centimetre) sluice-type hull valve mounted adjacent to the battery ventilation inlet and outlet valves under the fin. External to the hull it was fitted with a ventilation trunking and a mushroom-shaped splash guard.

With *AE1*'s fin now having toppled forward, all five ventilation trunks have been displaced. Three have fallen in place. The fourth and fifth have not been identified and are not inside the fin so are probably among the ballast tank debris on the seabed. The fin and trunking have been displaced, allowing an inspection of the ventilation valves. One battery ventilation valve was obscured by debris. The other three were visible and seen to be shut or silted up in a way that they can be assumed to be shut. The ship's ventilation valve can be seen to be open by ~60%.

The valve is operated by a handwheel located inside the pressure hull. The handwheel rotates the valve actuator via a right-angle bevel gear linkage. Rotation of the actuator causes the sluice to move into the housing. Figure 24 shows that the right-hand edge of the sluice is visible, leaving an opening of about 60% of the fully opened position. A piece of (apparently rectangular) debris is resting on the sluice. In other images this can be seen to be soft debris – probably marine growth.

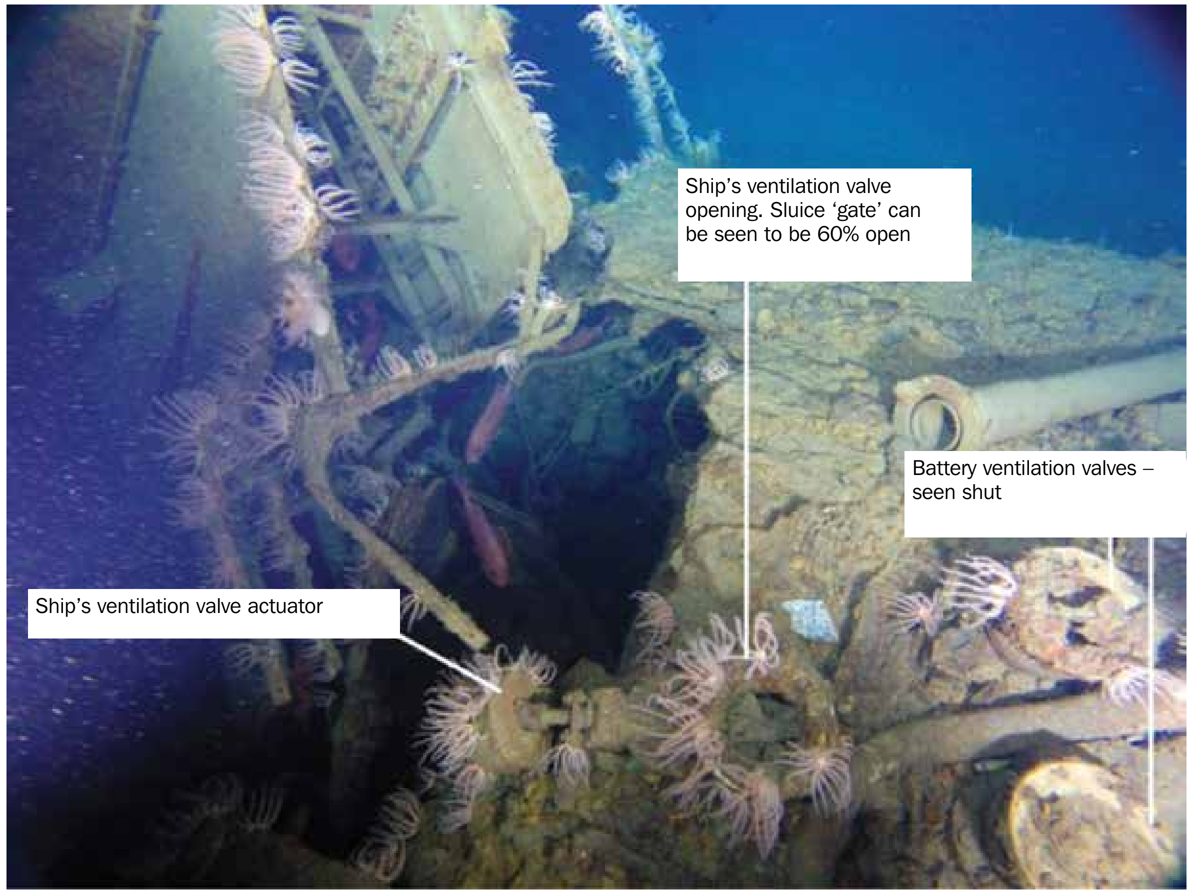

Figure 24 – Ship's ventilation hull valve.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Given that the valve actuator is in the ruptured pressure hull and that the area has been subjected to some severe forces as the fin has torn the systems away, consideration was given to the possibility that the actuator arm was subjected to an extreme longitudinal tension which wrenched the valve sluice into its current part-open position. However, the system drawing[3] shows the valve to be screw-actuated, thus movement of the sluice would not be possible without rupture of the actuator body, of which there is no visible sign. Furthermore, inspection of the valve body and actuator from the starboard side (Figure 25, opposite page) shows it still to be attached to the pressure hull, thus any longitudinal force would be borne by the actuator body, not the sluice.

From this we can only conclude that the valve was at least part-opened at the time of the accident. It is possible that it was fully open at the time of diving, which resulted in a flood to the ventilation trunking. On seeing the flood, attempts were made to shut the valve, resulting in it being in its current position.

If the submarine were to dive with the valve open or part (60%) open it would result in a large ingress of water at pressure to the ship's ventilation supply trunking. The build specification calls for the trunking to be fitted with a quick-closing valve similar to those fitted to the battery ventilation system. However, the drawings – neither ship and battery ventilating system drawing no. 2923 nor the general arrangement – show such a valve and the configuration of the internal pipework is such that it is hard to see where it could be successfully fitted. That is not to say a quick-acting valve was not fitted but it does increase the possibility that the open sluice valve could have led to a flood.

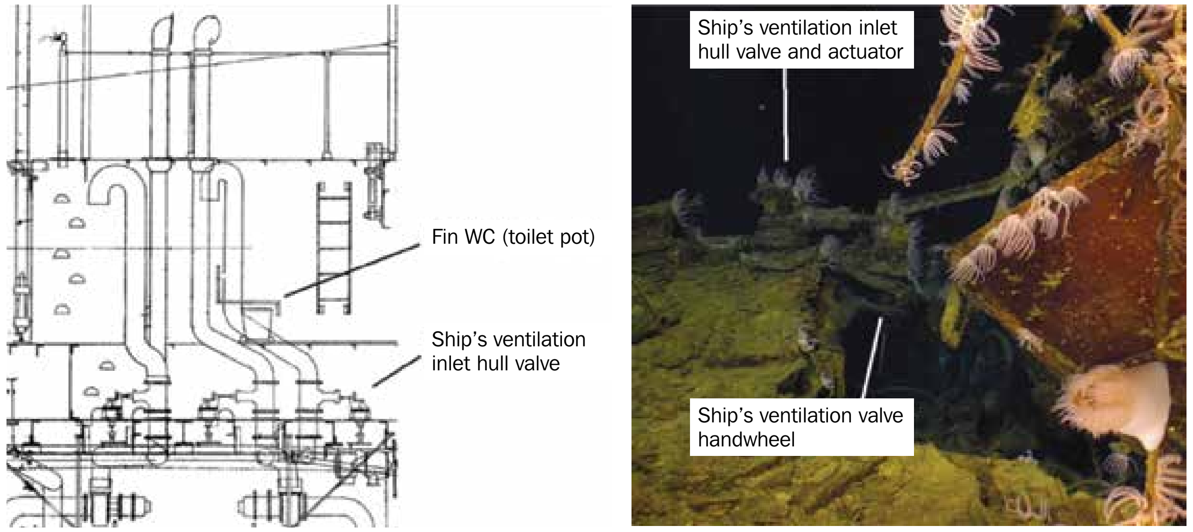

Figure 25 – Extract from general arrangement drawing of ventilation hull valves (L) and ship's ventilation hull valve (*Petrel*) (R). Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

A flood to the ship's ventilation trunking would result in water at pressure and volume being discharged from the ventilation louvres located at about shoulder height in the after compartments. This could result in:

- seawater ingress to the after battery compartment (located below the senior sailors' mess), leading to chlorine fumes and loss of electrics
- wetting of electrical systems, leading to loss of electrics to any number of systems
- wetting of the electrical supply to the port main motor or the motor itself, resulting in a complete loss of propulsion (noting that the starboard shaft was not available when dived).

The ingress of water would also lead to a loss of trim. Having a reduced buoyancy (being heavy aft), the submarine would assume a bow-up angle.

Much of the above is supposition. However, the open ventilation valve is undeniable evidence that the conditions were there for an accident to occur if the submarine were to dive.

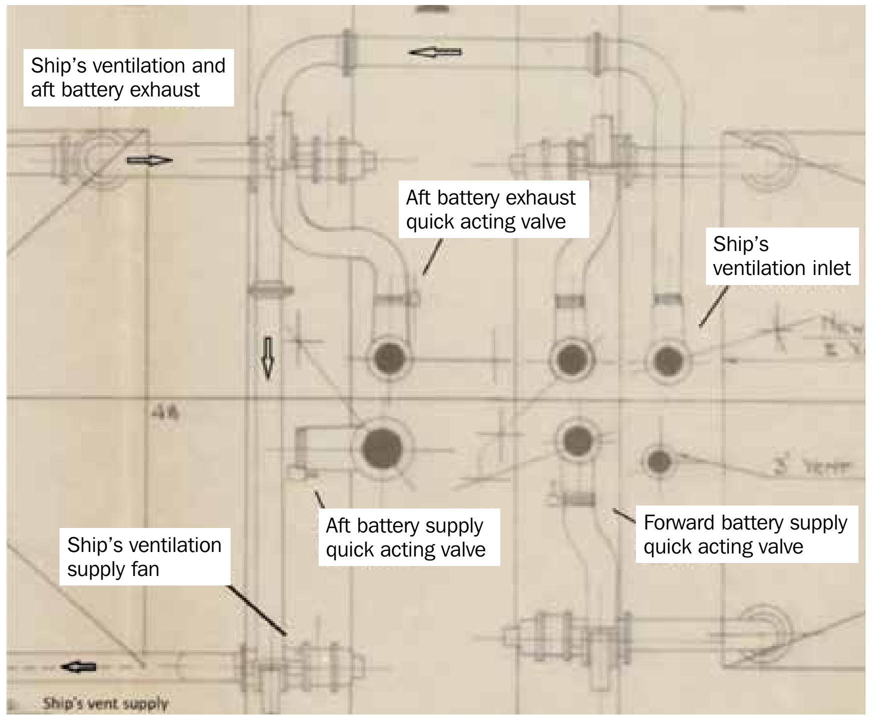

Figure 26 – Extract from ship's drawing No. 2923, 'Battery and ship's ventilation'. Note absence of quick-acting valve from ship's supply trunking. Image courtesy of NAA: MP551/1, 109/77

A comparison of the battery and ship's ventilation drawing (Figure 26) with the (later) general arrangement drawing (Figure 27) shows that the forward battery supply quick acting valve was moved to be just above its entry to the battery tank. It was in this position that such a valve was seen in *AE2*. The change to the design was presumably made because of the physical difficulty of mounting such a valve in the overhead trunking. There would have been similar difficulties with the ship's ventilation supply. It is also possible that in the face of those practical difficulties, a quick-acting valve was considered less of a priority when the trunking did not lead into a battery tank.

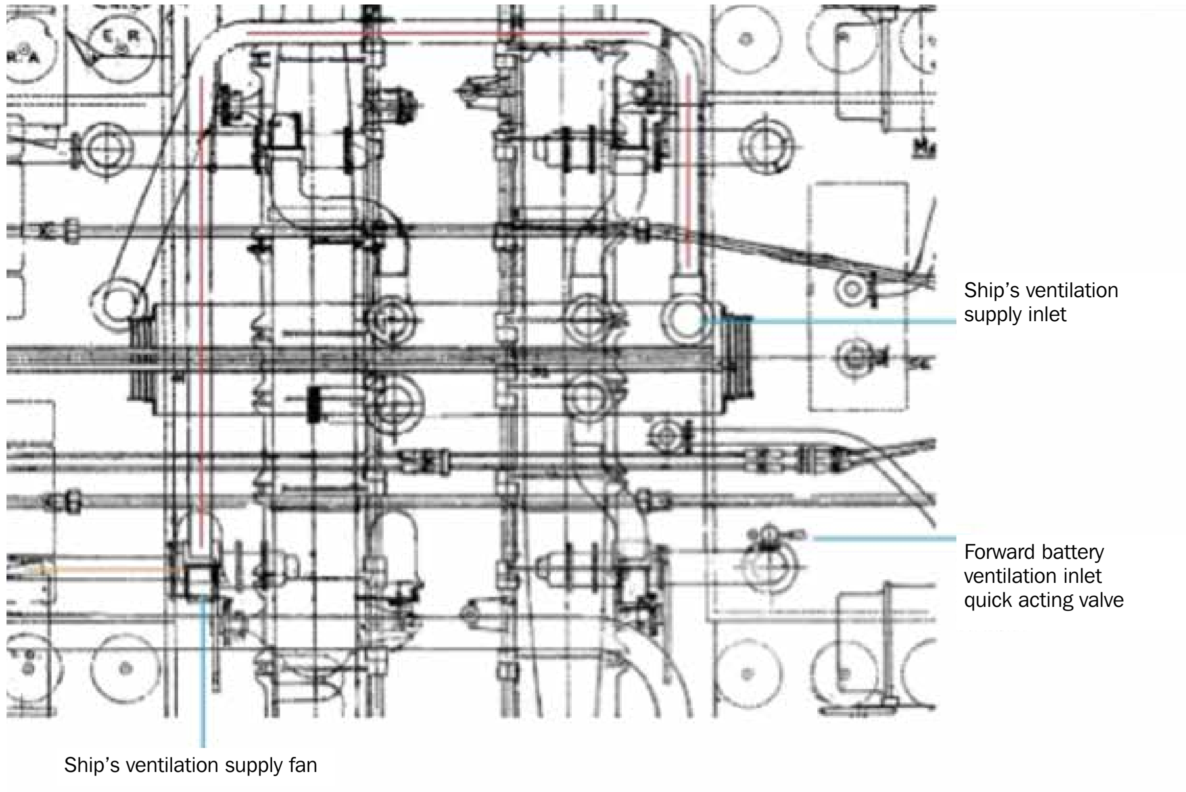

Figure 27 – Extract from general arrangement drawing of ventilation supply arrangement. Note new position of forward battery vent supply quick-acting valve and absence of quick-acting valve from ship's supply.

6.2 Stern cap open

The stern torpedo tube is fitted with an outer door or stern cap and an inner sluice valve to protect a loaded torpedo from seawater pressure. *AE1*'s stern cap is horizontal, being fully opened. The stern cap is operated by a handwheel to starboard of the inner door via rod linkage through two bevel gearboxes to a worm gear mechanism. The rotary action of the worm opens the stern cap.

It might be possible given the forces acting in the implosion and the impact with the seabed for the worm gear to slip a tooth or two, but it is hard to imagine that the stern cap could be 'flicked' to the fully open position, particularly as the whole of the stern area is intact and in fact quite well-preserved. Thus, if we accept that the accident occurred on diving (due to the open ship's ventilation valve) we must conclude that the stern cap was deliberately opened prior to the submarine diving.

Given that the stern tube is clear of the water when the submarine is at full buoyancy it is practical for it to be opened when the submarine is surfaced. It could have been opened as part of a weapons drill or perhaps with the intention to achieve a higher level of weapons readiness in the expectation of meeting the German steamer. We cannot know why the stern cap is open but the evidence is that it is.

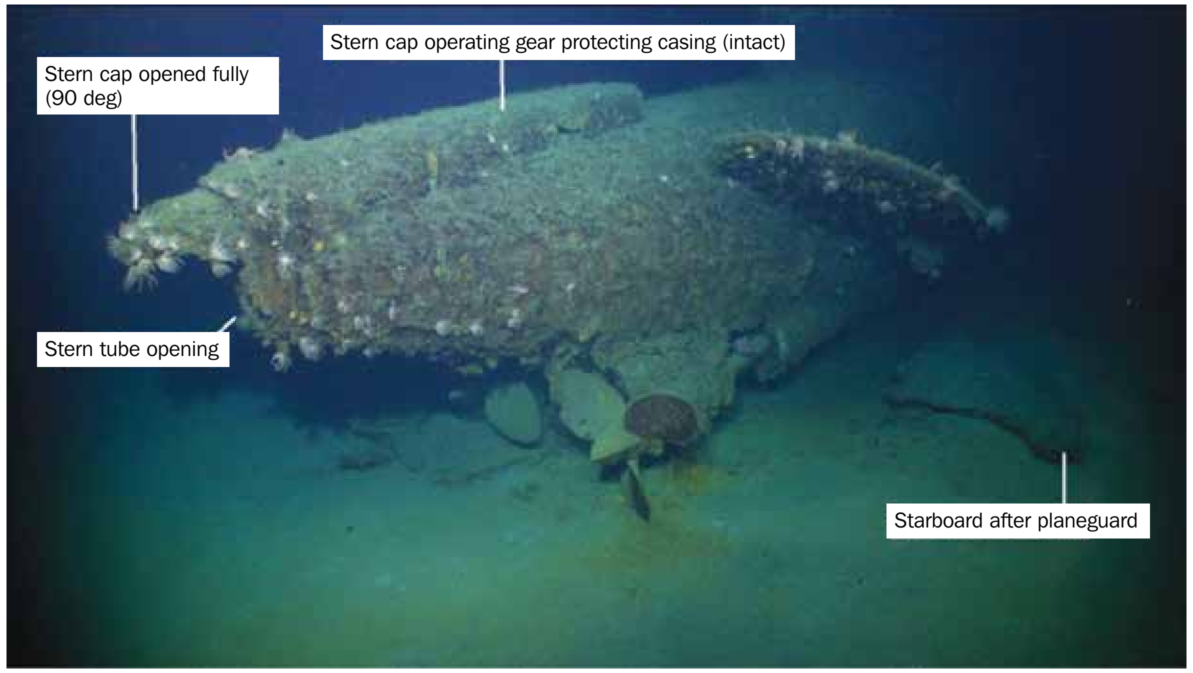

Figure 28 – View of after ends, showing open stern cap.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Having the stern cap open provided the opportunity to sight the sluice valve, located some 1.9 metres into the tube. This was successfully done, despite it being diligently guarded by a large eel.

Figure 29 – Inside the stern tube.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

With the stern cap open, the outer section of the tube would flood on diving. This represents an increase to the submarine's bodily weight of some 97 gallons (~367 litres, weighing some 440 kilograms) at the extreme after end. If compensation had not been made, the submarine would have had a reduced buoyancy, been heavy overall and significantly out of trim (heavy aft). From this we can conclude that the stern cap being open could have worsened the situation on diving.

Again, this sequence includes an element of speculation but is offered as one explanation as to why the stern cap is open and how it may have contributed to the accident.

6.3 The forward torpedo tube

The condition of the forward torpedo tube presents a puzzle.

- The forward torpedo tube outer door (bow cap) is open by some 20–25 degrees.
- The forward casing has slumped forward and down over the bow cap and can be confused with the bow cap itself, presenting a confusing perspective from some aspects.
- The forward tube rear door is exposed in the imploded forends area, allowing inspection of the rear door and the operating handwheels (see Figures 4, 30 and 31).
- Three of the four rear door retaining butterfly clips (4, 8 and 11 o'clock) have been dislodged. The fourth is obscured.
- The bow cap operating handwheel has been badly distorted downwards.
- The sluice valve operating handwheel has been dislodged but appears intact.
- Access to inspect the tube sluice valve was prevented by the narrow opening of the bow cap and the slumped casing.

The bow cap operating mechanism is similar to that of the stern tube, being a worm gear actuator operated by rod linkage which passes through two bevel gear actuators, all operated by a handwheel located to port of the rear door. The linkage is protected by the forward casing, which is now badly damaged through a combination of collapse and corrosion. The operating handwheel has been subjected to strong downward forces, presumably the consequence of the implosion.

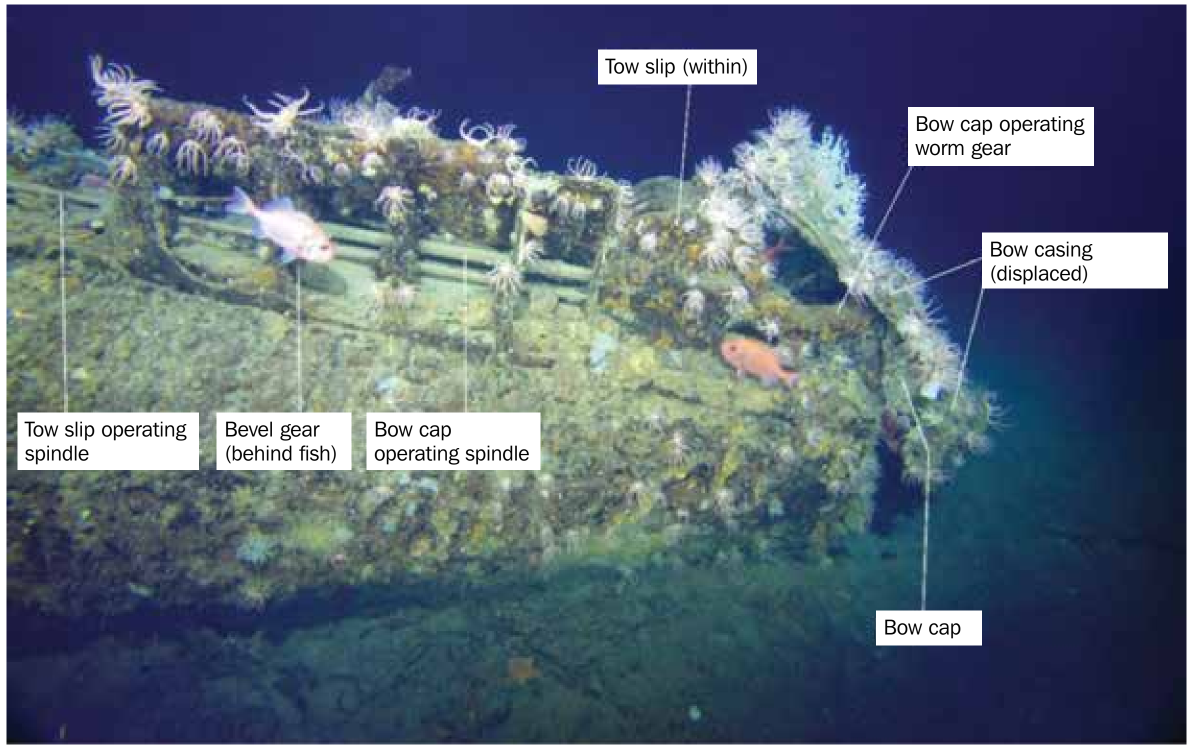

Figure 30 – Forward torpedo tube.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

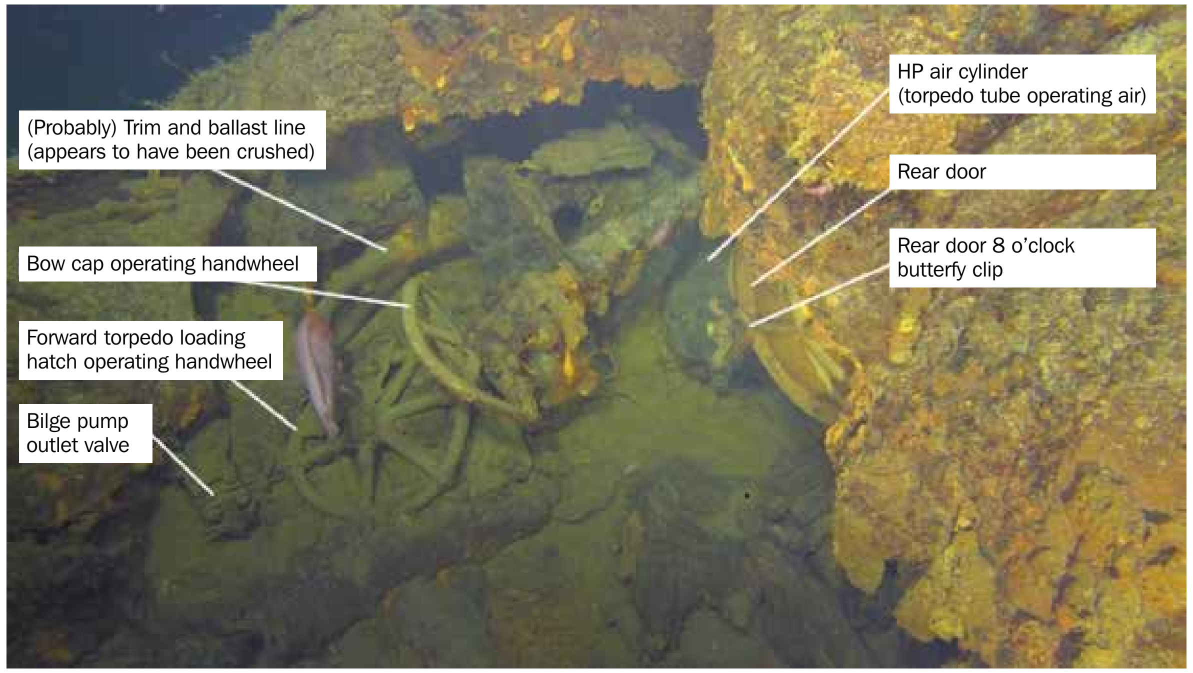

Figure 31 – Forward torpedo compartment implosion area (see also Figure 4, page 67).
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

To explain how the tube reached this condition requires some speculation, which presents four options:

- The forward tube had been partially prepared for firing while the submarine was on the surface (in the same way as the stern tube) but the bow cap had then been part shut to avoid damage from flotsam while in passage on the surface.
- The forward tube had been partially prepared for firing in the same way as the stern tube, with the bow cap fully open. On sinking, the combination of the implosion, the bottom impact and the fore-casing collapsing over the bow caused the bow cap worm gear to slip sufficiently for the cap to be 'flicked' down into its present position.
- The tube was in the process of being prepared at the time of the sinking, during which process the bow cap had been part-opened.
- The bow cap was shut at the time of sinking. The combination of the implosion event, subsequent shock wave and bottom impact caused an internal pressure wave which dislodged the bow cap and 'blew' it outwards to its current position.

In each case the succession of external and internal pressure waves relieved the rear door of its tension, allowing the butterfly clips to be dislodged from their shut position. Despite this, the rear door remains shut, suggesting that it had not been 'flooded and equalised' and so could not be a source of a flood.

Also, in each case there is (similar to the stern tube) the possibility that, having part-prepared the forward tube, compensation was not then made for the additional 97 gallons (~367 litres, 440 kilograms) which would have entered the outer section of the bow tube. This would have made the submarine heavy overall but would have left the trim unaffected, having balanced out the effect of the stern tube also being part-flooded.

While it is possible to argue the relative merits of each of these options, the reality is that we can never know which of them occurred. Suffice it to say that the current condition is consistent with what we know of the submarine's actions and does not require us to reconsider the basic assumptions regarding the circumstances of the accident.

6.4 Hull crack at Frame 70

The pressure hull has experienced a major rupture at Frame 70. This is visible in Figure 32 but also in Figure 6 (starboard side internal) and Figure 33 (port side internal). The crack appears to have opened by 1–3 degrees and has allowed the pressure hull forward of this area to have settled somewhat lower than if the hull were complete.

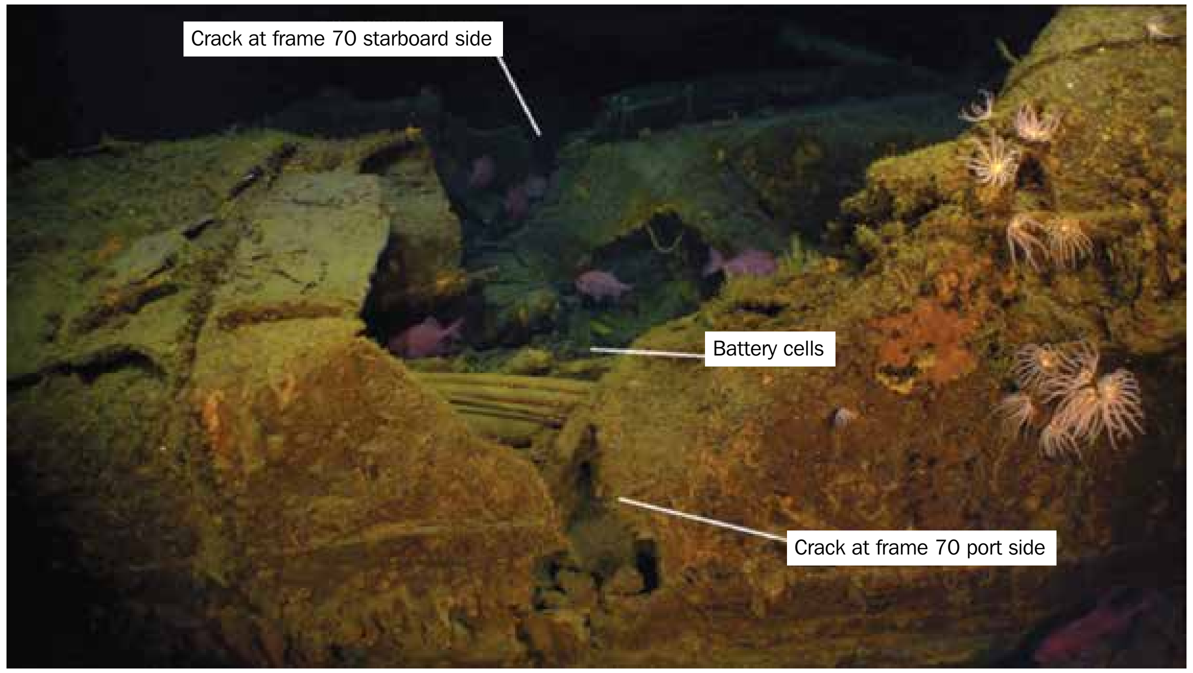

Figure 32 – Side-on view of Frame 70 pressure hull crack.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

The design of the keel is such that it is near level between Frames 34 and 68. Aft and forward of those frames the pressure hull begins to curve upwards. That the hull has cracked at Frame 70 would be consistent with a seabed impact at a (near) level trim. The combination of momentum and whiplash then caused the unsupported forward section to continue on down, tearing the crack at Frame 70.

That the bow section has settled somewhat and possibly not straight may also explain why the bow appears to have a list (2–3 degrees) to starboard while the stern appears to be near upright.

6.5 Exposed forward main battery section

The implosion of the control room caused widespread damage and left the area from c. Frame 62 to Frame 72 exposed, with the pressure hull collapsed down to about knee height above the control room deck. The deck comprised a double layer of teak boards covered with two layers of painted canvas. The deck provided a walkway throughout the control room but was also intended to provide a waterproof cover to the battery tank.

It was a surprise to find that much of that area is now fully open. The deck and its canvas cover have gone and a row of battery cells (row 5 counting from forward) has been exposed at the forward end of the battery tank (see Figures 6 and 33). One cell from row 6 is visible under the collapsed pressure hull on the outermost starboard side. The curiosity is that the remainder of rows 6 and aft are not visible. Instead, there is an apparently level area of sediment placed some 0.4 metres lower than the top of the battery cells of row 5. In Figure 33 the battery tank's teak wall (port side) can be seen extending aft from row 5. The height of the wall edge above row 5 is as per the drawings at around 0.2 metres. This suggests that the entire battery from row 6 aft has slumped by around 0.4 metres to provide a level area which has then been subject to sedimentation.

There is one possible explanation for this. The first five battery cell rows are located over main ballast tank internal B. The next thirteen rows are located over main ballast tank internal X. If at the time of the sea bottom impact, MBT internal X were (near) empty the momentum of the heavy lead acid battery cells could have caused that tank to collapse, or indeed the tank could have imploded, or a combination of both, allowing the cells to drop by the height of the tank, which is similar to the height difference between the top of the row 5 cells and the sediment layer.

It is probably not coincidence that this height change has occurred in line with the rupture in the hull at Frame 70, though how the two are related is unclear.

It is assumed that the teak deck and canvas were shattered in the implosion and subsequent impact and have since been consumed by rot or marine life. However, there are outlines of bits of debris in the sediment which could be their remains.

For interest, the upper section of the WT antenna stump has fallen into the battery tank void and is visible in Figure 33.

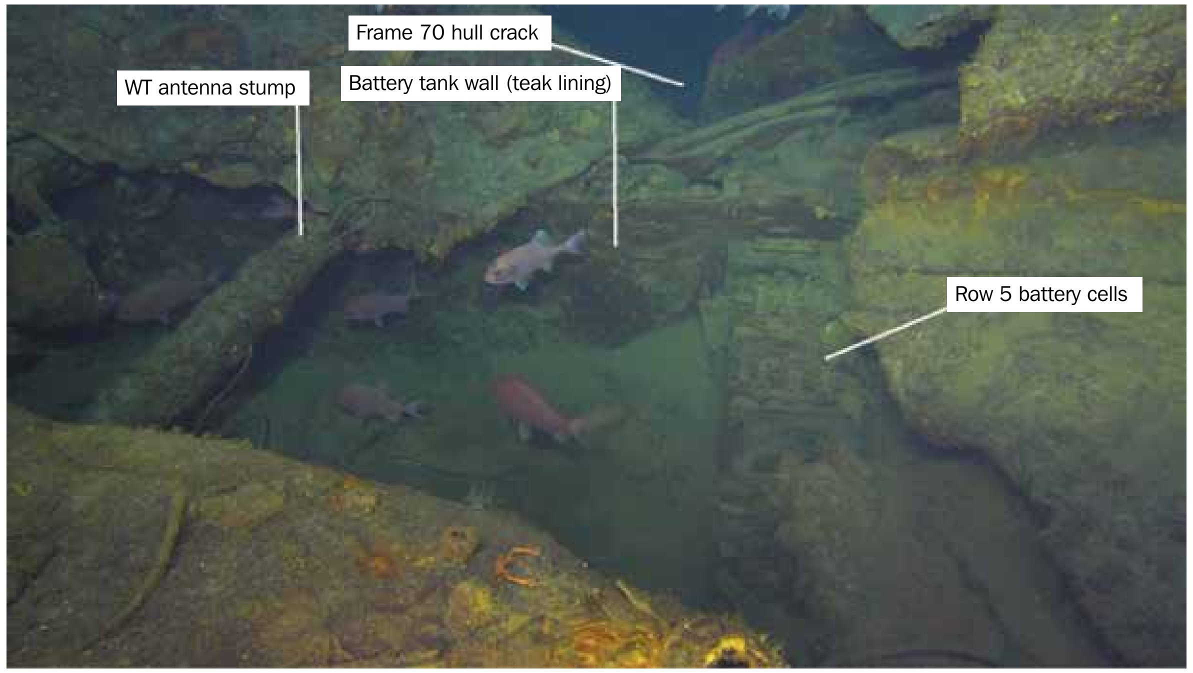

Figure 33 – Battery tank from starboard.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

It may also be noted (Figure 34) that there is what appears to be a screw-top bottle, missing its top but containing the residue of a heavy straw-coloured liquid, located on the debris above row 4 of the battery. Next to it is the broken neck of another glass bottle. To the left of the bottle is a square cornered piece of (probably) teak, which could be a remnant piece of furniture. Row 4 of the battery is directly beneath the after end of the officers' quarters. It is reasonable to assume that these items fell to their current position from the writing desk or the wardroom table. It is a delightfully curious coincidence that this, the only real 'human' artefact observed in the wreck, is a drink-related item located in exactly the same position as the port decanter found in the wreck of HMAS *AE2*.

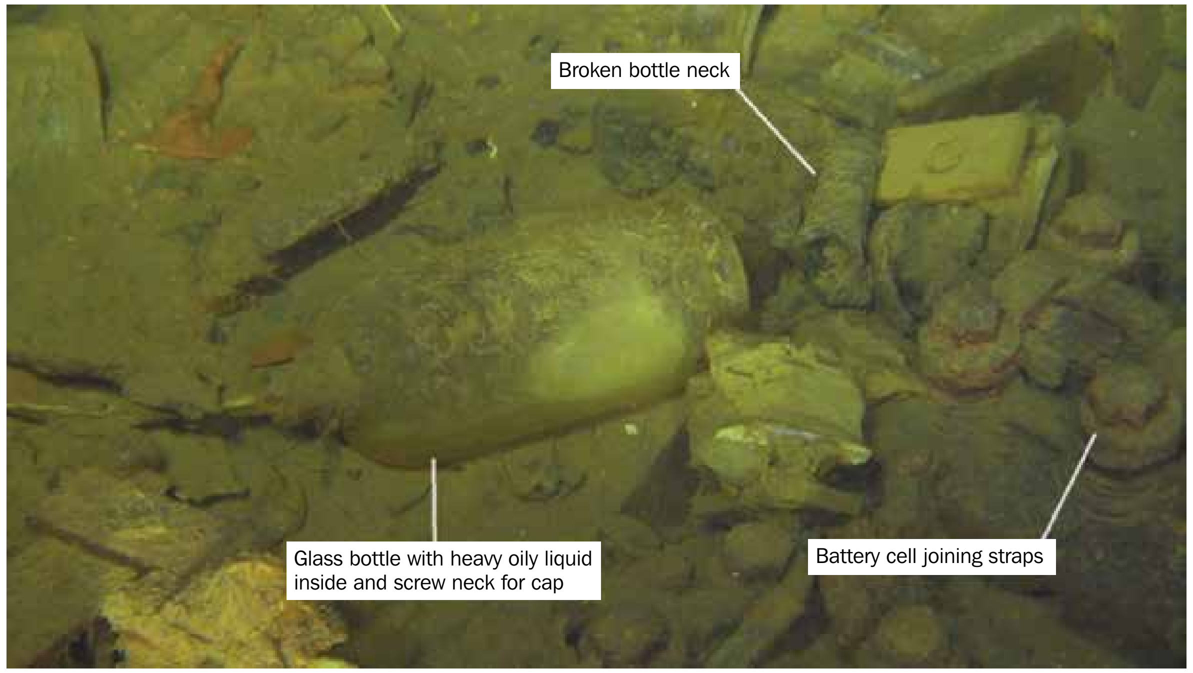

Figure 34 – Bottle located on row 4 battery.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

6.6 Collapsed rudder and skeg

The submarine was fitted with a large single rudder mounted on the centreline just aft and between the two propellers.

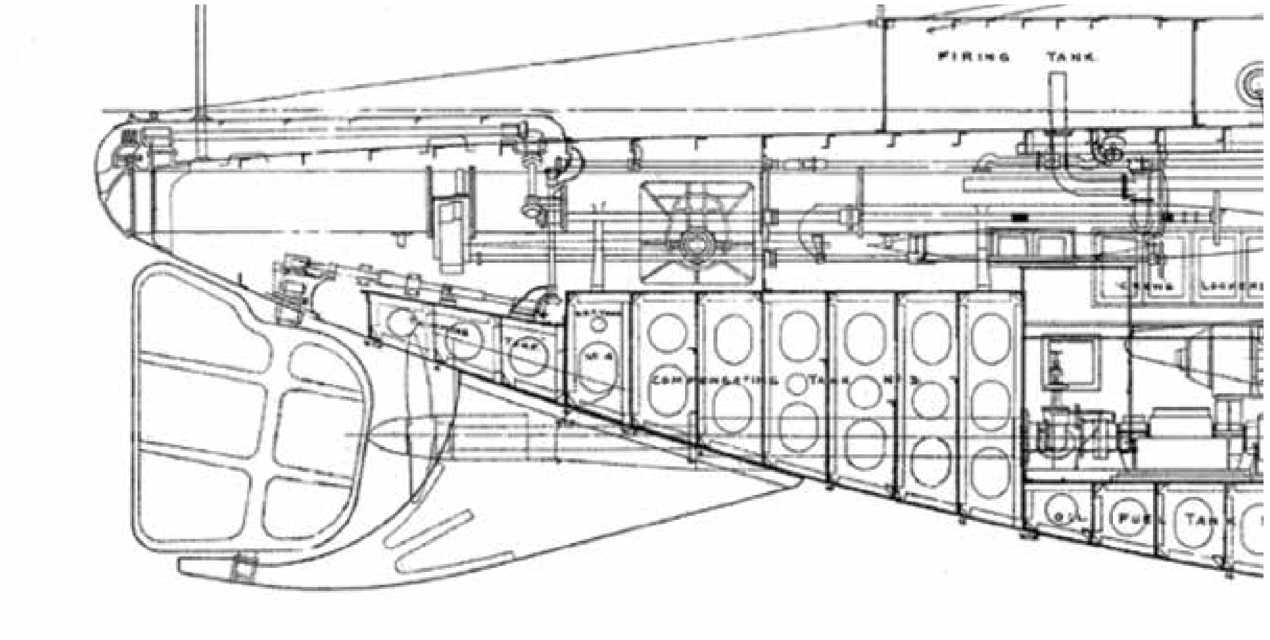

Figure 35 – Extract from general arrangement to show rudder and skeg.

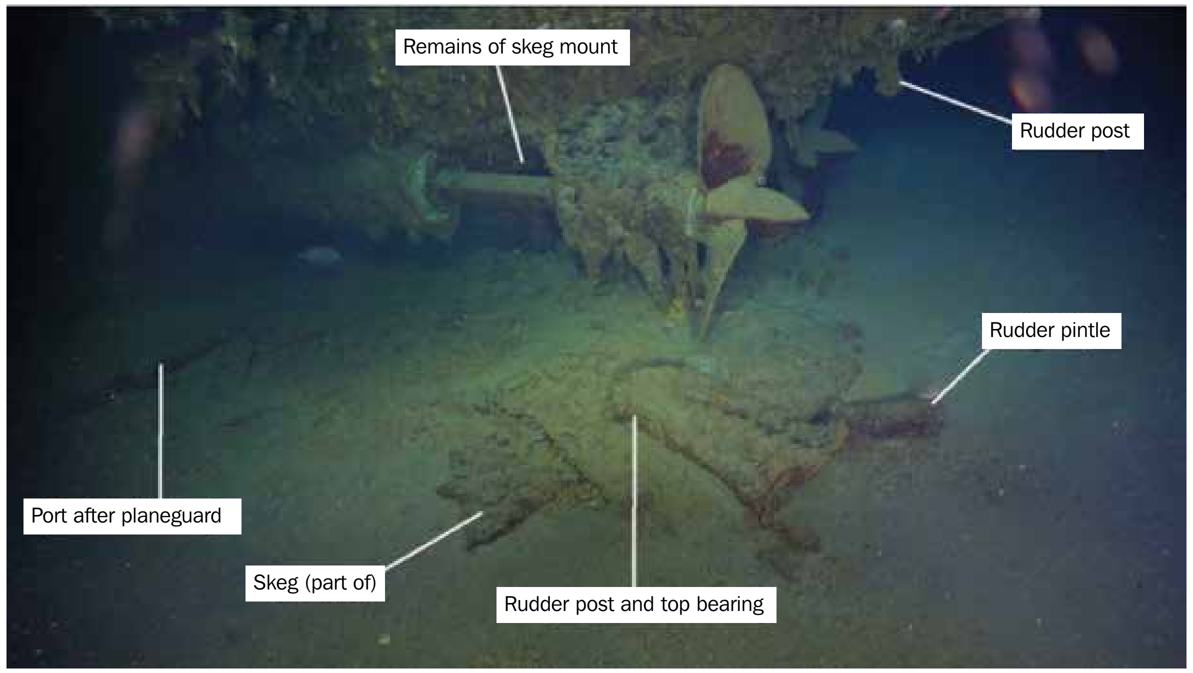

Figure 36 – Rudder and skeg on seabed.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

With the submarine at a level trim, the base of the skeg would sit about 1 metre above a level seabed. For the skeg and rudder to have been damaged so conclusively the submarine must have struck the seabed with a bow-up angle sufficient to close that gap. Measured from the general arrangement drawings, this would imply that the submarine would have had to impact the seabed with a bow-up angle of at least 3 degrees. However, the propellers are quite intact and therefore were not included in the impact with the seabed. For the propellers to remain clear of the seabed the bow-up angle could not have been greater than 7 degrees.

We can, therefore, conclude that the submarine has impacted the seabed with a bow-up angle of between 3 and 7 degrees.

6.7 The fin toppling

The Fugro Report imagery shows how the fin has toppled forward and to starboard. The *Petrel* imagery demonstrates that in the intervening four months the fin has moved still further. A clear indication of this is how the forward edge of the fin has moved relative to what remains of the pressure hull and how the forward periscope has now begun to 'cut' into the remaining section of the starboard pressure hull. It is not easy to measure this movement with any accuracy but it is estimated that in those four months the fin has descended by about 0.5 metres and probably somewhat further to starboard.

It is visible that the fin itself is remarkably well preserved. This is no doubt the consequence of the manganese bronze conning tower providing galvanic protection. This also means that the weight of the fin (estimated to be some 38 tonnes) is much as it was but meanwhile the support from the pressure hull is reducing as it corrodes away, which probably explains why the fin is continuing to descend.

A further indication is that the ventilation trunking and the ceramic shards from the fin WC are under (or near to) their original mounted position. This implies that the submarine was level when that damage occurred. From this we can conclude that the fin did not begin to 'topple' until after it had struck the seabed. A possible sequence could have been that the implosion removed much of the support for the fin. If the lower conning tower hatch was open (as would be expected in the early stages of a dive) the implosion shock wave would have passed up into the conning tower, possibly initiating failure of the conning tower flanged joint. Even if the lower hatch were already shut it is possible that the shock wave would still be felt in the conning tower as the hatch was designed to resist an out-to-in pressure, not to contain an in-to-out.

The combination of the submarine striking the seabed aft then falling onto its keel conspired with the momentum of the fin itself to cause it to begin its topple into the imploded control room.

By how much it moved at that stage cannot be estimated but the movement has certainly continued, presumably as a consequence of the pressure hull softening with the subsequent corrosion. Indeed, it is quite possible that the fin did not begin to topple until some time (possibly decades) after the sinking and did so only after its supporting flange and pressure hull had lost strength due to corrosion.

Figure 37 – Comparison of fin angle from *Fugro* image (L) to *Petrel* image (R).
Images courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

6.8 The mystery discs

The *Fugro* imagery revealed that there were certainly two, and possibly three, metallic discs resting on the pressure hull at different points. There was some conjecture as to where they had come from and how they had got to where they were. The *Petrel* imagery revealed that there are in fact six such discs, listed as follows:

- MD1, located at Frame 65 – lying on the pressure hull by the WT stump
- MD2, located at Frame 56 – lying on the port pressure hull/saddle tank join adjacent to a flanged hull opening.

Figure 38 – Mystery discs 1 and 2.
Images courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

- MD3, located at Frame 54 – lying on starboard saddle tank abeam vent trunk
- MD4, located at Frame 75 – lying on starboard pressure hull by the windlass.

Figure 39 – Mystery discs 3 and 4.
Images courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

- MD5, located at Frame 25 – lying on the starboard ballast tank; appears to have moved from its original position
- MD6, located at Frame 79 – a spiral wound gasket (only the asbestos spiral remains) lying on the pressure hull inside 2 main ballast tank and has therefore been deposited there after the ballast tank has disintegrated.

Figure 40 – Mystery discs 5 and 6.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

MD1–5 appear to be similar in dimensions: an estimated 4-inch (10-centimetre) outer diameter with a 1.5-inch (4-centimetre) orifice and six 0.5-inch (1.2-centimetre) bolt holes. These dimensions are commensurate with the discs being associated with a high-pressure system, possibly a seawater system or a high-pressure air system. The discs are coloured blue-grey, suggesting that they are made of lead. That the lead has retained its colour (and not turned white) suggests it has been alloyed with antimony. This would make it (comparatively) harder, so that it retained its shape on compression. This is typical for use in that era for the manufacture of the gaskets used to seal flanged joints in high-pressure systems. This notion is supported by MD4, which appears to be in place over the outlet to a piped system in that there is a recess behind its central orifice, possibly the opening to a pipe, which suggests it may be a system overboard discharge.

A possible solution to this puzzle emerged from the image of *AE1* showing two hull pads mounted on the pressure hull in the vicinity of the fin in a position where we could expect to see the main vent outlets. Based on its location we can propose that MD2 is the outlet for No. 4 main vent. The gasket appears to have fallen from the flanged outlet, probably as a consequence of the securing bolts having corroded. The general arrangement drawings show that No. 3 and No. 4 main vent outlets discharge to short pipe sections under the casing, the former being adjacent to the ship's ventilation valve. If this were the case it would be visible in Figures 24 and 25, whereas it cannot be found in any of the images of that area. This supports the possibility that the design had changed and that the main vents were routed direct to outlet hull pads in the pressure hull clear of the casing.

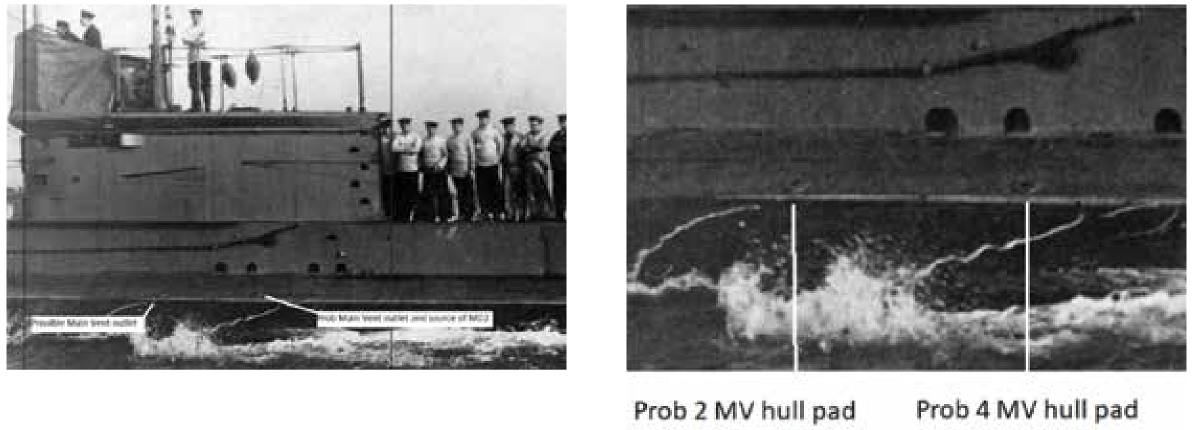

Figure 41 – External view showing No. 2 and No. 4 main vent hull pads

Pursuing the same line, from its location MD3 appears to be the outlet for No. 3 main vent, although it has apparently fallen from its original position to place it lower on the ballast tank. The original position of the outlet should be higher on the hull and is possibly where there is a hole in the pressure hull some 50 centimetres above where it now lies.

MD1 is in a position where it could be associated with No. 1 main vent outlet, but no pipe outlet can be seen behind the disc, suggesting that the disc fell from its original position before that pressure hull damage occurred. This might imply that the ongoing fin movement has contributed to the separation of the disc from its original position.

It is possible that these outlets are in fact associated with the ballasting system but if, as seems probable, they are indeed the main vent outlets it demonstrates a departure from the general arrangement drawing but does place the main vents in the positions where we would expect to see them today. Perhaps this is another indication of just how quickly the submarine design was evolving.

MD4 is located further forward and immediately over the starboard bilge pump, suggesting that it is the bilge pump high-level discharge outlet (Figure 42).

MD5 is located over the starboard side of the after ends and could be associated with the bilge and ballast line. It too appears to have moved from its original position.

MD6 differs from the others in that while of similar dimensions it appears to be the asbestos winding of a spiral-wound gasket (Figure 42). The supporting metal (usually copper-based) appears to have gone, which is itself curious in that any copper should have been preserved in favour of the contacting iron. This suggests that the event occurred some time after the sinking in order to establish an insulating layer of concretion. A further curiosity of MD6 is that there are no bolt holes, implying that this was a 'green' gasket which had not yet been drilled or that it was not from a flanged joint but from (for example) an air bottle cap seat.

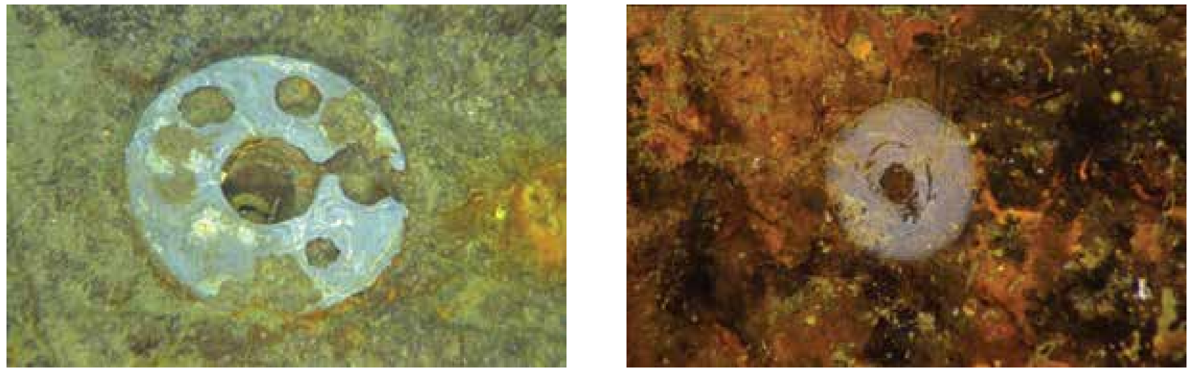

Figure 42 Mystery discs 4 (L) and 6 (R) (close-up). Note the recess behind MD4, suggesting that it is a pipe outlet.
Images courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

One possible explanation is that some parts of a high-pressure air system remained pressurised at the time of the bottom impact. That part then failed, either due to rupture during the event itself or due to subsequent corrosion. As the system failed, the gasket was freed while at the same time the escaping high pressure air blew it out of the wreck from where it fell to its current position. A possible candidate for such an event for MD6 is the forward torpedo firing air system bottles located nearby.

6.9 Bridge telegraph

The submarine was fitted with an engine room telegraph with dials in the control room and the conning tower, which operated mechanical rod gearing to transmit the engine orders to the engine room. An additional dial is located on the bridge.

It was a source of some puzzlement that *AE1*'s bridge dial is not fitted with the same handle that is visible in the other two telegraphs. However, the ship's drawings[4] reveal that although the conning tower and control room dials were linked with the transmitting rod linkage, the bridge telegraph was only linked to the reply transmitter. This can be seen in Figure 7, in which there are two rod linkages connected to the dial as opposed to the four which would be needed if it were also an order transmitter. From this we can conclude that the engine orders would be passed from the bridge (via voice pipe) to the control room (or conning tower) where the engine order would be set on the telegraph. The engine room would then acknowledge the order via the reply linkage whose signal would also be visible on the bridge.

The bridge telegraph in *AE1* (Figure 43) appears to have a broad arrow aligned at about 10 o'clock. There may also be a second broad arrow aligned at 12 o'clock. There are three external strengthening webs at 12, 4 and 8 o'clock.

Figure 43 – Engine room telegraph – bridge transmitter.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

The lettering on this telegraph cannot be read but from the conning tower telegraph of HMAS *AE2* and the build photographs of a later (unidentified) E-Class, we can conclude that *AE1*'s bridge telegraph is acknowledging an order for half-astern.

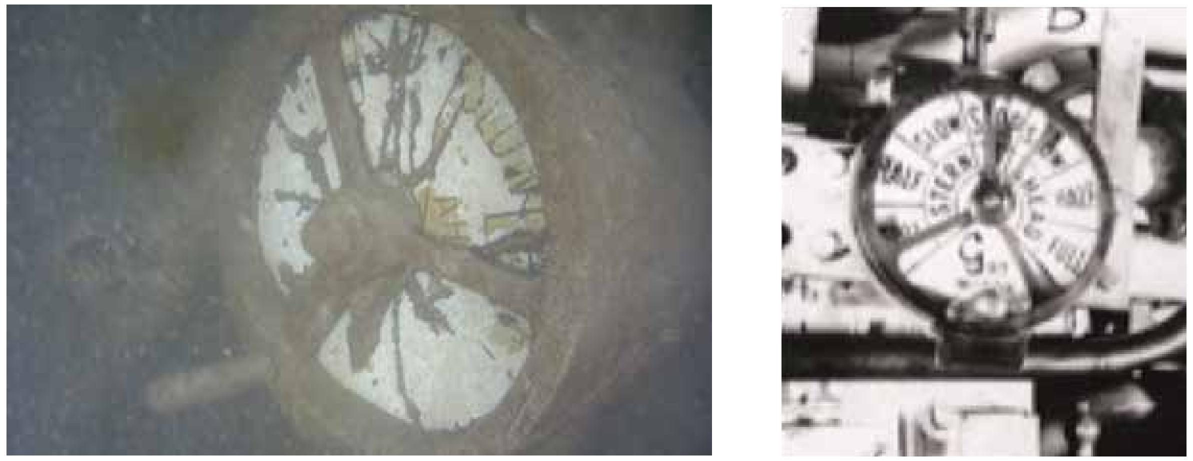

Figure 44 – Conning tower telegraph HMAS *AE2* (L), control room telegraph E-Class at build (R).
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Under diesel power, the E-Class could only propel ahead. To go astern, they would disengage the main engine clutch(es) and then operate the main (electric) motor(s). The main motors were controlled from the switchboard (located in the control room), for which orders could be passed via the voice pipe. When the submarine was dived, the orders could be voiced directly to the switchboard operator. Thus, the telegraphs could be used to pass the orders when manoeuvring on the surface but it is questionable why they would be used dived. There is a possibility that when dived, the telegraph was set merely to record the last order given.

If indeed the telegraphs were used when the submarine was dived to reflect main motor orders, it could be expected that *AE1*'s telegraphs would be placed to slow or half ahead: a normal order when in the process of diving. If the submarine had (as we are suggesting) a bow-up angle and was attempting to recover from a depth excursion, we would expect to see the telegraph at full ahead.

That the bridge dial is showing half astern can perhaps be explained by the disruption to the fin, which may have subjected the transmission rods to stress and movement. However, given that the rod linkage would require rotating to alter the arrow position, this is not considered a likely explanation.

The only conclusion we can draw from the evidence and from the position of the telegraph is that there is no firm conclusion to be drawn.

6.10 Fin WC soil pipe

Located close to the ventilation trunking is a length of pipework for which no compelling explanation can be offered. It comprises:

- Flanged entry (white), with remains of a metal gasket (also white) – possibly signs of another pipe having been inserted
- Three 2-metre lengths of ~4-inch pipe joined by two flanged joints from which the bolts are missing. Upper section may be a little longer
- No flange on the lower end (open discharge)
- White where the surface is exposed. Some sediment on upper surface
- Appears to have shaped curves in first pipe section (that is, not a straight run).

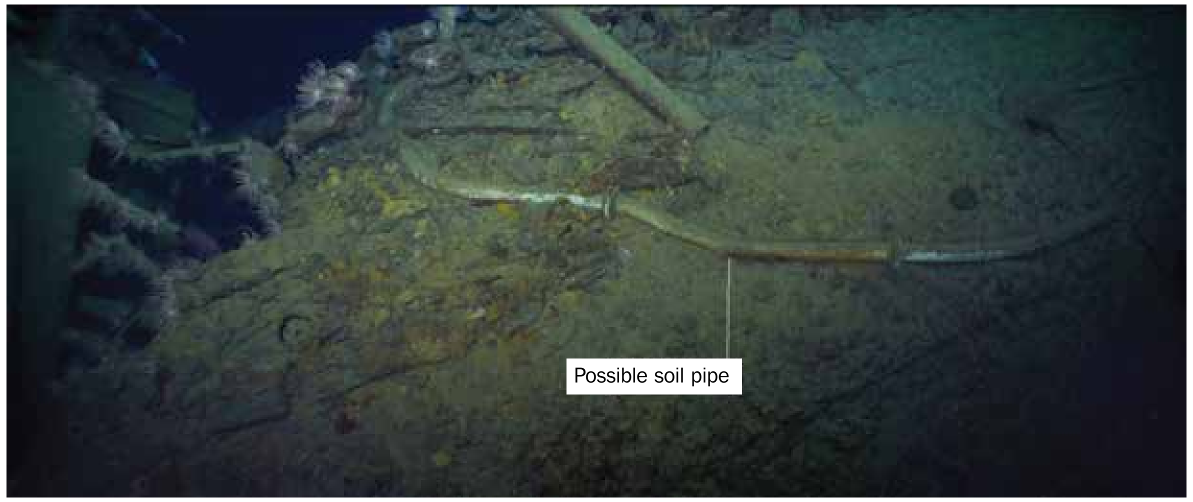

Figure 45 – Possible soil pipe located by ventilation trunking.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

The colour and state of preservation of the pipe suggest that it is made of lead, which was typically used in soil pipework.

The location of the upper-end flange is close to the ventilation system hull valves and directly under the fin WC. Close to it are the blue and white pottery shards which are assumed to be the remains of the fin WC. One possible explanation for the pipe is that the fin WC (shown on the general arrangement drawing as being a simple bucket and seat) had in fact been replaced with a ceramic pan and lead soil pipe. The pipe had been led below the casing such that it would drain directly into the sea.

However, it is hard to determine how a pipe of the length now visible could have been led under the casing and aft of the firing tanks without it appearing in any of the photographs of the time.

Regrettably, no better explanation can be offered.

Figure 46 – Possible soil pipe flanged upper opening (L – the other flange is a battery ventilation inlet) and (R) open-ended outlet.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

6.11 Hull deterioration

The hull has suffered, and is continuing to suffer, deterioration through corrosion.

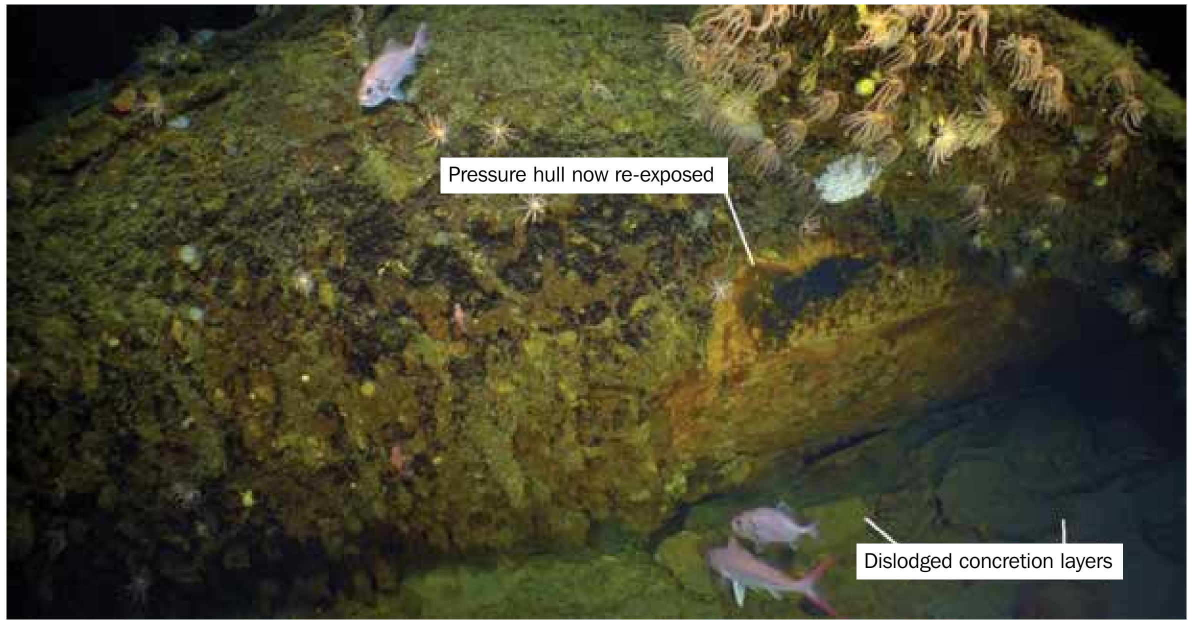

Figure 47 – Example of concretion delamination under foreplane. Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Some areas, for example the fin and stern tube, are remarkably well preserved while others are failing at a significant rate, as noted by the fact that the fin itself has descended by some 0.5 metres in four months. In other areas protective concretion has built up but then been dislodged, possibly triggered by seismic shock. An example is shown in Figure 47.

In many areas there is little concretion build-up and hence no protection. In those areas, the corrosion is active, as shown in Figures 48 and 49.

Figure 48 – Example of plate corrosion under port afterplane.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

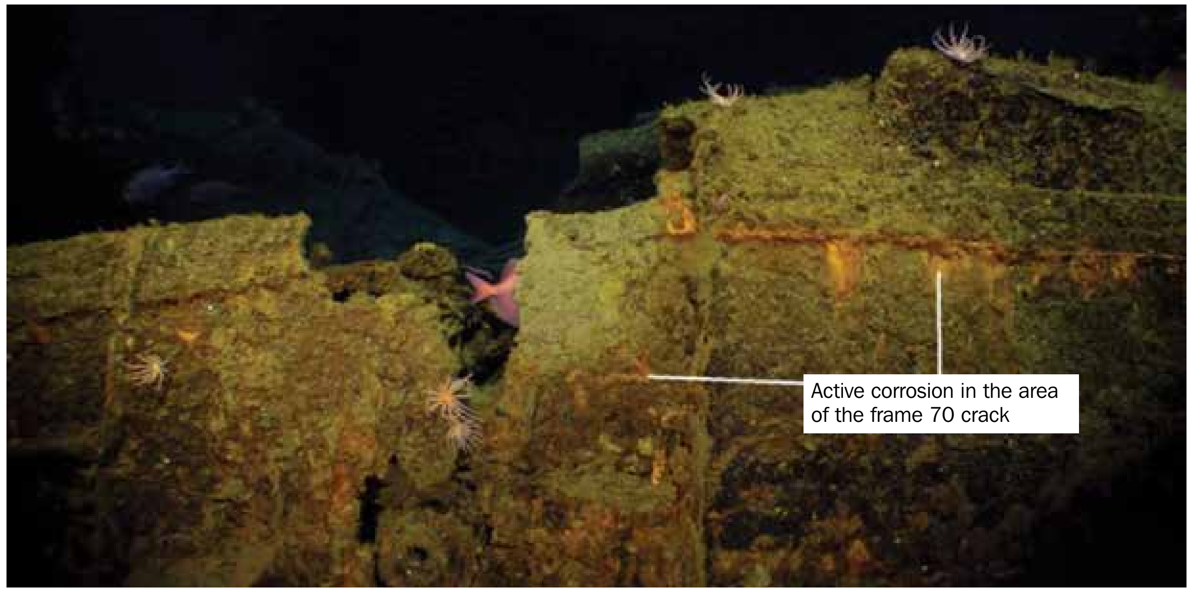

Figure 49 – Examples of (the many) areas of active corrosion.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Observations on the complexities of the corrosion mechanisms of the wreck are made in greater detail in Annex D (see page 102). A significant conclusion of that annex is that 'steel plate of less than 12.5lbs/in^2 has already been fully dissolved and hence is unlikely to be present'. Furthermore, local effects could result in faster decay rates.

6.12 Lower conning tower hatch

Under today's operating procedures, the lower conning tower hatch is shut at a specific point in the diving sequence; hence, knowing the position of the *AE1*'s lower conning tower hatch would be a significant indicator of what the crew were doing at the time of the accident. Given that the toppled fin has exposed parts of the interior of the conning tower, some effort was made to determine the position of the conning tower hatch.

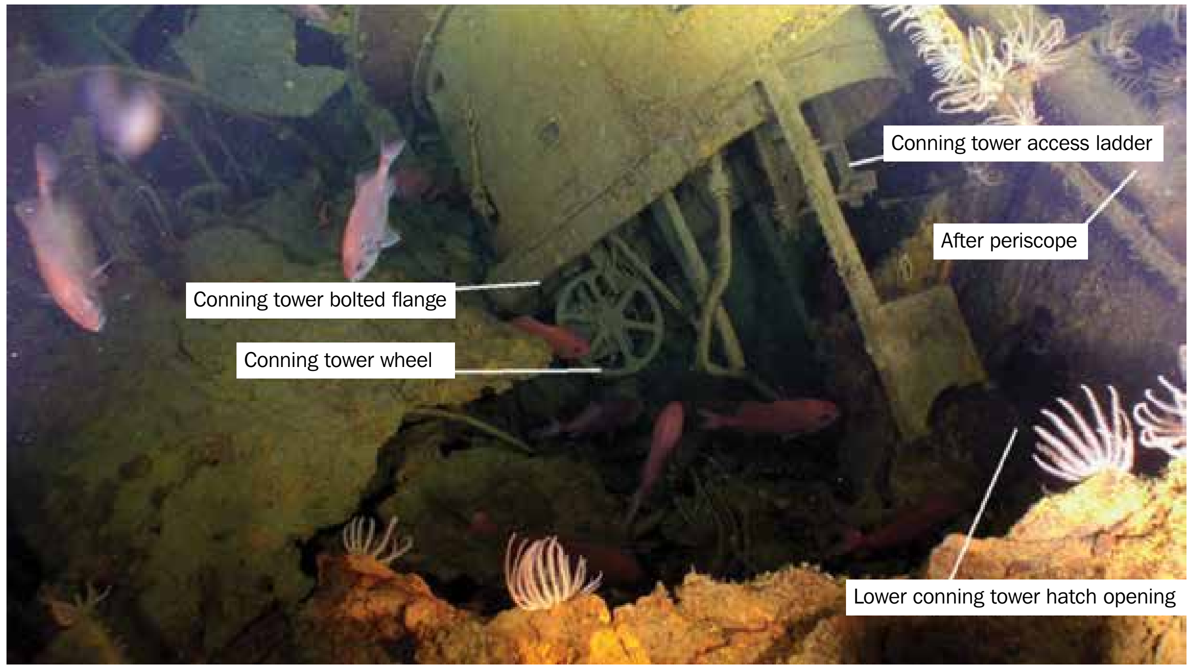

Figure 50 – Underside of toppled fin.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

In doing so, an opening was seen which is in the right location. However, there is no sign of the hatch, the hatch coaming or indeed of the conning tower lower section. These items were all manufactured of 20lb/in^2 steel, although the coaming may have been of a lighter structure. That they have all gone implies that there was a strong corrosion cell in the immediate vicinity of the conning tower upper section which resulted in these items dissolving completely. Regrettably, this means that the position of the lower conning tower hatch cannot be determined.

7 Deductions and sequence of events

The accumulated evidence allows us to draw a number of conclusions and from those to deduce a sequence of events. It must be emphasised, however, that this process requires a degree of speculation. The sequence described satisfies the evidence but the evidence is not necessarily complete and there are probably alternative sequences which would fit. Where presented with alternatives, the simplest solution has been postulated, which leads to the following suggested sequence.

- The submarine was on the surface making best speed on main engines in order to be 'home by dark'.
- The ship's ventilation system was in operation to improve habitability in the tropical conditions.
- Finding time in hand the crew prepared for a practice dive (stow bridge guardrails, etc).
- The crew:
    - Had partially prepared the forward and aft tubes for firing in readiness for action with the German steamer, with bow and stern caps fully open, or
    - Having partially prepared both tubes they then part-shut the forward tube outer door (bow cap) to reduce the possibility of flotsam damage, or
    - Were in the process of preparing the forward tube, thus causing it to be part-open, or
    - Had kept the bow cap fully shut.
- A dive was ordered and main vents were opened – it would be expected that the main ballast tank Kingston valves would have been opened on sailing.
- Upon diving, a flood ensued through the open ship's ventilation hull valve.
- The ship's ventilation quick-closing valve (if fitted) was not shut.
- Attempts were made to shut the ship's ventilation hull valve.
- Meanwhile, the ingress of water caused the submarine to become heavy in trim (negatively buoyant).
- The trim may already have been heavy (negatively buoyant) as a consequence of partial flooding of the stern tube (equivalent of 90 gallons, or 341 litres) and possibly the forward tube (a further 90 gallons or 341 litres). This could still have been the case, even if a trim dive had already been conducted earlier in the day.
- An ingress of seawater through the ship's ventilation system, if not immediately checked, would cause flooding in some or all of:
    - The senior sailors' mess
    - The after battery tank
    - The engine room and
    - The after torpedo compartment.
- The flooding may have caused loss of electrics and possibly loss of propulsion.
- Flooding the engine room lower level could have caused failure of the port main motor and complete loss of propulsion (noting that the starboard shaft was not available when dived).
- The planes were set to rise in an attempt to regain a bow-up angle and arrest the sinking.
- The combination of being heavy aft and operation of planes gave the submarine a bow-up angle.
- The single operating shaft (port) (if applied) was insufficient to drive the submarine upwards.

- Attempts at blowing main ballast (if made) were ineffective (insufficient time to shut main vents, orders not correctly carried out, orders not heard or understood in the noise and confusion, too deep for blow to be effective, etc).
- As the submarine went deeper the increasing seawater pressure would cause a rapid increase to the rate of the flood, hence making the submarine still heavier (more negatively buoyant).
- As the submarine went deeper it would have been compressed, hence making it still heavier (more negatively buoyant).
- At a depth of >90–120 metres the external pressure exceeded hull strength and the forward section in the region of the control room imploded – possibly initiated in the after end of the control room (the largest area of unsupported pressure hull) but ultimately extending further aft to around Frame 55.
- The implosion area extended forward to the forward torpedo compartment (Frame 85), probably initiating around the forward torpedo loading hatch though the implosion across the whole forward area was probably a single event lasting only milliseconds.
- One effect of a partial flood aft would have been to begin raising the pressure in that area, thus reducing the chance of an implosion.
- The shock wave generated by the implosion forward passed through to the after ends, thus equalising its pressure fully and saving it from subsequent implosion.
- The shock wave resulted in an explosive pressure which dislodged the engine room hatch.
- If the lower conning tower hatch were open (as expected at the time of diving) the shock wave would enter the tower and possibly initiate the conning tower flange rupture.
- If the lower conning tower hatch were shut, it is possible that the shock wave would still be felt in the conning tower as the lower hatch was not designed to contain an in-to-out pressure.
- Now fully flooded, the submarine continued down, retaining its bow-up angle.
- With little forward speed, no propulsion but an increasing near vertically downward speed of (assumed) 10 knots it would strike the bottom after a further 30–40 seconds.
- At that angle (3–7 degrees bow-up) the first point of impact would be the skeg and rudder – thus causing both to collapse.
- They having collapsed, the submarine then impacted on the after end of the keel.
- At that angle there would be no contact with the propellers or the underside of the stern tube.
- The submarine then fell forward to impact flat on its keel.
- The impact (which would have been substantial) caused the forward section (unsupported ahead of Frame 70) to continue down, causing the pressure hull to crack at that frame.
- The forward section settled somewhat lower due to the crack but not sufficient for the underside of the bow under-structure or forefoot to contact the bottom.
- If the bow cap had not been part-opened as part of a firing drill (Annex C page 83 – option 4) it could have been part-opened as the consequence of the implosion, its subsequent shock wave, the impact on the seabed or a combination thereof.
- Momentum caused the fin to begin a topple into the collapsed control room, resulting in:
    - the conning tower upper section hinging forward and shearing off at the join with the lower section.
    - The ventilation trunking separating from the fin and falling onto the pressure hull without scattering.
    - The fin WC pot falling from its stowage in the fin and shattering on the pressure hull.
- Plating on the after section of the fin was torn away from both fin and casing. It has not been identified in the seabed debris.
- The 'pancake' impact resulted in much damage to the lighter structures, for example the ballast tanks, which if they were full (or part-full) of water following the dive would have been heavy.

- Momentum and cantilever effect caused the planeguards to shear off and carry straight down.
- The impact caused a section of the forward battery (from row 6 aft) to crush the (possibly also imploded) ballast tank underneath it (MBT internal X), allowing that section of the battery to settle by some 0.4 metres.
- Either during the implosion or some time after, some part of the high-pressure air system failed, causing the spiral wound gasket to be deposited outside the pressure hull.
- Erosion/corrosion is causing the hull to continue to deteriorate.
- Loss of structural strength in the area of the control room due to the corrosion is allowing the fin to continue its descent into the control room. It has been seen to fall by around 0.5 metres between December 2017 and April 2018.
- Some large areas of concretion can be seen to be ‘peeling’ from the pressure hull.
- Continued damage to the concretion on the pressure hull may be triggered by the shocks associated with the seismic events regularly experienced in the geographic area of the wreck.
- Removal of the concretion will exacerbate corrosion of the pressure hull in the areas so affected.
- Exposure of the ruptured metal to the erosive effect of current-borne (largely ‘sharp’ volcanic) sedimentary sands may in some areas be contributing to the deterioration.
- This effect is reduced with distance from the seabed, hence (for example) the leading edges of the afterplanes show greater deterioration than the fin.

8 Conclusion

The Fugro Report concludes that the condition of the wreck of HMAS *AE1* and the observations made in the December 2017 search allow deductions to be made from which it is possible to conclude that the submarine foundered as the consequence of a loss of trim and or control while diving or dived and that any remedial action then taken was inadequate, possibly being aggravated by there being only one propeller shaft available when they were dived.

The evidence gathered on the *Petrel* expedition does not alter that conclusion in principle. However, it does suggest that the loss of trim occurred on diving and was the consequence of:

- A flood resulting from the open ship’s ventilation valve, or
- Being heavy (having negative buoyancy) as a consequence of preparing the stern tube and perhaps the bow tube, or
- A combination of both.

A difference in conclusion is that the additional evidence demonstrates that the submarine first impacted the seabed at a bow-up angle of 3–7 degrees.

Importantly, a further conclusion from the *Petrel* evidence is that the hull is continuing to deteriorate at a significant rate.

Finally, these comments have been derived from an examination of the extraordinarily comprehensive *Petrel* imagery. It is not claimed that that examination has been exhaustive and there is every possibility that the continuing examination and analysis may reveal further clues as to what happened.

The sequence of events can be represented graphically as follows:

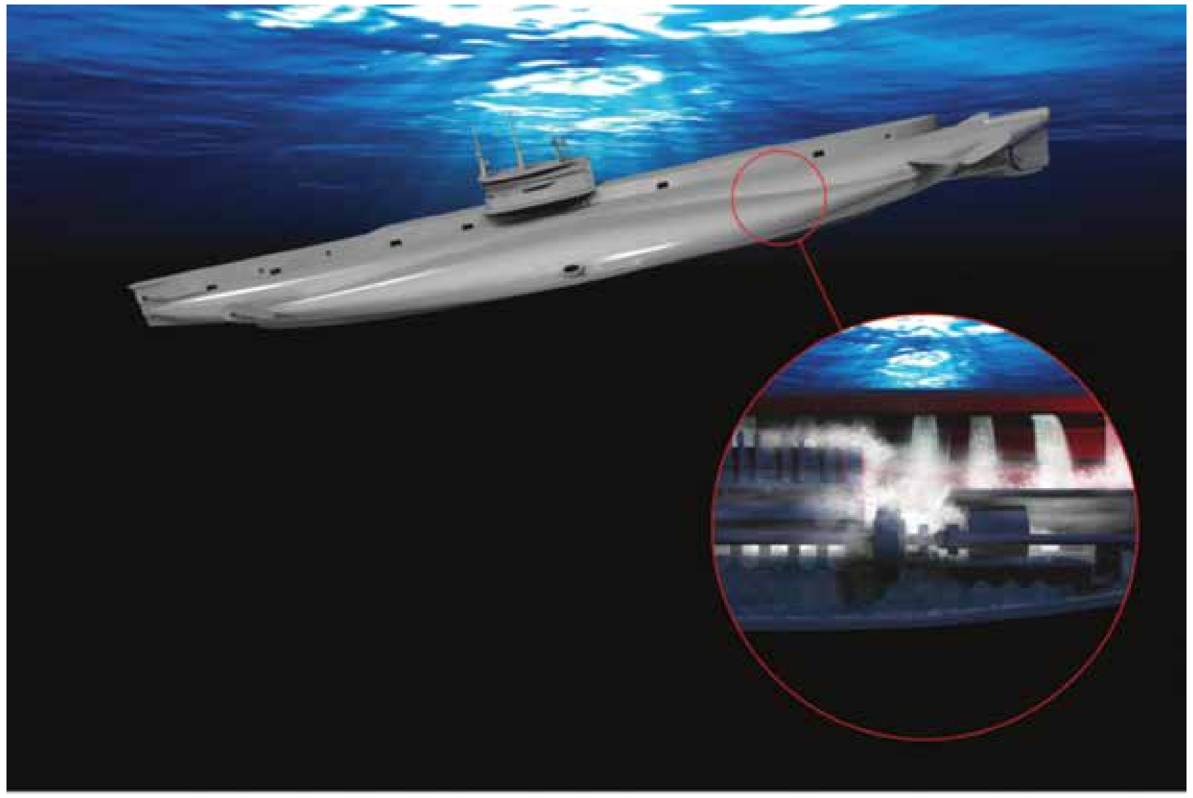

Figure 51 – *AE1* diving at or near periscope depth suffers a flood, resulting in loss of buoyancy and trim.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

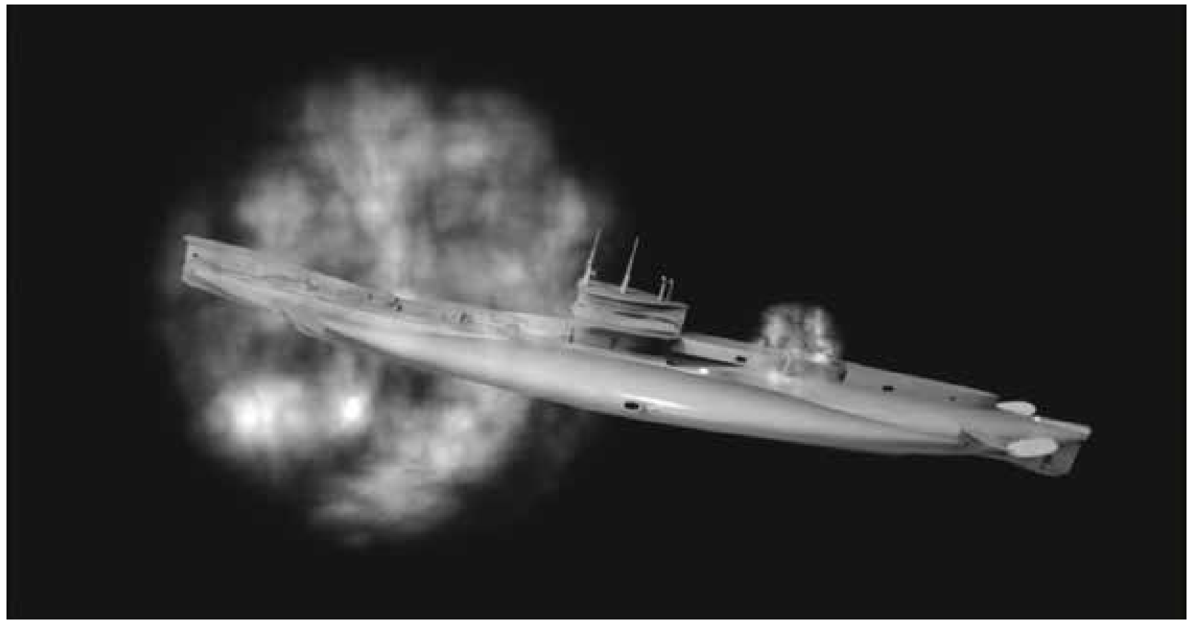

Figure 52 – Unable to recover, she carries on down until reaching crush depth when the control room and forward area implodes. The shock wave blows off the engine room hatch.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Figure 53 – *AE1* continues down, gathering way until she strikes bottom at a bow-up angle of 3–7 degrees, impacting on the rudder and skeg.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Figure 54 – The skeg and rudder collapse and a second impact occurs on the after end of the keel.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

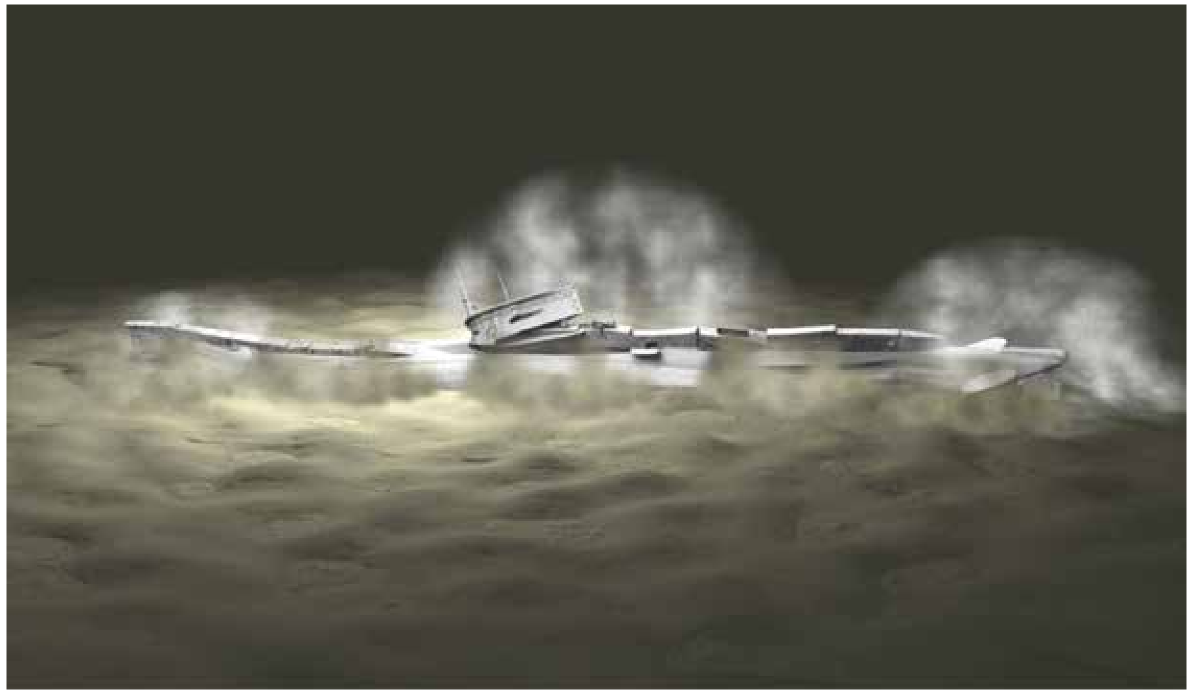

Figure 55 – The hull falls onto its keel, resulting in a third wave of damage, including dislodgement of the hydroplanes and initial dislodgement of the fin.
Image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University. © Navigea Ltd

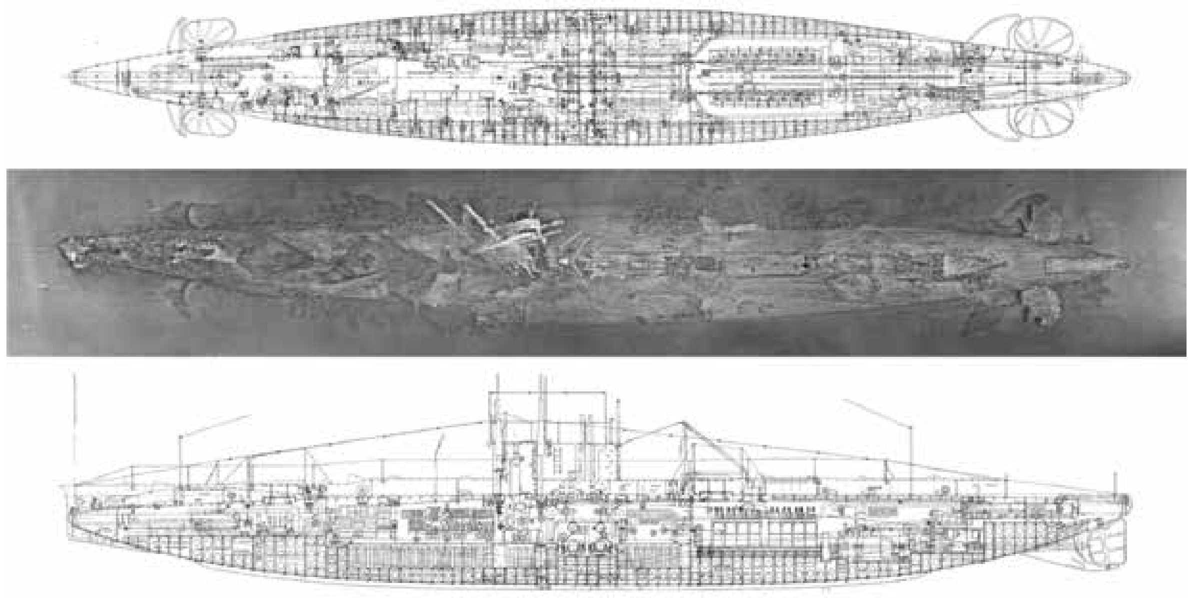

Figure 56 – HMAS *AE1* photogrammatic image and general arrangement overlay (see enlarged on fold-out following page 180).
Photogrammatic image courtesy of Paul G Allen, Find AE1, Australian National Maritime Museum and Curtin University.
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Endnotes

1 *HMAS AE1 – Finding the Men of* AE1 – 20 December 2017, January 2018 – the Fugro Report.

2 *Specification of hull for a submarine boat of E-Class* (NAA Series MP551/1, control symbol 109/1, barcode 889901), HMSO, London, 1914.

3 Ship's drawing No. 0142, 'Standard sluice valve submarine pattern'.

4 Ship's drawing No. 2823, 'Arrangement of bridge steering and engine telegraph gear'.

Annex D
Corrosion on the wreck site of HMAS *AE1*
Duke of York Islands, New Britain, Papua New Guinea
A report for Find AE1 Ltd

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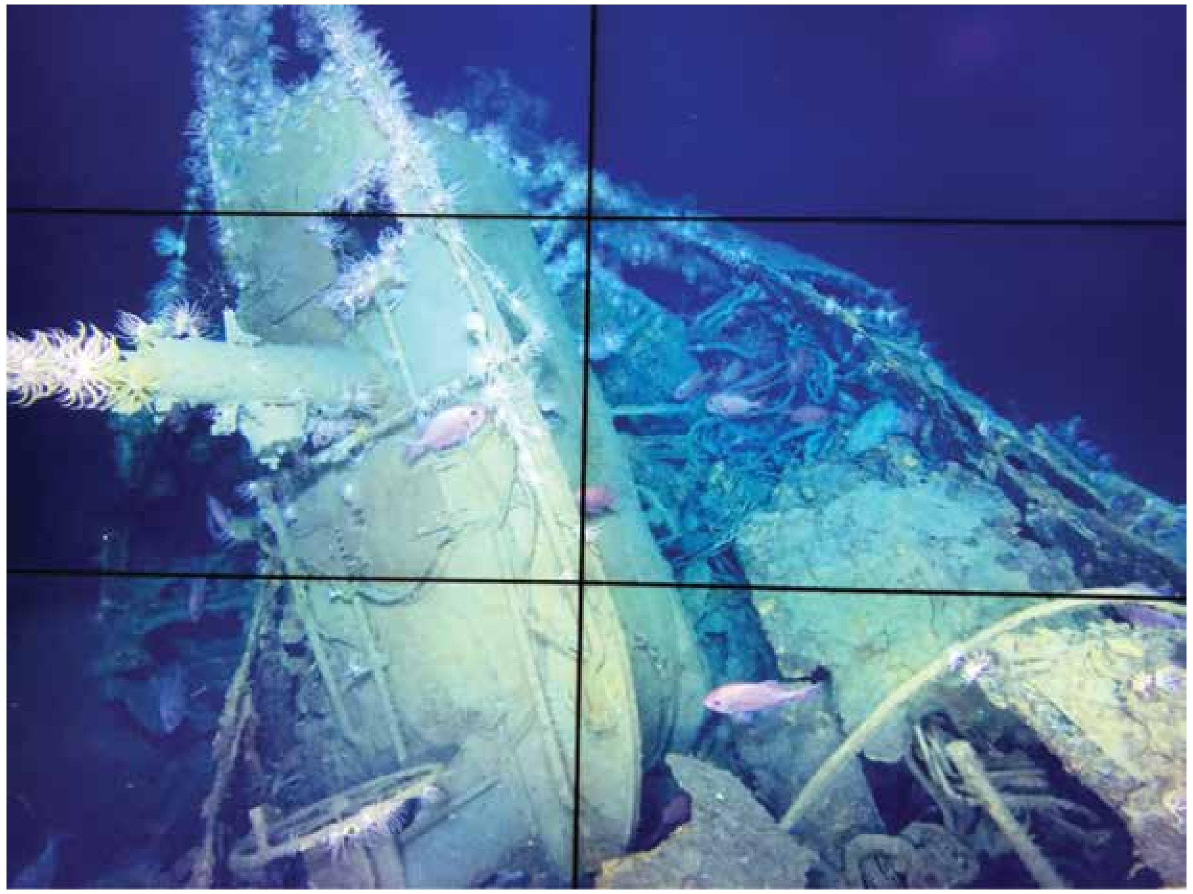

View of the fin and residual pressure hull showing implosion damage.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

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Executive summary

The physical oceanography of the wreck site was recorded by *Fugro Equator* on 18 December 2017 at depths up to 1500 metres. Both temperature and salinity profiles are complex, but the variables were linearised against water depth so that reasonable estimates of the wreck site conditions of the HMAS *AE1* site can be interpolated.

In the first 160 metres the salinity increases due to the diminishing influence of fresh water coming from the outflow of rivers and streams entering the surface waters. After the impact of fresh water has been overcome through dilution, the salinity decreases linearly with increasing water depth until just over 400 metres. The salinity reaches a plateau level at ~500 metres. Plots of the log of salinity versus depth enable the salinity present at the *AE1* site to be estimated at 35.0 ±0.8‰.

The temperature versus depth profile shows a linear decrease of the log of the temperature with increasing depth which gives a calculated wreck site value of 11.6˚C. When combined with the calculated salinity value the maximum dissolved oxygen content on the wreck, which is interdependent on temperature and salinity, is 8.8 parts per million. Studies on dissolved oxygen by the US Navy in deep water off the Californian coast show that at the depth of the *AE1* site the dissolved oxygen was 1.4 parts per million, which represents 16 ±1.5% of the surface value. This level of dissolved oxygen, when combined with an average current of up to 3 knots, means that the wreck is likely to have suffered significantly more corrosion than the sister vessel, HMAS *AE2*, lying at 73 metres in the Sea of Marmara.

Analysis of the April 2018 images of the wreck site has provided a snapshot into the overall rate of decay of the submarine, which is significantly higher than that of her sister ship HMAS *AE2*. The *AE2* is presently being conserved *in situ* with sacrificial anodes. There is characteristic rusticle formation on *AE1*, which indicates that the normal protective calcareous deposits are not forming on this boat. The decay processes are more akin to those on the very deep wreck sites of HMAS *Sydney II* in 2480 metres off the Western Australian coast.

Inspection of the corrosion damage on *AE1* shows that there is active rust formation which is consistent with mechanical collapse of structural elements leading to separation of the components of the boat. The combination of high current and the depth preventing calcareous deposits, as well as galvanic corrosion reactions from the fin, all indicate that a major collapse of the already damaged structure will occur in the next 5–12 years.

In summary it is concluded that:

- HMAS *AE1* is in an active corrosion environment, causing deterioration of the wreck at a pace which is probably double that of the deterioration of her sister ship HMAS *AE2*.
- The principal corrosion cell is being driven by the manganese bronze conning tower such that any steel plate of thickness less than 12.5 pounds per square foot (7.8 mm thick) has already been fully dissolved and is hence unlikely to be present.
- Local effects (galvanic, microbial or both) could accelerate deterioration in some areas.
- The pace of deterioration is such that after another 80 years it is likely that the only remaining structure other than the conning tower itself will be the engine bed plates.
- Without the data from future monitoring it will be difficult to confirm the overall conservation heritage management plan for this historic site, which forms a pivotal point of Australia's maritime heritage.

1 Background

The loss of HMAS *AE1* and all her crew in mysterious circumstances in the early stages of World War I has been well documented by others in earlier sections of this report. Being at the significant depth of >300 metres in what is essentially total darkness, it is not readily feasible to conduct a series of *in situ* corrosion measurements to determine what the conservation management of the site should be. In late 2017 the wreck was found. This marked the end of 13 searches for the vessel and in April 2018 good fortune smiled on the 'Find the men of *AE1*' team with the availability of the Research Vessel *Petrel*, which was made available to the *AE1* team to spend two days of detailed photographic documentation of the wreck. The corrosion observations have been based on the oceanographic data collected in the 2017 expedition by *Fugro* in December 2017 and on the video and still imaging conducted in April 2018.

2 Methodology

During the scramble to assemble the correct gear for capturing stills of the HMAS *AE1* wreck site the combined skills and experience of Tim Eastwood from the Western Australian Museum and Dr Andrew Woods from the Curtin University Hub for Immersive Visualisation and e-Research (HIVE) developed in a very short time frame the necessary cameras and lights that would be needed to get high-definition still images of the wreck. Without good lighting and high-definition cameras the imaging that has been used to tell the story of HMAS *Sydney II* and the HSK *Kormoran* wrecks would not have been possible. Although the physical size of the submarine and the light cruiser were significantly different, the technical challenges of operating equipment at depth cannot be underestimated. Oceanographic data was obtained from the *Fugro Equator* vessel and the complex nature of the water column between the surface and the wrecked boat at >300 metres has been previously reported (MacLeod 2018) and is reproduced here in an edited and updated form.

3 Introduction

The *Fugro Equator* assessed the physical oceanography of the area on 18 December 2017 at the position located off Mioko Island, Papua New Guinea, under job number GP 1587. The data was recorded at 1951 hours using the Midas SVX2 probes with Serial numbers (SN) 27530 and 27962. The seawater pH was 7.50 and the data relating to salinity and temperature were recorded up to depths of 1538 metres. The pH of the surface seawater was low due to the dilution impact of fresh water with the deep ocean waters. This is reflected in the fall of alkalinity from a pH of 8.1 ±0.1 for normal seawater, and makes the surface waters six times more acidic than typical values of seawater at 36 parts per thousand (‰). Statistical analysis has been conducted on data to the first 1000 metres since the next 500 metres of profile shows systematic trends in temperature and salinity.

4 Temperature

The surface temperature is essentially constant for the first 60 metres, after which it begins to fall in a logarithmic fashion to 470 metres, as shown in Figure 1. Beyond the depth of 470 metres the rate at which the log of the temperature falls with increasing depth is one third of the value relevant to the wreck site. This data is not shown in Figure 1 but is available on request.

Table 1 – Linear regression analyses on salinity to 160 metres and log temperature profiles

	27530 linear slope	27962 linear slope	27530 Intercept	27962 Intercept	27530 R^2	27962 R^2
Salinity 0–160m, ‰/m	0.0149 ± 0.0018	0.0129 ±0.0013	33.85 ± 0.17	33.79 ±0.13	0.9274	0.9239
log ˚C 0–470m	-0.00154 ± 0.00004	-0.0015 ±0.00004	1.5913	1.5892	0.9867	0.9910

Using the average depth of 350 metres for the wreck of *AE1*, the temperature can be calculated according to the equation 1 below:

$\log T_{350\ \mathrm{metres}} = (1.5913\text{-}0.0015*350)$ … (1)

The calculated temperature from both 27530 and 27962 was 11.6 ±0.1˚C.

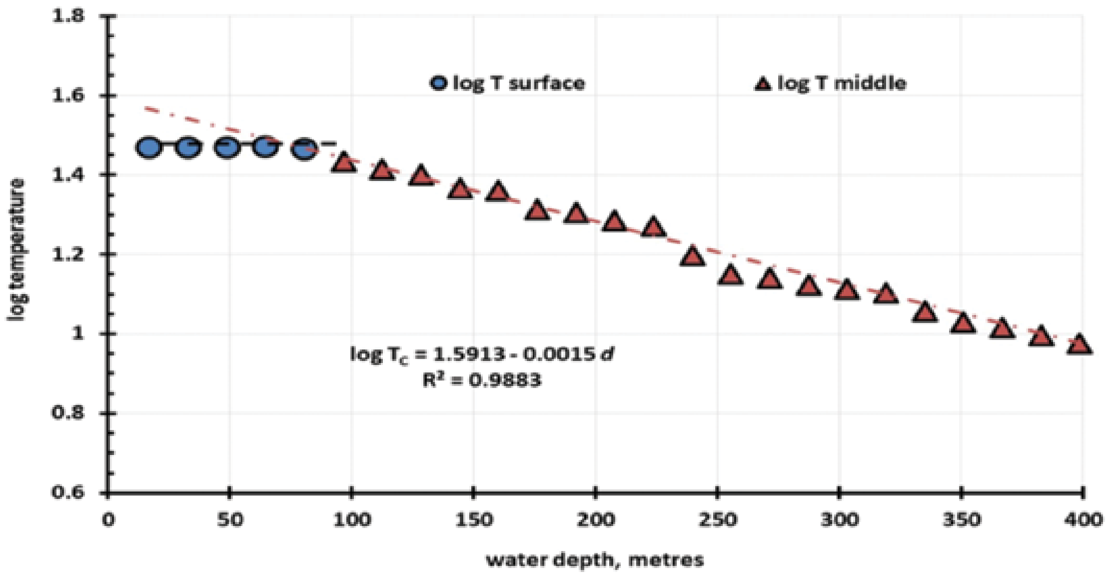

Figure 1 – Typical plot of the temperature profiles with depth in the waters adjacent to the *AE1* wreck site

5 Salinity

The salinity profiles showed more complex behaviour in that both sensors showed a linear increase in salinity for the first 160 metres and from that point onwards the salinity regularly fell with increasing depth, as shown in Figure 2. The data from the regression analyses (Table 1) showed that the period of increasing salinity with depth varied from +0.0149 ±0.0018‰/metre to 0.0129 ±0.0013‰/metre, depending on the instrument. Since the sum of the standard deviations of the two slopes is greater than the difference between the slopes it is apparent that both sensors recorded the same effective rate of increasing salinity with depth. The intercept values for the sensors were 33.85 ±0.17‰ and 33.79 ±0.13‰. The two linear regressions give intercept or starting points at surface waters, which are within 0.06 parts per thousand of each other and, since the sum of the standard deviations of the values is 0.30, this shows that the different intercept values are statistically indistinguishable from each other, as would be expected from analyses carried out at the same time and same day on the same site. The increasing salinity with depth is due to the gradual mixing of normal seawater with fresh water influx from the nearby terrestrial systems.

Inspection of the graph in Figure 2 shows that after reaching a maximum at 160 metres the salinity falls parabolically over the next 440 metres to reach a steady deep-water value of ~34.7‰. The salinity data analysis was then restricted to cover the depth range of interest to determining the values on the *AE1* wreck site. So when the salinity data from 160–400 metres was plotted against depth there was a strong correlation for a linear regression line, as shown in equation 2, which had a good R^2 value of 0.9612. The linear relationship allowed prediction of the salinity at the wreck site depth at 34.95 ±0.01‰

S ‰ = 36.63 – 0.0048 *d* … (2)

Using the calculated temperature of 11.6˚C and the above salinity, the maximum dissolved oxygen content at an air–seawater interface would be 8.75 ppm oxygen. The error in the intercept value was ±0.08 (0.2%) and the error in the slope was ±0.00029 or 6%.

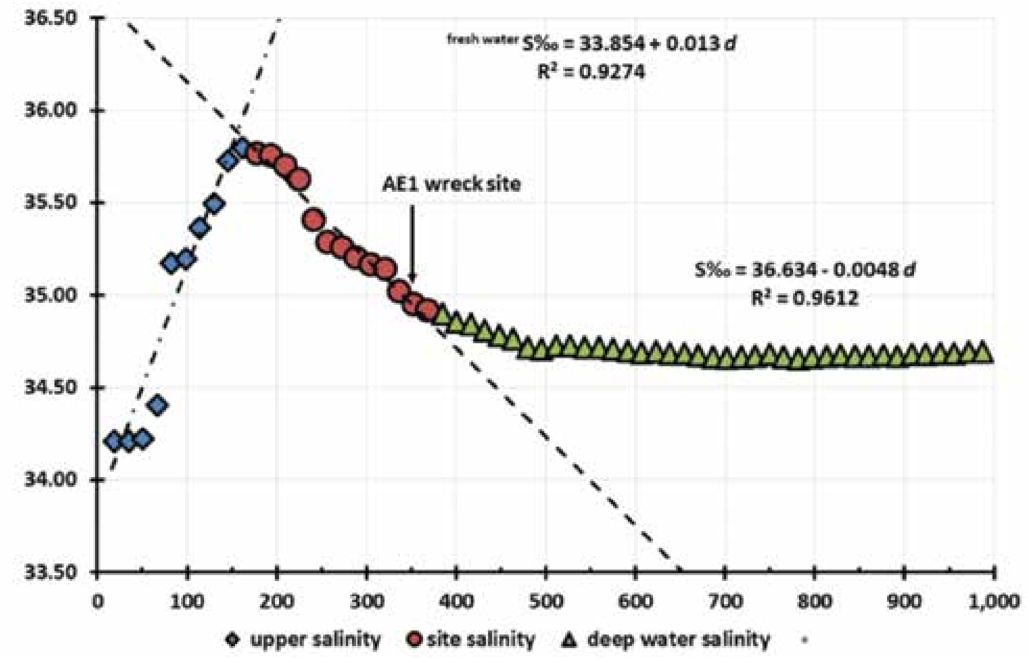

Figure 2 – Plot of the variations in salinity with water depth with both linear and cubic relationships

When the data from the two sensors is compared over the depth range of 160–400 metres the calculated surface salinity (assuming no influx of fresh water) was 36.6‰ and 36.5‰ for the 27530 and 27692 metres respectively. Since the surface salinity readings were of the order of 34.2‰ this provides an estimate of the impact of fresh water from the nearby islands of a dilution factor of 2.6%, which takes about 160 metres of mixing with deeper ocean water to bring it back to expected levels. Over the same depth range, the salinity from sensor 27530 falls at the rate of 0.00480 ±0.00029‰/metre, which is experimentally the same as the rate observed in unit 27962 of 0.0045‰/metre.

In the absence of data directly obtained on the *AE1* wreck site, it is worth considering active measurements of dissolved oxygen on deep-water sites in the Pacific Ocean that were assessed by the US Navy for long term (12–18 months) corrosion experiments (Reinhart and Jenkins 1972). Plots of the dissolved oxygen versus water depth shows complex behaviour where the concentration of oxygen initially decreased from surface levels until it reached a minimum at ~600 metres. At the equivalent depth of the *AE1* site the amount of dissolved oxygen was 1.4 ppm, which represents a saturation point of 16 ±1.5%. This concentration of dissolved oxygen is still sufficient to provide a significant corrosive force that will consume the steel of the submarine. In comparison with the *AE2* wreck at 73 metres in the Sea of Marmara, this submarine is at a salinity varying from 38–41‰ with dissolved oxygen levels at the depth of the wreck varying between 3–5 parts per million. While the current on the *AE2* site was ~0.2–0.5 knots the reported current over the *AE1* was up to 3 knots. Since corrosion rates are determined by the flux of dissolved oxygen to the metal surface, concreted or unconcreted, the product of dissolved oxygen and current for *AE1* is 4.2 ppm.knot, while that for *AE2* varies between 1.0–2.5 ppm.knot. Note: this means that the *AE1* site is roughly twice as corrosive as the *AE2* site in Turkey. As will be seen in the subsequent section, which discusses the lack of calcareous concretion on the *AE1* site, the net impact of the lack of concretion and the higher flux of dissolved oxygen is that the corrosion of the first submarine is going to be much higher than observed on her sister boat.

For a more complete discussion regarding the variations in temperature and salinity down to the depth of 1000 metres, please refer to the initial report on the oceanography of the HMAS *AE1* wreck site (MacLeod 2018). The overall salinity of the waters around New Britain is largely controlled by the movement of less saline water from the deep waters of the North Pacific Ocean, whence it flows past New Guinea and across Australia's north through Torres Strait and across Indonesia, where it eventually meets up with currents in the North Indian Ocean (http://ocean.stanford.edu/courses/bomc/chem/lecture_03.pdf). This phenomenon explains why the salinity on the site falls from the maximum value of 35.7 at 160 metres down to a plateau level of 34.6‰ at 500 metres depth. This amounts to a fall of only 0.3% in the salinity at the end of December 2017, so in the overall scheme of things the subtle changes in salinity are not going to have a material effect on the decay rate of the submarine *AE1*.

6 Corrosion processes via the video log and still images

It was noted that the colonisation by anemones was much more intense on both the bow and stern caps than in all other locations on the shipwreck site. Similar localised colonisation processes were viewed on the HSK *Kormoran* (1943) wreck compared with the HMAS *Sydney II* and this is most likely due to the higher phosphorus impurities in the *Kormoran* mild steel which would have been using less than military specifications for the alloys used in its construction (MacLeod and McCarthy 2016). Under the cover of corrosion products from the oxidation of the metallic iron a suite of anaerobic bacteria converts inorganic iron phosphide (Fe_3P) inclusions present as the eutectic phase steadite. Because of their metabolic activity bacteria convert the inorganic metallographic phase into volatile phosphines which promote marine growth, since phosphorus is normally a limiting agent to growth of marine organisms, particularly in the darkness of deep ocean waters (MacLeod 1988).

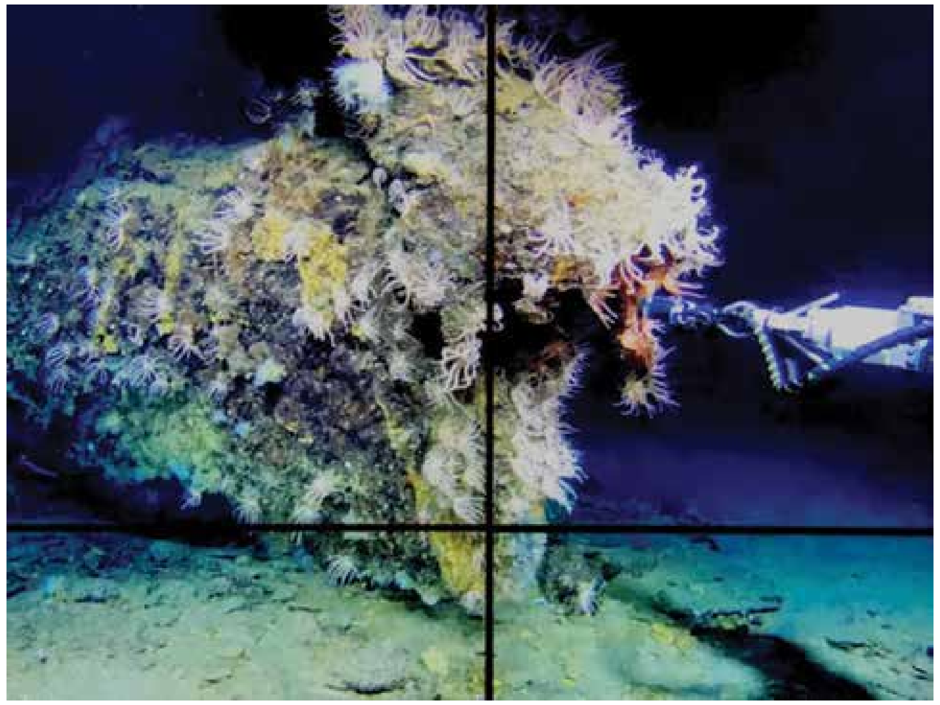

Figure 3 – Image of the bow cap with prolific marine growth from dive 90. The black horizontal and vertical lines that appear in most of the images are because they were photographed off the high-resolution tiled display at the Curtin University HIVE visualisation facility.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

The reason why there is much greater growth of the brisingids on the bow and stern caps is due to their different composition, as they are most likely cast iron elements or cast steel which has a richer phosphorus impurity level in it than the plates used in the construction of the casing, the ballast tanks and the pressure hull itself. Under the bow section there appears to be some scouring loss of the seabed, which is consistent with local water movement being associated with the current experiencing resistance from the structure.

Note: Metal thickness expressed in pounds per square foot can be readily converted into steel plate thickness by multiplying the pounds per square foot value by 0.622.

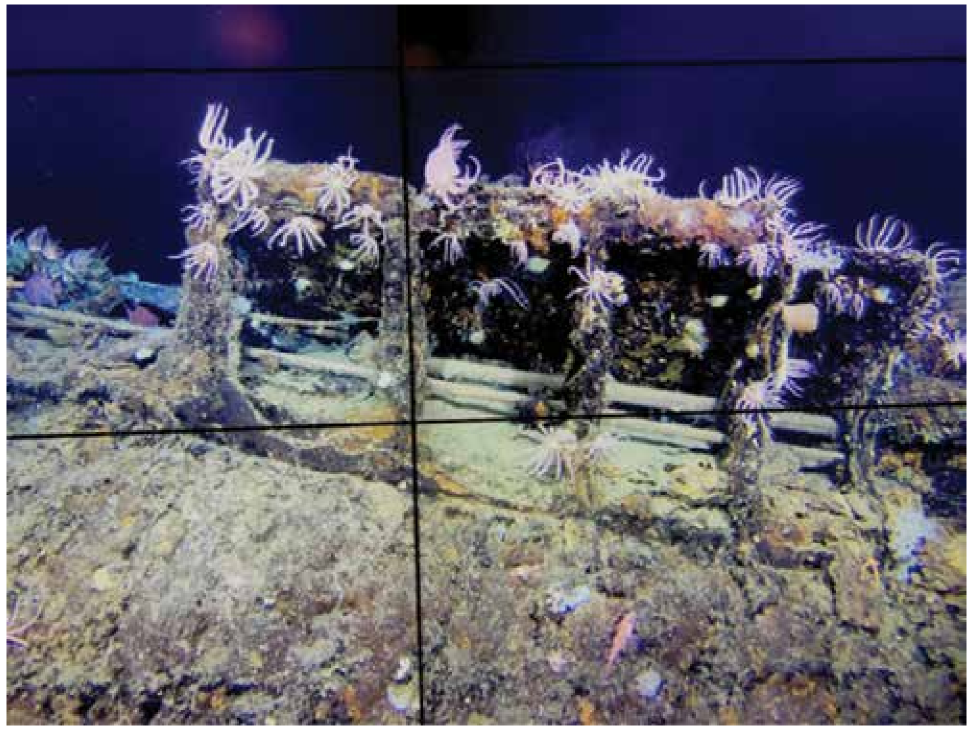

Figure 4 – A few metres aft of the bow the 17-pound (10.6 mm) plate of the forward firing tank has corroded away leaving the frames in a half-corroded state.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

At the foot of the first frame on the left-hand side of Figure 4, a section of metal and corrosion products has been exposed and the smooth external surface is indicative of the original surface, with remnants of the grey paint visible. In this image there is also a line of yellow staining from iron(III) corrosion products which is consistent with the recent separation of a section of the original plating from the frames within the previous few weeks before the image was recorded. The 5-pound (3.1 mm) plate of the adjacent casing has gone altogether. It is curious that the starboard side of the firing tank has corroded completely while the port side remains largely intact, despite the fact that the prevailing current would impact primarily on the port side. The different rates of corrosion could be explained in several ways but suffice it to say that something has caused a difference in the molecular structure of the two sides which has ultimately resulted in a significantly different rate of decay. Detailed analysis of a 3D model may provide the answer.

Interpretation of the image shown in Figure 5 shows that there is a clear line of separation of the plating associated with the frame that supported the plates attached to the casing and the secondary colonisation of the iron in the upper quadrant indicates that there is a high level of activity from sponges. The most striking element about the surface of the submarine is the absence of marine concretion, which characterises corroded iron wrecks in the first few hundred metres of submerged depth. Rusticles, such as those seen in Figure 3 in the lower section of the forward bow cap, dominate the wreck site of HMAS *AE1*. Rusticles from the RMS *Titanic* (1912) have been characterised by scanning electron microscopy and consist of an outer brittle shell of the red-brown iron(III) mineral lepidocrocite (γ FeOOH) with a mixture of goethite (orange) (α FeOOH) and other minerals such as iron(II) carbonate siderite ($FeCO_3$). Among other corrosion products was the iron silicate hisingerite ($Fe_2Si_2O_5(OH)_4.2H_2O$), with the source of silicon being the skeletal remains of siliceous diatoms whose constituent elements are mobilised by bacteria present in the matrix (Stoffyn-Egli and Buckley 1995).

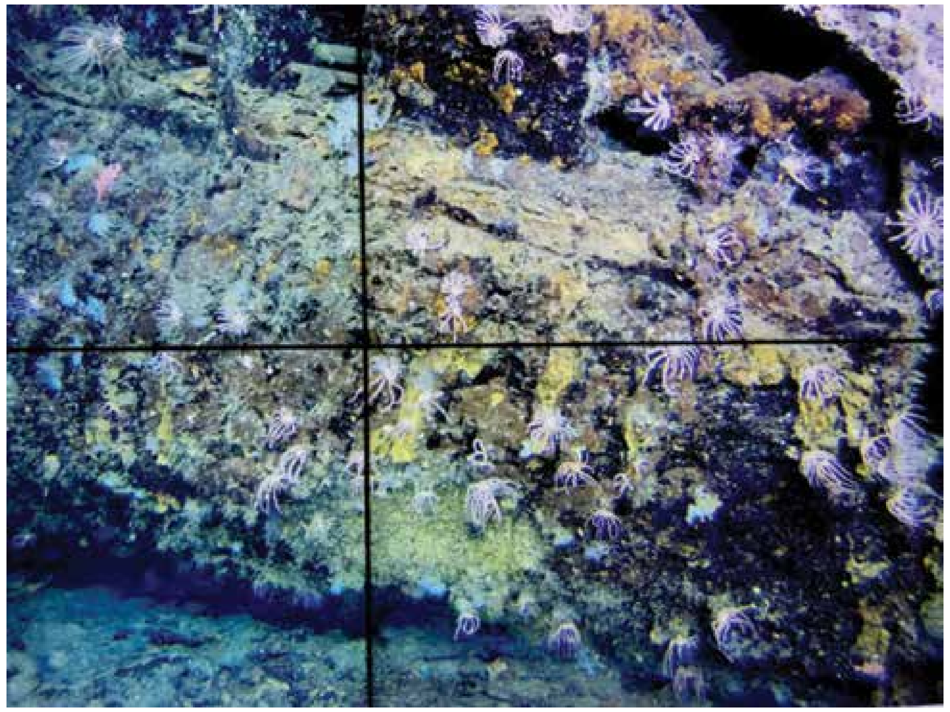

Figure 5 – Some weeping rusticles on port side and apparent separation of hull plates.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

There are also some signs of weeping iron(III) corrosion products which is consistent with a non-concreting microenvironment. Normally associated with deep-water iron shipwrecks such as the RMS *Titanic* and the HMAS *Sydney II* and the HSK *Kormoran*, the increased solubility of calcium carbonate with increased water depth (and associated pressure) means that the characteristic concretion that grows on marine iron is largely absent from this wreck site. This difference in chemical behaviour of the corroding iron surfaces is quite critical to the rates of decay on the submarine. The impact of water depth on the local chemistry is summarised below in Figure 6. The brown circle points in the graph documents the solubility product (K_{sp}) for calcium carbonate dissolving into its constituent parts:

$CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-}$ … (3)

Since the concentration of carbonate ions is also in chemical equilibrium with its decomposition into carbon dioxide and water, it follows that with increasing depth (pressure) the solubility of calcium carbonate would increase, as shown in the graph (Figure 6).

$CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$ … (4)

Over the range of interested depth values the solubility product increases by 0.0023 per metre according to equation 5:

$10^9 K_{sp} CaCO_3 = 4.696 + 0.0023\,d$ … (5)

The ionic product of seawater crosses the solubility line at ~180 metres, so below this depth calcium carbonate is no longer supersaturated in open ocean seawater and from that point on, calcium carbonate will spontaneously want to dissolve in seawater.

Examination of the footage on the HMAS *Sydney II* shows that the 70+ year old paint coating on the exterior of the hull is in generally good condition and that most of the corrosion activity seems to be associated with the massive amount of scatter from gunfire affecting the light cruiser. Wherever bullets and shells hit the mild steel plate the protection of the paint was lost and so the area experienced localised corrosion. The reason why concretion does not form on the *AE1* site is due to the ionic activity product (IAP) (the combination of all soluble ions in seawater) falling below the solubility product. This change takes place after a depth of ~180 metres, which also explains why sedentary epifauna on deeper wreck sites are dominated by soft-bodied marine organisms such as sponges, anemones and ascidians.

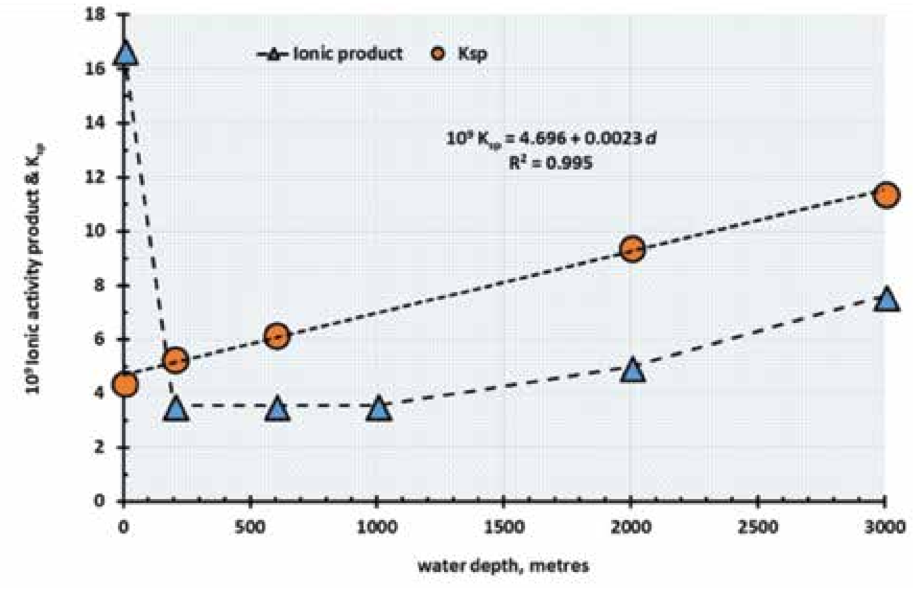

Figure 6 – Plot of solubility product (K_{sp}) and ionic activity product (IAP) as a function of water depth (using data from Feely et al., 2002)

The corrosion processes on the *AE1* submarine are a mixture of the steady localised decay leading to the formation of 'flowing' fronts of iron corrosion products (rusticles) and pitting corrosion such as seen in Figure 7 at the seam line between hull plates. Rather than produce a massive flow line of continuing corrosion products, these areas relate to the reactions in narrow confines or pits. Pitting reactions can spontaneously cease or at least become stifled through the formation of electrically isolating corrosion products such as lepidocrocite and goethite, as seen in this image. This localised pitting reaction is different to the nearby section shown in Figure 8 which is adjacent to the fin, which can be seen on the left-hand margin of the image. Given that the fin is made of non-ferrous metals, most likely a manganese bronze as detailed in the build specifications, and it is in direct electrical contact with the iron submarine, there will be a significant galvanic action, which was first observed by Sir Humphrey Davy in the 18th century. Such an electrical connection means that the corrosive forces are present for a considerable length of time, which is why the development of a mound of corrosion products does not stop and become stifled by the red-brown rusty decay products. Iron oxidation will continue underneath the surface layers and the mobile Fe^{2+} ions diffuse through defects in the lepidocrocite layer, whereupon it is subject to oxidative hydrolysis that produces the outflowing rusticle form.

The lack of calcareous marine concretion on the submarine has been described above but the apparently curiously bare metal look of the non-ferrous metal alloy in the fin structure is now fully explainable, in the light of the data shown in Figure 6. In shallow waters the more noble metal of the galvanic couple becomes cathodic, which is where the reduction of oxygen occurs. This electrochemical interaction normally increases the local surface pH and brings about precipitation of a protective concentration of inorganic calcite ($CaCO_3$). This coating can be seen inside the fin on the *AE2* submarine in Turkey. Owing to the ionic product being below the solubility product at a depth of >300 metres, this protective reaction cannot occur and so the impact of the galvanic coupling goes on until there is no remaining iron to inhibit corrosion of the brass structure. It was noted by team members that there was a marked increase in the forward angle of the fin against the hull structure in the few months between the *Fugro* and the *Petrel* documentation trips. These observations are consistent with issues observed during repeat submersible visits to the RMS *Titanic* site where it was surmised that the stirring up of oxygenation levels caused by the ROV motors, etc, was accelerating the decay. What in fact was happening was that the gradual decay of the iron structure would get to the point where there was insufficient residual thickness in the metal to support the structure. At this point it then appeared to undergo a rapid collapse, but it is just that the time for a good residual thickness had come to an end.

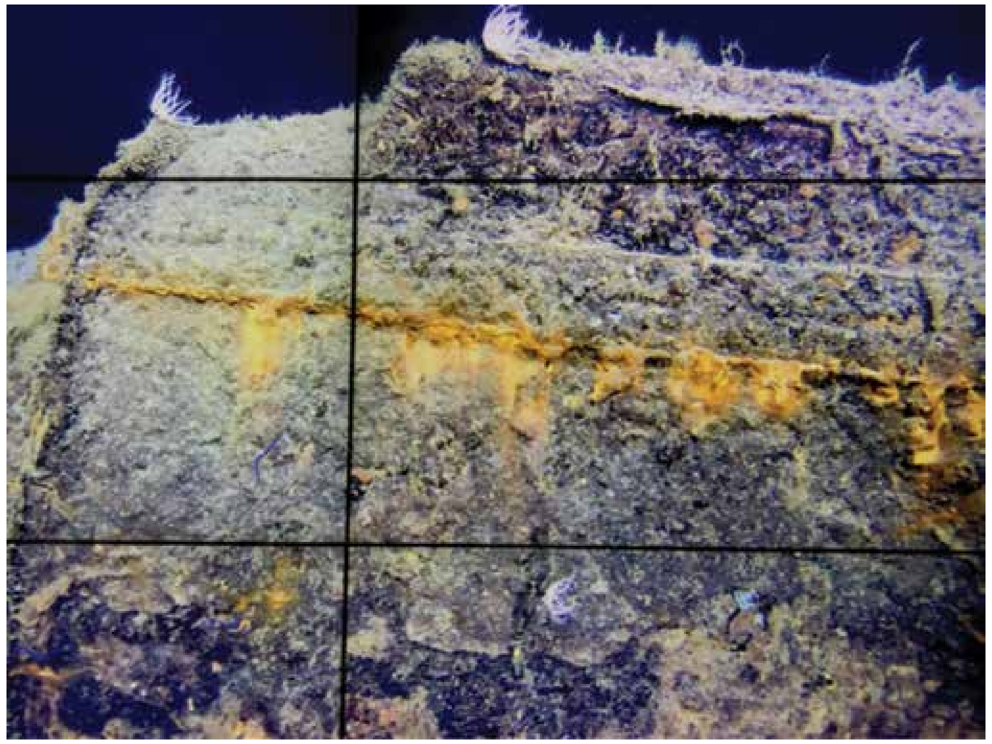

Figure 7 – Image 90-16134, showing corrosion at the join between plates below a doubling line.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University.

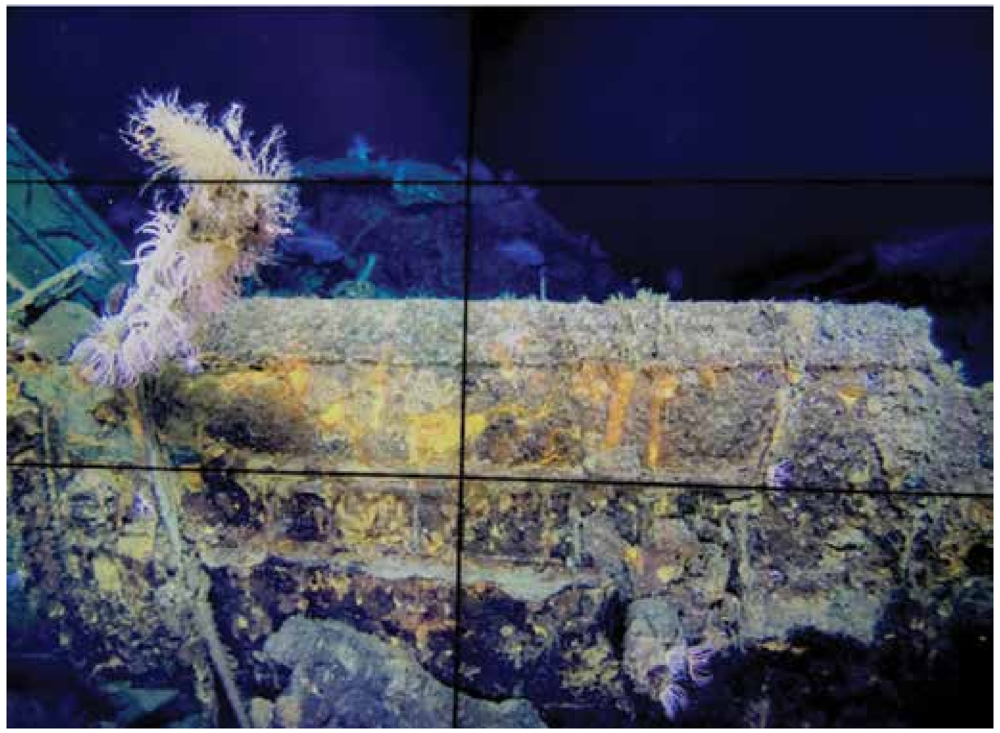

Figure 8 – Upper section of the submarine (starboard side of control room) showing weeping corrosion lines from the horizontal seam. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum, and Curtin University.

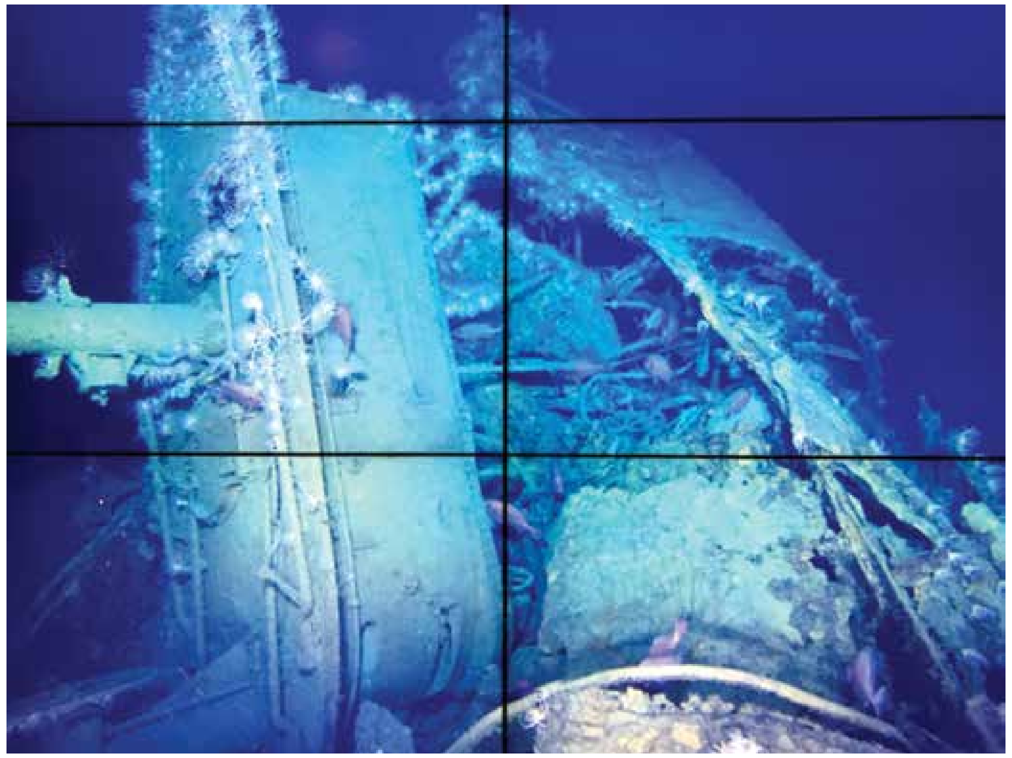

Figure 9 – Image 91-76913, showing fin free of marine concretion and a section of the pressure hull.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University.

The pressure hull at the maximum diameter of the submarine was made of 20-pound plate and an inspection of the corrosion data calculations in Table 2 indicates that even with galvanic coupling due to contact with the manganese bronze of the fin (60% Cu, 37% Zn, 2% Mn and 1% Sn) there is still about 5.6 mm of solid metal present in the pressure hull. The image 91-76913 (Figure 9) shows the well-defined remnant hull structure in the immediate vicinity of the fin. Although the residual metal represents a 45% loss of metal thickness since the submarine sank, there is still sufficient metal present to enable the form of the submarine to be maintained. These estimates of corrosion are based on 16-year experiments on various metal couples using a noble metal to iron ratio of ~1:7 (Zheng 2011). Naturally, corrosion issues will be exacerbated by the high current flowing through the site, but the data provide a guide to what can reasonably be expected to survive. Where galvanic corrosion is present the negative values for residual metal thickness shown in Table 2 simply mean that all the metal has corroded away, so in the worst-case scenario of galvanic corrosion any plate thickness less than 12.5 pounds per square inch is unlikely to be present. In addition, local effects (galvanic, microbial or both) could add to the rate of deterioration. Since there is no active concretion mechanism operating on the site, the once solid elements will be corroded away and removed by the current to feed the fishes.

It is noted that the extent of galvanic-induced corrosion will increase as the ratio of noble metal area compared with reactive metal increases. Owing to the very large surface area of the manganese bronze fin, the impact of this coupling on the parts of the submarine immediately adjacent to it will have been very significant. When this localised corrosion process is considered it should be remembered that there is also the added issue of microbial corrosion and differential aeration which further exacerbates the iron decay. Given that the specifications of *AE1* and *AE2* noted that the steel had to be able to withstand significant bending without brittle fracture, as would happen with cast iron, the collapse of the fin becomes more understandable. As the combined corrosion processes thin down the original 20-pound plate, the ability of the steel to support the deadweight of the fin and the dynamic load presented by the resistance of the fin to the prevailing current will diminish until it begins to fail under the tensile load. The fin will gradually topple forward, which only increases the stress and the concomitant corrosion rate on the remaining structure. This continued loss of support metal explains why the declination angle of the fin has increased in the time between the two surveys. It is possible that engineering modelling may be able to calculate when the fin first began to fall and so provide more of an idea of the overall degradation rate on this wreck site.

On inspection of the image 91-77813 shown in Figure 10 it was noted that there is essentially no living organism on the flat smooth surfaces of the fin, which appears to be sitting in an almost pristine condition on the wreck site. However, at the leading edges of the structure and on piping leading from the fin there is localised colonisation of the surface with the endemic marine organisms. Given that marine bacteria regularly utilise cycling of manganese ions in their metabolic processes it is likely that the marine organisms are utilising surface corrosion products to enhance their microenvironment. Thus, the enhanced growth on the edges of the fin and its fittings is likely to be due to marine organisms capitalising on the energy source associated with manganese, rather than with phosphorus as is likely on the bow and stern caps. Just as the localised increase in marine activity on the stern and bow caps was viewed as being a response to the release of phosphorus-containing species, resulting from anaerobic metabolic activity (Iversen and Olson 1983), so too the voltage gradient at the sharp edges is sufficient to bring about a subtle change in the corrosion microenvironment. Although the voltage of the fin will be the same throughout the structure, the voltage gradient in terms of the charge distribution is always higher at sharp edges. These differences are clearly enough to provide a niche environment for the colonising organisms. Within the biofilm on the fin's surface there will be a niche microenvironment for the anaerobic bacteria to mobilise the phosphorus in the copper alloy.

Table 2 – Calculation of residual metal (mm) after 103 years of corrosion

Structure	Pounds per square foot	thickness mm	Residual metal max	Residual metal min	Residual metal galvanic
Casing	5.00	3.11	0.12	-2.87	-3.74
Deck	7.00	4.35	1.36	-1.63	-2.49
Hydroplanes	7.38	4.58	1.60	-1.39	-2.26
External ballast	8.50	5.28	2.29	-0.69	-1.56
Ends of ballast	10.00	6.21	3.23	0.24	-0.63
Battery brackets	12.50	7.77	4.78	1.79	0.92
Shafts propeller	15.00	9.32	6.33	3.34	2.47
Transverse frames	17.00	10.56	7.57	4.59	3.72
Firing tanks	17.50	10.87	7.88	4.90	4.03
Hull plates < 15.5' Dia.	19.00	11.80	8.82	5.83	4.96
Hull plates > 15.5' Dia.	20.00	12.42	9.44	6.45	5.58
Broadside torpedo	23.00	14.29	11.30	8.31	7.44
Engine joists	61.30	38.10	35.11	32.13	31.26

Images of the hydroplanes indicate that there is still some residual metal present and so their physical construction makes it likely that they have suffered corrosion from a single surface (seaward) leaving an estimated 1.6 mm of metal. This observation is also consistent with them being in electrical isolation from significant non-ferrous metals; that is, there is no galvanic coupling.

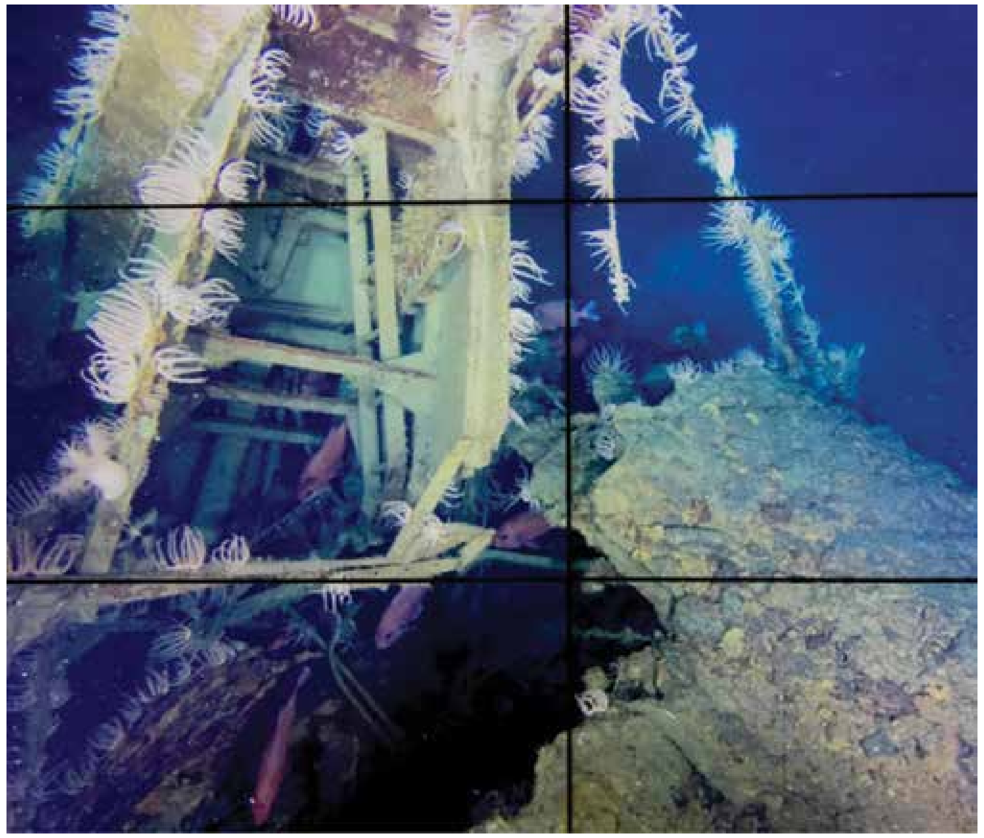

Figure 10 – Image 91-77813, showing ladder inside fin and marine organisms on leading edges of the structure. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

Inspection of the stern of the vessel shows up the increased colonisation of the stern caps due to the higher phosphorus content of the special cast steel and the impact of the anaerobic bacteria on the mobilisation of the phosphorus impurities in the alloy. It would be good to examine historic samples of all the steel and non-ferrous metals from the Vickers yards to see if a detailed metallographic map could be made of the *AE1* and the *AE2* submarines. A characteristic of the galvanic coupling from the propeller to the drive shaft and the 'A' bracket seen in image 91-76390 (Figure 11) is that the bracket is continuing to corrode despite the inherently passivating nature of the formation of lepidocrocite on the surface of the fixture. In this situation the passive partner in the galvanic coupling is the propeller.

It is of considerable interest to look at the blue colour of the copper alloy stern tube outer seal through which the propeller shaft passes out of the boat to the external environment. The bolts are clear of any fouling by marine organisms, as is now expected for the site, but the intense blue of the gland fitting is due to the bronze alloy being cathodic and so the local pH has increased and has caused secondary mineralisation of malachite, $Cu_2(OH)_2CO_3$. Although the fitting is essentially galvanically protected there will still be a low corrosion rate and under the conditions of the combined impact of the dissolved oxygen level and the 3-knot current, there is sufficient corrosion taking place to get the patination that is observed. It is interesting to compare the patina on the fin and the propeller as they reflect different alloy compositions, with the propeller having a thicker covering of passivating corrosion products, which inhibit some of the impact of the galvanic corrosion coupling.

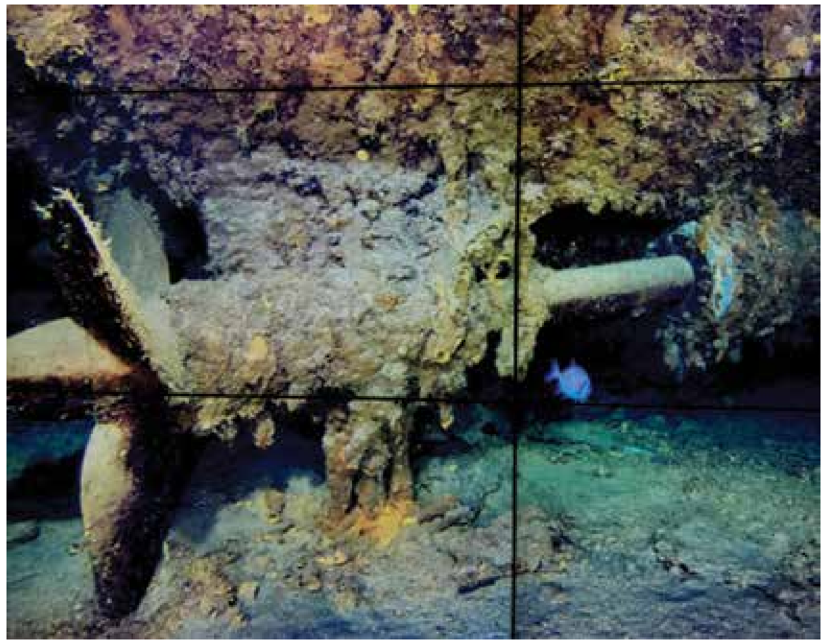

Figure 11 – Image 91-76390, showing starboard propeller and rusticles flowing from the A bracket.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

The image no 91-79170 (Figure 12) provides confirmation of the material loss of iron from the submarine in the region of the ballast tanks, which were 8.5 pound per square foot, and according to the data in Table 2, there is between -0.16 and -0.7 mm of residual metal thickness left; that is, there are large holes in the structure, which is clear. The interior image thus exposed is of the pressure hull, which is intact with a calculated residual thickness of between 5 and 5.5 mm, depending on either combination of both sides corrosion or galvanic coupling. It is important to conduct periodic monitoring, on a 5 to 10 year time frame, to monitor the decay of the residual metal structure. At present there are only two points, which are close together and only a few months apart after more than 100 years of decay in the warm, deep, tropical waters off Mioko Island. Without the data from future monitoring it will be difficult to confirm the overall conservation heritage management plan for this historic site, which forms a pivotal point of Australia's maritime heritage.

Figure 12 – Image 91-79170, showing ballast tank holes overlaying the pressure hull.

Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

The image shown in Figure 12 illustrates the general distribution of iron corrosion products on the hull, with weeping runs of soluble iron precipitating in the oxidising microenvironment of the wreck site.

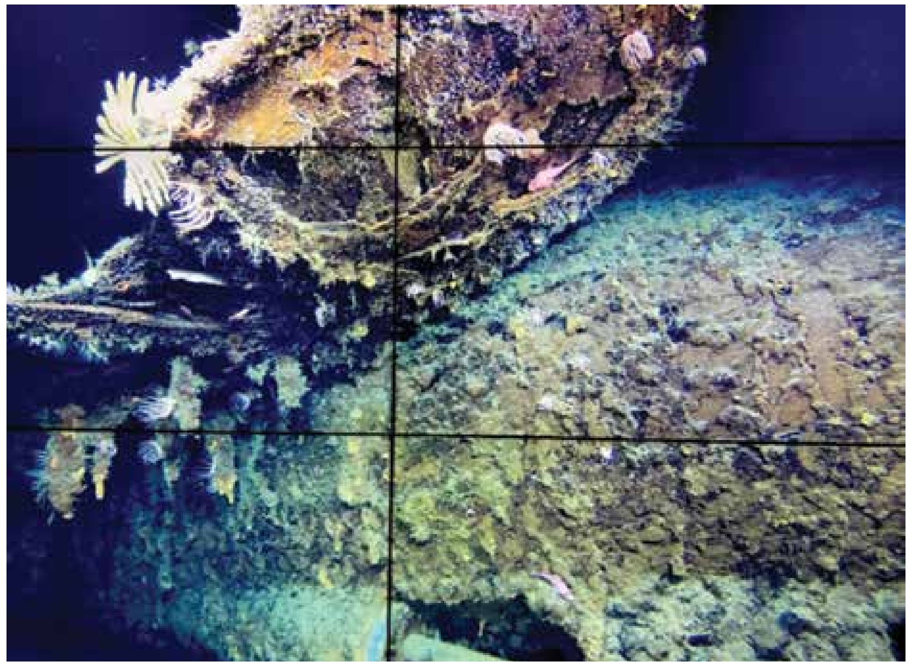

Figure 13 – Image 91-76463 of the port aft hydroplane, showing partial skin loss.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

With a calcareous concretion, the corrosion loss would be less apparent, and a concreted wreck would provide a false preservation image, for it would seem to be sound but there would be large areas of no residual metal content. In the image of the aft port hydroplane (Figure 13, image 91-76463) the lower half shows that the metal has been lost to the elements, which is consistent with the data in Table 2 for a 7.4-pound plate undergoing corrosion on both sides of the skin or being subject to a mixed abrasion corrosion regime from a single face. The metal loss is consistent with a residual metal thickness of -1.4 mm while the balance of the coverage over the framework of the hydroplane shows a slightly lower corrosion rate that has left a very thin layer of metal about 1–1.6 mm thick. At this thickness the metal has very little resilience for surviving accidental impact with an ROV. The mixed plate survival on the hydroplane agrees with the calculated values shown in Table 2 of between -1.4 and +1.6 mm thickness.

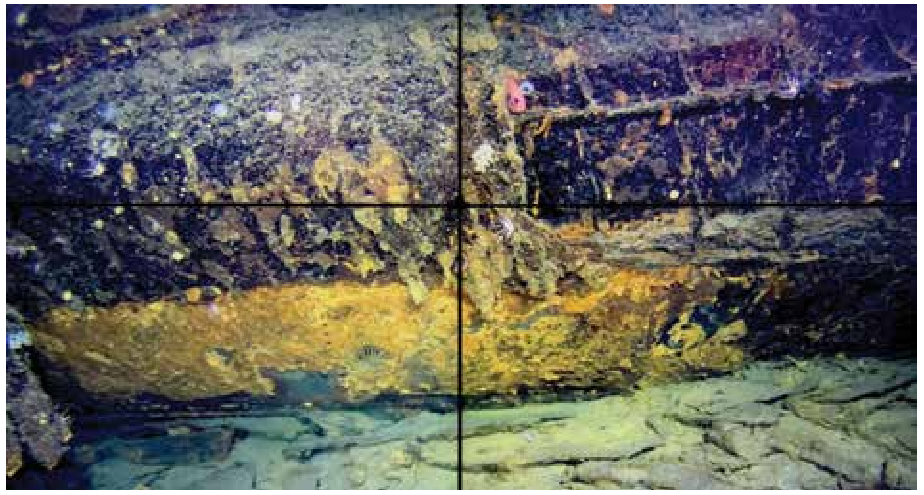

Figure 14 – Image 91-78424, showing significant active corrosion of lower hull plate among debris.
Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

This penultimate figure (Figure 14) shows the pressure hull of the submarine in an active state of decay, with all the plate on the right-hand side having gone, leaving the heavier-gauge frames. This view is consistent with an area where the external ballast tank has sheared off from the pressure hull – probably the consequence of the bottom impact. The tank would have been flooded and hence very heavy – the momentum of the bottom impact would have caused it to shear: hence the debris on the seabed immediately below. The lower half of the image, around the grilled opening which is probably the starboard bilge and ballast line outlet, is undergoing sheet corrosion. What used to be submarine structure lies on the seabed in a scattered and heavily fragmented pattern. This debris field is likely to have arisen from the force of the bottom impact when the submarine hit the seabed and the relatively high corrosion rate, brought about by the combination of a moderate level of dissolved oxygen and a strong current. It is noted that a whole line of rivets on the left of the bilge and ballast line outlet has disappeared and this indicates that the lower plate has recently come away from its frame support and the minimal protection it had with the soft-bodied marine colonisation has been lost. The upper sections of the image also have active rusticle formation. There is an overall impression of an actively degrading submarine lying on the seabed.

The image in Figure 15 shows three of the five ventilation trunks which once rose from their associated hull valves to their vented openings inside the after section of the fin. The bright white flanged opening has been the subject of considerable debate as to its function and purpose and where any waste material may have exited the submarine. However, some advice on the corrosion products formed on the non-ferrous metal alloys may be of assistance in managing the wreck site. It is highly likely that the piping is a lead alloy as material of this type has been used since the 1870s for removal of waste from steamships through direct porting to the external seawater. Owing to the ease of formability of lead, it was found that in a constrained physical environment the addition of antimony brought about a significant improvement in mechanical strength. The need to overcome the tendency of pure lead to creep and not to maintain its structural form is why the 12-tonne keel for the *Australia II* yacht was cast from a lead–antimony alloy (MacLeod and Kelly 2001). Assuming the colour in the image 91-76750 is reasonably accurate, the off-white patina of the pipe seen top left of the image is likely to be lead sulphate (anglesite) with some mixed lead–antimony oxides, which have a pale brown hue and have been found on 'lead sculptures' where there has been oxidation of the as-cast eutectic alloy composition (MacLeod 1991).

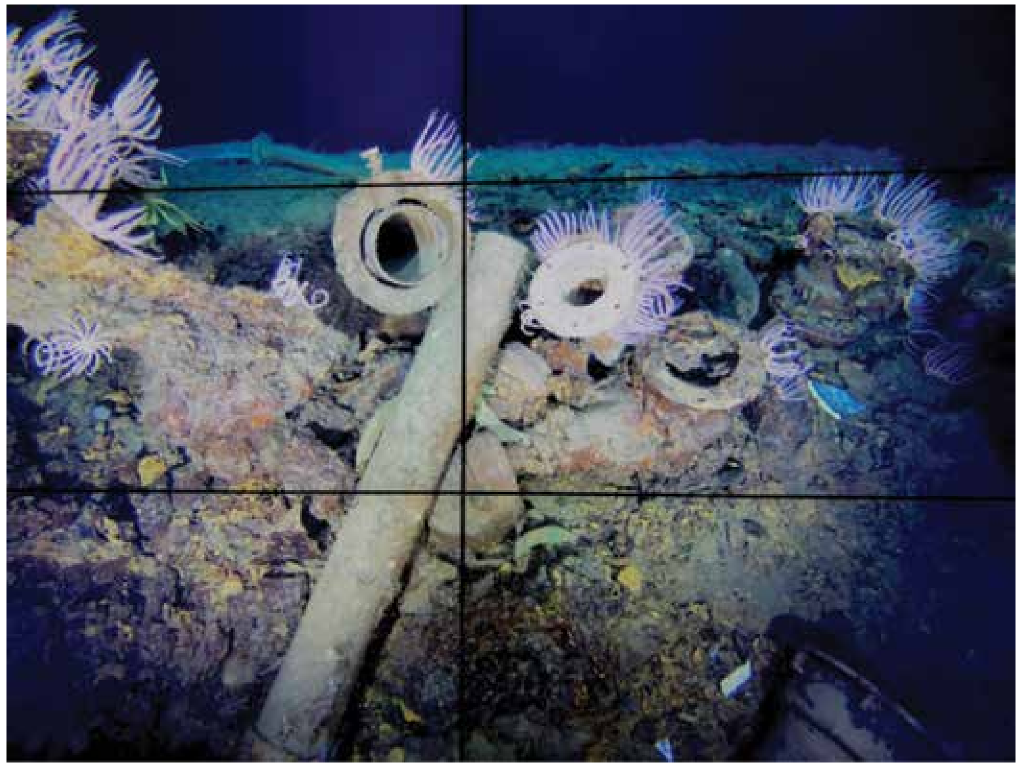

Figure 15 – Image 91-76750, showing debris field of ventilation trunking and flange plates probably associated with waste removal. Image courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Navigea Ltd

It is very likely that there is a range of lead and lead–antimony alloys used in the construction of the waste removal system, which is why there is a variety of colours in the patina of the objects. When a lead alloy was being used as a flange seal for a pressure line it is likely that a lead–antimony alloy would have been used, as this will be less likely to lose its mechanical strength under tension and compression. Owing to the ease of fabrication of this system of alloys and the way in which the addition of small amounts (1–3%) of copper produces products that have a very fine surface finish, there is nothing in this image that is inconsistent with the piping and gaskets being made of various alloys in which lead was the principal component. A point of confusion as to why some gaskets appear to be made of copper may be cleared up if they were in fact made of something akin to Britannia metal, a tin–lead–antimony–copper alloy. Selective corrosion of copper can occur when the lead-rich phases have become passivated with adherent corrosion products. Some of the differences in patination are also likely to be due to galvanic coupling between iron of the submarine and the lead alloys. Although the voltage difference in flowing seawater between lead and iron is significantly less than the coupling between copper-based alloys and iron, if there had been galvanic coupling of the lead alloys it is unlikely that the impact would survive to the present times, for lead passivates quickly in seawater (MacLeod and Wozniak 1996). Lead and its corrosion products have good erosion resistance in currents up to a few knots, which is why it was used as an outer sheathing layer of copper-sheathed sailing vessels at the gripe, where the high water flow would too quickly erode the copper sheet (MacLeod and Wozniak 1997).

7 Conclusion

Subject to verification from metallographic and spectrophotometric analysis of standard materials in the Vickers shipyard collection, or samples from the Imperial War Museum, it appears that the variable intensity of marine colonisation of the wreck site is due to the chemical formulations used in the construction of the boat. The greater intensity of the feather-like marine organisms (brisingids) on the bow and stern caps indicates that the special cast steel had a higher phosphorus content than the mild steel plate used throughout the submarine. It is a well-established outcome of anaerobic bacterial corrosion that microorganisms have the enzyme capacity to reduce phosphorus from +3 (phosphides) oxidation state to -3 (phosphines). This reduction process makes inorganic solids volatile and so provides colonising organisms with a unique energy source, since both phosphorus and iron are normally limiting reagents that control cellular activity and dramatically affect reproduction and growth rates. In the absence of analytical results from the time of construction the differences in the extent of colonisation provide a unique insight into the composition of the structural elements of the submarine. Although the composition of manganese bronze listed in the general arrangements does not include a percentage of manganese, modern alloys do include between 2.5–5.0% manganese. Marine bacteria living in the colonising organisms are well adapted to utilising the cycling of manganese redox systems to assist in their metabolic processes. The localised colonisation around the fin and its structures is likely due to these processes.

The forward movement of the fin over the space of a few months most likely reflects the gradual thinning of the residual metal thickness of the supporting steel structure amidships. Calculations of the long-term corrosion rate have been based on US Navy trials and other long-term – up to 16 years – tests in marine locations in deep waters off the Californian coast in the Pacific Ocean. It is interesting to note that there is a diminution of the dissolved oxygen with increasing depth but that after 1000 metres the prevailing currents can lead to localised increases in the supply chain of the primary oxidant for marine iron and steel structures. The minimum corrosion rate assumes decay from a single face, with limited water movement on the interior surfaces of structures and the maximum decay rate assumed equal water movement on both sides of the steel plate. The third variable is the additional corrosion rate for when the iron is in electrical contact with a non-ferrous metal object. Under these conditions (corrosion on both sides coupled to a galvanic contact) all structures ≤ 10 pounds per square foot (48.8 kilograms per square metre) will have lost all integrity. Given that the *AE1* wreck site is characterised by a lack of concreting organisms and that the matrix of iron corrosion products and soft-bodied marine organisms such as sponges, tunicates and algae has little mechanical stability, it means that such structures will largely dissolve and disperse into the marine environment. For example, battery brackets which were 12.5-pound plate will have a residual thickness of less than 1 millimetre.

The implications for the interpretation of the present structures and what has happened to 'missing' elements such as hatches are far-reaching. It is highly likely that less substantial sections of the submarine will have totally corroded away. Owing to the damage caused by the implosion of the boat, the smooth external surfaces (as seen, for example, in a submarine like *AE2* in the Sea of Marmara) were dramatically altered. The debris field created a series of complex eddies and water flow over, in and around the scattered remnants of the submarine increasing the flux of dissolved oxygen which is the primary determinant in the rate of corrosion of historic iron structures. Based on the corrosion rates observed through the photographs obtained during the voyage of the RV *Petrel* to the wreck site, it is now possible to gauge when the structure of the remaining principal elements will undergo significant change.

The fin will continue to move towards the bow as its significant weight (estimated to be in the order of 38 tonnes) continues to impact on the residual metal in the immediate vicinity of its reach of galvanic attack. As the supporting structure becomes progressively weaker the fin may well topple sideways and lie on its long side. Using the data in Table 2 as a guideline it can be predicted that in 10 years there will be no metal left on plates that were originally 10-pound rated; in 20 years the 12.5-pound rated plate will be gone; and in 40 years the 15-pound plate will have disappeared. After 80 years, only the 20- and 23-pound plate will be present and after another century the only remaining structural element will be the heavy steel plate that once formed the engine bed.

Once data on the current and dissolved oxygen profiles is obtained over the coming 12–18 months it will be possible to further refine the predictive loss modelling for the submarine HMAS *AE1* off the Duke of York Islands. The predicted impact of earth tremors on the rate at which the boat is decaying is unlikely to be significant since the concretion appears to be soft and does not conform to the hard concretion microenvironment found on shallower wrecks. However, given the weak connection between the colonising marine organisms and the iron corrosion products, major tremors are likely to hasten the collapse of residual metal structures. It is apparent from the images of the wreck site that it is presently undergoing significant steps in its disintegration, as witnessed by the active rust formation points as seams open and the corroded weight bears down on the diminished structural supports.

Given the advanced state of decay that the submarine is in and the lack of structural continuity and the great depth at which the wreck is located, it is not practical to institute any form of direct site management to reduce the rate of decay of the vessel. The best option for management of the site is to liaise with the Papua New Guinea government to expedite declaration of an exclusion zone around the wreck site to prevent looting. It is recommended that the Australian government liaise with the Papua New Guinea government to develop appropriate surveillance monitoring of the site and to develop a training program for the local community members to act as guardians of the dead entombed in the remains of HMAS *AE1*.

In summary it is concluded that:

- HMAS *AE1* is in an active corrosion environment causing deterioration of the wreck at a pace which is probably double that of the deterioration of her sister ship HMAS *AE2*.
- The principal corrosion cell is being driven by the manganese bronze conning tower such that any steel plate of thickness less than 12.5 pounds per square foot (7.8 mm) has already been fully dissolved and hence unlikely to be present.
- Local effects (galvanic, microbial or both) could accelerate deterioration in some areas.
- The pace of deterioration is such that after another 80 years it is likely that the only remaining structure other than the conning tower itself will be the engine bed plates.
- Without the data from future monitoring it will be difficult to confirm the overall conservation heritage management plan for this historic site, which forms a pivotal point of Australia's maritime heritage.

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Annex E
Still images and 3D reconstruction processing in telling the story

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This annex describes the 3D imaging survey aspects of the April 2018 expedition to HMAS *AE1* using RV *Petrel* and the subsequent post-processing of the collected still image dataset and provides relevant background on the technologies used.

When the opportunity to revisit the wreck of *AE1* to conduct a remotely operated vehicle (ROV) survey came up, naturally there was a collective desire to capture still images of the site using one or more digital still cameras. Digital still cameras can provide high-quality, high-resolution images of the site that can be used for a wide range of different purposes, including detailed inspection and analysis, publication in magazines, reports and other print media, and large-scale reproduction in exhibitions. Importantly, still images can be processed using an emergent technology called photogrammetric 3D reconstruction (P3DR) (also known as photogrammetry or 3D reconstruction), which is an incredibly powerful technique in being able to generate highly detailed and visually accurate digital 3D models or digital reproductions of real-world objects.

It is also worth saying that compelling images can also be captured with video cameras; however, full high-definition video cameras can only provide a maximum resolution of 2 mega-pixels (2 million pixels) per frame, whereas digital still cameras can provide images of significantly higher resolution – 10 mega-pixels, 20 mega-pixels or higher depending upon the camera used. Additionally, video sequences are often heavily compressed using lossy compression techniques[1] to minimise file size, which can also limit the quality of the still image video frames grabbed from a video sequence. As hard as it might be to believe, most ROVs used in industry are often fitted with multiple video cameras but are very often not fitted with any digital still cameras. For P3DR purposes, it is therefore highly beneficial to capture digital still images of the site.

Our experience with P3DR processing has included work on several different shipwrecks including HMAS *Sydney II*, HSK *Kormoran*, the VOC ship *Batavia*, the *Santo Antonio de Tanna*, and the *Rouse Simmons*. We led the technology development on the *Sydney–Kormoran* Project, which in April/May 2015 conducted a detailed 3D imaging survey of the wrecks of HMAS *Sydney II* and HSK *Kormoran* (lost 1941), located in 2500 metres of water, ~200 kilometres due west of Shark Bay, Western Australia.[2] For that project we developed a custom lighting and camera system suitable for fitment to industry standard work-class ROVs – consisting of 14 digital still cameras and five high-definition video cameras, of which six systems were stereoscopic capable for fitment across two ROVs. There is no natural light at 2500 metres water depth, so we fitted each of the two ROVs with 3 kiloWatts of underwater LED lighting, which provided an even field of high-intensity light. That expedition collected around 500,000 images and around 300 hours of high-definition video footage. The team at the Curtin HIVE are processing the huge 50TB dataset to generate digital 3D models of the *Sydney* and *Kormoran* wrecks and parts of the debris fields. It is our understanding this is the largest dataset ever captured for P3DR processing and is far larger than any shipwreck dataset processed to date. To date we have used approximately four million core hours of processing time at the Pawsey Supercomputing Centre and work on processing this dataset is ongoing. The work on the VOC ship *Batavia* (lost 1629) has been conducted with the support of the Australian Government–supported ARC Linkage Project 'Shipwrecks of the Roaring Forties: A maritime archaeological reassessment of some of Australia's earliest shipwrecks' (LP130100137), led by the University of Western Australia and WA Museum.[3, 4] This project has involved scanning and processing around 3500 underwater photographs originally captured on 35 millimetre film during the 1970s when the wreck was excavated. Our processing of this legacy photography has generated several detailed 3D models of several large areas of the *Batavia* ship hull timbers as they lay wedged in the reef before excavation. The work on *Santo Antonio de Tanna* (lost 1698) consisted of processing 570 images of the wreck captured in the 1970s using a novel underwater stereoscopic camera tower. That work has generated a large 3D model of a portion of the remaining submerged hull of the ship.[5] In 2014 the HIVE team helped to process a dataset of the *Rouse Simmons* (lost 1912) to produce an early 3D model of that wreck.

The relevance of these projects to *AE1* is twofold. Firstly, the camera and lighting system developed for the *Sydney–Kormoran* Project and used on HMAS *Sydney II* and HSK *Kormoran* was both an incredible learning experience, but also a resource to use on future shipwreck imaging projects. Secondly, the experience gained in the P3DR processing of these datasets has been invaluable in developing best protocols for conducting surveys suitable for P3DR processing.

The equipment used during the ROV survey of *AE1* consisted of an Argus Bathysaurus XL work class deep-water ROV rated for 6000 metres operation. The ROV is fitted with an array of underwater LED lights, two full-high-definition video cameras on the front of the ROV, and a selection of other standard-definition video cameras on other locations on the ROV. The deep-water digital still camera used on this project was provided by the WA Museum and Curtin University and was one of the back-up digital still cameras used on the *Sydney–Kormoran* Project. This particular camera was chosen because of its simplicity due to the limited preparation time and limited integration time with this particular project. The camera captures 12 megapixel images and was set to capture an image every 5 seconds.

When conducting an image capture survey suitable for P3DR processing, the general aim is to image every surface of the wreck from at least three different angles. For *AE1* this is most easily achieved by performing longitudinal passes 'up and down' the wreck at various angles. Additional detailed photography around complicated and occluded areas of the wreck is necessary to ensure good coverage.

The ROV survey of *AE1* was conducted as a series of five separate dives. The five dives are described as Serial 1–5, or Dive 88–92 (representative of the total number of dives the ROV on RV *Petrel* has undertaken).

Dive record

- Serial 1 – Dive 88: First ROV dive on HMAS *AE1*.
- Serial 2 – Dive 89: First dive with the digital still camera. Three longitudinal passes along wreck (port side, top, starboard side) to collect an initial overview of the wreck for initial P3DR processing and to confirm correct operation of camera.
- Serial 3 – Dive 90: Detailed survey of starboard side of stern and two further detailed passes along the starboard side.
- Serial 4 – Dive 91: Further close survey of stern, several close passes of starboard side, detailed examination of superstructure items including the fin and the implosion areas.
- Serial 5 – Dive 92: Deployment of flag tribute, and one further pass around the fin.

As soon as Dive 89 was completed and image data became available, data processing commenced onboard RV *Petrel* to generate test models from the dataset, to confirm everything was working correctly from a quality assurance perspective, and to produce early models to satisfy an appetite to see results as quickly as possible. A dedicated high-end laptop computer was brought on the expedition to allow P3DR processing to be performed as quickly as possible. At the end of the expedition, interim low-resolution test models had already been built of the stern (Figure 1), bow (Figure 2), starboard ballast tanks (Figure 3) and the fin area (Figure 4) and shared with the team.

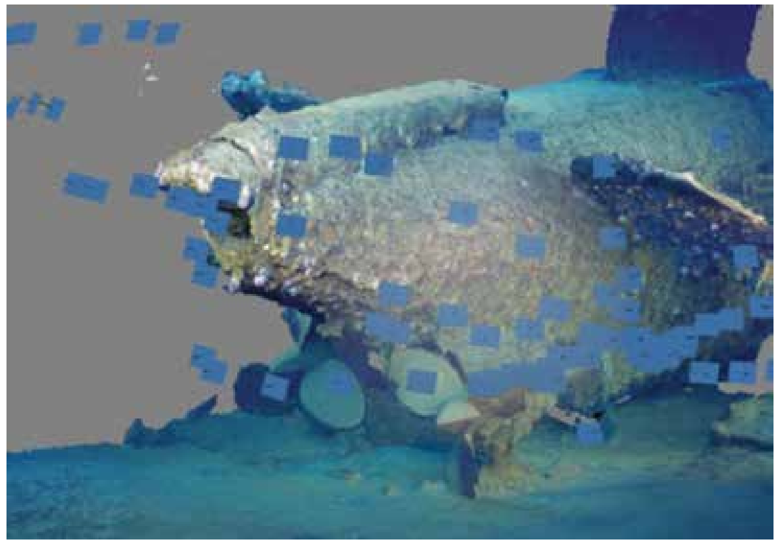

Figure 1 – Initial low-resolution 3D model of the stern of HMAS *AE1*. Blue squares are the camera locations.

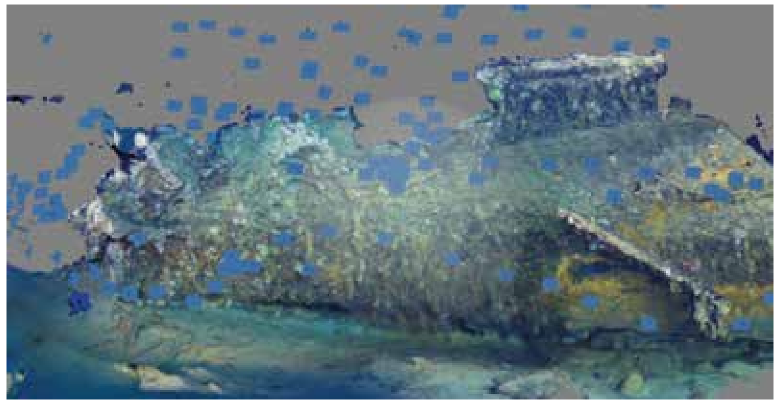

Figure 2 – Initial low-resolution 3D model of the bow of HMAS *AE1*. 3D models by Curtin University from images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Curtin University

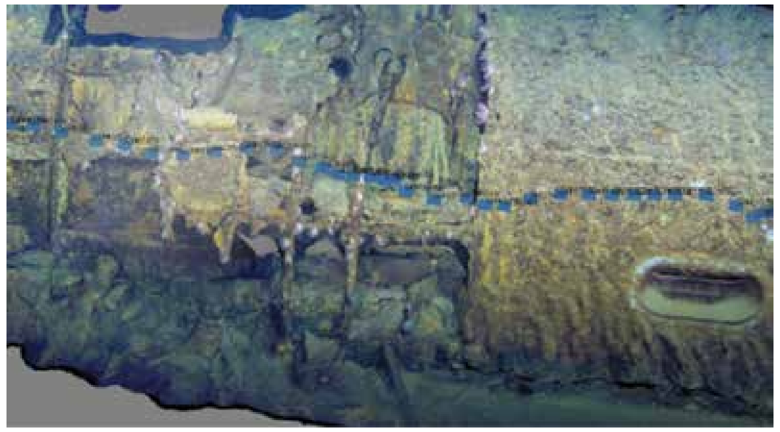

Figure 3 – Initial low-resolution 3D model of the starboard ballast tanks on HMAS *AE1*.

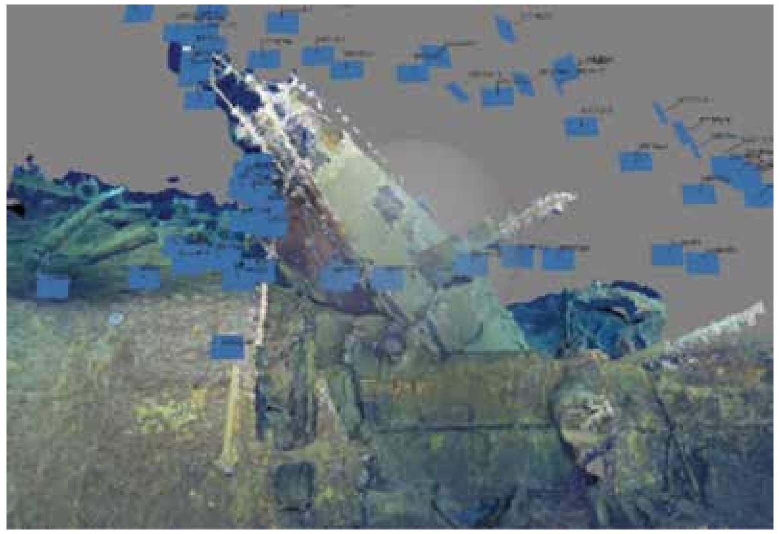

Figure 4 – Initial low-resolution 3D model of the fin area on HMAS *AE1*. 3D models by Curtin University from images courtesy of Paul G Allen, Find *AE1* Ltd, Australian National Maritime Museum and Curtin University. © Curtin University

At the end of the expedition a total of 8367 images and around 25 hours of full high-definition video had been collected. It is worth comparing this with the dataset collected on the *Sydney–Kormoran* Project, which comprised over 500,000 images and around 300 hours of HD video. The *Sydney* is 170 metres long and has a complicated superstructure, whereas *AE1* is only 55 metres long and has a much sleeker, less complicated structure. *Kormoran* was 164 metres in length but was the subject of a massive explosion when the sea mines it was carrying detonated, hence most of the ship is distributed in pieces across a large debris field and only around 40% of the ship (the bow) remains as a single piece. *Sydney* also has an extensive debris field that mostly comprises items that were ripped off the superstructure of the ship when it sank. By comparison, *AE1* has no discernible debris field. The 8367 images collected at the *AE1* site are substantially less than the dataset collected on the *Sydney–Kormoran* Project, but due to the significantly simpler wreck site, this dataset size is sufficient to adequately capture the site for P3DR progressing.

Subsequent to the expedition and once back at the Curtin HIVE, processing of the full dataset started in earnest.

The first output we usually generate from the stills dataset is what we call a 'stills video-log'. This is a video file which streams through all of the stills frame-by-frame at 25 or 50 frames-per-second. The video-log provides a great way to quickly visually review the full collection of images and gain an overall impression of the progression of the expedition. In the video-log file, each frame is individually annotated with the filename of each still image and the day/time it was captured. The video-log is a great way for all team members to be able to review the image collection (without needing access to the full dataset) and allow them to quickly identify or select individual images that they might be interested in reviewing in further detail. The video-log can be rendered in full HD (2K) or ultra HD (4K) resolution, as needed. We have used this technique with HMAS *Sydney II*, HSK *Kormoran*, and now *AE1*.

The main task, however, is to perform the photogrammetric 3D reconstruction (P3DR) processing. P3DR processing is performed in several discrete stages:

1. Feature identification: Each image is individually processed to identify visually unique features in the image. Those features might be edges or textures in the image that are mathematically unique. One common algorithm for doing this stage is called the scale invariant feature transform (SIFT), which allows features to be described and matched regardless of their size or orientation. The feature identification stage might identify around 20,000 unique features in each image. In Figure 5a each identified feature has been marked with a dot.
2. Feature matching: Every image is compared to every other image in the dataset to find matching features between images. In Figure 5b, the matched features have been joined with individual line segments.
3. Bundle adjustment and coarse point cloud generation: Using the feature matches from the previous step, an algorithm called a bundle adjustment is used to calculate the 3D locations of the feature matches and camera positions and orientations, which in turn are used to calculate a sparse point cloud. Figure 5c shows the calculated camera positions as blue squares, and it can be seen that the individual dots of the coarse point cloud roughly show the outline of the anchor first shown in Figure 5a.

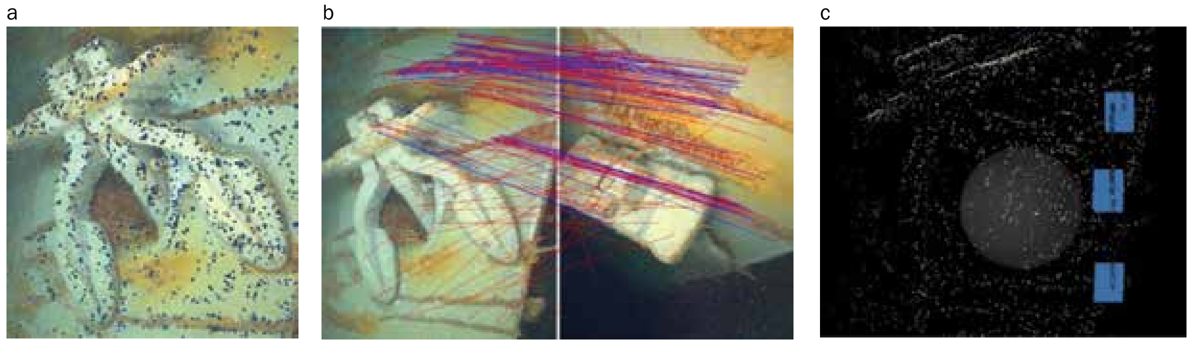

Figure 5 – (a) Feature identification, (b) feature matching, and (c) bundle adjustment and coarse point cloud. Anchor of HMAS *Sydney II*. Images courtesy of Curtin University and WA Museum. © WA Museum

4. Dense point cloud generation: Once the camera locations are known and a coarse point cloud exists, further parts of each image can be matched in finer detail to produce a dense point cloud. As illustrated in Figure 6a, the point cloud now looks much more like the original image (Figure 5a), but it is still made up of individual points in 3D space.
5. Meshing the point cloud: In this stage the point cloud is converted into a mesh of individual triangular shaped surfaces laid across the surface of the point cloud. Think of the way cling wrap would be vacuum-packed to follow the surface of a three-dimensional object. Looking at Figure 6b, you will notice that the mesh appears to follow the surface of the object that is being reconstructed – although this is hard to fully see because it is a 2D representation of a 3D surface.
6. Texturing the mesh: The final stage is for the images from the cameras to be projected onto the mesh to produce a realistic texture that covers the surface of the mesh. The final result is a visually realistic digital 3D model of the original object as illustrated in Figure 6c. In both Stage 5 and 6, the mesh and texture can be produced at various resolutions, depending upon the complexity of the object and the planned use for the digital 3D model.

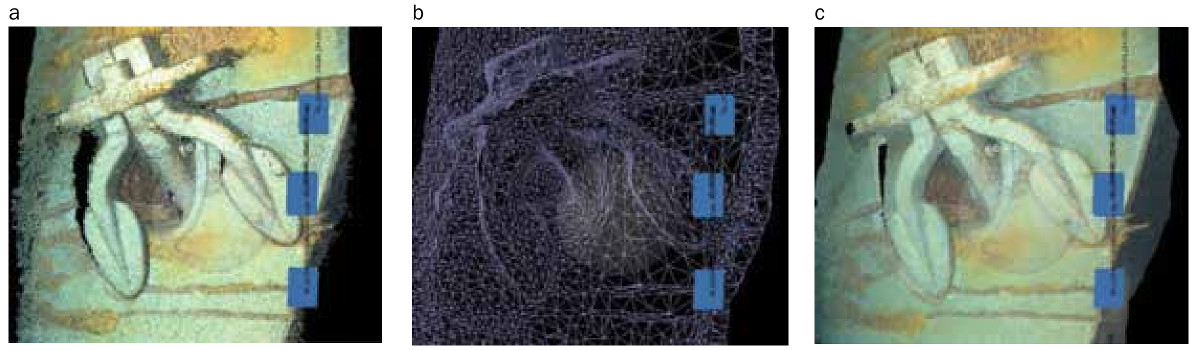

Figure 6 – (a) Dense point cloud generation, (b) meshing the point cloud, and (c) texturing the mesh. Anchor of HMAS *Sydney II*. Images courtesy of Curtin University and WA Museum. © WA Museum

The P3DR technique is capable of producing extremely realistic reproductions of objects on the sea floor. Of course, the technique is not always perfect and there can be anomalies and errors in produced models. A high level of skill is necessary to ensure the dataset is captured in a way that will optimally process, and experience also comes into play to optimally use the software to produce the desired 3D model results.

P3DR processing is often highly computationally intensive. Every time you double the number of images, the amount of compute quadruples. Thus the processing time can escalate very quickly. We calculated that the 500,000 images from the *Sydney–Kormoran* Project would take ~1000 years to process using fast computers with conventional processing techniques – hence we are currently developing our own codebase (that will run at the Pawsey Supercomputing Centre) and implementing a range of other optimisations that will reduce processing time considerably. The *AE1* dataset is much smaller at 8000+ images, which can be processed using conventional techniques. Nevertheless, this dataset took about three weeks of continuous processing on one of the HIVE's high performance machines to generate the interim full 3D model of the wreck which will be described later.

There are a wide range of software products available for P3DR processing in the marketplace, including: Visual SFM, Agisoft Photoscan, Pix4D, Bentley Systems ContextCapture, Capturing Reality RealityCapture, Adam Technology 3DM Analyst, iWitnessPRO, and more. The software we have used for initial processing of the *AE1* dataset is Agisoft Photoscan, and we look forward to using this dataset with other products. As mentioned earlier, we are also developing our own code-based designed specifically to process large-scale datasets (such as the *Sydney–Kormoran* Project dataset) that comprise hundreds of thousands of images.

There are a wide range of uses of photogrammetric digital 3D models. Applications include:

- Visualisation and interpretation
- Scientific analysis, measurement of lengths, angles, areas and volumes
- Visual animations for cinematography purposes
- Immersive virtual environments and virtual reality on screens large, medium, and small, including head-mounted displays (such as the HTC Vive, Oculus Rift, Google VR, Oculus Go), for:
    - Visual story-telling about *AE1*'s crew, service record, the sinking event, the wreck as it is now, gradual degradation of the site, marine life on the site, etc
    - Performing analysis and interpretation
- Augmented reality and mixed reality experiences
- 3D printed models.

At the time of writing this annex, the following P3DR post-processing of the HMAS *AE1* dataset had been completed:

- Detailed 3D model of stern and generation of an animated fly-around video – see Figure 7 and https://www.youtube.com/watch?v=tVt8gDFZQYQ
- Interim low-resolution 3D model of the entire wreck – see Figures 8 and 9.

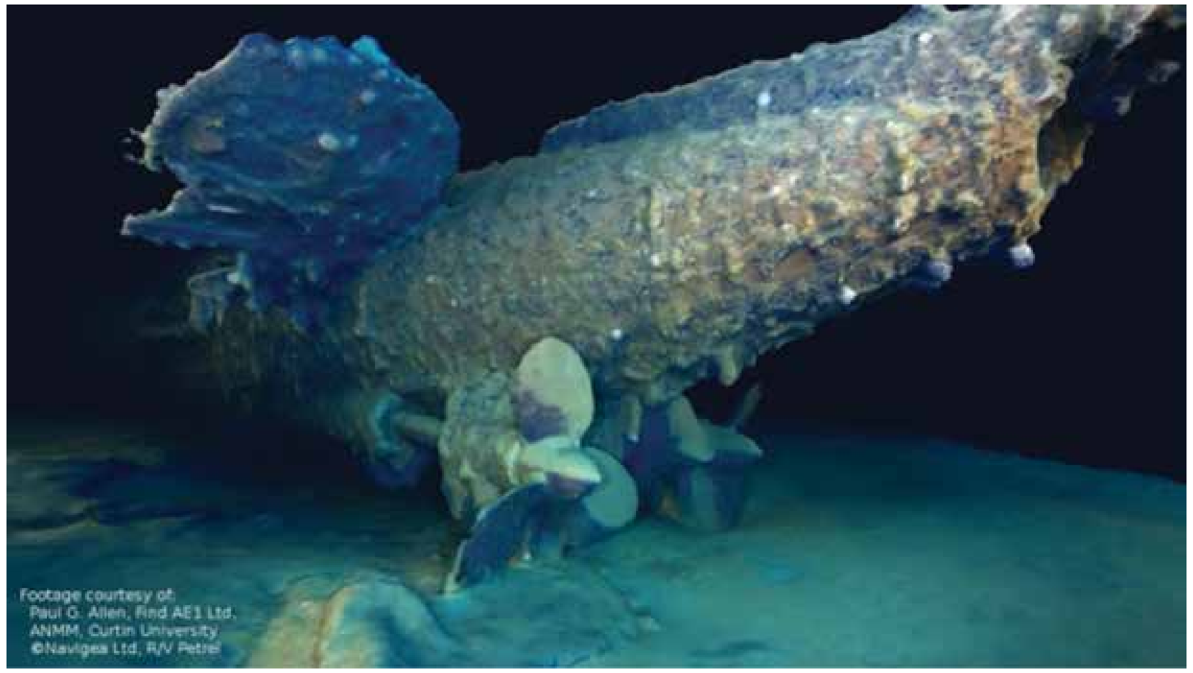

Figure 7 – Detailed 3D model of the stern of HMAS *AE1*. 3D model by Curtin University from images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Curtin University

Figure 8 – Interim full 3D model of the wreck of HMAS *AE1* – showing port side (bow on left and stern on right). 3D model by Curtin University from images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Curtin University

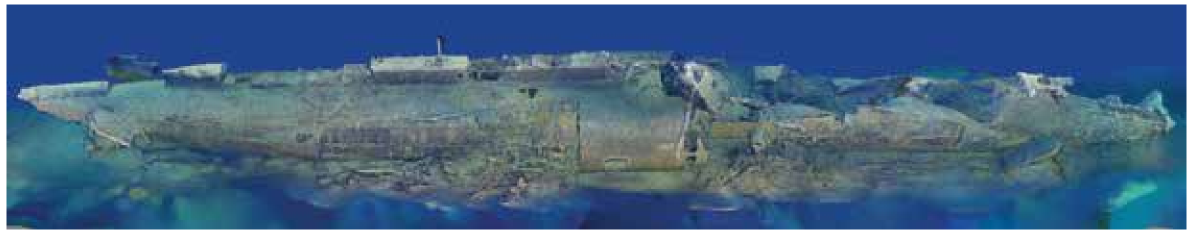

Figure 9 – Interim full 3D model of the wreck of HMAS *AE1* – showing starboard side (stern on left and bow on right). 3D model by Curtin University from images courtesy of Paul G Allen, Find AE1 Ltd, Australian National Maritime Museum and Curtin University. © Curtin University

The availability of a photogrammetric 3D model of the entire wreck is a very significant step. This is the only way to see a full visually realistic reproduction of the whole shipwreck as a single object. Normal underwater photography has a maximum range of perhaps 10 to 20 metres, so there's no way to see *AE1*'s 55-metre length in one full view. The full 3D model is advantageous to both experts and the public. This particular model is labelled 'interim' because it has only been rendered at low resolution. Work continues to develop a high-resolution model of the full wreck site.

The image shown in Figures 8 and 9 is of course just a 2D representation of the 3D model. The 3D model itself can be rotated to various angles and zoomed in to various parts of the wreck. The model lays bare the massive implosion area in the forward sections of the submarine from the control room to the forward torpedo room. The fin (containing the conning tower) can also be seen as falling into the collapsed control room. The hydroplanes at the bow and stern ends of the wreck can be seen in the hard-to-rise position. The ballast tanks on the sides of the submarine can be seen to be in various stages of collapse.

This is an incredibly amazing dataset and work is continuing to produce higher-quality models from the captured images. Once a high-quality full 3D model of *AE1* is generated, there will be opportunities to create virtual experiences suitable for exhibition use at the ANMM, WA Museum and other locations, as well as online. These techniques can allow visitors to have a virtual experience of visiting *AE1* – something that won't even be possible in the real world, due to the depth and remoteness of the wreck.

Two example digital interactive experiences that have been developed about other submarine wrecks include the 'HM Submarine *A7*' (lost 1914) and the 'German submarine *U8*' (lost 1945). The 'HM Submarine *A7*' experience was developed in Unity by a team led by Professor Robert Stone at University of Birmingham.[6] The *A7* digital interactive includes both pre-wreck and post-wreck 3D models of the submarine developed using the 3DS Max modelling package based on archival information and allows the user to fly over the virtual wreck. The '*U8* Educational Virtual Dive' is a website that includes static 2D views and 360 photo-bubbles generated from both pre-wreck and post-wreck 3D models of the submarine using 3D modelling software. The website also contains a vast amount of background information about the wreck.[7] Neither of these examples uses photogrammetric 3D models of the wrecks but they do provide some good examples of the type of information and experience that can be included in a digital interactive.

Another digital interactive that has some relevance, although not about submarines, is 'Beacon Virtua', which is a virtual reality simulation of Western Australia's Beacon Island.[8] Beacon Island is where the Dutch VOC ship *Batavia* sank in 1629. Beacon Virtua provides users with the capability to virtually visit the island, understand its layout, and learn about the fishing-based history and shipwreck history of the island. Beacon Virtua has also been developed in Unity and has been deployed to around 16 different platforms, providing a great deal of flexibility in its delivery to different users. Beacon Virtua was developed at the University of Western Australia and the Curtin HIVE, and provides some more examples of how a digital interactive for *AE1* could be developed.

At the Curtin HIVE we have a selection of large-screen immersive displays such as the Cylinder display (see Figure 10), as well as a selection of immersive head-mounted displays. Large-screen immersive displays provide the capability for group or collaborative virtual reality experiences. We look forward to the opportunity to experience the wreck in virtual reality simulations on immersive screens large and small.

Figure 10 – A virtual experience of digital 3D models from the *Sydney–Kormoran* Project at the Curtin HIVE Cylinder display. 3D model by Curtin University from images courtesy of Curtin University and WA Museum. Image © Curtin University

Acknowledgements

Tim Eastwood (formerly at WA Museum)

Andy Bickers (independent subsea engineer)

Numerous staff at Curtin University who assisted with expedited approvals and arrangements for my participation in the expedition.

Footnotes

1 https://en.wikipedia.org/wiki/Lossy_compression

2 McCarthy, M (2016) *From Great Depths: The wrecks of HMAS* Sydney II *and HSK* Kormoran, UWA Publishing and WA Museum.

3 Woods, A, Oliver, N, Hollick, J, Green, J and Baker, P (2018), '3D Reconstruction of the *Batavia* (1629) wreck site from historical (1970s) photography', IKUWA6 Conference Proceedings (refereed) [in review].

4 Helmholz, P, Belton, D, Oliver, N, Hollick, J and Woods, A (2018), 'The influence of the point cloud comparison methods to the verification of point clouds using the *Batavia* reconstruction as case study', IKUWA6 Conference Proceedings (refereed) [in review].

5 Shaw, L, Helmholz, P, Belton, D, Hollick, J, Woods, A, and Green, J (2018), 'The photogrammetric analysis of the *Santo Antonio de Tanna*', Curtin HIVE internship report, Department of Maritime Archaeology, Western Australian Maritime Museum, report no. 326.

6 Holt, P, Williams, M, Hass, M, Stone, R and Hiscock, K (2015), 'HM Submarine *A7* – An archaeological assessment', ProMare, The SHIPS Project.

7 'The *U8* Educational Virtual Dive', https://www.cloudtour.tv/u8/information

8 Woods, A, Oliver, N, Bourke, P and Green, J, 'Beacon Virtua – a virtual reality simulation detailing the recent and shipwreck history of Beacon Island'. In McCarthy, Benjamin, van Duivenvoorde '3D-Modelling and Interpretation for Maritime Archaeology', Springer [in review].

Annex F
Timeline of RN submarine accidents and key appointments for Thomas Besant and Dacre Stoker 1901–1914

Introduction

This timeline has been compiled by Peter Briggs with input and assistance from Darren Brown and Barrie Downer, both experts in the period. It tracks the career paths of Lieutenant Commander Thomas Besant, the commanding officer of *AE1,* and his colleague in *AE2*, Lieutenant Dacre Stoker, during a period of extraordinary development and growth in the Royal Navy's fledgling submarine arm. In doing so it endeavours to set the context for the loss of *AE1*.

Table 1 – Dates of key milestones, accidents and career points for Thomas Besant and Dacre Stoker

Date	Submarine	Accident	Losses	Remarks
15 May 1900				Thomas Besant awarded Midshipman's certificate, 3rd class pass. Ref B
30 May 1901				Stoker awarded Midshipman's certificate. Ref B
20 August 1901				HMS *Hazard* (Captain Reginald Bacon) commissioned at Portsmouth for Service with submarines.
2 October 1901				*Holland No 1* launched. Ref B, V1 p5
9 July 1902				*A1* launched, first boat designed by Vickers. 207 tons submerged displacement. Ref B, V1, p8
Early 1903				5 Hollands delivered. 122 tons submerged displacement (Ref B, V1, p 6)
12 February 1903	*A1*	Explosion	0	7 Vickers workmen injured in explosion at Barrow. *Barrow Weekly News*, 14 February 1903. Rescue led by Lt Murray Fraser Sueter. MF Sueter's Service Record in National Archives.
4 March 1903	*Holland 2* or *1*?	Explosion	0	4 injured at Portsmouth. *Barrow News* of Saturday 7 March 1903 reported *Holland 1* was involved. On balance, Darren Brown logs and CO's photo album confirm it was *Holland 2*, not *1*. Ref D
15 May 1903				Thomas Besant Sub Lieutenants Courses. Ref B
1903/1904				B1 ordered, 300 tons displacement.
18 March 1904	*A1*	Collision	11	Run down by SS *Berwick Castle* whilst practice attacking HMS *Juno.* All crew lost. Ref A and https://en.wikipedia.org/wiki/HMS_A1. Submarine recovered, refitted and returned to service.
1 October 1904				*B1* launched.
1904/1905				*B2–11* programmed.
0 February 1905				Thomas Besant awarded Bridge Watchkeeping Certificate HMS *Russell*. Ref B
10 January 1905				Thomas Besant posted HMS *Thames* for submarine training. Ref B
16 February 1905	*A5*		6	Two explosions while alongside HMS *Hazard* at Queenstown. Attributed to petrol fumes. Ref A and https://en.wikipedia.org/wiki/HMS_A5
8 June 1905	*A8*	Swamped while running on the surface	15	Bridge crew survived. Battery explosion followed. Training class of one officer and seven ratings lost in addition to crew. Submarine recovered, refitted and returned to service. Ref A and https://en.wikipedia.org/wiki/HMS_A8

Date	Submarine	Accident	Losses	Remarks
19 March 1905	*A4*		0	Sank due flooding through ventilator, blew MBT to regain surface. Submarine subsequently sank after an explosion without crew onboard while trying to tow her into a dock. Raised, refitted and remained in service until 1920. Ref A
1 April 1905				Last A-Class – *A13* launched. *A13* had a heavy oil engine. There were four batches of A-Class, each with substantial differences in design. Ref C
8 November 1905	*A6*	Crushing accident	0	Five injured when barrel of gasoline broke staging and fell on top of five men in lighter hold. *Manchester Courier* and *Lancashire General Advertiser*. Ref D
18 September 1905				Thomas Besant posted HMS *Thames* for submarines, posted to *A12* as 1st Lieutenant, under command Lieutenant Coplestone. Ref D
5 February 1906	*A6* (no – *A3*)	Man overboard	1	Lost man was Leading Seaman Ernest Thompson O/N 200135. Details of submarine from his service record in UK National Archives (ADM/188 series)
13 February 1906	*A9*	Collision	0	Run down by SS *Coath*. HMS Forth deck log. Ref D
1 May 1906				Thomas Besant posted HMS *Thames* for command of *Holland 5*.
10 June 1906				Thomas Besant posted HMS *Mercury* for command of *A5*. Ref B
30 October 1906				*C1* commissioned, submerged displacement 320 tons. 38 C-Class built plus 2 for Japanese Navy.
1906				*D1* ordered 600 tons.
26 April 1906	*B8*	Grounding	0	Haslar Creek.
01 November 1906				Thomas Besant HMS *Bonaventure* for command *C12* until November 1907, ie 18 months. Ref B
31 July 1906	*A6*	Grounding	0	Off Shanklin, Isle of Wight.
15 August 1906				Stoker posted HMS *Mercury* in Portsmouth for submarine training. Ref B
21 August 1906	*B4*	Collision	0	Collision with dredger. Murray Sueter, The evolution of the submarine boat, mine and torpedo.
22 August 1906	*B8*	Collision	0	Collided with hopper barge, beached to avoid sinking. *Dundee Courier*. Ref D
31 October 1906				Stoker posted HMS *Thames*, submarine depot ship Portsmouth. Ref B
01 March 1907	*B2*	Grounding	0	Grounded 200 yards from Sandown, Isle of Wight. Refloated following day.
13 June 1907	*C8*	Explosion	1	CO (Lieutenant Guy Hart) killed, two injured in petrol explosion. HMS *Bonaventure* log. Ref D
01 November 1907				Thomas Besant appointed CO *C12*. Ref B
17 May 1908	*C2* and *C5*	Grounding	0	*C2* and *C5* swept away by strong tides at Yarmouth and grounded on Haven Bridge. *Evening Telegraph*. Ref D
01 May 1908				*D1* launched, one of 8 x D-Class. Diesels, external MBT and HF radio. https://en.wikipedia.org/wiki/HMS_D5
14 July 1908	*A9*	Gassed by petrol fumes	0	Close call for all crew below. *Lancashire Evening Post*. Ref D
10 November 1908 (?)	*C4*	Grounding	0	Ref D
16 January 1909				Stoker in command *A10*. Ref B
08 March 1909	*A12*	Grounding	0	Haslar Creek.

Date	Submarine	Accident	Losses	Remarks
19 June 1909	*A4*	Petrol explosion	0	CO (Lieutenant Thomas Cecil Benfield Harbottle) and three ratings injured in petrol vapour explosion.
23 June 1909	*C26*	Explosion	0	Three crew injured in petrol explosion off Grantown. Ref D
05 July 1909	*C11*	Collision	13	Collision with MV *Eddystone*. Three survivors. https://en.wikipedia.org/wiki/HMS_C11. Survivors rescued by *C12*, Lieut. Besant in command.
05 July 1909	*C16* and *C17*	Collision	0	https://en.wikipedia.org/wiki/HMS_C16
15 July 1909	*C15*	Man overboard	0	Lieutenant Hubert Vaughan-Jones washed overboard and rescued by Able Seaman R O Atkinson. Royal Humane Society records
17 July 1909	*C3*	Not under command	0	Propeller fouled by trawl on passage Dover to Portsmouth. Taken in tow by HMS *Terpsichore*.
20 November 1909	*A2*	Battery explosion	0	Two injured – CERA Frederick Charles Cull O/N 269508 and ERA Reginald Edwin Jupp O/N 272396.
31 March 1910				Last C-Class, C38 commissioned plus two for Japanese Navy.
January 1910				1910/1911 E Class 1–8 programmed.
1 January 1910				Stoker appointed in command *B8*. Ref B
02 April 1910	*C37*	Man overboard	1	CO (Lieutenant Alfred Bayley Prowse) washed overboard off The Lizard and lost.
10 April 1910	*A8*	Diving accident	0	Submarine stuck on bottom of Whitsands Bay off Devonport (~170 feet, 52 metres) after main motor failure. Submarine recovered to surface after ~1 hour. *The Times*, 11 May 1910
26 May 1919	*C19*	Man overboard	1	Charles Edwin Henderson O/N 298512 washed overboard in Firth of Tay and drowned. Leading Seaman Thomas Daniel Denchfield O/N 212676 awarded Bronze Medal of the Royal Humane Society for attempted rescue.
02 July 1910	*B4*	Collision	0	Collided with HMS *Sharpshooter* off Milford Haven. *Aberdeen Journal*, Tuesday 5 July 1910
06 August 1910	*A1*	Explosion	0	Two officers and five ratings injured in petrol explosion alongside Fort Blockhouse. *Aberdeen Press and Journal*. Ref D.
08 August 1910				Thomas Besant hands over command of *C12*, after 34 months in command. Ref A C Appendix IIIA. Besant returns to general service (HMS *King Edward VII*) for advancement. Ref D
26 August 1910	*Holland 5*	Grounding	0	In entrance to Portsmouth Harbour
03 December 1910				*AE1* and *AE2* ordered. E-Class 796 tons submerged. Ref B
16 December 1910	*C8*	Collision	5	Collided with tender HMS *Elfin*. *Elfin* sank, five men lost from *Elfin*. *Evening Telegraph* and HMS *Thames* log. Ref D
August 1911				Stoker posted HMS *Forth* in command *B8* when overseas flotilla formed at Gibraltar, until August 1913. Ref B
10 August 1911				Thomas Besant posted to HMS *Hercules*. Ref D.
06 February 1912	*A3*	Sunk in collision	14	Collided with HMS *Hazard* in the Solent. All crew of 14 lost. Ref A
15 August 1912				Thomas Besant posted HMS *Vulcan*, for CO *C30*. Ref B
04 October 1912	*B2*	Sunk in collision	15	Collision with SS *Amerika* off Dover. One survivor, remainder lost. https://en.wikipedia.org/wiki/HMS_B2 and Ref A

Date	Submarine	Accident	Losses	Remarks
28 June 1912	*C8*	Collision	0	Collided with *C2* at Harwich. *Courier* and HMS *Thames* log. Ref D
28 January 1913	*C21*	Man overboard	1	Accident at River Tay entrance. Lieut. Thomas Chalmers Meryon (CO) washed overboard and lost
27 March 1913	*C27*	Man overboard	0	Man recovered by nearby tug
02 June 1913	*C32*	Collision	0	Collision with HMS *Prince of Wales*
08 June 1913	*E5*	Engine explosion	3	Three killed (died in hospital) and 11 injured (including two Vickers engineers). Ref B, V1, p 33. One of the injured was Stoker James Guild, who later volunteered for the Australian E-Class and who died in *AE1*. Ref D
15 June 1913				Thomas Besant posted HMS *Dolphin* additional for submarine after 10 months in command, total command experience 44 months. Ref B
04 September 1913				Thomas Besant appointed HMS *President* for loan to RAN in command *AE1*. Ref D
October 1913				Stoker loaned to RAN and posted CO *AE2* after 45 months in command of A and B class submarines. Ref B
20 November 1913	*B4*	Man overboard	1	Able Seaman William Henry Ball washed overboard in Bigbury Bay near Devonport. Two others had narrow escape. *Lincolnshire Echo*. Ref D
10 December 1913	*C14*	Collision	0	Sunk in collision with Government Hopper 27. All rescued. *C14* raised, refitted and returned to service. https://en.wikipedia.org/wiki/HMS_C14. Ref A
31 December 1913				Thomas Besant promoted to Lieutenant Commander after 8 years as Lieutenant. Ref B
16 January 1914	*A7*	Sunk	11	Diving accident in Whitsands Bay off Devonport. https://en.wikipedia.org/wiki/HMS_A7 and Ref A
23 April 1914	*AE1*	Man overboard	0	Second Coxswain of *AE1* (Petty Officer Henry Hodge) fell over the side at Suez and narrowly avoided being dragged into the propellers before being rescued by the crew of a local boat. Marsland Diary
04 April 1914	*C2*	Collision	0	Collided with HMS *Hebe*. Damage to *C2* and *Hebe*'s propeller. *The Times*, 4 April 1914. Ref D
14 September 1914	*AE1*	Sunk	35	Diving accident
Total losses			**134**	

References

A AS Evans, *Beneath the waves: A history of HM submarine losses 1904–1971*, 2010, Pen and Sword Maritime.

B MWD White and Barrie Downer, *Australian submarines: A history*, 2nd edition, 2015, Australian Teachers of Media. Career details on Stoker and Besant taken from biographies by Barrie Downer published as appendices IIIA and IIIB to Ref B.

C BR 3043, http://rnsubs.co.uk/dits-bits/br-3043.html

D Darren Brown, Darren Brown collection of log books, postcards and newspaper articles from the period.

Annex G
Early submarine training in the Royal Navy

LCDR Barrie K Downer RN Rtd (Vice Chairman and Secretary, branch historian, Barrow in Furness Submariners Association, June 2018) has compiled a detailed account of early submarine training in the Royal Navy during the period from 1901 to 1914 when the RN Submarine Service was established and rapidly expanded in the prelude to World War I. These notes are drawn from his unpublished research.

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1 Introduction

In determining the possible causes of the loss of HMAS *AE1* one of the factors which must come into the discussion is the level of training of the crew as a whole and the length of submarine experience of the individual crew members. However, before assessing the level of training or experience of the *AE1* crew, a short review of early (pre World War I) submariner training is thought to be useful.

2 Submarine training – The early days

2.1 Rapid expansion and development 1901–1914

There are few detailed records of the instruction manuals or operating procedures for the rapidly evolving designs and increasing numbers of boats.

The omission of details from the memoirs of prominent early inspecting captains of submarines and the lack of surviving official publications strongly suggests that the training was largely ad hoc, relied heavily on word of mouth and on-the-job training for the experienced submarine officers and sailors to pass on their knowledge. There does not appear to have been a central authority responsible for training standards but rather the practice whereby individual submarine depot ships had the task of training personnel for particular classes of submarines. The captains and commanders in the depot ships were responsible for training the crews to the required level, with oversight by the inspecting captain of submarines.

2.2 Numbers of submarines

The table from Wikipedia[1] below illustrates the rapid increase in numbers and equally rapid development of submarine design in the period from the delivery of *Holland 1* in 1901. Notwithstanding the inherent additional hazards imposed by use of petrol engines for propulsion, the loss rate of these early designs, ~12%, suggests that training to provide competent crews could have been better. These losses, coupled with the improvements in diesel engine technology, drove the decision to change to diesel electric propulsion.

2.2.1 Petrol electric

Holland class – 5 boats, 1901–1902

A-Class – 13 boats, 1902–1905

B-Class – 11 boats, 1904–1906

C-Class – 38 boats, 1906–1910

Total – 67 boats

Lost by accident 8 boats

Note that the early designs approximately doubled the size of the preceding class with commensurate increases in length, crew size and complexity of the equipment installed. (The B- and C-Classes had essentially the same dimensions, with some improvements incorporated in the C-Class.)

2.2.2 Diesel electric

D-Class – 8 boats, 1908–1912

E-Class – 58 boats, 1912–1916. Includes *AE1* and *AE2*

F-Class – 3 boats, 1913–1917

S-Class – 3 boats, 1914–1915

V-Class – 4 boats, 1914–1915

W-Class – 4 boats, 1914–1915

Note this table only includes the classes of submarines whose construction was started up to and during 1914.

2.3 Operating manuals and instructions

Although a 38-page electric boat pocket book entitled *General description of Electric Boat Company's submarine torpedo boats Type 7-P* including notes on care and handling – printed in New York by Arthur, Mountain & Co, 111 Liberty Street, NY (undated) – is extant, there is no record that it was actually used by the RN.

Detailed operating instructions and standing orders for the majority of these submarines have not been found, with the standing orders for HMS *E27* being the most recent now held.

2.4 Personnel training and selection

The process of submarine officer selection and training is described in the book *The story of our submarines*:[2]

> 'Before I get on to the War itself I want to give a short description of the entry and training of our personnel both before and after the War began.
>
> In peacetime, an Officer who wished to join the Submarine Service had first to receive a recommendation from his own Captain. He then had to produce either a first-class certificate for his Torpedo examination for Lieutenant, or, if he had not that qualification, a certificate from the Torpedo-Lieutenant of his ship to the effect that he showed special zeal in that branch of his duties. If his name was accepted it was placed at the bottom of the candidates' list, and in due time, after an interval which varied from year to year, he was appointed to Fort Blockhouse, the Submarine Depot at Gosport. There the batch of new Officers was medically examined, and (the standard being high) the unfit were weeded out and returned to their ships.
>
> For the next three months he went through a course of practical submarine instruction, his training period terminating in examinations, which provided another obstacle, the meshes of which prevented certain candidates from proceeding further.
>
> The Officers of the class were then sent as 'third hands' to different boats to await vacancies as First Lieutenants. After two to four years as First Lieutenant (the time varied with the number of new boats built), an Officer obtained command of an A boat (of 204 tons), from which he rose by seniority to larger and more powerful commands.
>
> The men entered in much the same way, being recommended, of first-class character and of excellent physical standard. They went through a less comprehensive training course, but had the same weeding-out to undergo, so that as far as possible the 'duds' were got rid of before they had cost the country much in useless teaching.
>
> In wartime it has not been possible to spare the time for the full instructional courses, but the courses continued, although much shortened. The shortage of personnel in the Navy generally cut down the field from which volunteers were drawn, but in spite of this the Submarine Service was able to keep up its voluntary entry, and to continue to retain its standard by drafting back those who were by nature or capabilities unfit for such work. The submarine sailor is a picked man and is the admiration of his Officers. There is a Democracy of Things Real in the boats, which is a very fine kind of Democracy. Both men and officers in a submarine know that each man's life is held in the hand of any one of them, who by carelessness or ignorance may make their ship into a common coffin; all ranks live close together, and when the occasion arises go to their deaths in the same way. The Fear of Death is a great leveller, and in submarines an officer or a man's competency for his job is the only real standard by which he is judged.'

Klaxon also describes a method of training which had developed in the submarine building shipyard, which allowed the crews to 'learn their submarine – its layout and its systems' without disrupting the building process:

> 'here (is) an account of a typical trial of a new boat, using an E boat of the early 1916 vintage as an illustration.
>
> The boat I would use as an illustration was in 1915 very new indeed. She was just a standard E boat, with war-taught improvements and additions, and with a war-taught complement of officers and a half-taught complement of men. For a month the men had been given a queer but useful course of instruction by being taken by their First Lieutenant at 'Diving Stations,' in a disused shed in the building firm's premises. On the walls and floor names and rough sketches of most of the important valves and wheels of the boat herself had been chalked, and though the men laughed and swore at the make-believe, they had learnt a good deal of their drill and the probable sequence of diving orders, without the work of the builders of the E boat being interfered with. Except in the dinner hour, or during the infrequent holidays, no drill could be carried out aboard owing to the crowds of men working there. Overtime had been continuously worked (by the Shipyard workers), and nothing could be allowed to interfere with the firm's sacred 'date' – the day on which the Admiralty had been promised delivery.'

Note that Klaxon here is describing a method of crew training in a building shipyard in World War I but even today access by crew members to submarines 'in build' is similarly restricted. There is no reason to suppose that a similar system of crew training was not used by the crew of *AE1* (and *AE2*) in the Barrow shipyard, nor is there any evidence to support this proposition.

2.5 Volunteers versus drafts

The Admiralty's first call for volunteers to join the submarine service met with a disappointing response.[3] Just thirteen lieutenants applied for the six available slots for officers of which only one, FD Arnold-Forster, was qualified in torpedo. And within a year he asked for and was given a transfer back to general service. Among enlisted men the response was even less enthusiastic. There were sufficient volunteers to crew only three of the five Holland boats. When submarine boats 'Four' and 'Five' began their trials at Barrow during the winter of 1902, therefore, the Admiralty was forced to draft men from the battleship *Jupiter* to bring the submarine section up to establishment.

2.6 Financial incentives

In early 1903 measures were taken to make service in submarines appear more attractive to volunteers. Officers and men on the books of submarine depot ships were entitled to draw submarine pay – or 'hard lying money' as it was called. Officers in command of submarines were in addition authorised to draw 'command pay' – an allowance that effectively doubled their take-home pay. The first inspecting captain of submarines, Captain Reginald Bacon, insisted this extra incentive to officers was necessary because he anticipated a high rate of turnover among submarine captains. He believed that the burden of commanding these vessels would be so great that officers would be able to stand the strain for no more than two years and would then have to be returned to general service. If he was correct then turnover would indeed be high and the submarine service would require a constant flow of new men. Bacon thus hoped that the prospect of receiving command pay would ensure an adequate supply of volunteers. Note, however, that Bacon's successors were to hold exactly the opposite view and tried to keep experienced officers for as long as possible.

Numbers of volunteers among enlisted men did not rise to a level where the extra incentives could be discontinued. Furthermore, in direct contrast with his views on officers, Captain Bacon became convinced that retention of already trained enlisted personnel, especially the skilled higher rates, was far more important than recruiting new volunteers. They feared that payment of hard lying money could not be withdrawn without the risk of provoking an exodus of trained petty officers and engine room artificers from the submarine service.

2.7 Training standards

Successive inspecting captains of submarines were of the opinion that the safe operation of submarine boats depended upon minimising the possibility of human error.

This required men that were not only highly skilled but also highly trained. Stringent standards were maintained by accepting only those volunteers assessed as 'above average' during the initial acquaintance course and subsequently training them intensively. Even then, the new men were incorporated into the service only very slowly. Inspecting captains were careful not to dilute existing crews with too many recruits at once. As much as possible, they tried to keep experienced crews together and to accept only enough volunteers to replace natural wastage plus a margin to allow for expansion. Captain Bacon encountered many difficulties in keeping his best men. First and foremost, he had to persuade them to remain in what was an unhealthy and hazardous occupation. This was accomplished most easily by continuing to pay hard lying money.

2.8 Less formal working conditions

In addition, there are indications that Bacon and his successors deliberately fostered a less formal, and therefore more attractive, working environment than existed elsewhere in the Navy. Dress regulations on board submarines and depot ships, for instance, were much more relaxed. Sports facilities (soccer pitches) were laid out close by on shore and the men encouraged to use them – though it is true that there were medical benefits to this practice. Informality between officers and the lower deck was tolerated to a degree that would have been unthinkable in a surface ship. Perhaps most importantly, men were usually allowed to go home after 4 pm. The significance of this was that the majority of submariners were drawn from the Portsmouth division (where the submarines were based) and that a large proportion of the higher rates were married. The additional money for serving in submarines, indeed, allowed many officers and seamen to get married – or, according to legend, buy a motorcycle instead! (Motorcycles, perhaps, were found easier to maintain and offered a less bumpy ride.) In any case, submariners were given the money and time to indulge their interests.

2.9 Personnel administration

Second, Bacon had to fight the civil servants running the Admiralty's M (manning) branch. Keeping men in one place was administratively complicated because, among other reasons, men in submarines were unavailable for rotation overseas until three overseas flotillas were formed in Gibraltar, Malta and Hong Kong in 1911. According to regulations, indeed, submariners were not part of the seagoing fleet; on paper, all submarines were attached to Portsmouth command as part of the reserve. So long as the numbers of men involved remained small, the headache of administering two personnel lists was manageable. But once numbers rose above 500, the civil servants began to protest.

2.10 Personnel numbers

Nonetheless, from a standing start in August 1901 when the first personnel were appointed/drafted to HMS *Hazard*, by 4 August 1914 submarine personnel had built up to 168 officers and 1250 ratings.

By 11 November 1918 the numbers stood at 612 officers and 6058 ratings.

Add to this the fact that by November 1918 143 officers and 1137 ratings had been lost in accidents, and that many more had been invalided out of the submarine service or rejected as unsuitable, and the scale of the training effort required becomes apparent.

3 *AE1* crew: Training and experience – a review

As will be seen from Annex F the commanding officers had considerable submarine and submarine command experience (bearing in mind that the Royal Navy had only operated submarines since August 1901) but only in the smaller Holland, A-, B- and C-Class boats. *AE1* and *AE2* were the commanding officer's first E-Class submarines. The other *AE1* and *AE2* officers had also served in the smaller submarines. A summary of their submarine experience at time of their appointment to the RAN is as follows.

Officer	Total submarine service	Total command experience
Besant	7 years 9 months	3 years 8 months
Stoker	7 years	3 years 9 month
Moore	2 years 4 months	Nil
Haggard	3 years 3 months	Nil
Scarlett	2 years 4 months	Nil

A review of the submarine experience of the Royal Navy ratings of *AE1* (on being loaned to or on joining the RAN) shows that, between them, they had accumulated 97 years and 8 months of submarine service, averaging 5 years 5 months each, with the longest service being Stretch with 9 years in total and the shortest being Woodland with 2 years 2 months. Their experience was in all classes of submarines up to that time except that, unsurprisingly, they were nearly all new to the E-Class, which was, of course, the latest design in service. Those with the least submarine experience were the RAN members of the crew but they had all benefitted from the standard Royal Navy submarine training courses.

The RAN ratings who volunteered for submarine service and who served in *AE1* were all drafted to the RAN London depot between July 1912 (Kinder) and February 1913 (Blake, Bray and Jarman) but the majority joined between December 1912 and February 1913 (service records in AWM). In his diary Stoker Petty Officer Henry Kinder describes his introduction to submarines. He was already in the UK when he saw the notice in the depot (probably the barracks at Portsmouth) calling for volunteers, although he doesn't report the date of his joining HMS *Dolphin*. However, an educated guess would suggest the Australians started submarine training in March 1913. Kinder reports serving in both submarine *D2* and in *E5* before he joined *AE2* in October 1913 but also indicates that the crew of *AE1* were chosen and went to Barrow earlier – probably in September 1913. If all the Australian members of the *AE1* crew started training in March and went to Barrow in September 1913 they should have accumulated at least 6 months' experience each before leaving Portsmouth for Australia

4 Conclusions

There is nothing to suggest that the crew of *AE1* were any less trained, experienced or qualified than any other submarine crew to take their submarine to sea and to carry out all the procedures expected of them. Admittedly, many of the RAN crew members had less experience than the RN or ex-RN crew members but, as in any submarine crew, there are always some with less experience than others.

The crew members of *AE1* at the time of her loss were essentially the same as the crew who had 'stood by' the submarine in the shipyard. There were a few new members – the telegraphist and the 'third hand', who only joined in August 1914 in Australia – but the bulk of the crew had been working together for nearly a year.

AE1 had a very experienced crew and command team by the standards of the day, but they were all very inexperienced in operating an E-Class and had conducted few dives. Nor had *AE1*'s program given them much opportunity to rectify this – the voyages from build in Barrow in Furness to Sydney were all on the surface, as was the transit to Rabaul.

AE1 and her crew were thrust into a wartime setting with no work-up and were probably operating without a close escort for the first time in the experience of the submarine's command team.

Footnotes

1 https://en.wikipedia.org/wiki/List_of_submarine_classes_of_the_Royal_Navy.

2 'Klaxon', *The story of our submarines*. William Blackwood & Sons, 1919, Chapter 1, pp 2, 3 and 4. 'Klaxon' was the pseudonym of Commander John Graham Bower – a submarine commanding officer who was appointed to his first submarine command pre World War I.

3 *The submarine service 1900–1918*, Navy Records Society, 2001, ISBN 0 7546 0294 X.

List of acronyms

3D	3-dimensional
ANMM	Australian National Maritime Museum
AWM	Australian War Memorial
CT	conning tower
DST	Defence, Science and Technology
ER	engine room
GA	general arrangement
HIVE	Hub for Immersive Visualisation and eResearch
MBES	multibeam echo sounder
MBT	main ballast tank
MOU	memorandum of understanding
PNG NMAG	PNG National Museum and Art Gallery
RAN	Royal Australian Navy
ROV	remotely operated vehicle
SAA	Submarine Association of Australia
SIA	Submarine Institute of Australia
WAMM	Western Australian Maritime Museum

Attachments

Attachment 1
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dated 26 March 2018 145

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Attachment 1
Notes on *AE1* workshop discussions at ANMM, Monday 12 March 2018

Present

Tim Eastwood, WAM

Dr Ian MacLeod, Find AE1

Gus Mellon, Find AE1

Ian Noble, Find AE1

Terry Roach, Find AE1

David Nicholls, Find AE1

Ken Greig, Find AE1

Roger Turner, Find AE1

Michael Harvey, ANMM

Dr James Hunter ANMM

Dr Michael White, Find AE1, Chair

Peter Briggs, Find AE1

Bayden Findlay, Sensible Films

John Moore, Sensible films

Dr Andrew Woods, Curtin University, by teleconference

Opening remarks: Peter Briggs

1. The Petrel offer to divert from existing survey operations in the Solomon Islands to undertake a 2–day ROV video survey of the wreck represents a unique opportunity. *Petrel* has a highly skilled team operating excellent equipment as demonstrated by the recent footage of USS *Lexington*.
2. There would be no charge for the ship and its equipment. This equates to a significant donation, say $2M as typified by *Fugro*'s recent unsolicited offer to use a ship fitted with a work class ROV to undertake a survey (albeit deploying laser scanning and photometric cameras).
3. The offer is provisional. It is dependent on a range of scheduling factors, including a firm date for a refit in Singapore NLT of 17 Apil 2018. The proposal has yet to receive Vulcan Inc's approval.
4. An approved permit for the survey is the key prerequisite to commence the final Vulcan approval process.
5. An initial draft of the MoU has been agreed with the Vulcan Operational Director as suitable. Preserving the tenor of this draft will ease the approval process.
6. Any application for an PNG NMAG permit will require the support of the RAN and ANMM.

Item 1 – ANMM's requirements for future wreck management and telling the story

7. The gold standard is a laser scanning survey carried out in conjunction with a 3D photogrammetric survey. However, a comprehensive video survey would still provide an excellent basis for developing a wreck management plan, improving our understanding of what may have occurred and telling the story. There may also be some possible technical options to achieve a level of 3D model from this footage.
8. Tim emphasised the criticality of photographs to communicate the story to the public, as the site is otherwise inaccessible to them. As a baseline record the photographs will also be important in tracking the decay of the site; the argument for an early collection is strong.
9. The footage from the *Lexington* examination is of a very high standard and indicates a very capable set of equipment and skilled operators.
10. We should also collect environmental data on the site. Ian MacLeod supported this, observing that there is a remarkable amount of information on the decay process to be gleaned from high–definition footage. He would be happy to investigate the availability of suitable instrumentation and advise.

Action: Dr Ian MacLeod

Post-meeting

Vulcan advise that:

- We will investigate options to lay an instrument collecting ocean current and other data such as dissolved oxygen during the examination. We can deploy instrumentation with the ROV or onboard crane as necessary.
- What instrumentation is available on Petrel/ROVs? The only direct environment monitoring from the ROV is via a Valeport Mini SVP… providing sound speed, pressure, temperature and conductivity.
- Recovery of some sediment data/samples would also be of benefit. We have a small plunger–style core sampler for use with the ROV manipulator.

Item 2 – Issues for technical examination

11. Roger Turner reviewed the list of technical issues for follow–up examination to gain a better understanding of what happened to *AE1*. Most will be covered in the closure of a detailed photographic examination; some will require dedicated tasking of the ROV and two will entail inserting a camera into:

- The forward torpedo space to view the state of the reload torpedo and its separately stowed warhead.
  - There appeared to be a gap of approximately 90 centimetres below the lip of the pressure hull edge at the implosion area.
- The engine room hatch to inspect the state of the engine room forward and aft of the hatch.
  - The hatch opening forward of the remaining strongback should be approximately 114 centimetres x 76 cm centimetres.

Post-meeting:

Vulcan have advised that Yes, we have a small POV camera and a light that can be mounted to the T4 manipulator for viewing inside confined areas.

Item 3 – Protocol for conducting the examination

12. It was agreed that we should approach Vulcan for a copy of their protocols for managing an examination. Vulcan advise that they brief on the procedures and issues prior to each serial, rather than follow a fixed template. They would be happy to address particular concerns if we care to raise them.

Action: James Hunter to set out issues to be addressed.

Item 4 – Optimising results from a *Petrel* ROV examination

13. The possibility of adding additional lighting and stills cameras was discussed.

Post-meeting:

Vulcan have advised that We currently use two HD cameras, HD SDI 1080p/60 and the other is HD1080P/30. We run both cameras as 60fps due to fast motion to reduce trailing artefact effect in the video. Still images we capture are post processed from uncompressed full resolution HD video.

Changing or adapting hardware into the vehicle at this late stage is going to be a challenge. I do have one fibre path and one rs232 channel and 24vdc switched output available BUT I do not currently have a penetration in the termination box to access to that fibre; I'm reluctant to drill holes for a temporary installation.

14. I suggest we should not pursue plans to modify the camera arrangements, endeavour to maximise our collection via the current cameras and look at the best post–expedition processing options to maximise its utility.

Post-meeting:

Vulcan advise that: Assuming we go ahead, do you need a copy of the survey data from the Fugro search? It's not critical, however a geotiff of the sidescan mosaic would be useful for integration to our ROV's navigation solution for reference. This could be provided via digital access once we confirm the project is a go and we're en route to the location.

Action: Roger Turner

Item 5 – MOU issues

15. An amended version of the draft MOU, incorporating the changes suggested, has been circulated to the RAN and ANMM for agreement.

Conclusions and summing-up

16. The chairman thanked participants for their contribution and participation in such an open and transparent manner.

P Briggs
14 March 18

Attachment 2
Memorandum of understanding Vulcan Inc – ANMM – Find AE1, dated 26 March 2018

MEMORANDUM OF UNDERSTANDING ON
UNDERTAKING AN EXAMINATION ON THE WRECK OF HMAS *AE1*

1

1. **Commencement; Term and Termination**
1.1 This Memorandum of Understanding (MoU) commences on the date it is signed by both parties and it will be effective until the end of the Term (as defined below).

1.2 Except as it pertains to exploitation of the Materials as defined below, the Term of this MOU shall be for a period of three (3) months. The term may be extended by the parties by written amendment to this MOU. Any party may terminate its involvement in this MoU prior to the expiration of the Term by giving the other parties 10 days' notice in writing.

(a) Clauses regarding confidentiality (7.10), intellectual property (7.7), publicity (7.8) and the release of liability (10) of each party shall survive after termination of this Agreement until such time as their expiry is mutually agreed in writing.**2. Parties**

2.1 The parties to this MoU are:

(a) **VULCAN Inc (Vulcan)** of 505 Fifth Avenue S. Seattle, WA 98104-3179...........;
(b) **Find AE1 Ltd (Find AE1),** ABN 331 673 313 39, of 51 Arkaringa Crescent Black Rock, VIC 3193;
(c) **The Australian National Maritime Museum (ANMM),** of 2 Murray Street, Sydney NSW 2000.

3. **Purpose**

3.1 The purpose of this MoU (the "Purpose") is to outline the roles and responsibilities of the ANMM, Vulcan and Find AE1 in relation to:

(a) Undertaking a detailed photographic and videographic non-invasive maritime archaeology survey of the HMAS AE1 (the "Survey") to establish a historical baseline of the wreck of HMAS AE1, which Survey is intended to inform the development of a wreck management plan by the ANMM,
(b) The transfer of use and licensing of any photo and video material generated by Vulcan in the course of examining the wreck of HMAS AE1 (the "Material") to the ANMM,
(c) The sharing of expertise and key contacts developed by Find AE1, including (but not limited to) Find AE1 team members.
(d) The conducting of the Survey by the Vulcan research vessel Petrel owned by Vulcan's affiliate, Navigea Ltd. (the "Vessel") using a Remotely Controlled Vehicle ("ROV"), which Survey will be conducted in compliance with all permits and with due regard to the Government to Government relationship between Australia and Papua New Guinea, and compliance with local laws and arrangements.
(e) The protection and preservation of the HMAS *AE1* shipwreck site and consider and advance ways in which to advocate for its protection under appropriate legislation, agreements or arrangements.

3.2 This MoU is not a legal agreement and no legal liabilities, remedies or rights accrue to the parties other than as they pertain to confidentiality, intellectual property

2

and publicity and the release of liability of each party. The Parties commit to using their best endeavours to achieve the Purposes and Objectives set forth in this MOU.

4. **Interpretation**

4.1 Definitions

Unless otherwise indicated, terms defined below have the following meaning

(a) Vulcan Inc, a Washington state corporation located in Seattle, WA, USA
(b) Find AE1, the limited by guarantee company of the same name, ABN, 331 673 313 39
(c) ANMM – Australian National Maritime Museum of 2 Murray Street, Sydney NSW 2000

5. **Objectives**

5.1 The objectives of this MoU (the "Objectives") are to facilitate the Survey by the Vulcan Vessel to:

(a) Establish a baseline for the 'as-found' condition of the wreck site of HMAS *AE1*. Find AE1 and ANMM anticipate that the Survey information will enable an assessment of its archaeological integrity, inform the development of a shipwreck management plan and enhance such parties' understanding of HMAS *AE1* and its history.
(b) Allow Find AE1 and ANMM to investigate specific technical issues to achieve a better understanding of what led to the loss of HMAS *AE1*.
(c) Provide Find AE1 and ANMM with a foundation for future management of HMAS *AE1* in the wake of a successful search by Find AE1 to locate and identify the wreck site.

5.2 Find AE1 and Vulcan will transfer all Material to ANMM as set forth in this MOU and consistent with the license grant in Section 7.7 and two existing Memoranda of Understandings regarding Find AE1 (Attached as Attachments 1 and 2).

5.3 Vulcan, ANMM and Find AE1 will undertake all efforts under this MOU consistent with the Purpose and the Objectives.

6. **Background**

6.1 HMAS *AE1* was lost with all hands (35 crew embarked) on 14 September 1914 off the Duke of York islands, PNG. The wreck was identified on 20 December 2017 by a search undertaken by Fugro and Find AE1.

6.2 The wreck is regarded as a site of maritime significance to Australia, equivalent to a 'war grave' (though the *War Grave Act* does not extend to maritime sites). Apart from an external examination to provide images to tell the story and endeavour to ascertain the circumstances of her loss, the wreck must be left undisturbed and protected against illicit interference.

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7. Roles and Responsibilities of the Parties

7.1 Each party will meet its own expenses and carries its own risks/insurances involved in furthering the Objectives and the Purpose under this MOU, with the exception that Vulcan's affiliate, Navigea Ltd. ("Navigea") will fund the catering and accommodation costs for ANMM and Find AE1 personnel while they are embarked on the Vessel for the Survey.

7.2 The Survey will be conducted pursuant to the permit granted by the National Museum and Art Gallery (NMAG) of Papua New Guinea (attached as Attachment 3).

(a) Find AE1 will ensure that the Survey is conducted in accordance with the permit and will facilitate all communication with NMAG regarding the permit and any compliance with the same.
(b) Find AE1 may give reasonable direction to Vulcan about the conduct of the Survey to achieve this outcome and, subject to any safety concerns or issues, the crew shall endeavour to comply with such direction, or, if requested by Find AE1, abort the Survey.

7.3 Vulcan will carry out the Survey using the Vessel, the ROV and the support and expertise of Find AE1 and ANMM. The Survey will be conducted under the mutually agreed protocol (attached as Attachment 4).

7.4 Vulcan will provide reasonable access to the Vessel and equipment to Find AE1 and ANMM staff to witness any examination of the wreck during the Survey. Find AE1 and ANMM understand that the Vessel is a working vessel and Vulcan will have other projects and filming underway on the Vessel. Find AE1 and ANMM personnel agree to comply with directions from Vulcan and Navigea to ensure no disruption to the Vessel's or any other initiatives occurring on the Vessel.

7.5 A copy of the all Material including data (if any), images and footage generated during the course of the Survey will be transferred to ANMM by Vulcan before ANMM representatives depart the Vulcan Vessel. ANMM and Find AE1 will use the Material in accordance with the license granted under Section 7.7.

(a) ANMM will provide the necessary storage medium for the Material.
(b) The Material will be provided in raw format and will not be catalogued or indexed by Vulcan.

7.6 On completion of the Survey, the results will be made available by the ANMM in collaboration with Vulcan to the public to inform, educate and honour the men of HMAS *AE1*.

(a) The timing of public release of the results shall be mutually agreed.
(b) Photographs containing human remains and personal artefacts may not be published without mutual agreement of the parties7.7 Vulcan will own the copyrights, trademarks and all other intellectual property rights in and to all of the Material, elements and versions thereof. Vulcan grants to ANMM a world-wide, royalty free, non-exclusive, irrevocable, license to use the Material solely in non-commercial contexts (e.g., there shall be no associated ad sales and no fees will be charged to any party licensing/sublicensing the materials including, but

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not limited to distributors or the general public, etc.) to tell *AE1*'s story, as well as engage in ongoing research and management of the AE1 wreck site. Vulcan will be credited, in a manner to be pre-approved by Vulcan, for collecting the Materials, and for undertaking the first ROV examination of *AE1*. Other than as set forth above, the use of Vulcan's trademarks, names, logos and/or source identifies and the names of Vulcan's owners and employees must be preapproved in writing on a case-by-case.

7.7. Vulcan (and its affiliates) shall be afforded an opportunity to participate in any telling of the AE1 story that involves the use of their Material, in the form of programming.

(a) ANMM may sublicense the Material to the Royal Australian Navy (RAN) and Find AE1 in conjunction with the activities under existing MoUs (Attached) and for purposes consistent with the Purposes set forth herein.
(b) Each of ANMM, Find AE1 and RAN may use the Material to further the Objectives and the Purpose and to sub licence use of the data to others in a manner consistent with the Objectives and the Purpose and solely for uses consistent with the same.
(c) It is understood and agreed that ANMM is not granted a license in this MOU to any topside footage, video or material of Vulcan or its affiliates, except as agreed separately and any such rights, if granted, would be pursuant to a separate agreement with Vulcan or its affiliates. Without limiting the foregoing, Vulcan shall have the right to restrict use of any footage or other Materials that it reasonably deems may tarnish its reputation.

7.8 ANMM will take the lead in managing media matters in Australia, New Zealand and the United Kingdom in consultation with the Royal Australian Navy and Vulcan. Vulcan will also manage media and media outlets in the United States and other territories outside of Australia, New Zealand and the United Kingdom in consultation with the Royal Australian Navy and ANMM.

(a) For avoidance of doubt, Vulcan is free to publicise the Survey and use all Materials in its social media feeds and Paulallen.com, as well as in any documentary or other project developed, produced and/or financed in whole or in part by Vulcan Productions, Inc., subject to the approval of ANMM after consultation with the Royal Australian Navy, which will not be unreasonably withheld or delayed. Failure to notify Vulcan of any specific objections to a particular use within fifteen (15) days of written request shall be deemed approval.
(b) Moreover, nothing in any MOU or agreement with any other party prohibits such use by Vulcan or its affiliates. Vulcan may in its sole discretion both mention and accord credit to ANMM and Find AE1 on programming and other content that use the Materials. Size, placement and overall prominence of such credits shall be determined in Vulcan's sole reasonable discretion.
(c) ANMM will be credited, in a manner to be pre-approved by ANMM. Other than as set forth above, the use of ANMM's trademarks, names,

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logos and/or source identifies must be preapproved in writing on a case-by-case.

(d) For the avoidance of doubt, the ANMM is able to provide imagery and/or footage from the survey to media to accompany a media release, noting all required credits/acknowledgements are in place.

7.9 Any relevant agreements with third parties are attached to this MoU.

(a) No other agreements will be entered into that commit Vulcan or its staff to use of resources or to taking specific actions, without amendment to this agreement or a separate signed written agreement with Vulcan.

7.10 Confidentiality. The following arrangements shall survive this Agreement:

(a) The precise location of the wreck is to remain confidential.
(b) All personnel associated or involved with the Survey will be required to sign a Vulcan form of confidentiality agreement.
(c) Find AE1 and ANMM will sign a confidentiality agreement regarding any non-public information regarding the Vessel and Vulcan or its projects.
(d) Prior notice of the Survey must not be publicised.
(e) The Survey is to be conducted discreetly with the primary intent of protecting the location of the wreck site.
(f) The Vessel's AIS transponder must be switched off for the duration of the examination and whilst in the immediate vicinity of the wreck.
(g) Images and data published in the wake of the Survey must not include geographical coordinates.
(h) The timing of any public declaration or press release (and the substance thereof) of the Survey and release of the Material generated must be mutually agreed by all parties to the MoU.

8. Collaboration and Program Management

8.1 Vulcan shall be listed in media releases as the party undertaking the first ROV examination of the HMAS *AE1* wreck site, such listing shall be in a manner agreed upon in advance by Vulcan.

8.2 The parties will agree in advance upon any procedures for making major announcements regarding the examination and results obtained, noting the responsibilities for media management in clause 7.8.

8.3 Once results are in the public domain, the ANMM shall be given reasonable access to all Find AE1 and Vulcan personnel, subject to availability, for interviews and statements to support its efforts to create both a historical record of the Survey work undertaken, and to promote the project through exhibits, websites, social media channels and educational resources.

9. Representatives of Parties and Liaison

9.1 Vulcan representative will be Robert Kraft

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9.2 The Find AE1 representative will be the Chairman, currently RADM Peter Briggs AO CSC RAN Rtd.

9.3 The ANMM representative will be the Assistant Director Public Engagement and Research, currently Michael Harvey.

9.4 The liaison officers agree to cooperate to ensure that development of the program, conduct of the examination, and handover of data to ANMM and Find AE1 are managed within an achievable schedule.

10. Dispute resolution; Liability

10.1 For any matter in relation to this MOU that may be in dispute between the parties, the parties will attempt to resolve the matter at the workplace level, including, but not limited to:

(a) The parties or their representatives meeting and conferring on the matter.
(b) If the matter is not resolved at such a meeting, the parties arranging further discussions involving more senior levels of management meeting and conferring on the matter until such time as the matter is resolved.
(c) Each Party will be fully responsible for its own acts, errors or omissions, as well as those of its representatives related to its activities under this MOU and the use of the Materials.

10.2 Each of Find AE1 and ANMM acknowledges that its and its representatives' presence and participation in the activities contemplated by this MOU can be inherently dangerous, present unique hazards, and potentially involve risk of serious injury and death. SUCH PARTIES ASSUME ALL KNOWN AND UNKNOWN RISKS ASSOCIATED WITH PARTICIPATION IN THESE ACTIVITIES INCLUDING THE RISKS OF PERSONAL HARM OR INJURY, INCLUDING DEATH, AND OF PROPERTY DAMAGE. EACH OF AE1 AND ANMM HEREBY RELEASES AND AGREES TO DEFEND, INDEMNIFY AND HOLD HARMLESS VULCAN, ITS AFFFILIATES AND THEIR RESPECTIVE OFFICERS, DIRECTORS, EMPLOYEES AND AGENTS, FROM ANY AND ALL DAMAGES, CLAIMS OR LIABILITY RELATED TO THEIR PRESENCE ON THE VESSEL AND/OR PARTICIPATION IN THE ACTIVITIES CONTEMPLATED BY THIS MOU.

10.3 Vulcan makes no express or implied representations or warranties as to the condition of the Materials, merchantability and/or fitness for a particular use.

Signed by:

Director
Vulcan Inc.

Date 3/23/2018

Witness
Janie Eklund

Date 3/23/2018

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Peter Briggs
Rear Admiral RAN rtd
Chairman
Find AE1 Ltd

Date 25 March 2018

Witness

Date 25 March 2018

Kevin Sumption
Director and CEO
Australian National Maritime Museum

Date 26 March 2018

Witness

Date 26 March 2018

Attachments:

1. Memorandum of Understanding on transfer of Find AE1 Ltd Search Data, between the Australian National Maritime Museum and Find AE1 Ltd, dated 7 November 2017.
2. Memorandum of Understanding No.2 between The Silentworld Foundation, RAN, Find AE1 Ltd and ANMM, dated 20 October 2017.
3. Permit of the NMAG of Papua New Guinea
4. Protocol for examination and site management.

MEMORANDUM OF UNDERSTANDING
ON
TRANSFER OF Find AE1 Ltd Search Data

1. Commencement and timeframe

1.1 This Memorandum of Understanding (MoU) commences on the date it is signed by the parties and it will be effective for the remaining lifetime of the program or until termination. This agreement is subject to a two-yearly review involving all parties.

1.2 Any party may terminate its involvement in this MoU by giving the other parties 60 days notice in writing.

2. Parties

2.1 The parties to this MOU are:

a) **THE Australian National Maritime Museum (ANMM),** 2 Murray Street, Sydney NSW 2000;
b) Find AE1 Ltd, ABN 331 673 313 39, 51 Arkaringa Crescent Black Rock, VIC 3193;

3. Purpose

3.1 The purpose of this MoU is to outline the roles and responsibilities of the ANMM and Find AE1 Ltd in relation to:

The transfer of search data and IP generated by Find AE1 Ltd in the course of searching for the wreck of HMAS AE1 to the ANMM, along with the sharing of expertise and key contacts developed by Find AE1 Ltd, including (but not limited to) Find AE1 Ltd team members.

3.2 This MoU is not a legal agreement; however, the Parties commit to using their best endeavours to achieve its purpose.

4. Interpretation

4.1 Definitions

Unless otherwise indicated, terms defined below have the following meaning:

a) ANMM – Australian National Maritime Museum.
b) Find AE1, the limited by guarantee company of the same name, ABN, 331 673 313 39.

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5. Objective

5.1 The objectives of this MoU are to:

a) Establish the ANMM as the Australian Commonwealth Government's lead agency for the safekeeping and facilitating public access to the results achieved by Find AE1's search for HMAS AE1.

5.2 Facilitate collaboration between the ANMM and Find AE1 to transfer ownership of the search data, IP and assets prior to the closure of the company on completion of a successful search.

5.3 Establish an ongoing dialogue between Find AE1 and the ANMM so that once the vessel is located and its situation is understood (in terms of location, depth, condition and the territorial jurisdiction in which it lies) ANMM's ongoing role can be clearly defined. Both ANMM and Find AE1 will continue to advocate for the protection of and further research on the wreck site.

6. Background

6.1 HMAS *AE1* was lost with all hands (35 crew embarked) on 14 September 1914 off the Duke of York islands, PNG. The wreck has never been located.

6.2 It is anticipated that when located, the wreck would be regarded as a site of maritime significance to Australia, equivalent to a 'war grave' (though the War Grave Act does not extend to maritime sites). Apart from an external examination to endeavour to ascertain the circumstances of her loss the wreck should be left undisturbed and protected against illicit interference. In the event that the wreck is identified in any initial searches as being at a depth accessible by divers, protocols for the management of human remains will be agreed with the R.A.N. and the Commonwealth Department of Veterans' Affairs in advance of any further action.

6.3 Any existing agreements with third parties undertaken in the course of the search should be attached to this MoU. No other agreements will be entered into that commit the ANMM or its staff to use of resources or to taking specific actions, without prior written approval from the museum. With prior written consent from the ANMM before concluding such an Agreement, the ANMM then undertakes to honour these Agreements with the parties listed.

6.4 Find AE1 has agreed to provide public recognition to all sponsors.

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7. Roles and responsibilities of parties

7.1 The ANMM will fund any activities undertaken by its maritime archaeology team.

7.2 The ANMM acknowledges the work of the "Search for AE 1" project is of national significance and as such commits to making financial contributions to the search effort that builds on the $10k the ANMM contributed in 2014 and an additional $15k in 2015, with $10k in 2016 and 2017 (should AE1 not be found beforehand), to a total value of $45k.

7.3 Find AE1 will offer access to ANMM staff to witness any search or examination of the wreck where logistic arrangements permit.

7.4 Find AE1 will arrange the transfer of all data, IP generated during the course of the search for HMAS AE1.

7.5 Find AE1 Ltd will transfer any remaining assets on closure of the company to ANMM.

8. Collaboration and Program Management

8.1 The Find AE1 search strategy is:

To search the Primary area set out in the Search Report prepared by AE1 Inc, followed by the secondary area, using suitable technology to locate the submarine. Vessels of opportunity and suppliers prepared to sponsor their services will be used where possible to reduce costs. Find AE1 will endeavour to fund these searches from sponsorship. The deeper areas > 300m will require a deep towed Side Scan Sonar (SSS) or suitably equipped Automated Underwater Vehicle (AUV) to clear. The costs are likely to prove beyond the scope of sponsorship and will require a Commonwealth Government grant. An application for this has been submitted to the Department of Veterans Affairs, with a view to obtaining funding in the May16 Federal budget, enabling a search in 2017. Vessels of opportunity and service providers prepared to support the search with in kind sponsorship will be used to reduce costs.

8.2 The ANMM shall be given access to all Find AE1 personnel for interviews and statements.

8.3 Where practical ANMM personnel may attend all searches and contact examinations. All expenses for their attendance shall be the responsibility of the ANMM.

8.4 The ANMM shall be listed in media releases as a sponsor and supporter for the search and examination. Find AE1 and ANMM will agree any procedures for making major announcements regarding the search efforts and any results found. ANMM will respect any press embargo that is established. Once any results are in the public domain, the ANMM shall be given access to all Find AE1 personnel for

interviews and statements to support its efforts to create both a historical record of the work and to promote the project through exhibits, websites, social media channels and educational resources.

8.5 Find AE1 shall arrange for the production of a documentary covering the story of the loss of AE1, the project and search leading to her location.

9. Representatives of Parties and Liaison

9.1 The ANMM representative will be the Assistant Director Public Engagement and Research, currently Michael Harvey.

9.2 The Find AE1 representative will be the Chairman, currently RADM Peter Briggs AO CSC RAN Rtd.

9.3 The liaison officers agree to cooperate to ensure that the development of the program and deliverables and the handover to the ANMM are managed within an achievable schedule.

10. Transfer of research and Intellectual Property

10.1 The ANMM fully recognises the prior research conducted by the AE2CF for the purposes of locating the *AE1*. Prior to any publication and/or presentation of findings generated as a result of the search for *AE1*, a framework will be put in place to ensure that: 1) all parties agree on, and are happy with, any content produced; and 2) there is no accidental ‘overlap’ in the material generated. I am thinking primarily in terms of academic publications and presentations, but the same could apply to material generated for the broader public.10.2 Subject to this MoU, Find AE1 will facilitate the transfer to the ANMM of research, search data and IP generated by Find AE1 as well as the management responsibilities for these products, including:

a) Archive material (such as documents and video material);
b) Research data (search data, conservation data)
c) The Find AE1 website, which will remain stand-alone though linked to the ANMM website.
d) All rights to the documentary to be produced.

11. Dispute resolution

11.1 For any matter in relation to this arrangement that may be in dispute between the participants, the participants will attempt to resolve the matter at the workplace level, including, but not limited to:

a) The participants or their representatives meeting and conferring on the matter
b) If the matter is not resolved at such a meeting, the participants arranging further discussions involving more senior levels of management meeting and conferring on the matter until such time as the matter is resolved.

12. Funding and Costs

12.1 The ANMM shall contribute $20K towards the cost of the documentary. This amount is in addition to the $45k per section 7.2, which has been paid by the ANMM. The $20k shall be paid in November 2017. The balance shall be funded by Find AE1.

12.2 Unless separately agreed each party will meet their own costs.

Signed by:

Kevin Sumption
Director and CEO
Australian National Maritime Museum

Witness

F. Shapter

Date

Date

Peter Briggs
Rear Admiral RAN rtd
Chairman
Find AE1 Ltd

Witness

Ken Greig

Date **7NOV17**

Date **7NOV17**

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MEMORANDUM OF UNDERSTANDING

BETWEEN

SILENTWORLD FOUNDATION

AND

ROYAL AUSTRALIAN NAVY

AND

FIND AE1 LTD

AND

AUSTRALIAN NATIONAL MARITIME MUSEUM

FINDING THE MEN OF AE1

Background

1. The Australian submarine HMAS AE1 (**AE1**) was lost off the Duke of York Islands in Papua New Guinea waters on 14 September 1914. No trace of the submarine or her 35 man crew has been found.

2. This proposal builds on the previous work of the late Commander John Foster, OAM RAN Retired and earlier searchers for AE1. The Parties formally acknowledge the seminal work of John Foster, Dr Jeremy Green and other supporters in providing the historical antecedents to future efforts.

PB.

3. This Memorandum of Understanding (MOU No.2) is not intended to be legally binding. It sets out the general understanding of the Parties to it as to how they will progress the activities described in it. No Party will be liable to compensate another Party if the activities described in this MOU No.2 are not performed, or for any other cause related to those activities or to this MOU No.2, unless and until a legally binding contract is entered into in relation to those matters.

4. This MOU No.2 describes various roles and responsibilities in summary terms only. To give effect to those matters the Parties intend to cooperate with each other to develop a project plan, which will set out how the Parties will further develop and define those roles and responsibilities (including applicable standards, policies or guidelines to be observed, obtaining licenses and approvals and liaising with the PNG government and regulatory agencies, such as the Commonwealth War Graves Commission, and what happens if these matters are not completed), enter into related contracts and the timeframes for undertaking those matters.

Parties

5. Four Parties are involved in this MOU No. 2.

a. The Silentworld Foundation (**Silentworld**) of 289 Mona Vale Rd. St Ives, NSW. **Silentworld** was founded with the purpose of supporting maritime archaeology in Australia and to support the efforts of institutions, companies and individuals seeking to know more about our maritime past, through providing financial and physical support to projects and general research. In particular, the Foundation directs its support activities towards field work and the active search for, and identification of, shipwrecks of particular historical interest to Australia.

b. The Royal Australian Navy (**RAN),** represented by the office of Chief of Navy, R-1-4-C004, Russell Offices, Canberra 2610, operated **AE1** as a unit of the RAN. Commander Glen Miles is the Project Officer/Liaison Officer for the **RAN.**

c. Find AE1 Ltd (ABN 331 673 313 39) (**Find AE1),** registered offices 51 Arkaringa Crescent, Black Rock, 3193, is a not for profit limited by guarantee company formed exclusively to find AE1.

d. The Australian National Maritime Museum (**the ANMM**), of Wharf 7, 58 Pirrama Rd., Pyrmont, 2009. The **ANMM** wishes to establish itself as the Australian Commonwealth Government's lead agency for the safekeeping and facilitation of public access to the results achieved by Find AE1.

PB. BAL CS TWB

Purposes

6. **The Parties** wish to find and examine the wreck of HMAS AE1, lying in PNG waters near Rabaul, to enable the cause of her loss to be determined and to facilitate future protection of the wreck as a significant Australian maritime site.

7. This **MOU No.2** is intended to facilitate **Find AE1's** planning for and the conduct of a search **(the Search)** to find and examine **AE1.**

8. The provision of funding and in kind sponsorship for the search are intended to be covered by separate agreements. **The Parties** will liaise with each other to put such agreements into place, with the expectation that they will include provisions that cover the approval of a detailed budget and budget changes, timing of payment of the funding (e.g. instalments), ongoing reporting of spending against budget, reporting of the achievement of milestones or outcomes, repayment of unspent funds and auditing of compliance with these arrangements.

The Understanding

9. **The Parties** recognise and support the objectives of an existing Memorandum of Understanding between Find AE1 and the ANMM (Attachment 1) and note that:

a. The **ANMM** will be the recipient of all data generated by the search and, subject to any future agreements regarding the funding provided by **Silentworld** or the **RAN**, **Find AE1** resources remaining on completion of the search.

b. The **ANMM** will manage the subsequent release of this information to the public in agreement with the **RAN,** so as to protect the site from illicit interference.

10. The **Parties** agree as follows:

a. The **RAN** agrees in principle and, subject to further agreements, to provide a grant totaling 50% of the total cost of **the Search,** estimated to be up to $2.4M.

b. **Silentworld** agrees in principle and subject to further agreements, to provide a grant and in kind sponsorship totaling 50% of the total cost of **the Search,** estimated to be up to $2.4M.

c. **Find AE1** will be the Project Manager for the planning and execution of **the Search.**

d. **The RAN** will, in consultation with the other **Parties**, take the lead in all media, public announcements and advice to other Governments involved (including the Governments of PNG, UK and NZ).

PB. BAL CS TWB

e. An AE1/AE2 Inter Departmental Working Group (**the IDWG**), chaired by the RAN will provide inter Departmental coordination.

f. **The Parties** agree to assist **the RAN** as requested to facilitate the work of **the IDWG**.

g. The preferred weather window for the best weather conditions for **the Search** is November/December 2017 or alternatively, January/February 2018.

h. If this proves impractical, **the Search** may be delayed until November/December 2018 or alternatively, January/February 2019.

i. **The Parties** shall have full access to the planning process undertaken by **Find AE1**.

j. **The RAN** may choose not to reveal the precise location of **AE1** in order to protect the wreck site from illicit interference. **The Parties** agree to preserve the confidentiality of information on the location of the site.

11. Unless separately agreed, **the Parties** shall meet their own operating costs.

12. **The RAN,** subject to mutual agreement, will facilitate access to associated agencies and members of the Australian Defence Force to facilitate **Find AE1's** planning and conduct of **the Search.**

13. **Silentworld**, subject to mutual agreement, will facilitate access to information on its assets and any in kind sponsorship partners to facilitate **Find AE1's** planning and conduct of **the Search**.

Managing Risk

14. The Parties will liaise with each to undertake a risk assessment in connection with the activities described in this **MoU No.2**.

a. As part of that process they will allocate risk among them and endeavour to agree how the risks are best managed.

b. It is intended that Find AE1 will, as between the Parties, bear the risks associated with the Search and that such risks will as far as possible be transferred to subcontractors involved in the Search.

c. The other Parties will have a right to be satisfied as to the allocation and treatment of such risks.

PB. KS TWR

Deliverables

15. **Find AE1** shall deliver a plan for undertaking **the Search,** including schedule, details of sub contractors and budgetary costs to facilitate a decision by **the Parties** to proceed and the development of the necessary funding agreements prior to engaging a contactor for the search.

Termination

16. This **MOU No.2** remains in force until 31 March 2019 unless terminated in writing by any of **the Parties** prior to this date or replaced by further agreements.

a. Should the **MOU No.2** be terminated by any **Party** the remaining **Parties** are then free to continue **the Search** on such terms as they may agree.

17. Information on the precise location of AE1 shall remain confidential unless **the RAN** agrees to make it public. This condition shall remain in force despite termination of this **MOU No.2.**

PB. KS TWR

Signatures

Date: 24 Oct 17

Tim Barrett, AO, CSC
Vice Admiral, RAN
Chief of Navy

Date: 1 – 11 – 17

Kevin Sumption
Director and CEO
Australian National Maritime Museum

Date: 25.10.17

John Mullen
Chairman
Silentworld Foundation

Date: 24 Oct 17

Peter Briggs, AO, CSC
Rear Admiral, RAN (Rtd)
Chairman
Find AE1 Ltd

Attachment:

1. Memorandum of Understanding on Transfer of Find AE1 Search Data

KS PB. TWB

NATIONAL MUSEUM & ART GALLERY

Po Box 5560 Boroko,
National Capital District
Papua New Guinea

Telephone: +675 3252458/3252422/3252405
Fax: +675 3251779
Email: nationalmuseum@museumpng.gov.pg
Website: www.museumpng.gov.pg

Protecting and preserving our historical and natural heritage and securing our cultural future

P D Briggs AO CSC
Find AE1 LtD
51 Arkaringa Cres
Black Rock, VIC 3193
Australia

11 November 2017

RE: FINDAE1 REF: 17LET1102

Dear Admiral Briggs,

This letter serves as a permit for Find AE1 and its collaborators to conduct a non-invasive remote sensing-based maritime archaeological survey for the wreck of Australia's first naval submarine, HMAS AE1, in the territorial waters of Papua New Guinea surrounding the Duke of York Islands (East New Britain Province), as detailed in the Research Proposal submitted to the NMAG dated 31 October 2017.

We wish your team a safe and successful survey. Please keep us updated on your progress.

Best regards,

Alois Kuaso
Acting Director
PNG National Museum and Art Gallery

Protocol for Examination of The wreck of HMAS AE1

1. The wreck is to be treated with respect as the resting place of her 35 man crew.
2. Its location is to be kept Confidential and protected as far as practical.
3. The results from the examination are to remain confidential until a mutually agreed date for publication.
4. A briefing for the survey team is to be held prior to each serial to agree arrangements and procedures.
5. The examination is to be a non-interference survey; no artefacts are to be removed.
6. All practical measures to avoid damaging the wreck are to be taken.

Attachment 3
Find AE1 research permit application dated 18 March 2018

FIND AE1 Ltd
ABN: 33 167 331 339
Registered Office: 51 Arkaringa Crescent, Black Rock, VIC 3193

18 March 2018 FINDAE1 REF: 18LET0318

Mr Alois Kuaso
Acting Director
PNG National Museum and Art Gallery

Dear Mr Kuaso,

AE1 – Baseline Survey

This letter is a request for a permit to conduct a non-invasive Remotely Controlled Vehicle (ROV) maritime archaeology survey of the wreck of HMAS AE1, in the territorial waters of Papua New Guinea, off the Duke of York Islands (East New Britain Province).

The successful search located AE1 on 20 December 2017 was conducted under a National Museum and Art Gallery permit issued to Find AE1 Ltd on 11 November 2017. The Research Proposal provide in support of that application remains germane.

A unique opportunity to exploit an offer from Vulcan Inc, the owners of the Research Vessel Petrel, which is operating near Papua New Guinea has arisen. The survey will establish a baseline on the current state of the wreck. It will be governed by clear protocols to ensure it is non-intrusive and presents no risk to the site.

The survey will be attended by observers from the Australian National Maritime Museum and Find AE1 Ltd and has the support of the Royal Australian Navy and Australian National Maritime Museum. I attach a letter of support from the Australian National Maritime Museum.

To avoid any deleterious impact on the security of the site, the survey will be conducted discretely and without publicity, in advance of the establishment of a joint Papua New Guinea-Australia protection zone around the wreck. No results will be publicly released until after this zone has been established.

FIND AE1 Ltd
ABN: 33 167 331 339
Registered Office: 51 Arkaringa Crescent, Black Rock, VIC 3193

We are aware of a narrow window of opportunity for this work due to the availability of the vessel, it is expected that the work would be completed by mid-April. Therefore, we would appreciate a rapid resolution of this permit request to enable Find AE1 to accept and Australian National Maritime Museum obtain the benefit of this generous offer.

The results and all data from the examination will be transferred under licence to the Australian National Maritime Museum and inform a wreck management plan to be jointly developed, setting out the future management of the wreck.

Thank you very much for your time and attention regarding this request, and please feel free to contact me with any questions you may have.

Yours sincerely,

Peter Briggs AO CSC
Rear Admiral, RAN Rtd
Chairman

Attachment:

1. ANMM Letter of Support dated 16 March 2018

AUSTRALIAN NATIONAL MARITIME MUSEUM

FROM THE DIRECTOR KEVIN SUMPTION

16 March 2018

Mr Alois Kuaso Caretaker Manager
PNG National Museum and Art Gallery
P.O. Box 5560
Boroko, NCD, Papua New Guinea

Dear Mr Kuaso,

I write in support of a permit application by Find AE1 Ltd to undertake a non-invasive Remotely Operated Vehicle examination of the wreck of HMAS AE1.

A unique opportunity to exploit an offer from Vulcan Inc, the owners of the Research Vessel Petrel, which is operating near Papua New Guinea has arisen. The examination will be attended by observers from the Australian National Maritime Museum and Find AE1 Ltd.

To avoid any deleterious impact on the security of the site, the examination will be conducted discretely and without publicity in advance of the establishment of a joint Papua New Guinea-Australia protection zone around the wreck. It will be governed by clear protocols that ensure it is non-intrusive and presents no risk to the site.

We are aware of a narrow window of opportunity for this work due to availability of the vessel and it is expected that the work would be completed by mid-April. Therefore we would recommend a rapid resolution of this permit request so that Find AE1 is able to accept and obtain the benefit of this generous offer.

The results, Intellectual Property and data from the examination will be transferred to the Australian National Maritime Museum and inform a wreck management plan to be jointly developed, setting out the future management of the wreck.

I commend find AE1's application for your early consideration.

Yours sincerely,

Kevin Sumption PSM
Director & CEO

Australian National Maritime Museum
Wharf 7, 58 Pirrama Road PYRMONT NSW 2009
P: 02 9298 3602 | F: 02 9298 3688 | E: ksumption@anmm.gov.au

anmm.gov.au

Attachment 4
NMAG research permit dated 19 March 2018

NATIONAL MUSEUM & ART GALLERY

Po Box 5560 Boroko,
National Capital District
Papua New Guinea

Telephone: +675 3252458/3252422/3252405
Fax: +675 3251779
Email: nationalmuseum@museumpng.gov.pg
Website: www.museumpng.gov.pg

Protecting and preserving our historical and natural heritage and securing our cultural future

P D Briggs AO CSC
Find AE1 LtD
51 Akaringa Cres
Blackrock, VIC 3193
Australia

19 March 2018

Re: FINDAE1 REF: 18LET0318

Dear Admiral Briggs,

This letter serves as a permit for the Research Vessel Petrel, operated by Vulcan Inc under contract from Find AE1, to conduct a non-invasive Remotely Controlled Vehicle (ROV) maritime archaeology survey of the wreck of HMAS AE1, in the territorial waters of Papua New Guinea, off the Duke of York Islands (East New Britain Province).

The NMAG understands that the survey will take place by end of April 2018, to establish a baseline on the current state of the wreck. The NMAG requires that Find AE1 adheres to the conditions laid out it its permit application (FINDAE1 REF: 18LET0318) dated 18 March 2018, namely that the survey will be governed by clear protocols to ensure it is non-intrusive and presents no risk to the site.

We wish your team a safe and successful survey. Please keep us updated.

Best Regards.

Alois Kuaso
Acting Director
PNG National Museum and Art Gallery

Attachment 5
Find AE1 Individual Agreement

RV *Petrel* survey of the wreck of HMAS *AE1* – Individual Agreement

Situation

Vulcan Inc are to undertake a survey of *AE1* under a 3 way Memorandum of Understanding (the MoU) between ANMM, Vulcan Inc and Find AE1 (Attachment 1) using the Research Vessel *Petrel*, deploying a Remotely Operated Vehicle (ROV) to carry cameras. The survey will be supported by survey equipment, specialists and analysists.

This Individual Agreement is intended to pass on Find AE1's responsibilities under the MoU, provide the ground rules for participation in the expedition and facilitate personal preparations.

Preconditions

The arrangements given are provisional and may be subject to change as negotiations with Vulcan Inc are ongoing.

Expedition Team Members commit endeavouring to achieve the Objectives set out in the MoU.

There is a restrictive email and telephone policy in place after joining RV *Petrel* until returning to Australia. Individuals may not pass any information on the survey, including success or failure to outside parties by telephone, social media or email during the expedition.

Participants will have to complete a Confidentiality Agreement provide by Vulcan Inc, protecting their operations onboard *Petrel* from public commentary (Attachment 2).

The occurrence and results of the survey and location of *AE1* are to remain confidential unless this information is specifically authorised for release by Find AE1.

All Intellectual Property (IP) generated onboard RV *Petrel* during the survey, including data and images are the property of Vulcan Inc or their subsidiary, Navigea Ltd.

The ANMM is to be given a free and unfettered licence in perpetuity to use the data obtained during the survey to tell *AE1*'s story, as well as to engage in ongoing research and management of the wreck site.

(a) Vulcan will be credited for collecting the imagery and other data and for undertaking the first ROV survey of *AE1*.

(b) This licence may be sub licenced to others.

(c) These organisations may use the data to further the Objectives and to sub–license use of the data to others for this purpose.

Those requiring a sub licence should obtain agreement from the ANMM for a licence to use any IP, including images or data taken or obtained during the expedition.

Individual Responsibilities

Find AE1 has responsibility for conducting all interaction with Vulcan Inc in order to undertake the survey, with this responsibility comes the authority over all expedition team members for conducting the survey:

- Team members will be consulted by the Expedition Team Leader and in matters relating to their specialist areas may recommend cessation of the survey or alteration of the plan for undertaking it.
- This advice may not be unreasonably ignored, however decisions relating to the conduct of the survey ultimately rest with the Expedition Team Leader.
- Only the Expedition Team Leader may give direction to Vulcan Inc and its employees relating to the survey.
- Team members are to avoid making any remarks that could be construed as giving direction to Vulcan or its employees.

Unless otherwise advised, individuals or the organisation they represent are responsible for:

- Meeting their own expenses, carrying their own risk and insurances in accordance with clause 10 (c) of the Vulcan Inc–ANMM –Find AE1 Memorandum of Understanding.
- Obtaining a valid PNG Visa.
- Travel to and from the ship.
  - The joining port is expected to be Rabaul/Kokopo.
- Being medically and dentally fit to undergo the deployment in a remote, tropical area.
- Any relevant medical condition should be advised to the Expedition Team Leader prior to sailing.
- Personal anti–malaria prophylactics.
- Obtaining appropriate travel insurance, including coverage for a medical evacuation from PNG if required.
- Arranging and funding their personal mobile phone and data requirements.
- Making available to FIND AE1 Ltd their personal details necessary for the conduct of the expedition and agreeing to this information being made available to third parties as necessary for the conduct of the expedition.
- Assisting Roger Turner, who will coordinate logistic arrangements.

Notes:

1. Accommodation and victualling onboard RV *Petrel* will be provided by Vulcan Inc at no charge.
2. The search area has reasonable PNG Digicel mobile telephone coverage.
3. Personal data and telephone connection is an individual responsibility, but please note the restrictive telephone and email policy set out above.

Expedition Team Members

Roger Turner – Find AE1, Submarine Engineering Analysis and Logistics

Dr James Hunter – ANMM observer, maritime archaeology adviser

Dr Andrew Woods – Stills photography

Peter Briggs – Find AE1 Expedition Team leader

Individual members are to sign a copy of this Agreement, signifying that they accept these Ground Rules and a copy of the Vulcan Confidentiality Agreement and return a signed hard or scanned copy of both to Roger Turner (rbturner9@gmail.com).

P Briggs
RADM RAN
Expedition Team Leader
30Mar18

Signature of Expedition Team Member accepting the above conditions:

Name:

Signature:

Date:

Witness

Name:

Signature:

Date:

Attachment:

1. Memorandum of Understanding Vulcan Inc – ANMM – Find AE1, dated 26 March 18.
2. Vulcan Inc Confidentiality Agreement

Footnote

1 Intellectual Property means:

a. inventions, discoveries and novel designs, whether or not registered or registrable as patents or designs, including, but not limited to, developments or improvements of equipment, products, technology, processes, methods or techniques;

b. copyright (including future copyright) throughout the world in all literary works, artistic works, computer software, and any other works or subject matter in which copyright subsists or may subsist in the future;

c. Confidential Information, trade secrets and trade and service marks (whether registered or unregistered); and

d. proprietary rights under the Circuit Layouts Act 1989 (C of A).

Attachment 6
Find AE1 queries and desired shot list

Note: With respect for the crew members whose remains lie within the pressure hull, no intrusion into the pressure hull will be made without specific authority.

Item	Frame Number	Side	Height	Object	Question
1	100	Mid	Deck level and under	Forward torpedo tube, bow cap, damage to underside of bow cap and to casing	Estimate angle of impact of submarine when it struck the sea bottom (perhaps twice)
2	99	Port	Sea bed	Oblong object with strengthening ribs	Identify – possibly fwd torpedo hatch cover
3	96	Port	Deck level and under	Rounded object out hanging from casing	Identify – possibly the anchor
4	90	S	Mid hull	Stbd hydroplane guard housing	Identify form of failure
5	90	S	Sea bed	Stbd hydroplane guard housing	Identify object lying on top of planeguard
6	90	S	Mid hull	Stbd hydroplane	Estimate angle of rise
7	90	Port	Mid hull	Port hydroplane guard	Identify form of failure
8	90	Port	Mid hull	Port hydroplane	Estimate angle of rise
9	85	Mid	Deck level	Pressure hull rupture	Investigate overhang lip and whether access to forends is possible. If possible check state of fwd reload torpedo and warhead which may be stowed separately.
10	86	Mid/ port	Deck level	Valve handwheel(s)	Identify handwheel (possibly fwd bilge pump). Investigate other handwheels located aft of that visible in the tilecam. Investigate other handwheel nearer to centre line and fwd (fwd tube operating valve)
11	77	Mid	Deck level	Pressure hull rupture	Investigate overhang lip and whether access is possible
12	76	Mid	Deck level	Capstan	Identify capstan and damage
13	80–70	Stbd	Mid hull	Saddle tank and sea bed	Investigate state of saddle tanks and seabed debris
14	80–70	Port	Mid hull	Saddle tank and sea bed	Investigate state of saddle tanks and seabed debris
15	74	Mid	Deck level	Pressure hull rupture	Investigate overhang lip and whether access is possible
16	73	Mid	Deck – inside rupture	Winch	Investigate object which may be the winch
17	70	Mid	Deck	Pressure hull rupture	Investigate overhang lip and whether access is possible
18	67	Mid/ stbd	Deck	Mystery disc (MD1) and nearby pressure hull rupture and small bore pipework	Investigate location, identify mystery disc, investigate flange (MD4) and whether it matches MD1
19	67	Mid/ stbd	Deck	Small bore pipework and HP air system	Investigate pipework, possibly HP air related. Investigate, if possible, HP bottle groups.
20	66	Mid/ stbd	Deck	WT Antenna stump	Investigate and look for evidence of how it was used
21	65	Stbd	Sea bed	Oblong object	Identify size and shape and possible origin – could it be a piece of the fin plating?

Item	Frame Number	Side	Height	Object	Question
22	64–52	Mid	Fin and bridge	Area	Investigate fin damage, state of hatches, look into fin hatch. Locate fin hatch cover (square). Estimate heights of periscopes
23	64–52	Mid	Deck level	Conning tower and after fin	Investigate conning tower, look up into tower (flag locker, ladder, WT aerial wire). Look down at lower conning tower hatch (into control room)
24	60–56	Stbd	Sea bed	Figure 8 shape	Investigate
25	58	Port	Mid hull	Cylindrical shape in saddle tank rupture	Investigate – possible ballast pump oulet pipework
26	56	Port	Mid hull	Mystery disc (MD2) (resting on saddle tank join to pressure hull and nearby pressure hull rupture	Investigate origin of MD2
27	54	Mid	Deck	Pressure hull rupture	Investigate lip and whether there is access to the beam tube area
28	52	Stbd	Mid hull	Mystery disc (MD3)	Investigate circular shape – possible matching MD1 and 2 (or maybe a sponge!)
29	52–50	Mid	Deck	Ventilation system trunking and debris	Investigate pipe work and flanges, observe sluice valves and their position (open or shut)
30	48	Port	Mid hull	Regular shaped hole in No6 Main Ballast Tank	Investigate possible cause
31	52–44	Port	Mid hull	Cable lying on saddle tank	Investigate – possibly antenna wire
32	49–46	Centre	Deck	Fwd beam tube firing tank	Investigate – why is it not crushed.
33	48	Centre	Deck	Fwd beam tube firing tank	Investigate mystery disc located on top, forward port side – possibly ventilation system related
34	47–43	Centre	Deck	Fwd beam tube firing tank	Investigate – why is it crushed.
35	43–41	Centre	Deck	Derrick winch	Investigate
36	42–41	Centre	Deck	Rounded oblong shape resting on derrick	Investigate. Possibly ER hatch or coaming
37	40–36	Centre	Deck	Engine Room hatch opening	Investigate – identify after strong back, determine if possible to enter
38	40–36	Port	Mid hull	Rounded oblong shape resting on saddle tank	Investigate – possible engine room hatch cover
39	46–41	Stbd	Mid to low hull	Ballast tank damage	Investigate
40	35	Port	Saddle tank	Rounded shaped object	Investigate
41	29–27	Centre	Deck	Exhaust tank outlet pipework	Investigate – specifically the large gearwheel centre/stbd and absence of overboard discharge pipework.
42	16–12	Centre	Deck	Aft firing tank	Why in such good condition
43	14–10	Port	Mid hull	Port after planeguard	Investigate failure mechanism
44	10–4	Port	Mid hull	Port afterplane	Investigate erosion/corrosion effect. Estimate angle of rise
45	4	Port	Under hull	Port propeller	Investigate
46	2	Port	Sea bed	Debris	Investigate
47	14–10	Stbd	Mid hull	Stbd after planeguard	Investigate failure mechanism
48	10 – 4	Stbd	Mid hull	Stbd afterplane	Investigate erosion/corrosion effect. Estimate angle of rise
49	4	Stbd	Under hull	Stbd propeller	Investigate
50	2	Stbd	lower hull	Curious shaped debris	Investigate
51	0	Centre	Deck	Stern tube outer door	Investigate for impact damage under

Attachment 7
Operations complete email message

Dear Madam and Sirs,

This message is not for public comment or distribution.

Serial 4, 0830-1350 today has completed the comprehensive ROV HD stills examination required for the 3D imaging survey of the wreck.

- Over 8300 still images taken during serials 2–5.
- Snapshots using 3D capable viewing software employed by Dr Andrew Woods from Curtin University, show spectacular effects.
- This is a link to an example using an app to achieve 3D effect – model of the stern:

  https://sketchfab.com/models/e119db0942de4298bcf225132935f7fe

  - Note that the starboard propeller is actually intact, the missing pieces shown in the model are gaps in the limited number of photos used, to speed up processing,
  - The final model will overcome this by adding more images to this model set.
- Over 3000 GB of data was collected by Vulcan from the ROV's several HD and SD cameras during the survey.
- Final Serial 5 completed at 1800 positioned a flag display of Australian, NZ and UK flags from a float anchored on the bottom, adjacent to the bow for the parting shot.
- A brief memorial service was conducted onboard to remember the 35 submariners entombed in *AE1*.
- In water ops completed, no further SITREPs will be sent.

Some memorable shots from a very successful two days' surveying:

1 Examining the stern tube to ascertain the status of the stern tube sluice valve, positioned 1.5 metres into the tube in order to determine if this torpedo had been fired. It was shut, making it less likely that it had been fired; however, we are still examining the torpedo tube systems to get a better understanding of the significance of this find. The rudder is lying on the seabed under the port propeller.

2 Examining the bow tube, to ascertain the status of bow tube sluice valve (indeterminate, unable to access far enough into the tube due to restricted access by partially open bow cap)

3 Approach to look into the engine room hatch

4 The flags

We have completed a thorough, non-invasive baseline survey of *AE1*:

- Our timing was none too soon; the fin has moved noticeably and dropped further into the wreckage of the control room in the 3 months since the wreck was discovered.

IN CONFIDENCE

5 The fin has tipped further forward into the wreckage of the control room.

- We have added significantly to our knowledge of the wreck, including:
  - The discovery of the open stern cap – although this currently raises more questions than it answers.
  - The bow is bent back, from substantial impact damage.
    - The impact appears to have forced the bow cap open and the flexing has arguably released 3 of 4 wing nuts securing the bow tube rear door (state of fourth wing nut indeterminate under rubble).
  - The rudder and its supporting skeg have broken off during the impact and are lying on the bottom by the port propeller.
  - The four hull valves on the battery ventilation systems (these were a potential source of a flooding incident) all appear to be correctly shut.
  - The ship's ventilation hull valve is 1/3 open – it should have been shut and this may constitute the source of a flood.
    - We will continue to examine the implications.
    - It may have been possible for the implosion of the hull in its vicinity to have caused it to slide partly open.
- We were able to get a limited view inside the engine room and forward portion of the midships tube space.
  - These areas are clear of sediment.
- We did not come across any human remains.

Thank you to Navy, ANMM and the Submarine Institute of Australia, whose support got us to the starting line for this survey.

The significant benefit of HD stills photographs to create a precise, 3D-capable image set has been comprehensively demonstrated – thank you Curtin University for providing the services of Dr Andrew Woods.

The generosity of RV Petrel's owner and performance of Rob Kraft and Petrel's highly skilled and professional survey and marine crews did the rest.

The survey honours the memory of the men of *AE1* and will provide a sound foundation for the future management of their last resting place.

Regards,

Peter Briggs AO CSC
RADM RAN Rtd
Chairman Find AE1 Ltd
ABN 331 673 313 39
peterbriggs1955@mac.com
0401 004 688
www.findae1.org.au

IN CONFIDENCE

Attachment 8
Current and wind observations from RV *Petrel* bridge

	current direction (from) & speed		wind direction & speed		Vessel status
4:00					
5:00					
6:00					
7:00					
8:00					
9:00	256.0	1.2	033.0	8.0	FULL DP
10:00	256.0	2.0	028.0	10.0	FULL DP
11:00	255.0	2.9	034.0	7.0	FULL DP
12:00	250.0	3.0	353.0	9.0	FULL DP
13:00	238.0	3.0	345.0	10.0	FULL DP
14:00	233.0	2.7	333.0	10.5	FULL DP
15:00	247.0	1.4	330.0	15.0	FULL DP
16:00	230.0	1.4	319.0	11.0	FULL DP
17:00	265.0	1.6	330.0	8.0	FULL DP
18:00	030.0	1.4	335.0	6.0	FULL DP
19:00					
20:00					
21:00					
22:00					
23:00					
0:00					
1:00					

A composite image of the wreck of *AE1*, comprising thousands of individual photographs, juxtaposed with plan and elevation drawings of the vessel. Images Find the Men of *AE1* Ltd