Report

REPORT OF OPERATION SILENT ANZAC MARITIME ARCHAEOLOGICAL ASSESSMENT OF HMAS AE2

	Name	Position
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KEY OUTCOMES

- The objectives of the MAA were achieved.
- The submarine is lying in a low corrosion environment.
- The pressure hull is in a good state of preservation though a more detailed survey would be required to both confirm this impression and support full scale recovery.
- Before either moving or raising additional data would be required.
- The remaining torpedo must be located and the risk from its warhead removed before any effort to move the submarine is made.
- The casing and fin have suffered significant deterioration arising from corrosion and impact by nets and anchors.
- Development of options for future management is now proceeding.
- The joint workshop in Istanbul in April 2008 is intended to provide a recommended way ahead.
- Irrespective of which option may be adopted the following immediate actions are recommended:
    - Ongoing site monitoring.
    - Installation of site physical protection measures.
    - Installation of cathodic protection.
    - Implementation of Turkish cultural heritage controls at the site.
    - Support from all parties for the joint workshop.
    - Education programs to be delivered in Australia and Turkey.

EXECUTIVE SUMMARY

1. Introduction

1.1 HMAS AE2 was located in 1998 by Turkish diver, Mr. Selçuk Kolay. An Australian archaeological team headed by Dr Mark Spencer with Maritime Archaeologist Mr. Tim Smith, positively identified AE2 in September 1998. The submarine was the first to penetrate the Dardanelles Straits during the Gallipoli campaign in 1915, leading a submarine campaign which sank over 200 Ottoman ships, forcing the Ottoman Army defending the Gallipoli peninsula to be resupplied by much slower land routes. AE2 was sunk on 30th April in a battle with the Ottoman ship SULTAN HISSAR.

1.2 Background. The Submarine Institute of Australia (SIA) established the AE2 Commemorative Foundation (AE2CF) to manage the project. In collaboration with the Turkish Institute of Nautical Archaeology (TINA), a multi-disciplinary team of volunteers came together to conduct a Maritime Archaeological Assessment (MAA) of AE2, to gather sufficient data to assess the structural integrity of the submarine and to record its archaeological significance in context. A plan setting out the methods and approach to obtain the necessary data on the archaeological wreck site was developed. The emphasis on safety included a comprehensive Risk Management Plan, prepared as part of this document. The probable presence of an unexpended torpedo, combined with advice from the Royal Navy that indicated that based on their experience with similar vintage weapons, the warhead could be unstable, required additional precautions when gathering data.

1.3 The Expedition Team. The team consisted of ten divers and a supervisor, two Defence Science and Technology Organization (DSTO) personnel with a Remotely Operated Vehicle, experts in corrosion science, maritime archaeology, naval architecture, a Turkish cultural advisor (who also acted as the Media Liaison Officer) and project management personnel. The Project Manager remained behind in Australia due to illness.

2. The Survey

2.1 The survey tasks were conducted in accordance with the Turkish Government permit coordinated by a professional Maritime Archaeologist and were consistent with the objectives of the UNESCO Convention of the Protection of the Underwater Cultural Heritage 2001.Arrangements. A shore Headquarters was set up in the fishing village of Karabiga and the diving activities were conducted from a chartered diving support vessel DETEK SALVOR (DTS) moored in close proximity to AE2. Two fast launches, chartered for the purpose, ferried the team members to and from their accommodation ashore to the wreck site as necessary. Daily activities started when the first launch left at 0700 for DTS and concluded around 2030 – 2100 each evening on return. Divers spent approximately 35 minutes on the bottom during a 140 minute dive. ROV operations were conducted simultaneously with diving operations.

2.2 Initially the current, weather and visibility was favourable, however both conditions deteriorated as the week progressed and finally the last planned activities had to be curtailed. DTS dragged its moorings overnight on 12th September and the shot line weight (a 2 tonne concrete block) was dragged across the after casing of AE2 scraping concretion from the ballast tanks and dislodging a section of casing. This incident was reported to Turkish authorities and an apology tendered.

2.3 Diving Incident. An incident occurred on Wednesday 12th, when one of the divers experienced equipment difficulties shortly after entering the water. With the assistance of the buddy diver and the two DTS standby divers the distressed diver was recovered to the deck unconscious, without respiration or pulse; immediate treatment was administered and the casualty was resuscitated and stabilized. The Turkish Navy Liaison officer arranged for the rapid transport of the casualty to a modern intensive care unit in a hospital in Bursa by a Coastguard fast patrol vessel and a Turkish Navy helicopter. Thankfully the diver has since made a full recovery.

2.4 Diver numbers were halved as a result of the diving incident and other extraneous reasons. In conjunction with the deterioration of the weather, this reduction caused the cancellation of a number of data gathering serials and the final clean up serials to remove guidelines placed to identify data points on AE2 despite an attempt frustrated by bad weather on the day after the programmed completion of the diving time.

3. Pictorial Recording

3.1 Still photography during the initial period provided good images of the bow and forward casing section as well as extensive coverage of the torpedo tubes, stern and propellers. Coverage was restricted by delays in the customs clearance of the shipment of one of the two diving photographer's equipment. Diver held video recording of the archaeological structure and survey operations provided high definition digital footage augmented by divers manipulating handheld lighting aids. The exceptional water clarity during the early phases of the expedition enabled greater than usual depth of vision.

3.2 The deployment of a video camera (the 'drop camera'), specially developed by DSTO, into the conning tower and control room of the submarine was one of the most successful outcomes of the 2007 expedition. It provided images of the conning tower and control room for the first time in 92 years. The camera successfully imaged the interior of the tower and recorded one of the scuttles, or viewing ports in the tower used to provide external vision when conning and steering from the tower (hence the name conning tower). Also seen were a steering wheel, engine repeater and possibly, a voice pipe.

3.3 Important findings included an appreciation of the state of the internal hull and fittings which showed only limited evidence of marine growth coverings and particularly, corrosion products. In fact, the general appearance was that of limited aggressive corrosion. Critically, the inspection confirmed that there was no appreciable amount of sediment inside the submarine hull. This came as a surprise based on the state of many other submarine sites. The water inside the submarine appeared very still and clear. No isolated archaeological relics were observed within the immediate area on the floor of the control room, noting limitations in the depth and field of view of the camera and lighting system. Most of the major items of machinery, piping and equipment could be quite clearly seen and identified.

4. ROV Operations

4.1 The ROV proved itself to be an excellent data collector. A comprehensive video survey of the submarine's entire visible area was completed including clear images of marine flora growing on the submarine and corrosion effects. This is the major data set available for methodical analysis. In addition, the vehicle was used to take a series of ultrasonic thickness measurements on a clean portion of the submarine ballast tanks. The vehicle proved extremely agile for this task and enabled the surface research team to focus in on areas of interest, free of any in-water dive time constraints.

4.2 A survey of the sediment level by the ROV indicated little change since the 1998 expedition although additional evidence was obtained from analysis of a concretion sample that the hull has been buried by sediment on four occasions since the submarine was sunk. A sonar survey confirmed previous surveys that the seabed environment of AE2 is homogeneous and uniformly flat within the immediate environs and showed that AE2 is lying on a heading of 200°. A hand-held sediment coring was completed and indicated that the upper metre of sediment in close proximity to the submarine was of a regular fine silty nature, that tended to become mobile and suspended readily. The Penetrometer survey confirmed that the seabed matrix is uniform in its depth with no obvious evidence of any denser substrate, other than compacted sediment profiles with depth.

5. Corrosion Studies

5.1 The corrosion survey of the AE2 hull started after the completion of still and video recordings of the site. Pairs of divers removed concretion from a small area with a pneumatic drill and then used a corrosion meter to measure the corrosion potential at the site. Whilst the data collection went smoothly, the dive incident and rising sea state curtailed collection so that only six data sets were obtained. However enough data was collected to confirm the corrosion rate predicted by the corrosion scientist so that extrapolations across the hull can be made with confidence.

5.2 A hand held and the ROV mounted Cygnus Multiple Echo Ultrasonic Digital Thickness Gauge was used to measure the thickness of the plating, however inconsistent readings were obtained; possibly due to concretion and sediment. The readings obtained can not therefore be used without further calibration of the gauges.

6. Sampling and Analysis

6.1 The Turkish Archaeological Work Permits limited the amount of actual contact allowed with the AE2 hull and restricted collection of samples of marine plants and concretion. Analysis of these natural coverings was therefore restricted to photographic documentation.

6.2 Water Quality Assessment. In the immediate vicinity of AE2, the seawater was sampled for salinity, dissolved oxygen and temperature at one metre intervals. The most striking characteristic is a strong halocline (change in salinity) at 14-22 metres which also coincides with a marked thermocline (change in temperature; the water temperature fell from 26°C to 18°C. The surface salinity of the top 18 metres was 21 parts per thousand (ppt). This value largely reflects the influx of relatively fresh water from the Black Sea, (an average of 18 ± 0.5 ppt). The bottom 50 metres is dominated by the hyper-saline waters (42 ppt) that flood through the Dardanelles from the Aegean Sea. The smaller thermocline had a turning point at 39.6 metres with the maximum temperature being 18°C and the minimum being approximately 16°C. The site is characterised by a relatively benign corrosion environment, with the dissolved oxygen levels being approximately 50% of the surface saturated values. The surface dissolved oxygen was 6.3 parts per million (ppm) while at the wreck site it had fallen to 3.1 ppm.

6.3 Marine Concretion. A sample of original AE2 ballast tank plating concretion was recovered along with a ring bolt bracket that was dislodged from AE2. These were handed to the care of Turkish authorities once they had received initial analysis and treatment. The small ((8.8 x 4.7 centimetre) sample was analysed on return to the surface, photographed, measured and subject to analytical testing. Preliminary analysis of the concretion sample showed a number of layers of sediment indicating that the submarine has been buried in a fine layer of silt that covered the vessel up to the base of the fin. There may have been a number of such events since the vessel was scuttled.

6.4 Corrosion Assessment. The *in situ* measurements of corrosion potential and pH were limited by the working conditions to one set of data. The observed degree of corrosion of AE2 is consistent with the vessel having corroded for long periods in an essentially anaerobic to very low oxygen microenvironment.

6.5 Battle Damage Survey. No conclusive evidence of battle damage was found. It is likely that the concretion, corrosion products or marine flora have obscured the 37 mm shell holes which caused uncontrollable flooding when the holes were submerged. It was this battle damage which compelled LCDR Stoker to abandon ship and to scuttle the submarine to prevent its capture by Ottoman forces.

6.6 Structural Analysis. The structural analysis of the hull was critical to determine if the strength of the hull girder was sufficient to withstand lifting. Firstly a 3D computer based surface model of the submarine was developed. This model was then validated by a ‘grounding’ analysis to simulate lifting of the hull with two sets of slings. The analysis identified the maximum stress points where hull thickness data was to be collected. The combination of the results of the structural analysis and corrosion data then enabled areas of particular concern in relation to the ability of the hull to withstand lifting, to be identified.

6.7 Sufficient evidence was gathered to form the opinion that the pressure hull is in a remarkably good state of preservation though a more detailed survey would be required to both confirm this impression and support full scale recovery. The overall impression gained was that the submarine is strong enough to be lifted from the bottom and be moved to a shallow water location. Additional data would be necessary before considering either moving or a full scale recovery.

7. Summary of Archaeological Findings.

7.1 Fin and Casing. The major finding of the 2007 expedition is the significant increase in the amount of damage sustained to the upper exposed portions (the casing and fin) of AE2 since its discovery in 1998. At that time the casing was largely intact except for some isolated damage from contact with fishing nets. However the bow of AE2 now bears little resemblance to the photographs taken in 1998. The bow is almost totally torn apart, with the extreme ends bent up, to port and aft, with many plates dislodged, forming a localised debris field on the seabed to the port side of the submarine. It appears that this damage has probably been caused by significant force applied to the port towing pendant, almost certainly larger than that able to be provided by a fishing boat.

7.2 The slope in the forward casing as the casing line lowers towards the bow is completely gone. This feature was a major identifier that this submarine was indeed AE2 when first found, as only the Group One construction E-boats including AE2, had this feature. The fin is more degraded than when inspected in 1998 with a significant portion of its aft plating now entirely missing. The front of the fin and the bridge, remain unchanged, together with the two periscope standards and the horizontal mine jumping wire. A new feature observed on the aft side of the forward periscope standard might be the attachment point for the external steering wheel or perhaps compass. This item is so concealed by colonising marine growth that it is difficult to discern its exact form or attribution.

7.3 The aft end of the fin showed significant loss of plating on its vertical faces. Approximately 1.2 metres of the aft plating has been removed. Continued corrosion has resulted in the removal or collapse of the aft portion of plating, reducing the visual scale of the original fin surface area. It is possible that further net hook-ups have occurred here since 1998, speeding up the deterioration and deformation process.

7.4 The after casing and stern are largely intact and remain as they were last seen in 1998. The dragging of the mooring by DTS resulted in the shot line weight being dragged across the submarine. The impact left an approximately two-metre wide scrape mark on the submarine’s port side saddle tank just aft of the fin where the marine growth and concretion coverings were removed. While not causing structural damage to the ballast tank (other than some ‘popped’ rivets), the shot line weight, in passing over the submarine, dislodged a section of the casing in the vicinity of the aft torpedo hatch. While this unfortunate event was of great concern it provided a unique opportunity for unimpeded observation of the ballast tanks. This revealed a plate surface that appeared to be structurally sound and that has retained an exceptional level of surface integrity.

7.5 The impact revealed a relatively sound and obviously intact lower hull. As the corrosion, ultrasonic and water quality data confirmed, the main hull elements of AE2 have survived in remarkably sound condition based on the low energy marine environment, and the fabric-preserving, essentially anaerobic-to very low oxygen micro-environment. It is considered that the permanently buried portions of the AE2 hull will be in a better state of preservation based on the observed and quantified data. Equally, the interior of the AE2 hull was found to have a benign environment that has resulted in minimal deterioration of the structural elements, fixtures and fittings that were revealed by the images from the drop camera.

8. Condition Summary

8.1 The macro and microenvironment in which AE2 sits has been instrumental in determining its current state of preservation and integrity. It also suggests that without damage caused by local fishing operations (that have accelerated corrosion activity and degradation of the more light-weight upper structure), AE2 would have retained even greater integrity. AE2 is preserved because it is situated in a relatively benign environment of highly anaerobic sediment and a relatively passive water column, with low levels of dissolved oxygen. Any change to these parameters might put AE2 at increased corrosion risk.

8.2 The drop camera images from inside the tower and control room showed the water inside the submarine to be very clear and still. This indicates that, except for the partially open upper hatch, there are few openings into the hull to allow water movement. Of equal interest was the absence of significant corrosion products or marine growth coverings on the internal features. Although analysis of these images to identify the features and artefacts discerned was difficult many internal fittings and fixtures could be identified. The camera found that there is little sedimentation inside the hull. The only visible sediment appeared on the rungs of the internal ladders (where it had accreted through the upper hatch and fallen down), and a small mound of sediment on the control room deck beneath the hatch area.

9. Basis for Options Development

9.1 The starting point for developing options for future management is the hull of AE2 is remarkably well preserved and appears in good enough condition to be lifted clear of the sea bed for relocation to a shallow water site. Further structural analysis would be required before attempting this move or to recover AE2 from the water. It is likely that an elaborate slinging technique would be required. This option can now be sensibly considered, subject to further analysis after additional data on hull thickness has been gathered. As a precondition for recovery or moving AE2 the unexpended torpedo would firstly have to be rendered safe. See ANNEX H.

9.2 The 2007 survey has indicated that AE2 has suffered some additional deterioration. Some naturally caused by ongoing fabric corrosion and destabilisation, other damage caused by mechanical action through contact with fishing nets and a lifting force applied to the port towing pendant, possibly from an anchor fouling it. The damage observed at the site within a short nine year period shows that AE2 is vulnerable to this activity if unchecked. It suggests that one immediate pro-active management option could be through deployment of a defensive barrier around the site, to reduce the possibility of nets, anchors or trawls fouling the submarine.

9.3 The natural deterioration of the superstructure of AE2 could be further limited by the application of sacrificial anodes to the hull. An array of zinc or aluminium anodes could be attached to lower the active corrosion rates significantly. This is a task requiring the skills of a commercial dive team. The anodes would need annual monitoring and anode replacement, probably conducted by ROV as a relatively cheap, non-invasive and effective way to arrest the current corrosion activity. The area of the hull cleared by impact with the shot line weight will cause enhanced, differential corrosion until a protective layer of concretion is re-established. This has the potential to significantly weaken the hull in this area. This outcome could be avoided by affixing protective anodes. See Appendix 2 to ANNEX E.

9.4 The development of options for the future management of AE2 consideration of the options is now underway. Considerations include whether to implement a least-impact approach to site management, undertake certain activities to prolong site retention and management *in situ*, or more extensive interventionist approaches are required or warranted to seek effective protection, management and interpretation, such as:

- Recovery to shallow water for preservation and display, or
- Recovery, preservation and display in an interpretive centre ashore in Turkey.

9.5 The AE2CF will continue to develop these considerations in appropriate forum(s) involving Government, professionals and industry experts in order to establish a hierarchy of appropriate responses to the AE2 site. The next critical step will occur at a joint AE2CF & TINA Workshop planned for late April 2008 in Istanbul in Turkey. This workshop will draw on the information gained from the site that forms the basis of this report.

10. Recommendations

The following recommendations are made:

- Ongoing archaeological and environmental monitoring surveys.
- Installation of site protective measures.
- Effective implementation of Turkish cultural heritage controls and fishing moratoriums.
- Cathodic protection of the AE2 site is a priority to avoid differential corrosion arising from the damage caused by the impact with the diving shot and should be implemented immediately.
- The joint AE2CF-TINA Workshop in Turkey should be supported by all parties to enable development of an agreed option and strategy for long-term management and interpretation of the AE2 site.
- Location and elimination of the risk from the unexpended torpedo in AE2 will be a pre-requisite if the preferred management option involves moving the submarine. The state of this weapon is unknown, although the probability that the warhead could

be dangerous, is low, as the consequences of warhead explosion would be catastrophic, its existence constitutes a risk which must be rendered safe.

- Educational programs should be delivered including:
    - a television documentary,
    - a website with suitable historical content,
    - the placing of commemorative plaques at significant locations in Turkey and Australia , and
    - An Education Program to provide all Australian primary and secondary schools with teaching and learning resources kits that tells the story of AE2.

Report

REPORT OF OPERATION SILENT ANZAC
MARITIME ARCHAEOLOGICAL ASSESSMENT OF HMAS AE2

	Name	Position
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REPORT OF OPERATION SILENT ANZAC

1. Introduction

1.1 The wreck of HMAS AE2 was located in 1998 by Turkish diver and (then) Director of the Rahmi Koç Industrial Museum (Istanbul), Mr. Selçuk Kolay. An Australian archaeological team headed by Dr Mark Spencer with Maritime Archaeologist Mr. Tim Smith, positively identified the wreck to be AE2 in September 1998, when a preliminary recording and assessment of the wreck site was made. This expedition - Project AE2 provided initial information on the state and complexity of the significant new Gallipoli war relic, and established its historical and archaeological values (Smith 1999 and 2000).

1.2 Since then AE2 has only been visited occasionally by the Turkish discovery team. The importance of the wreck in adding to the interpretation of Australia's involvement in the 1915 Dardanelles Campaign has been cemented since that time through academic publications disseminated by the Project AE2 team and through popular histories (e.g. White, Frame and Brenchley). Post discovery, discussion has focused on how best to manage the site in its current contextual setting, and what other options might be available. To answer these questions, the original 1999 Conservation Management Plan prepared for the site (Smith 1999) identified the need to derive additional quantitative data on the state and condition of the hull, associated relics and the environment in which the wreck sits.

1.3 Two technical workshops held in Istanbul (2002 and 2004) aimed at generating a shared approach to the management and interpretation of the site and in fostering an innovative approach to its protection. The discussions confirmed the need to develop a management policy for the site and the need to build on the exploratory 1998 work by initiating standard detailed archaeological and environmental surveys.

2. Location

2.1 The wreck site lies in the inland Sea of Marmara within Turkish territorial waters and subject to the heritage controls of the Republic of Turkey. The site has been identified to be of national heritage significance to Australia, and similarly an important site in the focus of Turkish interests in their ultimate defence against the Allied invasion of the Gallipoli Peninsula during the early stages of World War One (Battle of Çanakkale). As such, both governments have taken an increasing interest in safeguarding the site, with the Turkish Government specially declaring the AE2 submarine an item of archaeological heritage protected under their national heritage legislation in 2006[1]. This fulfilled a key recommendation of the 1998 report and introduced a critical element of legislative protection for the site.

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[1]Turkish cultural heritage legislation. *2863 sayili Kültür ve Tabiat Valiklanni Koruma Kanunu (1983)*

3. Significance

3.1 AE2 played an influential role in the Allied Dardanelles offensive by making the first successful penetration of the Dardanelles Strait to create a diversion, during the landings at ANZAC Cove (25 April 1915). Although subsequently caught on the surface by Turkish gunboats, critically damaged and forced to scuttle (30^{th} April), AE2 led Australian forces into battle, opened up the ensuing successful Allied submarine campaign, and compelled the movement of Turkish supplies and troops via a circuitous land route. AE2's successful wireless message to the Commander in Chief considering evacuation on the evening of the awful landing at ANZAC Cove (Ari Burnu), may have had a seminal role in the decision to keep the troops ashore. That decision may have led to the name "Digger" being adopted for the Australian and New Zealand ground forces, compelled to "dig, dig, dig" and hold their initial positions. AE2 was the first RAN warship to torpedo an enemy vessel and was the first to be lost in battle.

3.2 The wreck survives as one of the few E-class submarines located underwater internationally, and one of the most intact and undisturbed. AE2 is one of 57 completed E-type British submarines that served as the backbone of the Royal Navy Submarine Force during the Great War. Its archaeological potential is therefore significant, with potential to generate new insights into the design, construction and operation of this class of submarine. No other E-class submarine wreck site has been the focus of controlled archaeological survey.

3.3 Lying in 73 metres of water, the AE2 archaeological wreck site provides challenges to proper archaeological survey and recording, necessitating a specialist dive team trained in advanced deep wreck diving techniques and surface support requirements. The Turkish government has endorsed the objectives through consideration of archaeological work permits to conduct the necessary site investigations.

4. Operation Silent ANZAC

4.1 The Submarine Institute of Australia (SIA) undertook this endeavour to preserve and protect the wreck of HMAS AE2 and to promote the telling of the story of the heroic crew of the submarine and their epic feat. Under the auspices of the AE2 Commemorative Foundation (AE2CF) – explained in greater detail in Annex B, and initiated by the SIA in collaboration with the Turkish Institute of Nautical Archaeology (TINA), a multi-disciplinary team of volunteers came together whose mission was to conduct a Maritime Archaeological Assessment (MAA) of the site. A list of Team Members is at Annex C.

4.2 The purpose of the MAA was to gather sufficient data to assess the structural integrity of the wreck and to properly interpret and record its archaeological significance in context– its geography, hydrography and environment. This information is fundamental to any future discussions on the management of the historic site. Unless the site's significance values are fully appreciated, the state of the hull and associated fittings evaluated, and the impact of the environmental setting assessed, no sound policy to preserve and protect the site can be formulated. An important component of this analysis is an assessment of factors affecting the integrity of the structure, both in terms of natural deterioration processes and those man-assisted. A plan setting out the methods and survey approach to obtain the necessary data on the archaeological wreck site was promulgated.

4.3 The safety of all personnel during the conduct of the MAA was paramount. Diving protocols were to be strictly observed, in particular decompression procedures. A Risk Management Plan set out the risks identified and the measures to manage the various risks. Data gathering protocols within five metres of the torpedo tubes and adjacent to the fuel and oil tanks in AE2 were quickly identified and prohibited as having the potential to be a risk. The precautionary approach was adopted because of the probable presence of an unexpended torpedo and the risk of initiating a possible fuel leak. Such sampling restrictions were rigorously observed.

4.4 Key objectives were established to provide a comprehensive database on which to make an assessment of the wreck and its immediate vicinity. Data gathering was not permitted to disturb the wreck site, other than that required to collect data. The methods and tasks to achieve the following objectives were the responsibility of the task leader as designated:

- Evaluation of historic records **Tim Smith**
- Comprehensive pictorial imaging of the site **Craig Howell**
- Determine the physical layout of the site, including an environmental survey comprising geophysical survey and sampling programs which would facilitate environmental studies to identify localised site characteristics **Tim Smith**
- Corrosion and hull thickness survey to identify state of physical fabric and to provide the data for a corrosion study of the exposed portion of the hull to determine chemical activity and site longevity **Ian MacLeod**
- 3D animation to assist archaeological surveys and interpretation **Roger Neill**
- Naval architectural study of structural integrity, including the identification of 'as built' and residual vessel strength. Battle damage survey. **Mike Rikard-Bell**
- Remotely Operated Vehicle (ROV) operations and drop-camera insertion into hull to determine internal characteristics, condition and existence of relics **Roger Neill**
- Report generation and assessment of findings Personnel as designated

4.5 This MAA report is to provide a sound basis to generate an understanding of natural and cultural (i.e. human) processes responsible for site preservation and artefact distribution. The report specifically addresses the site formation processes which are critical in explaining why the site appears as it does today. The dynamics of these processes as described are an important part of the preparation to protect this site; to assist in the consideration of site management options, from low impact to high-end options including possible relocation or recovery for research and display. The understanding the complex AE2 archaeological site provided in this report provides a fuller picture of site integrity and will underpin discussions leading to the development of sound management options.

5. Narrative of Events

5.1 In the lead up to the MAA, RADM Briggs and CDRE Roach called on the Turkish Navy Fleet Commander ADM Ugur Yigit and the Commander Turkish Navy Submarine Group RADM Serdar Duller, both of whom were very cordial and warm in their welcomes. Both were well informed about the AE2 story and were well aware of the planned MAA. The operation was based in the small port of Karabiga in the provincial area administered from Çanakkale is at the western end of the Sea of Marmara, adjacent to the site where the submarine lies.

5.2 The dive team consisted of ten divers and a supervisor. However the delivery of one of the diver's equipment was delayed and he was unable to dive. In addition there were three divers in the Electric Pictures (documentary maker) team. The ROV had a crew of two Defence Science and Technology Organization (DSTO) personnel to operate it. Additional expertise in corrosion science, maritime archaeology, and naval architecture was also in the team. Two members of the dive team were hyperbaric physicians and there was also an orthopaedic surgeon and a paramedic. The team management had a Turkish cultural advisor who was also the Media Liaison Officer. The Turkish Navy provided two liaison officers – one (with diving qualifications) for afloat operations and one for shore support. The Project Manager was unable to travel owing to illness though managed an unexpected administrative load in Australia whilst on light duties.

5.3 The expedition headquarters ashore were established in the local dive club, which was very well suited to the purpose. A comprehensively equipped operations room with good mobile phone communications, broadband internet access; and a UHF base station provided communications with the dive team onsite. Large scale laminated plans (2-3m long) of AE2, white boards and projector provided ready support to briefings for the divers. A large open space to support dive gear maintenance was well suited to the task. The documentary crew had ample space for their activities also. The team was accommodated in the only hotel in the town, (somewhat Spartan standards) where another broadband Wi-Fi net was installed.

5.4 Activities started as the sun rose over the mountains at 0700 approx when the two fast boats (chartered for the purpose) ferried the team out to DTS. Diving operations commenced on arrival and the documentary crew recorded the activities on deck and in the water as the day progressed. ROV operations ran concurrently with the divers. On most occasions the divers were in the water for approximately 140 minutes which included approx 35 minutes on the submarine. As diver numbers permitted, they invariably operated in pairs at least; morning and afternoon shifts were used as appropriate for the tasks being undertaken. The fast boats were used to ferry personnel to and from shore as necessary. On most nights the last members of the team returned to shore at 2030-2100, to prepare for the next day's diving.

5.5 Operations were conducted from a diving and salvage vessel – DETEK SALVOR (DTS) chartered for the purpose from a Turkish company, Detek Offshore Marine. DTS was moored adjacent (approx 25 metres) to the submarine site and remained on site throughout. Strong winds and current caused the DTS to drag its anchors and it was compelled to reposition towards the end of the period. This caused the loss of a day for diving operations. A shot line, with a large concrete clump block attached, resting on the sea bed, was secured to DTS. A light line provided a ready guide to the submarine some 25 metres away. The DTS provided two surface support divers at immediate standby throughout the periods whilst divers were in the water. The recompression chamber with three Turkish hyperbaric physicians in attendance was also at immediate readiness throughout. DTS maintained a Rigid Inflatable Boat (RIB) at immediate readiness to recover a diver who may have surfaced away from DTS and who could have been swept away by current. One fast boat was always kept at immediate readiness at DTS for casualty evacuation if necessary.

5.6 A full report on ROV operations is at Annex E. The DSTO ROV proved itself to be an excellent data collector. Expert operation by the ROV crew allowed concurrent operation of the vehicle and the divers. The excellent visibility early in the week permitted the completion of a comprehensive video survey of the entire submarine visible. In addition clear images of marine flora growing on the submarine and corrosion effects were collected. As the current gained strength, the drag on the umbilical cord made operation more difficult until the operators worked out a way to reduce the effect. The vehicle was a key element in finding the casualty's diving gear which was dropped during the recovery. In addition, the vehicle was used to take a series of ultrasonic thickness measurements on a clean portion of the submarine ballast tanks. See later discussion in Annex E Conservation Assessment etc. and Annex F Report on ROV Operations etc.

5.7 The weather started out well but deteriorated in the latter days. Initially visibility underwater was excellent, with little current, however as the week progressed and the current grew stronger, visibility for the camera crews declined. The team observed a wind Force 6 overnight on Wednesday 12th evening with an increase in the current to perhaps 1.5 to 2 knots. Invariably the current was out flowing towards the Dardanelles Straits. The DTS dragged its anchors in this strong wind and the shot line weight was dragged into impact with the submarine, scraping the ballast tanks and casing in one location on the port side just aft of the fin. Fortunately the strong wind and consequent seas subsided on Thursday 14th and boat traffic and diving operations were not disrupted. Subsequently on the Saturday 15th night there was another Force 6 wind and DTS dragged again to such an extent that it became necessary to recover the mooring, to relocate the submarine and to relay the moor. This meant that only one dive sortie was achieved on the Sunday 16th before the rising sea state curtailed operations. The tasks allocated for these last sorties had been to recover the marker tapes laid out on the submarine to assist the precise locations of points from which to gather ultra sonic data. The recovery of these tapes and some remaining light lines from deployed surface marker buoys (SMB) was frustrated by the necessity to relay the moor and the rising sea state. The effect of weather was to severely curtail the opportunities to dive; some 40% of allocated survey time was lost.

5.8 Extension of Planned dive operations. On Monday 16th, despite the closure of the dive operations on Sunday and complete demobilization of the survey vessel, another attempt was made to complete the task of recovering the marker tapes. It was deemed important that all attempts should be made to leave the site in an orderly state, following standard archaeological principles. DTS sailed to support this task, however the high sea state again prevented boat traffic and transfers and this last additional task had to be finally aborted.

6. Diving Incident on Wednesday 12th September

6.1 During the afternoon sorties on Wednesday 12th, one of the divers experienced equipment difficulties shortly after entering the water leading to a near drowning. With the assistance of the buddy diver, the distressed diver was brought to the surface where the two standby divers entered the water to bring the casualty to DTS. The diver was recovered to the deck unconscious, without respiration or pulse, immediate treatment was administered and the casualty was resuscitated and stabilized. The Turkish Navy Afloat Liaison officer arranged for a Turkish Coastguard fast patrol vessel to transport the casualty to shore where a Turkish Navy helicopter took the patient to a modern intensive care unit in a hospital in Bursa.

6.2 The Medical Protocols and MEDEVAC procedures set out in the Risk Management Plan in the SILENT ANZAC Operation Plan (which included the liaison visit by the Project Manager in February 07) for the management of the casualty worked extremely well and reflected great credit on the Turkish Navy. It appears that the diver has made a complete recovery. All agencies involved in the recovery operation were formally thanked by letter before the team departed from Turkey.

7. Survey

7.1 The diving casualty incident reduced the number of divers by three – the casualty, the Diving Supervisor (who had to be replaced by his deputy – another diver) and the Expedition Australian hyperbaric physician who accompanied the casualty and remained at the hospital for the initial sojourn there. One of the other divers had to return early to Australia for compassionate reasons. Coupled with the delayed arrival of the diving equipment of another diver, the effective diving strength was halved. This severely limited the number of ultrasonic thickness measurements that could be taken of the pressure hull and ballast tanks.

7.2 The archaeological survey methodology to obtain the required data was identified through a series of workshops held in Australia prior to the team's deployment. The combined team members had extensive professional backgrounds in iron and steel shipwreck assessment work, and in the study of submarine sites as discreet archaeological site types. The team included two members of the original 1998 Project AE2 team with extensive knowledge of the site.

7.3 The survey tasks were standard archaeological assessment tools regularly undertaken by archaeological heritage management professionals and followed standards employed internationally. All work was governed by the approvals processes of the Turkish Government and coordinated by a professional Maritime Archaeologist. The survey approach was consistent with the objectives of the UNESCO Convention of the Protection of the Underwater Cultural Heritage 2001, and was supported by the Australasian Institute of Maritime Archaeology (AIMA).

7.4 A key task of the maritime archaeological survey operations was the gaining of additional imagery of the submarine site. This reflected the limited recording opportunities during the discovery survey in 1988. There were two main elements to this operation:

- general views of the site in its contextual setting for interpretation purposes, and

- Detailed recording of key diagnostic elements, to investigate their state, level of corrosion and marine colonisation activity.

General images of the dive team at work were also needed to document the survey operations and for publicity purposes.

7.5 Due to the favourable sea conditions prevailing on the first four days of the survey period, the gaining of still and video footage was accelerated. The stills photographer was tasked with capturing specific areas of the submarine with a focus on the bow section which showed evidence of extreme deterioration since 1988 (pre-arranged shot list). The entire forward casing was documented in detail, together with the fin and conning tower upper hatch, both pre and post insertion of the drop camera (below), as a record of the expedition’s contact with the site. Another key task was the documentation of all visible torpedo tube ports to aid analysis of their form and state in order to assist later studies of the potential for the remaining torpedo to be retained inside the hull.

7.6 The stern quarters of the site were recorded in detail to assist the remote operated vehicle operation in search of signs of battle damage (see below). In this task, macro photographs of the exposed tips of the propeller blades were also imaged in case they showed any signs of deformation caused by the significant groundings as AE2 penetrated the Dardanelles Strait (inconclusive due to extensive burial of the propeller blades port and starboard). Another task of the stills recording was the documentation of marine growth cover at various points on the hull. While general footage of plant and marine growth was obtained, the detailed macro photography of a sample 25 x 25 centimetre section of hull was not completed due to the loss of diving days (above). Similarly the planned vertical photogrammetric survey of the topside hull surfaces was not completed.

7.7 Still photography has provided detailed high resolution captures of the submarine that have assisted later interrogation of the site. While significant tasks were completed, the operation was hampered by the reduction of the specialised photographic team from two to one, because of the delayed arrival of critical photographic equipment for the duration of the survey period. Similarly the consequent reduction in the range of cameras and lenses available affected the photography gained.

7.8 Diver-held video recording of the archaeological structure and survey operations was completed by a specialist British-based dive team, Mallison-Sadler Productions, working with the documentary film makers. This involved high definition digital footage augmented by divers manipulating handheld lighting aids. The filming operations were a highlight of the survey operations due to the extensive coverage obtained of AE2, appearance and its localised environment. The exceptional water clarity during the early phases of the expedition enabled greater than usual depth of vision, meaning that much more of AE2 could be sighted than usual, providing a unique glimpse of the wreck from a divers' perspective.

7.9 A specialised underwater lighting rig using OMD Monsoon 1000w AC system was brought to the site for permanent suspension in the water column under the survey vessel, DTS. Unfortunately the gantry proved insufficient for the sea state encountered and the rig had to be abandoned. The rig was to provide flood lighting at depth on site to assist underwater photography, and to provide an additional safety factor for divers' activities. However, the water conditions were generally sufficient to enable photographic recording with traditional techniques. The high quality footage provided another databank of material for post-expedition analysis, complementing the lower resolution video footage captured by the remote operated vehicle in its survey tasking.

8. Drop Camera

8.1 A successful drop camera insertion into the conning tower and control room of the submarine was successfully completed on 12 September 2007 and involved a surface ROV team and four individual teams of paired-divers during the day-long continuous survey operation. Gaining a visual understanding of the nature of the internal spaces of AE2 was deemed a critical survey requirement. Such imagery is invaluable in assessing the state of the internal pressure hull, particularly how much sediment is in the hull. The amount of internal sedimentation substantially affects the rate of internal corrosion processes, as well as the retention of scattered relics, and is a major factor in considering the options for future management of the wreck, in particular the options for relocation or recovery.

8.2 To obtain as much internal imagery as possible preparations were made to deploy a small Seabotix LBV150L ROV (controlled from the surface) into the AE2 hull. This was planned to be manoeuvred around the site as far as umbilicals, sediment, internal structural barriers, and general water visibility permitted. To assist this endeavour, a 3-Dimensional computer model of the internal spaces of the submarine was developed by DSTO. This computer generated imagery (CGI) has been of particular value in interpreting the images obtained by the drop camera. Additionally it has been valuable in evaluating the accuracy of the construction drawings of the AE2, in consultation with historic photographs of the internal elements of later completed E-class submarine boats, and in providing a useful vehicle for public education purposes.

8.3 Entry of the ROV into the submarine however, was dependent on the upper hatch to the conning tower being free to open sufficiently to introduce the vehicle. As disturbance to the archaeological structure was not permitted by the Turkish archaeological approvals, and therefore eliminated from the survey task plan, any inability of divers to fully open the hatch mechanism would terminate the attempt. In this eventuality, a backup option was developed, the deployment of a fixed pivoting ‘drop camera’. This could fit through the existing hatch opening without the need for any additional opening of the hatch. Both techniques however required the lower hatch to the control room to be also open. The status of this second hatch was much conjectured during the planning stages.

8.4 Preliminary planning meetings identified the probability that the upper hatch to the conning tower might be immovable due to natural corrosion processes since the vessel’s loss in 1915. This proved to be the case during the recent survey operations; hence the ROV survey task inside the submarine could not be attempted. The special drop camera and supporting guide frame was developed by the DSTO – Melbourne, under the direction of Dr Stuart Cannon. Its configuration was based on the dimensions of the hatch and tower shown on the original plans. The position of the upper conning tower hatch and the clearance available was known from the 1998 survey (providing a maximum 10 centimetres clearance). The 2007 drop camera survey was planned to be non-disturbance in nature and was successfully executed without any disturbance to AE2, its surrounding marine growth coverings, or internal artefacts. The entire operation was independently recorded by still and video photography both prior, during, and post deployment, to record any impacts with the hull or fittings.

8.5 Once the camera was positioned into the hatch opening by divers under direction from surface communication, the camera was slowly lowered into the conning tower. Progressive dive teams continued the deployment deeper into the hull as their individual dive times concluded. It was postulated that the internal hatch to the pressure hull would most likely be found open, based on an assessment of detailed drawings obtained of the locking mechanism and from expert knowledge of likely actions by the Commanding Officer to scuttle the submarine. This indeed proved correct, enabling the drop camera to be fully inserted into the AE2’s control room below the conning tower, to the level of the vessel’s floor plates.

8.6 The drop camera survey has been one of the most successful outcomes of the 2007 expedition. The camera successfully imaged the internal cavity of the upper conning tower and recorded one of the scuttles in the side of the tower used to provide external vision. Also seen were a steering wheel, engine repeater and possible voice pipe. The discovery that the lower hatch into the control room of the AE2 was an exhilarating moment for the entire expedition; it allowed the camera to provide images of the control room for the first time in 92 years.

8.7 Important findings included an appreciation of the state of the internal hull and fittings which showed only limited evidence of marine growth coverings and particularly, corrosion products. In fact, the general appearance was that of limited aggressive corrosion. Critically, the inspection confirmed that there was no appreciable amount of sediment inside the submarine hull. This came as a surprise based on the state of many other submarine sites.

8.8The water inside the submarine was very still and clear. No isolated archaeological relics were observed within the immediate area on the floor of the control room, noting limitations in the depth of view of the camera and lighting system. There was clear evidence of most of the major items of machinery, piping and equipment expected from the historic plans. These could be quite clearly seen and identified.

8.9 It was not possible to transit the wreck with this fixed vertically deployed camera however the limited extent of the survey has provided unique and critical information on the state of the internal parts of the AE2 submarine historic shipwreck. This information has been invaluable in interpreting the structural condition of the site in conjunction with the external hull corrosion and metal thickness remote surveys (see Annex E Conservation Assessment etc). Because of the inability to manoeuvre the camera through the hull, the state of the internal port and starboard beam torpedo tubes could not be ascertained. It was hoped that the footage might confirm the absence of any spare torpedoes in their original hanging frames above these torpedo tubes, hence discounting a probable location of the eighth and unaccounted-for torpedo. While this was unfortunate, an evaluation of historic records suggests that all four torpedoes probably allocated to these tubes had been expended before the vessel’s loss on 30 April 1915.

9. ROV External Imagery

9.1 The ROV was deployed to gather additional imagery of the external surfaces and condition of the AE2 as a supplementary (backup) system to the hand-held video recording serial. This provided greater flexibility in planning scheduled diver tasks, freeing up in-water dive times. The entire hull was traversed by the ROV whilst performing its other tasks including monitoring the work and condition of the divers, and in undertaking remote readings of metal hull thickness using a ultrasonic hull thickness measuring tool (see discussion below and in Annexes E and F). The vehicle proved extremely agile for this task and enabled the surface research team to focus in on areas of interest, free of any in-water dive time constraints. The resulting video footage has provided the major data set available for methodical analysis. Initial findings from these results are discussed in detail in Annex F ROV Operations

9.2 Due to the early termination of survey operations with the DTS mooring issues and inclement sea conditions towards the end of the survey period, the planned ROV photogrammetric survey of the AE2 upper hull and casing was not achieved. However the external sediment level survey was completed by driving the ROV around the interface level with the wreck. This visual survey provided sufficient data so that the extent of sediment levels around the exposed portions of AE2 hull could be readily marked on scaled drawings of the hull to indicate the burial depth. Discussed later, the findings generally confirmed the burial depth observed by the 1998 dive team. Generally the hull is covered by surrounding sediments to just under the level of the forward hydroplanes and slightly less at the aft hydroplanes (approximately amidships). The aft planes were raised sufficiently to allow the vehicle to be manoeuvred under them. This suggests that the AE2 has a slight bow down attitude. An evaluation of the sand levels at the propellers confirmed their similar coverage to 1998 levels, indicating that sediment transfer around the site might be quite stable.

10. Conventional mapping by divers

10.1 The reduced dive team and commitments to complete additional critical survey tasks restricted the amount of actual survey measurement work undertaken by the divers. Each dive pair was instructed to observe key features of the wreck structure, noting any obvious signs of change from the 1998 survey. Upon return to the surface, all observations were recorded onto dive sheets for later evaluation and task definition for subsequent dive serials.

10.2 In this manner, each dive team visually inspected the entire exposed surfaces of AE2. Their findings then dictated whether additional inspections were required to obtain data, generally undertaken by the remote operated vehicle which had no in-water time constraints. Due to the reduced diving operations, actual bottom measurements of key features, particularly scale of corrosion openings, was restricted. The observed form of the external structure was therefore largely captured graphically and scaled onto existing three-dimensional survey plans of AE2. This presents an opportunity to graphically depict the current external state of the hull and major areas of obvious deterioration or change since 1998. The ability to compare the state of the wreck within a 9-year interval has been very illuminating.

11. Deployment of side-scan sonar

11.1 The sides can sonar survey was conducted on Tuesday 18th September between 8.20 – 10.15 am. The operation was under the direction of Mr Selçuk Kolay, TINA, with Mr Tim Smith and Dr Roger Neill, using a CM2 C-Max side scan sonar with a cable length of 250 metres and plotter (Marimateck P-Sea Master 400). While the sea state of 2-3 included some surface chop, the towed body was readily deployed at an ideal depth of 9 metres above the seabed. The submarine was found on the first pass with a sonar beam range of 100 metres either side of the survey vessel (Targa 34). Unfortunately, due to the number of light survey lines that still existed on the AE2 (notwithstanding the cancelled sortie to recover them); the sides can survey was hampered due to the fear of accidental fouling. Several passes were made of the submarine from an elevated height of 16-18 metres at 1.8 knots with 90 meters of layback on the sides can. The resulting images clearly showed the form of the submarine and main structural elements as evidenced in the resulting ‘shadow’. Also clearly visible were the mooring positions of DTS and the furrow caused by the shot line weight, when dragged by the vessel when it was driven in the recent storm event. The furrow leading to the impact point on the hull was clearly depicted.

11.2 The sides can sonar imagery complemented that already obtained by Mr Selçuk Kolay and confirmed that the AE2 lies with its bow pointing towards Karaburun Point on a heading of 200º. General bathymetry data was extracted from the C-Max survey and confirmed that the seabed environment of AE2 is homogeneous and uniformly flat within the immediate environs.

12. Diver operated probe of surrounding sediments

12.1 The planned serial to deploy a hand held 3-metre steel probe (diameter 15mm), to investigate the structural composition of the seabed immediately adjacent to the submarine was cancelled, due to restricted dive time. However the hand-held sediment coring discussed below was completed and indicated that the upper metre of sediment in close proximity to the submarine was of a regular fine silty nature, that tended to become mobile and suspended readily. The Penetrometer survey (see Annex F) confirmed that the seabed matrix is uniform in its depth with no obvious evidence of any denser substrate, other than compacted sediment profiles with depth.

13. Corrosion Studies

13.1 The corrosion survey of the AE2 hull was an initial survey priority for the expedition. This serial was initiated after the completion of still and video recordings of the site. The operation involved teams of divers descending to the wreck site with a corrosion meter and pneumatic drill attached to an air cylinder. The serial had been extensively practiced in Australia on an equivalent World War One-era British J-boat submarine wreck in coastal water off Melbourne.

13.2 Whilst the data collection went smoothly, the intervening dive incident and rising sea state halted the survey tasking. In the end only six data sets were obtained before the task was halted. While not providing a corroborative sampling set, the readings were sufficient to enable the corrosion regime of the AE2 hull to be extrapolated across the hull. The rate of corrosion matched the postulated corrosion profile as determined by Dr Ian MacLeod, Corrosion Scientist. The serial was initially envisaged to collect eight measurement points at predetermined sites along the AE2 hull that would equate with possible points of designed hull weakness. The curtailment of this serial dictates that a future expansive corrosion survey be re-conducted at the site (more detailed discussion in Annex E Conservation Assessment).

14. Ultrasonic thickness testing

14.1 It had been planned to use a hand held Cygnus Multiple Echo Ultrasonic Digital Thickness Gauge to measure the thickness of the plating of the submarine. The gauge functions by identifying the successive reflections from the near and remote surfaces of the base metal layer, and calculating the thickness from the average transmission time of the acoustic signals through the metal.

14.2 The unit was tested during the training exercise conducted prior to the MAA; two of the divers became quite proficient in the use of the hand held instrument that required the orientation of the transducer be rotated until a steady reading was registered. The divers were also briefed on the readings to be expected at each of the specified sites on the pressure hull and the ballast tanks. A similar gauge was fitted to the ROV and this was also tested prior to the MAA.

14.3 The number of readings taken with the hand held instrument was restricted to 6, primarily because of the reduction in the number of divers available as discussed earlier. The reduction in visibility was also a factor. Only two of these readings were taken on the previously specified sites on the ballast tank and the remaining four taken on the vertical side of the casing. No readings were taken on the pressure hull.

The readings on the ballast tank averaged 10.7mm in an area in way of frame #27 where the only possible combination of frame and plating would be 9.6mm.

The readings on the casing plating averaged 4.8mm in an area where the nominated plating thickness was 3.1mm.

The divers found it extremely difficult to get steady readings due to the presence of both silt and a layer of extremely tough concretion.

14.4 The interpretation of the measurements taken with the hand held instrument was considered in conjunction with those readings taken by the unit mounted on the ROV. All readings were consistently higher than those that had been expected. Fortuitously a piece of concreted material had been recovered from the submarine by one of the film crew divers. The specimen had been placed in the custody of the Turkish Navy Liaison Officer on DTS. With his approval physical measurements of the specimen were noted followed by ultrasonic thickness readings.

14.5 The specimen was irregular in shape and measured approximately 13mm at its thickest point while the Cygnus unit only recorded approximately 6mm at the same point. The conclusion reached was that the Cygnus units were measuring the total thickness of plate plus concretion and that any conclusions derived from these readings in relation to actual steel thickness would be invalid. See Annex G Structural Analysis for further discussion.

15. Water quality

15.1 The gaining of quantitative data on the nature of the surrounding water column was a pre-requisite for the analytical interpretation of the corrosion and ultrasonic hull measurements. A TPI WD30 instrument which has a temperature and salinity measuring probe and a separate YSI dissolved oxygen meter head was deployed through the 74 metre water column in the vicinity of the fin. Readings of water temperature, salinity and dissolved oxygen content were obtained at 50-centimeter intervals, extending into the surrounding seafloor sediment for a depth of one (1) metre. The exercise was repeated on the following day to confirm initial reading levels.

15.2 The primary analysis of the site involved an assessment of the chemical environment created by the Sea of Marmara in the immediate vicinity of the wreck. The seawater was sampled for salinity, dissolved oxygen and temperature at one metre intervals, using a combination instrument that enabled the data to be logged at each depth. The most striking characteristic is a strong halocline (change in salinity) at 14-22 metres which also coincides with a marked thermocline (change in temperature). In this zone, the water temperature fell from 26°C to 18°C. The surface salinity of the site, which dominates the top 18 metres, was 21 parts per thousand (ppt). This value largely reflects the impact of the influx of relatively fresh water from the Black Sea, which has an average of 18 ± 0.5 ppt, which joins the Sea of Marmara at Istanbul as the water flows in through the Bosporus. The bottom 50 metres of the site is dominated by the hyper-saline waters that flood through the Dardanelles from the Aegean Sea. Once the upper waters had been traversed, the deeper water column had salinity values of 42 ppt, which is similar to the high salinity waters of the Aegean Sea from the Dardanelles and the Straits of Çanakkale. The smaller thermocline had a turning point at 39.6 metres with the maximum temperature being 18°C and the minimum being approximately 16°C.

15.3 Owing to the very difficult operating conditions on the site, with very limited visibility when the silt had been disturbed, only one set of pH and corrosion potential measurements were effected. Despite this, the nature of the data was sufficient to establish that the site was characterised by a relatively benign corrosion environment, with the dissolved oxygen levels being approximately 50% of the surface saturated values. The surface dissolved oxygen was 6.3 parts per million (ppm) while at the bottom it had fallen to 3.1 ppm.

16. Biological Sampling and Analysis

16.1 The proposed data collection serials were planned to maximize the amount of quantitative site data against which the modelled and actual corrosion profile of the hull could be interpreted. This serial was reduced in scope due to the final site testing approvals issued by the Turkish Ministry of Culture, through the Archaeological Work Permits received immediately prior to the team's departure. These approvals limited the amount of actual contact allowed with the AE2 hull and a restriction on sample collection.

16.2 Similarly, the recovery and export of marine plant coverings was cancelled. It was envisaged that the scientific analysis of algae and plant species resident on the AE2 hull by a professional Marine Biologist would augment the team's interpretation of the corrosion regime active at AE2. This included an ability to document the depth and density of marine growth coverings and the effect they had on the restriction of Oxygen molecules impacting on original metal hull fabric, and therefore on the rate of corrosion activity at depth. Analysis of these natural coverings was therefore restricted to photographic documentation. The review of these images is not yet complete.

16.3 A similar restriction on marine concretion products resulting from the 92-year natural deterioration of the hull was also restricted. Individual dive teams measured the visible depth of this concretion matrix when obtaining corrosion and ultrasonic hull thickness measurements and confirmed that the depth of accumulated concretion products was very small (3-5 millimetres). A sample of original AE2 ballast tank plating concretion was recovered along with a ring bolt bracket that was dislodged from the vessel and recovered by divers who handed the object to the care of Turkish authorities once it had received initial treatment. The bolt showed that it suffered normal wrought iron degradation in that the metal was torn rather than being fractured like a cast iron fitting would have been. There was very active corrosion around the tear line on the bracket and within minutes of recovery the normal weeping patterns of a clear liquid transforming into a red-brown akaganeite crusty growths. The amount of residual solid metal in several parts of the bracket was very small. It was not clear whether this sample was already removed from the submarine and lying in the adjacent sediment, or whether it had been dislodged from the casing by the impact. The sample appeared to comprise part of the upper casing of the AE2 (non-pressure hull), manufactured from thin steel plate. The small ((8.8 x 4.7 centimetre) sample was analysed on return to the surface, photographed, measured and subject to analytical testing. Discussion with relevant Turkish authorities enabled the small sample to be forwarded to a Turkish laboratory for detailed analysis. The results of this analysis have not yet been received.

16.4 This small sample has proved critical in the assessment of past corrosion activity at AE2. Sectioned, photographed and exposed to optical microscopic imaging, it became immediately clear that the upper portion of hull has experienced significant original metal thickness loss through corrosion, but relatively small formation of concretion products and marine growth coverings.

17. Concretion Assessment

17.1 Observations by the technical divers confirmed that the concretion was a classic anaerobic matrix, with a very dense milieu of sharp shell debris and black iron corrosion products, which consisted of magnetite (Fe_3O_4) and a number of iron sulphides. Analysis of a small sample of concretion that was recovered from the debris field associated with the damage caused by the shot line weight showed that the primary corrosion layer consisted of magnetite. It was possible to discern the original metal surface and the multiple layers of corrosion products and marine concretion that lay to the seaward side of this matrix. There was a mass of corrosion products beneath the original surface, which indicated that at that point, pitting corrosion on the submarine had eaten into the metal to produce a 3 mm layer of corrosion products. Preliminary analysis of the concretion sample showed a primary concretion layer roughly 1.6 mm thick, which was followed by a secondary layer 8.8 mm thick and a third layer to the outer zone of the concretion which was 3.9 mm thick. It is very likely that following the scuttling event, the vessel sank into a fine layer of silt that covered the vessel up to the base of the fin. At various intervals in the ensuing years, the amount of silt has varied in a clearly defined pattern associated with changing depths of burial which are connected to major storms. The concretion analysis indicates that AE2 was initially buried in silt to the base of the fin; it then became exposed to normal sea water after a storm, for a long period and was further buried and then exposed to be found in its present condition of being partially buried in a silt mound.

18. Corrosion Assessment

18.1 The *in-situ* measurements of corrosion potential and pH were limited by the working conditions to one set of data. Despite this, the pH of 7.3 and a corrosion potential of -0.391 volts vs. the Normal Hydrogen Electrode are characteristic of iron corroding in low energy marine environments. The divers reported a thin concretion layer of 3 mm located some 5.74 metres aft on the casing behind the fin. Thickness measurements with the hand-held Cygnus ultrasonic metal thickness unit gave an average value of 4.8 ± 0.9 mm for the exposed metal surface after removal of the external concretion layer. Given that the original thickness of the casing is likely to have been only 3.1 mm it is apparent that additional calibration of the instrument needs to be undertaken before it is possible to determine a corrosion rate that is based on loss of metal thickness. Tests with the gauge on a 13 mm sample of concretion gave a value of 6 mm which indicates that the instrument is picking up a signal from the magnetite corrosion products within the concretion matrix. An estimate of the corrosion rate of AE2 can be made using empirical equations based on the corrosion rates of iron shipwrecks in open ocean waters. Using a depth of 73 metres the estimated value for AE2 is 0.018 mm/year or an average loss of 1.66 mm for the external surfaces. Experience with the USS Monitor and other wrecks has shown that internal corrosion rates are typically one third of the external rates, thus a combined metal loss of 2.2 mm could be expected. The observed degree of corrosion of AE2 is consistent with the vessel having corroded for long periods in an essentially anaerobic to very low oxygen microenvironment.

19. Sediment coring

19.1 Two sediment cores were obtained from either starboard side of the AE2 hull away from the physical archaeological fabric. Each core was recovered (50-centimeter length, 50 millimetre diameter) using a PVC core tube manually inserted into the seabed, capped, and recovered to the surface. Upon recovery, the sediment's pH, temperature and dissolved Oxygen content were analysed at 1 cm intervals close to the bottom and top of the core for 10 cm and then at 5 cm intervals for the remaining length of the cores.

19.2 Sediment core samples were taken near the fin and at a distance from the vessel to gauge what impact AE2 had on the immediate physical environment. There were statistically significant differences in the way in which the redox or oxidation/reduction potentials varied in the two cores, with the off site voltage and pH relationship being dominated by the normal marine sediments and the on-site core being controlled by a different mechanism. The upper layers of the cores were dominated by the presence of dissolved oxygen, which rapidly fell to essentially anoxic values within the first 5 cm of the sediment layers. The on-site core had a mean pH of 7.82 ± 0.04 in the upper section but this fell linearly to a minimum of 7.40 over the bottom 7 cm of deposit.

19.3 Due to the restriction on export of samples to Australia for laboratory analysis of sediment (particulate) size and composition, a small sample was retained for analysis at a relevant Turkish Institution. The recovered sampled was packaged and transported to the Middle East Technical University Ankara where further analysis is being completed (survey data not at hand at time of writing).

20. Summary of Water, Biological, Concretion, Corrosion and Sediment Analysis

20.1 Further analysis of the voltage and pH measurements has shown that the iron corrosion products are in equilibrium with the black Fe_3O_4 which forms a coherent layer against the original fabric of the hull. This is consistent with the relatively small amount of flash rusting that was associated with the exposed hull section following the accidental impact with the mooring block. All the data indicates that AE2 has been corroding in a relatively benign environment for 92 years and that there have been periodic site disturbances that have altered the amount of sediment around the hull. These changes are likely to have been associated with severe storms and are therefore periodic in nature and cannot be predicted. Changes in the concretion profile have illustrated the fact that the site conditions have varied over 92 years.

21. Battle damage survey

21.1 As indicated above, the battle damage survey was identified as an important element of telling the 'AE2 story'. Firm evidence of the shell damage inflicted on AE2 by the gunboat Sultan Hissar would confirm the historical evidence of the hits and their catastrophic impact on the AE2 and its crew's fate.

21.2 Historical diaries of former crew, and the official account by LCDR Stoker, confirmed that three 37mm shells pierced AE2's hull in the engine room aft. The historical accounts do not dictate which side of the hull AE2 received this damage, and therefore the relative positions and orientation of the submarine and the gun boat at the time. Stoker said that the damage was above the waterline and therefore was not critical when the submarine was on the surface. Other crew state categorically that hull was holed after poking near vertically out of the water after recovering from the steep dive angle, this damage allowed uncontrollable flooding as AE2 dived quickly to evade the gunfire. Stoker was therefore forced to blow all ballast tanks to regain the surface. One record indicated that the shells hit AE2's hull in close proximity, with a crewman instinctively trying to plug the holes with his hands! This indicates that the shells struck an accessible portion of the inner hull (i.e. aft of the massive engine blocks). This further suggests that the shell holes must therefore have been located on the pressure hull adjacent to the surface water line of the submarine, and therefore should be visible through an external inspection of the area aft of the engine mufflers and forward of the aft hydroplanes.

21.3 The inspection involved free swimming divers and dedicated surveys by the ROV. Imaging on the starboard hull was not completed due to the inclement weather. However, in the areas surveyed in detail (~90% of the surfaces), no obvious signs of shell holes were observed although several holes of the appropriate diameter have been identified in ballast tank plating on the port side in the area cleaned by the shot line weight. This plating would have been visible during the submarine's excursions to the surface during the battle. Several larger (approximately 15x15 cm) corrosion openings were observed in the adjacent upper casing of the aft hull that might have originated from shell fire. However these exactly mirrored regular corrosion activity along the full length of this casing, reflecting the thin plate structure and damage resulting from abrasion by fishing nets.

21.4 A hole in the port muffler was intriguing and could constitute either battle damage or standard corrosion. It could be that the shell fire penetrated the upper 'deck' of the AE2, i.e. through the casing area, although this would not correspond exactly with eyewitness statements that indicate the shells passed through a readily visible portion of the hull in the engine room compartment. It could be that the 37mm shell holes, if not widened by resulting corrosion may have been partially concealed by the marine growth and corrosion products covering the hull. The inspection on the starboard side should be continued as a priority.

21.5 The structural analysis of the AE2 hull was a key part of the MAA to determine if the strength of the hull girder was sufficient to withstand lifting. The analysis involved the preparation of a three dimensional computer based surface model of the AE2 hull, conning tower and ballast tanks. Estimated structural weights and weights of machinery and equipment were then superimposed on the model which was then subjected to a 'grounding' analysis to simulate the lifting of the hull using two sets of slings.

21.6 This analysis identified the locations of maximum bending moments in the hull that, when related to hull plating thickness, enabled maximum stresses to be calculated and compared with acceptable stress levels. The measurement of hull thickness in these locations was then required to complete the analysis. These points are shown in the diagram at Appendix 1 to Annex G.

21.7 The combination of the results of the structural analysis and corrosion data then enabled areas of particular concern in relation to the ability of the hull to withstand lifting, to be identified. No firm conclusions could be reached regarding the strength of the hull and its ability to withstand lifting from the bottom. These results are considered in more detail in Annex G Structural Analysis.

22. Summary of archaeological findings

22.1 The major finding of the 2007 expedition is the significant increase in the amount of damage sustained to the upper exposed portions of the AE2 wreck since its discovery in 1998. At that time the upper casing that extends the length of the site was largely intact except for some isolated damage from contact with fishing nets - observed as a 'sprung' bow plate on the port side, net entrapments on the aft portion of the fin and at the underside of the stern. There was some limited loss of fabric from natural corrosion processes, perhaps exacerbated by earlier net contact, evidenced with the loss of the hatch cover over the forward winch and the hatch concealing the aft torpedo loading hatch. The casing, or superstructure, was made from 5-pounds/square foot steel plating attached to internal angle iron bars 2" x 1 ½" in section. A comparatively lightweight floodable structure not required to be pressure tight; the plate areas are susceptible to natural and physical deterioration due to their manufactured strengths and relative thicknesses.

22.2 The current 2007 survey has documented significant damage to the forward portion of AE2's casing which has now been destabilised from the telegraphy mast in front of the fin forward to the general location of the torpedo firing tank. Beyond that the casing is again intact until the bow is reached.

22.3 The bow of AE2 now bears little resemblance to the photographs taken in 1998. The mass of entrapped fishing nets are no longer present, revealing for the first time, the underlying structure. However the bow is almost totally torn apart, with the extreme end bent up, to port and aft. The entire bow has been ripped open with many plates dislodged, forming a localised debris field on sand to the port side of the wreck. The two steel wire tow lines with their short lengths of chain and shackles, once protruding from dedicated hawse pipes and neatly stowed along the outer casing aft, appear to have been caught by an anchor or other gear and to have assisted in violently tearing the plating apart. The casing damage is commensurate with the port towing pennant having been hauled to port and vertically and subsequently dropped back on the hull such that the pennant has been looped over the forward casing to starboard and then back to port. This damage is not commensurate with the towing pennant having been PICKED UP by either an anchor or fishing net. The tow wires are readily observed lying twisted within the wreckage. This impact is man-made and must have been caused by the crew of a small fishing boat, perhaps signifying a major fouling incident. It may not have been so apparent to crewmen in a larger vessel. The steel casting that forms the forward end of the pressure hull is now visible and intact as are the bow cap and the bow cap operating gear attached to the casting.

22.4 The resulting debris field was imaged by the expedition team and appears as a confused jumble of plating and threaded nets and lines. Material extends approximately five – six metres to port of the hull, but is concentrated against the hull around the bow area.

22.5 Travelling from the bow towards the fin, significant alterations are observed to the casing area once concealing the windlass and capstan for the bow anchors. As noted, this area had seen only limited structural deterioration in 1998 with the loss of the cover opening the machinery space. It was postulated at the time that the cover may have been of wood and had simply deteriorated. Today a much larger area of the casing atop the gear has been torn from the AE2, clearly not the result of continued natural deterioration of the light steel plating. Fishing nets have probably fouled the casing here and removed its upper surface and much of its vertical sides. Drift sand has entered the surviving casing cavity and partly obscured the internal fittings.

22.6 On the starboard side, the entire height of the casing has been removed in part, with sediment entering the resulting cavities. The remote operated vehicle caught a glimpse of a possible anchor shank within the confines.
This is a significant impact to AE2 as this portion of the hull constitutes one of its most diagnostic features – the slope in the casing as the casing line lowers towards the bow. This feature was a major identifier of the site being AE2 when first found, as only the Group One construction E-boats including AE2, had this feature. Today the visual appearance of this slope is entirely lost. Passing further aft, the wireless telegraphy mast base is intact together with the surrounding casing back to the fin.

22.7 The fin is more degraded then when inspected in 1998 with a significant portion of its aft plating now entirely missing. The front of the fin and the bridge, remain unchanged, together with the two periscope standards and the horizontal mine jumping wire. A new feature observed on the aft side of the forward periscope standard might be the attachment point for the external steering wheel or perhaps compass. This item is so concealed by colonising marine growth that it is difficult to discern its exact form or attribution.

22.8 The single oval crew access hatch (24” x 16” major & minor axis respectively), leading to the internal cavity of the conning tower is exactly as observed in 1998, with the hatch left approximately 10 centimetres ajar to starboard on its locking lug. This is just as the crew and LCDR Stoker left it on 30 April 1915 as they escaped the doomed vessel under fire. The amount of marine growth, corrosion products and sediment on the bridge appeared similar to 1998, and not sufficient to obscure major features such as lugs and other attachment points for the collapsible railings. The accumulated sediment comprises marine worms, oyster shells, sponges and other soft corals, and a fine dusting of silty sediment.

22.9 The entire upper section of the conning tower was of manganese bronze, non magnetic, so as not to affect the submarine’s compasses, the structure is largely intact. Even the guard stanchions or lifelines, the railings fitted around the tower to provide security to the crew, were made of hinged bronze stanchions with copper wire rope.

22.10 In comparison, the aft end of the fin showed significant loss of plating on its vertical faces. Approximately 1.2 metres of the aft plating has been removed. This includes the plating which once contained the foot-holds, allowing the crew to access the fin. After the first dive on the submarine in 1998, there was considerable speculation as to the possible causes of the then observed deterioration of the plating which showed evidence of advanced corrosion. While the external form of the plating was then still intact, some of the plating areas had been corroded back to adjacent vertical internal framing members. This had allowed divers to look completely through parts of the tower. At that time, the advanced corrosion was linked to the considerable amount of nets entangled in the tower which had obviously caused structural weakness and active corrosion through abrasion and removal of protective marine coverings. It was hypothesised that this level of abrasion would result in further deterioration of the vertical plating surfaces and perhaps eventual collapse of the fin itself.

22.11 The most noticeable increase in the level of corrosion since 1998 is in way of the steel plated fairwater or fin surrounding the internal conning tower and periscope forward and the battery ventilation trunk and fuel tank vents inside the tapered aft section. The fairwater and bridge deck are of relatively light 5 lb plate however the rapid increase in the rate of corrosion could either be attributed to the complete exposure of the structure above the silt line since the boat was scuttled and/or residual sulphuric acid exhausted from the battery tanks. The oval shaped conning tower is in excellent condition as the upper section is of a heavy manganese bronze casting while the lower section is of heavy 20 lb steel plate. Galvanic action between the two sections is unlikely as the galvanic voltages of both metals are extremely close together.

22.12 It is apparent that corrosion processes are significantly advanced and that limited original metal could survive in the underlying support framing. In many places the form of the fin is a complex matrix of remaining original metal plating, framing, corrosion products and marine growth. Conservation for museum display of the item would probably find insufficient original fabric to achieve a successful stabilisation and interpretation option, once the concretion matrix is removed. Externally, several diagnostic features were observed:

- The hand rail attached just under the ‘deck’ coaming to assist crew passing around the fin, fore and aft,
- The navigation light recesses, and
- The side scuttles.

The latter were fitted in the conning tower sides and front to enable the boat to be conned and steered from this position. One scuttle was tantalisingly glimpsed during the internal drop camera survey (above). The scuttle measuring 5 ½ “x 2 ½ “contained a glass viewing port 5/8th inch thick. Inside the conning tower they were framed with a gunmetal deadlight that could be locked. The deadlight in the observed scuttle was hanging down open on its hinges (see discussion at Appendix 1 to Annex F Initial Archaeological Findings Drop Camera Inspection). Several spray dodger stanchions on the aft end of the bridge deck were observed to be bent over towards the stern however it was subsequently established from both the Admiralty Build specification and the contract drawings that the stanchions were designed to fold in this position prior to diving.

22.13 The after casing remains largely intact. The aft torpedo loading hatch and the compartment for stowing the timber (pine) torpedo derrick (crane) shows some additional wear and proof of contact damage. A section of the framing members was immediately observed to be bent up above casing height. This circular ‘ring’ may well be the attachment point for the raised derrick frame, and appeared to have been caught by fishing nets again since 1998. When first discovered, there had been some localised damage to this area with the removal of the original hatch covers. The flat casing plating appeared now to have been destabilised further. Topping and lifting winches support the torpedo derrick but could not be readily identified within the casing.

22.14 The aft torpedo hatch and derrick stowage space was recorded in detail by still and video photography, to compare changes since 1998. Unfortunately, these features showed further destabilisation during the current survey. As discussed in Para 5.9 the dragging of the mooring by DTS resulted in the shot line weight being dragged across the submarine. The impact left an approximately two-metre wide scrape mark on the submarine’s port side saddle tank just aft of the fin. This resulted in the removal of marine growth and concretion coverings exposing bare metal. While not causing structural damage to the port ballast tank (other than some ‘popped’ rivets), the shot line weight dragged by DTS, bounced over AE2’s after ballast tanks and casing at this point. In passing over the casing, the weight removed a section of the casing in the vicinity of the aft torpedo hatch and derrick. The area of impact was recorded in detail following the incident to serve as a reference in any subsequent survey to monitor any longer term corrosion effect. The sides can sonar image of the AE2 wreck site clearly showed the furrow left by the weight in the seabed.

22.15 The stern, after hydroplanes and propellers appear much as they had in 1998, although sand levels appear slightly elevated at the propellers. An extensive visual assessment of the stern was made during the recent survey operations. It was here that signs of the 1915 battle damage were sought and therefore both port and starboard surfaces were imaged in detail. While evidence of conclusive shell fire damage was not obtained (see above discussion), additional detail was noted of corrosion activity around the after casing, and external exhaust pipes near the engine room. In most instances, corrosion holes were generally noted around the edges of the rectangular casing, and other hard edges, suggesting that the corrosion activity was being furthered by contact with fishing nets and associated lines dragging along the hull. Several snagged rope lines were observed wrapped between the after hydroplanes and hull (as in 1998), and an accumulation of nets were recorded suspended under the port and starboard hydroplanes – confirming that the stern of AE2 had been extensively fouled by nets in the past. Both after hydroplanes were found to be raised approximately 40 centimetres above the surrounding sediment levels, suggesting that the AE2 hull has a slightly bow-down attitude. Only the upper-half of one blade of each three-bladed propeller was exposed above the sediment, no deformation caused by AE2's groundings during the passage up the Dardanelles Strait could be seen.

22.16 At the extreme end of the submarine, a detailed scrutiny was made of the stern torpedo tube door. This formed part of an evaluation of the likelihood that the unexpended torpedo might be there. Previous historical analysis suggested that the most likely location for this torpedo was inside this stern tube or less likely in the after reload stowage. The survey detected the rim of the torpedo tube's external door which was confirmed closed, but due to the level of marine colonisation, no further observations could be made.

22.17 One of the unusual findings was the absence of the guard rails and stanchions fitted around the edge of AE2's upper casing. The uprights were made from galvanised forged steel stanchions, hinged to fold down fore and aft. Linking the stanchions was a 1 ¼-inch 1flexible steel wire rope to provide safety to crews working on deck. Normally these railings would be stowed whilst dived, but none of the stanchions or their support brackets, fixed to the casing, could be seen. It was noted that despite accumulated sediments and marine growth coverings, the free flood holes that exist along the entire casing could readily be seen. Historic photographs clearly depict the attachment brackets on AE2 prior to its deployment in World War One. It is most likely that the guard rails and stanchions were stowed under the casing or in the fin. Less likely they may have been left behind at the depot ship or at the dockyard at Malta. The external railings would have been a risk to foul mine mooring cables in the minefields known to have been laid in the Dardanelles Straits. A photograph of a contemporary British E-class submarine (perhaps E2) operating in the Dardanelles Campaign is also devoid of its railings.

22.18 As discussed above, the impact of the site shot line weight with AE2 was an accidental outcome of deteriorating weather conditions on the night of 13th September. The accident occurred when the chartered Turkish support vessel DTS dragged its four point moorings during a Force 6 wind and associated sea state that arose then. The ship dragged the block accidentally into the side of the AE2 at a point aft of the fin on the port side in the vicinity of Frame 41.

22.19 This impact was a major concern to the AE2CF Team who had pre-planned all archaeological survey activities to be have as minimal an impact as possible (in conformity with standard archaeological methodology, and as stipulated by the Turkish work permits). For example all corrosion and ultrasonic thickness testing, was planned to remove no more than a very small area (~1.2 cm^2) to provide access to the pressure hull.

22.20 The damaged area was immediately imaged by divers and the ROV as soon as the survey platform could be sufficiently realigned over AE2. It was immediately clear that the impact on the port side saddle ballast tank was substantial, though limited in actual physical deformation of the structure. The critical corrosion products and colonising marine growth that provides a protective barrier between the external seawater and encapsulated historic fabric had been breached. The impact had totally removed these coverings back to bare metal fabric, from the sediment interface with the hull to the height of the casing, in a swath measuring approximately two-metres wide.

22.21 Urgent plans were made to mitigate this unintentional damage which was immediately notified to the Turkish Liaison Officers afloat and ashore. However subsequent deteriorating weather conditions led to further loss of diving days as DTS again dragged its anchors. These delays resulted in the proposed targeted corrosion potential surveys of the impact site being finally aborted. This was an unfortunate outcome as the relevant equipment and expertise was at immediate hand to quantify the effect this damage would have on the AE2 ballast tanks.

22.22 The survey team have instead assessed the localised corrosion changes based on comparative site data (see discussion at Annex E Appendix 2 and Annex F) and suggested that initial corrosion rate increases of up to 4.4 times might now be expected at the impact site. These will naturally decline once the corrosion products (e.g. iron oxy-hydroxides) begin to cover the surface until the marine organisms can actively colonise the site, providing a lasting barrier. Until the site retains its relatively benign corrosion cycle, the exposed hull section could witness loss of surface detail and structural integrity, impacting on its archaeological values.

22.23 Observations of exposed hull features. While this impact event was a great concern to the AE2CF team it provided a unique opportunity to witness first hand the physical state of the previously concealed ballast tank plating now devoid of marine growth and concretion. The plating, while not in ‘as new’ condition appeared structurally sound and most flush headed riveted fastenings appeared to be intact. The exception was in the immediate area of the impact where five rivets in a single vertical row had ‘started’ i.e. they had moved in relation to the surrounding plate.

22.24 Subsequent investigation revealed that the single row of vertical rivets in question were in way of an internal frame and therefore not of the same structural significance as the double rows of rivets securing the plates to each other or to the pressure hull. The impact also provided the opportunity to compare the unusual configuration of the lapped strakes of plating (imagine a clinker planked dinghy) with the Admiralty Build specification viz:

- Longitudinal edge or seam laps 2 ¾” wide with double zigzag ½” diameter rivets spaced at 4 to 4 ½ diameters apart centre to centre, and

- Vertical butt straps 5 ½” long (wide) with double ½” diameter rivets spaced at 4 to 4 ½ diameters apart centre to centre.

- However, the excellent ROV footage revealed that the rivets in the longitudinal edge seams or laps were not ‘zigzag’ as expected but parallel.

22.25 The impact revealed a relatively sound and obviously intact lower hull. As the corrosion, ultrasonic and water quality data confirmed, the main hull elements of AE2 have survived in remarkably sound condition based on the low energy marine environment, and the fabric-preserving essentially anaerobic-to very low oxygen micro-environment (Annex E). It is now considered that the permanently buried portions of the AE2 hull will be in a remarkable state of preservation based on the observed and quantified data. Equally, the interior of the AE2 hull was found to have a similarly benign environment that has resulted in minimal deterioration of the structural elements, fixtures and fittings that were revealed by the images from the camera.

22.26 Hull Burial. The AE2CF team have obtained more accurate information on the state of hull burial through detailed photographic imaging. It is now clear that *AE2* sits deeper in surrounding sediments than first postulated. This is especially clear in the central section of the structure where much of the side saddle ballast tanks of the submarine are buried. It is clear that this depth of burial, creating an anaerobic environment has been one of the reasons that *AE2* has retained so much of its structural integrity and form. Evidence obtained from two small samples of AE2 structure recovered by the dive team has confirmed this visual impression. When recovered and processed for immediate conservation treatment, and following Turkish Government approvals, the samples have provided yet another unplanned insight into AE2's condition. The samples comprised a small section of plate with marine concretion attached (perhaps from the aft casing), and an isolated eye-bolt, perhaps also dislodged from the after casing or saddle tank. Analysis of the depth of corrosion products on the plate sample indicate that the AE2 hull may have been exposed to four major burial and exposure cycles during its 92 years submerged.

22.27 The depth of burial of the hull has been revised as a result of the artefact analysis, which has indicated that even the higher parts of the main hull might have been in a more anaerobic (i.e. buried) environment at times (see Annex E). The data suggests that the present sediment levels at AE2 might fluctuate based on extreme but limited storm events, leading at times to even greater burial than observed in 2007. The team observed a slightly greater level of sedimentation amidships in the position of the fin and adjacent ballast tanks than that observed post discovery in 1998. It is interesting to observe the analysis of the corrosion regime, the stillness of the internal waters captured within the hull (e.g. build up of sedimentation on internal ladder rungs), that suggests that the environment around AE2 is very stable for much of the time. Shipwrecks located in areas of high water movement, turbidity, increased temperature and oxygenated environments will generally present in a more deteriorated state than AE2.

22.28 This indicates that the macro and microenvironment in which AE2 sits is instrumental in determining its current state of preservation and integrity. It also suggests that without the identified human impact caused by local fishing operations (that have accelerated corrosion activity and degradation of the more light-weight upper structure), AE2 would have retained even greater integrity. These insights have significant implications for the long term survival of the site and the development of management options. They pre-suppose that AE2 is preserved because it is situated in a relatively benign environment where the highly anaerobic sediment and a relatively passive water column with low levels of dissolved oxygen. The corollary is that any change to these localised parameters might put AE2 at increased risk.

22.29 The AE2 hull was found sitting upright and immersed in the substantial layer of sediment on the bottom to a depth almost equating to her laden draft on the surface. This phenomenon is covered in greater detail in Annex F Report of ROV Operations.

23. Sediment Analysis

23.1 The remote survey of the surrounding hull sediments, using a Royal Australian Navy sonic `penetrometer' has provided a unique insight into the nature of the seafloor in the immediate environment of AE2 in the Sea of Marmara. It is clear (subject to confirmation by the analysis of the recovered sediment sample currently undergoing petrological and chemical analysis in Turkey), that the seabed comprises a very fine and uniform clay-like particle matrix. There appears to be no underlying harder substrate or rock/reef to support the AE2 hull within the penetration depth of the instrument (1 metre). The submarine is buried within this uniform sediment that naturally compacts with depth sufficient to be able to support the hull. This also has implications for any excavation activity at the AE2 site; as discussed in Annex F (ROV and Penetrometer Report) and Annex G (Structural Analysis) the submarine has settled to the extent predicted by modelling and confirmed by observation, so it should not settle any further.

23.2 The sediment is compromised of very fine particles which are very anaerobic, limiting oxygen penetration that would normally increase the corrosion rate of the site's steel plating. Analysis of the sediment cores immediately following extraction (measurement of pH, dissolved Oxygen, Redox potential), obtained near to the site and under the research vessel (Annex E) has confirmed the sediment to be essentially anaerobic.

24. Drop Camera Survey of Control Room

24.1 The successful non-disturbing camera insertion into the control room of AE2 has been one of the highlights of the 2007 survey. The survey was planned in detail to create no impact on the slightly open conning tower upper hatch or surrounding structure. A specially designed camera on a flexible umbilical hose and support frame enabled the camera and lighting to be carefully introduced into the hull and lowered by divers. The camera has provided the first images of the interior condition of the AE2 submarine in the 92 years since its loss.

24.2 The findings (see detailed discussion at Appendix 1 to Annex F Initial Archaeological Findings) have been critical in identifying the state of the interior metal surfaces and fittings. The water inside the submarine has been found to be very clear and still. This indicates that, except for the slightly open upper hatch, there are few openings into the hull to allow water movement. Of equal interest was the absence of significant corrosion products or marine growth coverings on the internal features.

24.3 While the camera could be lowered and rotated; it could not be manoeuvred around the control room. The images have revealed that the control room also appears to be very still and devoid of significant corrosion products. Many internal fittings and fixtures could be identified. The analysis of these images has required significant effort to identify the features and artefacts discerned.

24.4 The camera found that there is little sedimentation inside the hull. The only visible sediment appeared on the rungs of the internal ladders (where it had accreted through the upper hatch and fallen down), and a small mound of sediment on the control room deck beneath the hatch area. It is common for sunken submarine hulls to have at least some sediment entering the confined space through battle damage openings (e.g. mines/torpedoes) or through open vents and hatches.

24.5 The camera survey of this area did not find any traces of small relics associated with the operations of the submarine or related to the crew. It is likely that most small items will be found towards the bow of the submarine due to the nature of the wrecking process, where the submarine dived at very steep angles prior to recovering to the surface. Crew diaries report the tumble of artefacts as they fought to hang on during these steep angles.

25. What caused AE2 to lose trim?

25.1 LCDR Stoker recorded that the AE2 sank four nautical miles north of Kara Burnu Point (modern Karaburun) in the Sea of Marmara. Stoker estimated the water depth at 330 feet (100 metres). The wreck site was in fact located four miles north-north-west of the point in a water depth of 73 metres (240 feet).

25.2 During the fateful action on 30 April 1915, AE2, under heavy attack from the gunboat, lost all control of buoyancy and trim and twice exceeded the authorised deep diving depth (the submarine went beyond limits of the depth gauges) in two wild excursions and breaching the surface on three occasions. During one of these excursions, the engine room was hit by shells fired by the torpedo boat Sultan Hissar, leaving Stoker with no alternative but to abandon the vessel and to scuttle the submarine to ensure it was not captured.

25.3 Some presumed that the loss of buoyancy occurred as AE2 dived through a level of greater density (Chatterton, 1935:228). On face value this seems the most realistic cause. Sudden loss of buoyancy had effected B11 (Holbrook) earlier in 1914 at the Dardanelles entrance. E15 before it was lost had also risen unexpectedly from a lower layer of denser water (Jameson, 1962:35). Shankland & Hunter in *Dardanelles Patrol* (the story of Dunbar-Nasmith in E.11) referred to his 'resting' the submarine on the halocline (Shankland & Hunter, 1964:154). The authors also refer to a conversation by C.G. Brodie of the behaviour of the submarine B.6 when it went up to investigate the loss of E.15. The boat had been unable to get down below 40 feet, and then was carried inshore rapidly. When off again, the boat had "*apparently fallen straight down as through falling through space - but not to the bottom." At 90 feet* (27.4 metres), *as though landing on a ledge, she had suddenly straightened out and regained her trim*". This led Nasmith in E.11 to ponder the nature of the salinity levels and particularly currents before his entrance after AE2 (Shankland & Hunter, 1964:44ff, 152ff).

25.4 A more recent analysis by SIA experts suggests that it was an increase in buoyancy when AE2 left a denser layer of water to come to periscope depth in preparation for the rendezvous with E14 that caused the problem. Stoker's attempts to control this unexpected buoyancy led to the depth excursions and broaching the surface which ultimately offered the opportunity to SULTANHISSAR to bring AE2 under fire. The hits obtained by the gunboat caused uncontrollable flooding which led Stoker to abandon the submarine and to scuttle it.

25.5 The 1998 *PROJECT AE2* divers were immediately conscious of distinct water layers on their dives. A halocline was observed as they passed from a dirty surface layer into an almost crystal clear layer beneath. The divers noted that this layer was clearly visible at a depth of approximately 18 metres (60 feet). Similar observations were made by the 2007 expedition team and recorded by the remote operated vehicle.

25.6 A heavy undercurrent of saline water (more dense) flows into the Dardanelles from the Aegean, through the Sea of Marmara, then through the Bosporus into the Black Sea in the north. This flow prevents the Black Sea from becoming a fresh water body. The fresher surface water (less dense) discharging south would explain why *AE2* suddenly developed so much positive buoyancy as it hit this lower layer, bouncing quickly back up to the surface.

25.7 To build on these historical and 1998 observations, a survey task of the 2007 AE2CF & TINA expedition was to obtain empirical data to confirm these hypotheses. A water quality analysis, concentrating on salinity and temperature profiles, was initiated using a TPI WD30 instrument. The findings were conclusive, a marked change in water quality was observed at 14.8 metres where the waters changed from lower salinity (surface) to higher salinity (below). Temperature changes were also calibrated around this depth with a change from 26°C surface to 18°C below (see Appendix VV – Ian's).

25.8 The 1998-2007 depth differential between the upper more fresh waters (18 metres compared to 14.8 metres) discharging from the Bosporus and the more saline waters penetrating up the Dardanelles Strait might be explained by seasonal variations, the amount of fresh water runoff into the Black Sea and the Sea of Marmara, accuracy of dive instrument recording in 1998, or localised mixing based on surface water turbidity.

26. Management Options

26.1 The scientific investigation, survey, protection and management of historic submarine archaeological sites have seen significant advancement in the last decade (e.g. *U-166*, Warren 2004). The identification of submarines as a discreet sub-set of underwater shipwreck sites has revealed their capacity to provide unique insights into design changes, construction, operational use, and corrosion science (e.g. McCarthy 1998, Smith 1999b, 2000a, Weaver 2004). This in part is due to their unique place in the history of naval design and innovation, in their physical form and strength of construction that supports longevity as shipwreck structures. Because of the resulting integrity of the sunken submarine site, they offer a unique opportunity for archaeological examination, as associated fittings, fixtures and relics collections, are generally retained within a discreet archaeological context within the generally sealed hulls. This is in contrast to many iron and steel shipwrecks that tend to break down more readily in the marine environment (Riley, 1982), and lose a degree of integrity and context.

26.2 The broad range of management options available to the AE2 submarine site have been discussed post discovery (Smith, 1999a, 1999b, 2000). These discussions can now be extended based on the greater body of archaeological and conservation knowledge of the site obtained as a result of the 2007 survey. This data is critical to now making an informed decision on what actions, if any, should be taken at the AE2 to safeguard the remains, to effectively manage the site, and to maximise the research potential and public interest of the archaeological structure.

26.3 Fundamentally, any interventionist activities at the AE2 site must be guided by its significance values (e.g. Goodheart 1999). Heritage significance dictates which approaches are acceptable to enhance the preservation of the site's overall values. These values include, but are not limited to, historic fabric, associated relics collections, setting, aesthetic qualities, research potential, and historical associations. All interventionist approaches must consider their effect on the AE2 archaeological site, especially those that have the potential to impact on these values.

26.4 Historic shipwrecks dot the world's oceans and waterways and form part of the body of world archaeological heritage. In the majority of instances effective management is to limit interference, damage, threat from development and other human endeavours, and to observe their gradual and natural deterioration through time, with effective legislative protection where appropriate. Deterioration of archaeological sites, by its nature, is a natural phenomenon and an appropriate management response. However, sites of key historical or archaeological values commonly receive dedicated management intervention. In some cases, this takes the form of specific heritage and legislative protection, dedicated archaeological surveys, demarcation of no-entry zones unless for valid scientific or research purposes, and the implementation of strategies to prolong their archaeological integrity (e.g. cathodic protection, site security and surveillance systems and monitoring, etc).

26.5 In certain cases, limited or full archaeological excavation and recovery are deemed appropriate responses, either based on identified research potential of the site, rarity and outstanding historical values, sometimes to safeguard the site, if in situ retention would compromise site integrity and protection, etc. In isolated cases, scientific recovery and full excavation, conservation and display, has been adopted, for example the *H.L. Hunley* submersible (Murphy, 1998). However these undertakings are substantial and to date, no submarine recovery project has yet witnessed a satisfactory conservation outcome (e.g. *Holland 1*, Barker 1997). The final conclusion and costing for the small (13 metre) *H.L. Hunley* site recovery project will not be known for a further decade or more. This project stands as the current benchmark for sound scientific approach to submarine recovery. The excitement generated by the recovery of the German U-boat U-534 in 1993, by comparison, quickly escalated into a disaster for the archaeological structure and associated collections, once political, industry and financial support died away with the media interest. Today, 14 years later with no conservation program, support or firm home, the rusting wreck sits forlornly on a dockyard in the United Kingdom, a testament to worst case recovery activity.

26 6 In general the full recovery of complex archaeological structures from a marine environment are few, due to the complexities of recovery, excavation, conservation, display, curatorial requirements, and extraordinary preservation and management costs and demands. In all instances the financial requirement to mount a successful recovery project (approximately 5-10% of the required financial outlay), and the ongoing conservation and preservation costs (90-95% of the ongoing financial burden), are critical issues. Equally important is securing the long term expertise, human resources, laboratory and exhibition venue, and commitment to achieve a successful heritage and education outcome. Some sites like the small submersible *Resurgam* continue to be monitored on the seabed pending determination of the viability and ethical debate whether to recover for scientific and research purposes or to manage the site in situ (Bowyer 1999, Gregory 2000).

26.7 The development of options for the future management of AE2 and consideration of the options is now current:

- Whether to implement a least-impact approach to site management,
- Whether to undertake certain activities to prolong site retention and management in situ, or
- Whether other more extensive interventionist approaches are required or warranted to seek effective protection, management and interpretation,
- Recovery to shallow water,
- Recovery, preservation and display in an interpretive centre ashore in Turkey.

26.8 The AE2CF will continue this debate at appropriate forums involving Government, professionals and industry experts, to establish a hierarchy of appropriate responses to the AE2 site. Initially this debate will occur at a Joint AE2CF & TINA Workshop planned for late April 2008 in Istanbul in Turkey. This debate will draw on the scientific information gained from the site that forms the basis of this report.

26.9 Some initial comments can be made:

- The hull of AE2 is remarkably well preserved and is in good enough condition to be lifted clear of the sea bed for relocation to a shallow water site, using the two sling technique briefly outlined in Annex G Structural Analysis.

- Further structural analysis would be required to investigate recovery of the wreck from the water. It is likely that a more elaborate slinging technique would be required. However, this option can now be sensibly considered, but it would be subject to further analysis after additional data on hull thickness has been gathered. As a precondition for recovery the unexpended torpedo would firstly have to be rendered safe.

- The 2007 survey has indicated that AE2 has suffered some additional deterioration, some naturally caused by ongoing fabric corrosion and destabilisation. Other damage caused by mechanical action through contact with fishing nets and possibly anchors. The latter activity has largely ceased with Turkish Government restrictions on trawl fishing within the Sea of Marmara, policed by Turkish officials. The local fishermen state that the decreasing level of fish stocks has prompted the use of purse seine nets as opposed to trawls.

However the damage observed at the site within a short nine year period shows that AE2 is still vulnerable to this activity if unchecked.

26.10 It suggests that one immediate pro-active management option could be the safeguarding of the historic fabric through deployment of a defensive barrier around the site, to reduce the possibility of nets or trawls fouling the submarine. This could comprise concrete and steel tetrahedrons of an appropriate size with anchors placed in a ring around the site. This is a relatively simple and cost effective approach that will safeguard the values of the site whilst discussion continues on long term management options. The damage observed at the site can be mitigated successfully, with adequate surveillance and monitoring, effectively safeguarding the site through the natural deterioration process.

26.11 The natural deterioration of the upper surfaces of AE2 (that are structurally weaker by design) is not cause for significant alarm. This is part of a natural progression of deterioration over time. What is clear however is that this natural cycle could be further limited by the application of sacrificial anodes to the hull? An array of zinc or aluminium anodes could be attached via simple fastenings to lower the active corrosion rates significantly. While this would require a commercial dive team to implement and regular (annual) monitoring through ongoing corrosion study assessments, it would be a relatively cheap, non-invasive and effective way to address the current observed corrosion activity. The sacrificial anode technique has been used effectively in Australia, and internationally, to redress the deterioration of significant archaeological sites underwater. Prolonging the survival of these rare and irreplaceable structures provides a mechanism to retain their integrity, research potential, and appreciation for an interested community.

27. Future requirements

27.1 The 2007 expedition has obtained additional survey data that has greatly assisted appreciation of the state of the AE2 hull, internal spaces and setting, and will assist in the development of site management options. There is however the need for ongoing data sampling at the site to support these initial quantitative assessments and to assist in the refinement of condition assessments. A further maritime archaeological survey should therefore be considered as a high priority.

27.2 The legislative protection afforded by the Turkish Cultural heritage legislation is best placed to afford a layer of protection to the site. It is appropriate, with AE2 sitting within Turkish territorial waters, that the full coverage of the legislation be applied to the site, including any opportunities contained in the legislation to restrict access to, or implement penalties for disturbance to the site. The effective monitoring of the site by relevant Turkish Government authorities should also be advanced. The current application of the Turkish heritage provisions at the site should be clarified. Because of its expertise and familiarity with the site, the AE2CF should be invited by relevant parties to continue its activities relative to the inspection, investigation, interpretation and management of the site, with relevant authorities of Turkey and Australia.

28. Recommendations

28.1 The majority of recommendations contained in the 1998 survey inspection report (Smith 1999) have largely been implemented or actioned. These included recommendations:-

- To continue the archaeological and environmental survey of the AE2 site (the current 2007 expedition),
- To consider appropriate Turkish heritage legislative measures to protect the site,
- To advance Australian and Turkish appreciation of the feat of AE2 and the role it played in the Gallipoli Campaign (of relevance to both countries), and
- To further discussion of appropriate management options for the site and its associated relics collections, based on the site’s identified archaeological and heritage values.

28.2 Based upon this report including the annexes attached, options and recommendations for the future management of the site are as follows:

- Ongoing archaeological and environmental surveys. The 2007 expedition has confirmed the value of obtaining solid archaeological and environmental data on the AE2 site to inform management options. Such data is essential to understanding the current state and complexities of the archaeological site, to monitor change, and to inform management discussions and determination of options. The information is of importance even if actions at the site are limited to monitoring change through time.

- Installation of site protective measures. To prevent further damage to the superstructure of AE2 caused by accidental contact with fishing nets and anchors, an effective site security system should be installed. The AE2CF proposes that a defensive barrier (of concrete blocks or similar entrapments) be placed around the AE2 site to mitigate accidental damage by local fishing operations.

- Effective implementation of Turkish cultural heritage controls and fishing moratoriums. The AE2CF identifies the need to seek clarity on the current Turkish cultural heritage legislative protection that applies to the site, or opportunities to advance heritage protection through legislation and enforcement.

- Current restrictions on local fishing operations, monitored by Turkish officials, should be effectively implemented to reduce accidental damage to AE2. This should involve discussion with relevant Turkish and Australian Government agencies and include an education program for local Sea of Marmara fishing communities.

28.4 Cathodic protection of the AE2 site should be implemented immediately:

- To prolong the archaeological site whilst management options are evaluated, and to mitigate the damage accidentally caused during the 2007 survey, a cathodic protection system should be installed at the site.

- This sacrificial corrosion system will involve the deployment of zinc or aluminium anodes attached to the hull at predetermined positions, include a corrosion monitoring survey both pre and post deployment, and regular (annual) monitoring and replacement.

- The approval of the Turkish Government should be sought for this activity, through application of Archaeological Work Permits. The activity could be undertaken by commercial divers.

28.5 Joint AE2CF-TINA Workshop in Turkey to explore long-term site management options. In conjunction with TINA the AE2CF has initiated plans to conduct a Worksop to deliver the results of the 2007 MAA, and to deliberate on a strategy for long-term management and interpretation of the AE2 site.

28.6 Identification and rendering safe the unexpended torpedo in AE2 if the preferred management option involves moving the submarine. Through historical analysis, the AE2CF has identified that there is a very high probability that there is an unexpended torpedo inside the AE2 hull. The state of this weapon is unknown, but although the possibility that the warhead could be dangerous is low, nevertheless as the consequences of warhead explosion would be catastrophic, its existence constitutes a risk and limits the ability to conduct a comprehensive archaeological survey. If the option selected for future management of the AE2 site involves moving the submarine, then the rendering safe of this weapon, is a critical management task.

28.7 Educational programs should be delivered. The AE2CF has initiated a series of educational and public information programs to tell the story of the AE2, the role played by the Royal Australian Navy in the Gallipoli Campaign, and to further Turkish and Australian interest in the protection and management of this mutually significant site. These include:

- A television documentary,
- A website with suitable historical content,
- Placing of commemorative plaques at significant locations in Turkey and Australia , and
- An Education Program to provide all Australian primary and secondary schools with teaching and learning resources kits that tells the story of AE2.

The delivery of these, and other identified programs, should be given the highest priority and support.

29. Peer Review

29.1 The AE2CF will submit the approaches, findings and interpretation of the 2007 MAA Expedition, and this report, to peer review as a basis of future discussion of management options.

30. Acknowledgements

The AE2CF wishes to acknowledge the support received from:

- Former Minister Assisting the Minister for Defence – The Hon Bruce Billson MHR,
- Chief of Navy – VADM Russ Shalders AO CSC RAN,
- CEO ASC - Mr Greg Tunney and
- Chief, Defence Science and Technology Organisation - Dr Roger Lough
- Turkish Ambassador to Australia - Mr Murat Ersavci,

- Turkish Military Attaché – Colonel Memduh Hakbilen

- Consul General in Sydney - Mr Nihat Ersen

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PD Briggs AO, CSC, RADM RAN Rtd
Chairman
AE2 Commemorative Foundation Ltd.

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ANNEX A

ANNEX A REPORT of OPERATION SILENT ANZAC
PROJECT BACKGROUND – PREVIOUS WORK

	Name	Position
Prepared By:	Terence Roach	Director of Operations
Reviewed By:	Ken Greig	Project Manager
Authorised By:	Peter Briggs	Chairman AE2CF

ANNEX A - PROJECT BACKGROUND, PREVIOUS WORK

The search for the AE2 submarine wreck site was initiated by Mr Selçuk Kolay then director of the Rami Koç Industrial Museum at Istanbul with the support of the then Australian Ambassador to Turkey, Mr. David Evans. The discovery of a deep water wreck site (86 metres) in 1997 involved the Australian Project AE2 expedition team. While the diving survey revealed the wreck not to be AE2, it triggered additional searches by the Turkish team which were ultimately successful mid 1998. As noted, the Australian team again travelled to Turkey and conducted the preliminary archaeological surveys. This expedition had restricted aims:

- to confirm the tentative identification
- to conduct a preliminary archaeological survey
- to complete a Conservation Management Plan for the wreck, and
- to produce a wreck site condition model.

All of these objectives were completed with a minimal strength team through a week-long survey program.

1998 outcomes

The 1998 Project AE2 expedition, through the ensuing Conservation Management Plan, identified the need for a range of comprehensive investigations to better understand this unique site (Smith 1999).

The project identified the site and artefact collection to be of such significance that they must be protected at all cost. In order to maintain these values, it was considered` that the following activities be actioned:

Site protection

- Protective provisions of Turkish cultural heritage legislation be enacted to assist the long term survival of the site.
- Current mooring and fishing activities be assessed to limit unintentional damage to the site. That the wreck site position be added to coastal charts of the Marmara area.
- A site surveillance regime be implemented to promote the protection of the site.
- Strategies be implemented to increase public awareness of the site to promote an appreciation of its cultural significance and need for protection.

Future Field Studies

- A full archaeological assessment of the wreck site be conducted, concentrating especially on the structural condition of the wreckage, under the direction of suitably qualified personnel.
- A comprehensive environmental assessment of the wreck site be undertaken in order to determine environmental factors affecting the site's long term survival, in association with;

- A full corrosion survey of the wreck site. This survey should aim to establish the current condition of the hull, its probable structural strength and metal thickness in conjunction with local environmental parameters including water depth, temperature, dissolved oxygen levels, pH, etc. That this work be conducted under the guidance of a professional materials conservator
- A management and conservation strategy be implemented to include the site, artefact collection and records collection. That all interventionist processes at the site be guided by this plan.
- The site's archaeological research potential be identified. That archaeological excavation and salvage of the site only be carried out for justified research or conservation purposes by appropriately qualified individuals.

Interpretation

- Seek opportunities to educate the general public regarding AE2's important role in the Dardanelles Campaign.
- Address the significance of preserving the AE2 as an icon to the disastrous Gallipoli Campaign
- Incorporate the history and discovery of the AE2 wreck site in future ANZAC Day ceremonies held at ANZAC Cove, Gallipoli in Turkey.
- Highlight the important part played by AE2 as one of the Australian Navy's first submarine fleet units, particularly in terms of the then recent establishment of the Royal Australian Navy.

ANNEX B
REPORT of OPERATION SILENT ANZAC
PROJECT DEVELOPMENT SIA ACTIVITY

ANNEX B

	Name	Position
Prepared By:	Terence Roach	Director of Operations
Reviewed By:	Ken Greig	Project Manager
Authorised By:	Peter Briggs	Chairman AE2CF

ANNEX B - PROJECT DEVELOPMENT, SIA ACTIVITY

Subsequent to the workshop in Istanbul in 2004, the SIA had been involved in promoting the seminal role AE2 played in the birth of the RAN's Submarine Force. The Institute regularly promoted this history and its interest in furthering the results of the 1998 Project AE2 expedition, through its workshops and biennial conferences.

AE2 Planning Committee

The Institute formed an AE2 Planning Committee and was successful in gaining Australian Government grants and sponsorship from ASC to deploy a multi skilled team to Turkey. Additional corporate, financial and in-kind support has also been obtained together with assistance from the DSTO by the loan of a Remotely Operated Vehicle (ROV) and crew.

AE2 Commemorative Foundation

The Institute has established the AE2 Commemorative Foundation (AE2CF) a not-for-profit, charitable organisation with a Board of Directors, the majority of whom are independent, to manage the financial and commercial activity to conduct the MAA and other initiatives.

Memorandum of Understanding

To facilitate a shared involvement with the MAA objectives, the SIA entered into a Memorandum of Understanding (MOU) with the Turkish Institute of Nautical Archaeology (TINA), to collaborate on the development of options for the future management of the wreck site and to conduct the MAA. TINA members include Mr Selçuk Kolay who led the search team that located AE2 in 1998.

Australian Government Support

The SIA has received support from the Australian Government:

- Department of the Environment and Heritage - $ 25,000 to conduct a Feasibility Study,
- Department of Defence and the Royal Australian Navy $372,500 to conduct the MAA

Additional support has been provided by the Department of Foreign Affairs and Trade and the Department of Veterans Affairs.

Interdepartmental Working Group

The Institute has regularly briefed the Inter Departmental Working Group (IDWG) established to provide oversight of SIA activities and to provide advice to the Australian government. The MAA objectives have the support of the Australasian Institute of Maritime Archaeology (AIMA). Investigations into significant aspects of the wreck site have introduced critical expertise e.g. the analysis of the risk proposed by a probable unexpended torpedo and the guidance of the UK Ministry of Defence and other munitions experts.

Aims and Objectives

In respect of AE2, the AE2CF aims to deliver the archaeological, interpretation and management framework needs identified in the 1998 Project AE2 report. Three main streams of activity are being pursued:

- Management
- Academic
- Public education.

Management

The Institute has assembled a suitably qualified and multidisciplinary team that has the capacity to deliver the survey operations, scientific analysis of the results, and development of sound management options for the wreck site. There are two management tasks:

- Specific project management skills to facilitate team deployment and data gathering activities at the AE2 site, and
- Development of management options for the AE2 wreck site derived from the collection and evaluation of maritime archaeological data together with corrosion and hull thickness data.

The management team has coordinated all activity under the overall guidance of Rear Admiral Peter Briggs (RAN rtd), President of the SIA and Chairman of the AE2CF Board. Development of the project team, logistics and requisite support has been under the direction of AE2 Director of Operations Commodore Terence Roach (RAN rtd) and the AE2 Project Manager Captain Ken Greig (RAN rtd). Planning has involved three trips to Turkey to meet project partners and potential contractors, and to determine operational planning needs. The team is responsible for the identification and delivery of the MAA, logistics and operation planning in Turkey, and the successful presentation of survey results. The team has amassed experts in archaeological and materials conservation to guide the development of site protection and management options, post data analysis. These positions include:

- Director – Maritime Archaeology, Mr Tim Smith,
- Advisor – Corrosion Science, Dr Ian MacLeod, and
- Advisor – Naval Architecture, Mr Mike Rikard-Bell
- Director - Science & Data Management, Dr Roger Neill
- Director – Creativity and Photography, Mr Craig Howell

All activities at the AE2 wreck site are bound by the controls of the Turkish cultural heritage legislation and Archaeological Work permits issued to the project team. Further, the principles of the UNESCO Convention on the Protection of the Underwater Cultural Heritage 2001 will be upheld through the project work.

Academic

The AE2CF aims to promote studies generally on the operation and deployment of all aspects of AE2 and her crew. It seeks to engage relevant experts in the identification, assessment and reporting on site-based studies and to have these studies evaluated under peer review. The project has identified additional expertise requirements, including the scientific analysis of soil and marine biological samples, geology and marine science, with such studies being outsourced to suitable professionals. Popular historical accounts of the AE2 and the SIA project work have been identified to promote the story. It is intended that a range of specialised site-based studies will be presented to leading journals for publications.

Public education and outreach

To facilitate the broader public appreciation of the AE2 wreck site, its historical associations, and significance values, the AE2CF has:

- Initiated a media program, and engaged a Media Manager, Mr Trevor Rowe.
- Secured the support of published authors on AE2 in a reference capacity (Elizabeth and Fred Brenchley – Stoker's Submarine),
- Appointed Mr Vecihi (John) Başarin as the Turkish cultural advisor,
- Consolidated archival and pictorial source materials,
- Established an AE2 page on the Institute's web site, with an additional dedicated AE2 web site under the AE2 Commemorative Foundation, and
- Entered into an agreement with Dr. Ross Bastiaan (*http://www.plaques.satlink.com.au*), through an Education and Plaques Project, to deliver a series of permanent interpretative markers through Turkey to tell key elements of the vessel and crew stories.
- The institute has entered into an agreement with Electric Pictures (who in turn has decided to collaborated with Mallison Sadler Productions) to produce a documentary on the MAA phase and to tell the AE2's wartime exploits through re-enactment.
- The AE2CF is also considering the development and promulgation to all primary and secondary schools in Australia, of an Education Resource Kit which will facilitate the telling of the story of AE2 to all Australian school children.

Peer Review and Advice

To independently evaluate all survey approaches and analyses of results, a range of consultants were invited to provide advisory services to the expedition. These include:

- Maritime Archaeology and Conservation Science Dr Mac McCarthy West Australian Maritime Museum
- Naval Architecture; Lance Marshall Sinclair Knight Merz (SKM)
- Diving expertise; Richard Taylor, TDI/SDI
- Dr McCarthy and SKM will provide peer review of the presented technical assessments of the MAA findings.

Equipment

The necessary equipment to conduct the MAA has been obtained either through purchase, hire or provision in kind. This includes standard surveying gear and sample collection tools, corrosion and ultrasonic thickness meters, underwater video and stills cameras, a remote operated vehicle (ROV), underwater lighting, diving equipment including UW communications, and side-scan sonar systems. Logistical issues in transporting the project's field equipment have necessitated the appointment of a Logistics Officer and transport to Turkey via air-freight. All equipment was tested in a trial scenario at a similar J-class wreck site in Melbourne (4-6 February 2007) and some later at the DSTO quarry test site in Melbourne 7th August 2007.

3D animation

A detailed 3D computer model of the hull and interior of AE2 has been produced by DSTO under the direction of Dr Roger Neill to assist interpretation and understanding of the submarine. The aim of this computer generated model is to provide:

- high fidelity, three-dimensional virtual representation of *AE2*;
- operationally realistic simulations of candidate ROVs and their tethers;
- realistic, virtual survey missions to assess the probability of overall success.
- refine risk analyses of a proposed internal survey by ROV
- integration of available archival plans and photographs to populate the model;
- generation of animations of AE2 in operation
- mission rehearsal prior to any surveys which are ultimately undertaken, and
- visual public education and interpretation resource.

ANNEX C - TEAM MEMBERS

From Turkey

Family Name	Other Names	Title	Position
Aydemir	Oğuz	Mr	Chairman TINA
Edes	Enis	Mr	Detek Offshore, Diving Support Vessel
Karakaş	Savaş	Mr	Media Liaison, Electric Pictures
Kolay	Selçuk	Mr	Advice and Liaison, Support Vessel and Side Scan Sonar
Polat	Ayshen	Dr	Hyperbaric Physician, Istanbul University
Toklu	Akın	Dr	Hyperbaric Physician, Istanbul University

From Australia

Alhafith	Samir	Mr	Diver
Basarin	John (Vecihi)	Mr	Turkish Adviser/Media Management
Brenchley	Elizabeth	Ms	Co-Author, Stoker's Submarine
Brenchley	Fred	Mr	Co-Author, Stoker's Submarine
Briggs	Peter	RADM	Chairman, AE2CF
Cannon	Stuart	Dr	Diving Supervisor/Naval Architecture Adviser
Cannon	Helena	Ms	Diver/Paramedic
Fock	Andrew	Dr	Team Medical Officer
Garske	Paul	Mr	Diver/ Diving Supervisor
Graham	Peter	Mr	ROV Pilot
Harris	Richard	Dr	Diver and Photographer
Howell	Craig	Mr	Creative Director and Diver
Hughes	Jeff	Dr	Diver
MacLeod	Ian	Dr	Corrosion Adviser
Maher	Mervyn	Mr	Diver
Neill	Roger	Dr	Scientific Director/Data Management
Pearson	Steve	Mr	Diver
Rikard Bell	Michael	Mr	Naval Architecture & Engineering Adviser
Roach	Terence	CDRE	Director, Operations
Smith	Tim	Mr	Director, Maritime Archaeology

Wynd	Mike	Mr	Diver

Australia Based

Greig	Ken	CAPT	Project Manager
Turner	Roger	CAPT	Unexpended Torpedo Investigation, MODUK Liaison
Noble	Tim	Mr	Director, Maritime Archaeology
Rekkers	Peter	Mr	Media Liaison
Mussared	Jane	Ms	Strategic Communications & Media Adviser

Documentary Crew

Ayrton	Richard	Mr	Diver, Camera Operator, Mallison Sadler Productions
Batt	Ian	Mr	Cameraman, Electric Pictures
Grandile	Rose	Ms	Project Manager
Ogilvie	Andrew	Mr	Producer, Electric Pictures Australia based
Sadler	Crispin	Mr	Diver, Camera Operator, Mallison Sadler Productions
Stevenson	Dan	Mr	Diver, Camera Operator, Mallison Sadler Productions
Westh	Steve	Mr	Director, Electric Pictures
Woods	Norman	Mr	Diver, Camera Operator, Mallison Sadler Productions

Turkish Navy Liaison Officers

Akçay	Burak	LCDR	Liaison Istanbul
Orhan	Salih	LEUT	Liaison ashore – Karabiga
Sen	Cemil	LEUT	Liaison afloat- DETEK SALVOR
Yavuz	Ali	LCDR	Project Liaison

ANNEX D - SPONSORS

SPONSOR	ADDRESS
AMT	Port Melbourne VIC
AMOG	Notting Hill VIC
ASC	Osborne South Australia
Australian Geographic	Sydney NSW
Colkan International	Ulmarra NSW
Department of Defence	Canberra ACT
Department of Environment & Heritage	Canberra ACT
DSTO	Fishermans Bend VIC
Graphic Art Mart P/L	North Rocks NSW
Hellmann Worldwide Logistics	Mascot NSW
MARBA	Frankston VIC
Mrs. Cecily Belbin	St Ives NSW
Mussared Communications	Clareville NSW
North Shore Private Hospital	St Leonards NSW
NSW Heritage Office	Parramatta NSW
OMD Technology Ltd	Leicester England
Patrick Defence Logistics	Albion QLD
Paul Wetherill & Associates	Mt Eliza VIC
Pro Diving Services	East Botany NSW
Royal Australian Navy	Canberra ACT
SeaBotix	Applecross WA
SKM	Armadale VIC
TDI/SDI	Willoughby NSW
Thales Australia	Garden Island NSW
The Alfred Hospital	Prahran VIC
The Phillips Group P/L	Brisbane QLD
TKMS Australia	Mitchell ACT
TressCox Lawyers	Melbourne VIC
WA Maritime Museum	Fremantle WA
Weston Insurance Services	Melbourne VIC
Zimmer Inc	Frenchs Forest NSW
Becca Saunders & Mark Spencer	Boambee NSW

ANNEX E

ANNEX E REPORT OF OPERATION SILENT ANZAC CONSERVATION ASSESSMENTOF THE MICROENVIRONMENT OF HMAS AE2

	Name	Position
Prepared By:	Ian MacLeod	Corrosion Adviser
Reviewed By:	Roger Neill	Defence Scientific & Technical Organisation
Authorised By:	Terence Roach	Director of Operations

ANNEX E - CONSERVATION ASSESSMENT

Executive Summary

The primary analysis of the site involved an assessment of the chemical environment created by the Sea of Marmara in the immediate vicinity of the wreck. The seawater was sampled for salinity, dissolved oxygen and temperature at one metre intervals and the data logged at each depth. The most striking characteristic is a strong halocline (change in salinity) at 14-22 metres which also coincides with a marked thermocline (change in temperature). The surface water salinity, from 0-14 metres, was 21 parts per thousand (ppt.) while the deeper waters, from 22-73 metres, had a salinity of 42 ppt. which reflects the hyper-saline waters that flood through the Dardanelles from the Aegean Sea. The salinity of the upper waters is dominated by the Black Sea, which has an average of 18 ± 0.5 ppt, as it flows into the Sea of Marmara at Istanbul. The major thermocline coincided with the halocline and the water temperature fell from 26°C to 18°C while the second thermocline had a turning point at 39.6 metres as the temperature fell from 18°C to 16°C.

The site was characterised by a relatively benign corrosion environment, with the dissolved oxygen levels being approximately 50% of the surface saturated values with bottom readings of 3.1 parts per million (ppm) compared with surface readings of 6.3 ppm. Observations confirmed that the concretion was a classic anaerobic matrix, with a very dense milieu of sharp shell debris and black iron corrosion products, which consisted of magnetite (Fe_3O_4) and a number of iron sulphides and that the primary corrosion layer consisted of magnetite. It was possible to discern the original metal surface and the multiple layers of corrosion products and marine concretion that lay to the seaward side of this matrix as well as layers that reflected pitting corrosion beneath the original surface layer. The concretion analysis is consistent with the initial scuttling event resulting in the vessel sinking into a fine layer of silt up to the base of the fin. At various intervals in the ensuing years, the amount of silt has varied in a clearly defined pattern associated with changing depths of burial which are likely to be connected to major storm events.

Sediment core samples were taken near the fin and at a distance from the vessel to gauge what impact AE2 had on the immediate physical environment. There were statistically significant differences in the way in which the redox or oxidation/reduction potentials varied in the two cores, with the off site voltage and pH relationship being dominated by the normal marine sediments and the on-site core being controlled by a different mechanism. The upper layers of both cores were dominated by the presence of dissolved oxygen, which rapidly fell to essentially anoxic values within the first 5 cm of the sediment.

The *in-situ* measurements of corrosion potential and pH showed that the corrosion microenvironment was characteristic of iron corroding in low energy marine environments. Thickness measurements on the casing that were obtained with a hand-held Cygnus

ultrasonic metal thickness unit indicates a loss of only 1.55 mm in 92 years or an average corrosion rate of 0.017 mm/year which is consistent with the vessel having corroded for long periods in an essentially anaerobic to very low oxygen microenvironment. The general physical condition of AE2 can be described as being relatively well preserved due to a combination of the water depth, the small amount of water movement, the hyper saline environment and the fact that the vessel has spent prolonged periods largely buried in silt.

Introduction: Corrosion processes on iron shipwrecks

In warm tropical to sub-tropical waters, corroding iron and steel in seawater rapidly becomes encapsulated by encrusting organisms such as coralline algae and bryozoans (North 1976). This encapsulation begins the process of separating the anodic and cathodic sites of the corrosion cell, with oxygen reduction generally occurring on the outer surface and oxidation of the metal occurring underneath the marine growth (MacLeod 1989a). Under such conditions the anodic, or oxidation, reaction is not the rate determining step in the overall corrosion process but the decay of the metal object is controlled by the reduction of dissolved oxygen at the concretion-seawater interface. The corrosion process results in the inward diffusion of chloride ions from the sea, through the marine growth to the corroding metal, and the outward diffusion of the metal ions towards the seaward surface. Corrosion of concreted marine iron leads to elevated chloride concentrations and relatively high acidity at the metal-corrosion product interface, as shown in Figure 1.

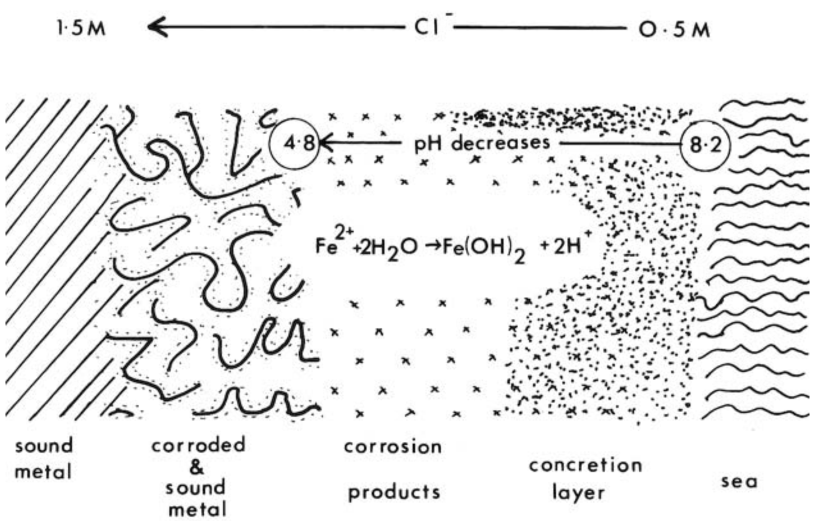

Figure 1: Schematic diagram showing accumulation of chloride and acidity at the concretion-metal interface for aerobically corroded marine iron.

The rates of corrosion are naturally dependent on a range of micro environmental parameters. For iron materials lying proud of or on the seabed, the primary cathodic reaction is the reduction of dissolved oxygen. For metal that is totally buried in the sediment and is not electrically connected to iron that is exposed to oxygenated waters, the major cathodic reaction will be the reduction of water and the associated evolution of hydrogen. For iron wrecks such as the submarine AE2 which has significant elements of its hull lying under a layer of silt, but still appears to be in electrical contact with the upper elements of the boat, it is likely that these sections of the vessel will be subject to the changing nature of a differential oxygenation cell. For electrically isolated elements of the submarine lying under the silt layer may be considered to be corroding under an anaerobic corrosion mechanism which is a state dominated by microbiological activity (Fischer, 1983) since the presence of dehydrogenase enzymes will often control the rate of hydrogen evolution (Sequeira and Tiller,1988 & Metals Society,1983), which is the dominant cathodic process.

Marine concretion acts as a semi-permeable membrane, and after 92 years of corrosion results in a substantially different micro-environment being established around the metal itself compared with the surrounding sea. For example, the chloride concentration can be increased by a factor of 3 above the mean seawater levels and the pH can fall from the normal value of 8.2 to as low as 4.2 (MacLeod 1989-2b). If the matrix of corrosion products and calcareous deposits are accidentally removed, the increased access to oxygen results in accelerated corrosion of iron in a chloride-rich, acidic micro-environment, and the loss of much of the archaeological values (MacLeod, 1981 & 1987).

On an iron wreck any non-ferrous materials that are electrically connected to metallic iron will be protected by galvanic coupling. One result of this interaction is that all the copper, brass and bronze fittings become covered with a thin, adherent white calcareous concretion (MacLeod 1982). Once the concretion has formed, the surface is no longer biologically toxic and so it is then subject to the normal colonisation mechanisms associated with the particular marine ecology of the area. Non-ferrous metals associated with the interior of the conning tower were seen by the ROV to be covered in a layer of concretion that conformed to the original form and shape of the brass fixtures. Owing to the galvanic protection afforded by the surrounding iron objects, there are no massive warty or pustular outgrowths of corrosion products and concretion from the surfaces of brass and bronze fittings on the submarine.

Given the structural complexities of various combinations of non-ferrous with ferrous metals that naturally occur in an operational submarine, it is highly likely that there will be numerous examples of proximity corrosion within the boat. This apparently novel form of corrosion has been observed on historic shipwrecks where the deleterious effects of galvanic coupling on the corrosion of iron materials is observed where there has been no direct physical contact. The initial research into the nature of this type of corrosion and the implications for structures has been reported by North (1989). Normally direct electrical contact is needed to have galvanic coupling or corrosion but long term corrosion on the wreck of the American China Trader *Rapid* (1811) showed that the electric field associated with a store of copper nails, spikes and bolts resulted in galvanic corrosion on a cannon at a distance of several metres. Although the sulphuric acid concentration in the AE2 batteries would have been low, owing to the prolonged sub-surface running prior to its final surfacing, there would have been sufficient electrolyte present to assist the incoming seawater in providing a good pathway between what had been electrically isolated batteries to surrounding iron materials. Studies on modern naval vessels that were scuttled to provide artificial reefs and sites for recreational divers have shown that the high-build military coatings on the steel hulls take several years before the full impact of the surrounding seawater is reflected in their corrosion properties (MacLeod et. al. 2004). Given that

AE2 was in operational order at the time of scuttling it is likely that there may have been an induction period before the long term corrosion associated with the site in its current condition was able to be established.

Burial and Exposure Phenomena on Iron Wrecks

The effects of the cyclical burial and exposure of wreck materials and the effects on corrosion mechanisms is best illustrated by analysis of the site of the SS *Xantho* which was an iron screw vessel that sank off Port Gregory, Western Australia in 1872. Analysis of the corrosion products around a copper wire in a water cooling device from the engine room showed that there were a large number of corrosion layers. When the logarithm of the spacings between the layers was plotted against the number of growth rings the linear relationships showed that the corrosion phenomena on that site can be described in terms of the Liesegang phenomena, i.e. of periodic precipitation (MacLeod 1986, 1992). The precipitation of the copper sulphides occurs with the change of the micro-environment from being aerobic, when the object was exposed to the strongly flowing seawater, to anaerobic when two metres of sand were deposited on the site. The rapidly changing nature of the seabed was noted in 1864 when the *Zephyr* found a discrepancy of 2.1m in the charted water depth and grounded at Port Gregory (Henderson 1988). In the space of the last 110 years approximately 16 bands were found in the corrosion product layers on the artefact. These changes amount to approximately a seven year cycle and it seems not unlikely that the site has been buried and exposed at least that number of times. The "newness" of the biological environment on the wreck site compared with the surrounding reef is most probably due to the fact that the whole site is periodically buried under several metres of sand.

The wreck of the *City of Launceston* (1865) in Port Phillip Bay in Victoria, also presents an interesting example of periodic burial and exposure that has resulted in formation of a copper sulphide patination on brass engine fittings on top of the engine, which is normally exposed to seawater. Presently the site is characterised by a silt mound with the bow and the stern sections being relatively free from the very fine silt layers that cover the deck and up to the gunwale in the amidships area. Site inspections over the past 18 years have shown that the profile of the silt mounds has not changed to any significant degree. The presence of copper sulphides in the upper parts of the site is clear evidence of the whole of the wreck being buried in silt at various stages of its lifetime on the seabed (MacLeod 2002). During the periods of exposure to open seawater the fitting was in a passive corrosion state and suffered negligible corrosion. Under anaerobic conditions the passivating nature of the Cu_2O film was rendered inactive and so significant corrosion took place each time the site was reburied. This type of corrosion illustrates how the corrosion mechanism of materials can change as a function of burial conditions. During the time interval associated with historic shipwrecks it is probable that significant changes have occurred on the wreck site of AE2 in the Sea of Marmara. It should be noted that the colonisation of the conning tower and the upper sections of the combing is very different to lower parts of the wreck. This is consistent with the fin having been subjected to continuous corrosion in a slowly flowing seawater microenvironment.

Corrosion Surveys

The corrosion potential ($E_{corr.}$) of the vessel was measured using a high impedance digital multimeter, sealed in a custom-built plexiglass waterproof housing that had been pressure tested to 100 metres of seawater. The measured voltage refers to the difference in electrical potential between a platinum working electrode and a silver/silver chloride/seawater electrode $Ag/AgCl_{sea}$ which is attached to the meter box and is less than 15 cm from the measurement points. Platinum is used as the working electrode because it is electrochemically inert and therefore the measured voltages refer to the object itself and are not due in part to the nature of the electrode material. The E_{corr} was measured by firmly pressing the platinum electrode onto the exposed section of metal where the drill bit had penetrated the rock hard marine concretion. Despite the very bad visibility the divers were able to determine that the measured voltage reading was very stable, changing only ±1mV. Measurements of surface pH were effected by a BDH GelPlas flat surface pH electrode connected to a Cyberscan 200 pH meter sealed inside the same custom-built plexiglass waterproof housing as the digital multimeter. The surface pH was measured by mechanically removing a small area (~1.2cm^2) of concretion. Since alkaline sea water tends to flood into the drilled space, the divers recorded the minimum pH value before going on to do the E_{corr} measurement. The water depth was measured with a digital dive computer. The temperature, salinity and dissolved oxygen concentration of the seawater column was measured on-site at 0.5-1m intervals to a maximum depth of 74 metres with the appropriate sensors connected to a TPS 90DC Microprocessor Dissolved Oxygen and Conductivity meter.

The routine measurement of electrochemical parameters such as the surface pH of degrading artefacts and the corrosion potential, $E_{corr,}$ of metal objects on wreck sites has a very recent history (MacLeod, 1981 and North, 1982). Corrosion scientists have found that the knowledge obtained through these on-site measurements is an invaluable aid in understanding the corrosion mechanisms and the modes of deterioration of materials on archaeological sites. The corrosion potential ($E_{corr.}$) is very significant parameter for quantifying the rate of decay in historic iron shipwrecks. The corrosion potential is a parameter that is very sensitive to the rate of corrosion of the metal. The primary corrosion product occurring underneath the concretion is ferrous chloride ($FeCl_2$), which is present as an almost colourless straw green liquid that rapidly turns the brown colour of Fe (III) corrosion products when freshly recovered concretion is handled on the surface of the support vessel. Ferrous chloride subsequently undergoes hydrolysis to β {$Fe(OH)_2.FeCl_{2.}$}. As the ferrous chloride solution diffuses out through the concretion matrix and undergoes hydrolysis the resultant increase in acidity causes the dissolution of the calcium carbonate in the marine organisms. Re-precipitation of iron carbonate follows with concomitant oxidation of the iron (II) corrosion products to iron (III).

Concretion Microenvironment

Correct interpretation of the corrosion micro environmental data obtained from analysis of concretion and the gases that are evolved when the protective layer is penetrated during underwater surveys can provide much needed insights into the processes that control decay. Analysis of the voltages, pH and the gases that were liberated during the corrosion survey of iron artefacts on the seabed showed that the microenvironment of the metal is essentially anaerobic even when there are relatively high levels of dissolved oxygen in the immediate vicinity. The data shows that corrosion potentials ($E_{corr.}$) are often in strongly reducing conditions with E_h values at -0.290 ±0.015 volts at pH 4.8, i.e. just below the hydrogen evolution potential for the same pH. Hydrogen has been identified as a major component of the gases released when concretions are penetrated for the first time in centuries (MacLeod 1988). Amongst the other gases were carbon dioxide (from acid dissolution of calcite and aragonite as a result of hydrolysis reactions with the marine shells and debris) and methane. Analysis of the carbon isotope ratios of $^{13}C/^{12}C$ in the methane gave an isotope shift $\delta^{13}C$ of -4.7 ppt which showed that the methane was inorganically derived via reduction of inorganic carbon dioxide,

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2 \qquad (1)$$

If the methane had been produced by bacteria, which preferentially metabolise ^{12}C, an isotope shift ($\delta^{13}C$) with a value in the range of -55 to -75 ppt (relative to the standard limestone, PDB) would have been observed (Hunt 1979). Inspection of the carbon Pourbaix diagram shows that methane is the thermodynamically stable form of carbon under the lower portion of the range of E_h and pH (Pourbaix 1974) that have been recorded on wreck sites at depths up to 22 metres.

Corrosion and Water Movement

The effects of the movement of water, and with it the changing flux of dissolved oxygen, on the corrosion rate of the iron materials was clarified in studies associated principally with the wrecks of the SS *Xantho* (1872) and HMS *Sirius* (1790). The water depths of these site varies from 3.5-5.5 and from 1.5-3.5 metres respectively. During the initial survey on the SS *Xantho* it was noted that the apparent extent of corrosion varied quite markedly across the site, which was ostensibly uniform in that it was well oxygenated and in shallow enough water to get good mixing from wave action. The *Xantho* site showed a high degree of variation in the extent of corrosion with the windlass containing no solid metal whereas the engine, boiler, and the frames near the stern reflected lower corrosion rates. Work on the HMS *Sirius* showed that for the same depth the E_{corr} for cast iron was approximately 70 mV more anodic (less negative) than the wrought iron objects (MacLeod 1989a). Analysis of the E_{corr} data and the depths of corrosion (graphitisation) showed that the corrosion rate was dependent on the water depth and the profile the object has on the wreck site. The model also demonstrated that the corrosion rate is very dependent on water depth and the flux of dissolved oxygen.

The worst affected items on the SS *Xantho* were at a shallower depth and exposed to localised eddying of current while the engine was sheltered behind the boiler and was at a greater water depth. The corrosion potentials for the wrought iron objects such as the boiler and frames can be compared with cast iron materials on the engine if "corrected" by 70 mV for the ennobling effect of the carbon. Armed with knowledge of water depth and site profiles and the way in which water moves over a wreck, it is possible to interpret the corrosion potentials on iron shipwrecks and to develop appropriate management strategies. The temperature effects on corrosion potentials have not been directly determined, but repeated measurements of the *Xantho* boiler at Port Gregory (MacLeod 1998) over a period of four years gave an E_{corr} of -0.274±0.003 volts with the temperature at 4 metres depth ranging from 18.5-25.0°C. The small variation in E_{corr} values indicates that after more than 100 years immersion the objects are not as sensitive to temperature effects as objects at 30 days exposure (La Que 1975). *In-situ* measurements on corroded ordnance on Japanese vessels in Chuuk Lagoon in the Federated States of Micronesia indicates that at increased depth the difference in corrosion potential between steel or wrought iron and cast iron is diminished to only 10-20 mV owing to the differences in the kinetics of the corrosion processes of the carbon-rich (in cast iron) and carbon-deficient (in steel and wrought iron) phase becoming less owing to the lowered flux of dissolved oxygen in the sheltered waters of the lagoon (MacLeod, 2006). Although AE2 is an electrochemically complex object or series of interconnected objects, the differences in materials performance of cast iron, wrought iron and steel at the great site depth are likely to be less than for shipwrecks corroding in more sheltered waters.

Effects of Partial Excavation on Corrosion

Provided that no concretion is removed from the surface of the corroded and concreted material, archaeological intervention on a site can have a minimal impact on the rate of deterioration of the remainder of the site. An example of this can be found on the site of the SS *Xantho* where the historic Penn's horizontal trunk steam engine was removed for the purposes of display and research (Kimpton & McCarthy, 1988). Prior to removal of the engine the E_{corr} values of the significant site features were recorded and the measurements have been repeated within 24 hours of the *extraction* and again after intervals of 13, 34 and 83 months. The $E_{corr.}$ value for the boiler showed no change over the entire period and had a steady value of -0.270±0.005 mV vs. NHE (the Normal Hydrogen Electrode). Admittedly the boiler is upstream of the engine location but the results do indicate that provided that the integrity of the surface conditions of the concreted iron works is maintained, the corrosion rates are not going to be subject to major change. It was not possible to provide the same data set for sections of the site downstream of the engine room since the stern section has been subject to in-situ conservation treatment using sacrificial anodes (MacLeod, 1998)

Site description for AE2

The wreck site is located at approximately 1°47.313 South and at 21°38.010 East of Greenwich in the Sea of Marmara at a depth between 68 and 73 metres, with the bottom of the submarine resting in approximately 73 metres of water. The physical oceanography of the site is complicated by the presence of one halocline and two . Prior to arrival in Turkey it had been planned to take a series of E_{corr} and pH measurements along the length of the submarine from bow to stern on both the port and starboard sides, as had been done in the rehearsal off Queenscliff on the WWI submarine J5 which lies in 35 metres of water in Bass Strait. Owing to operational difficulties only one set of corrosion potential and pH measurements were made after the divers had struggled to drill through the 3-5 mm concretion layer which was described as being “rock hard”. Very dense and rock hard concretions are a characteristic of marine iron that has been formed in an anaerobic environment or at least one that has had prolonged periods of anaerobic activity mixed in with limited periods of aerobic corrosion.

Salinity profiles

A series of temperature, dissolved oxygen and salinity measurements were made using the TPI WD30 instrument which has a temperature and salinity measuring probe and a separate YSI dissolved oxygen meter. The salinity probe was standardized using a reference 36 ppt (‰) solution of standard seawater. Salinity data for the AE2 site were recorded at one metre intervals from the surface waters to the bottom of the site and into the silty sediment in the immediate environment of the submerged vessel.

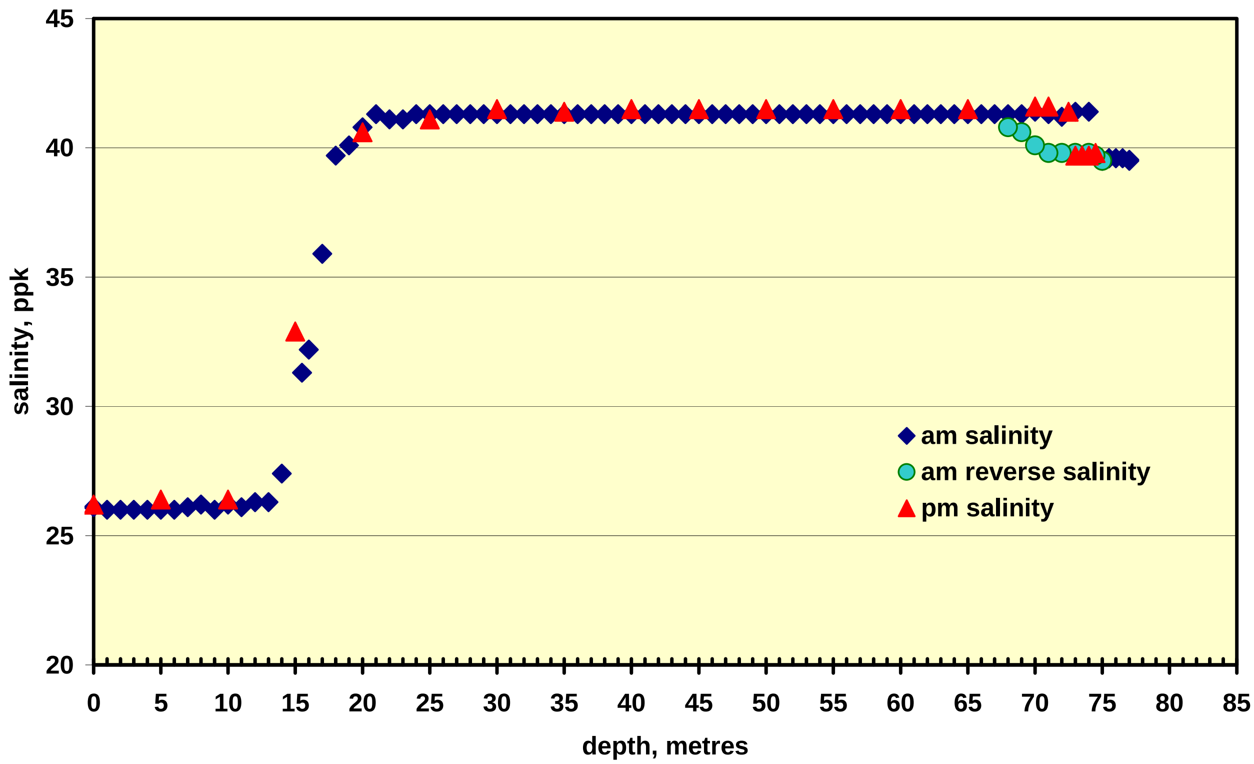

Figure 2: Salinity profile on the AE2 site, Sea of Marmara, September 2007

Since a 2kg lead weight had been attached to the sensing heads for the dissolved oxygen and salinity probes, to keep the sensors vertical in the water column, the salinity values recorded during recovery of the long cable leads may reflect the chloride activity in the upper sediment layer. The mean salinity of the surface waters was 26.1±0.1 ‰ or parts per thousand and this reflects values associated with the influx of waters from Black Sea, which has a mean salinity of approximately 18‰, into the Sea of Marmara. The increased salinity of the upper water compared with the Black Sea is due to the low run-off of streams feeding the Marmara and due to the relatively high evaporation rate. In order to characterise the salinity data the sigmoidal curve of salinity vs. depth was analysed through plots of the values of *log*{S bottom /(S depth $_x$ – S bottom)} which are used to determine the inflexion point in the salinity depth graph.

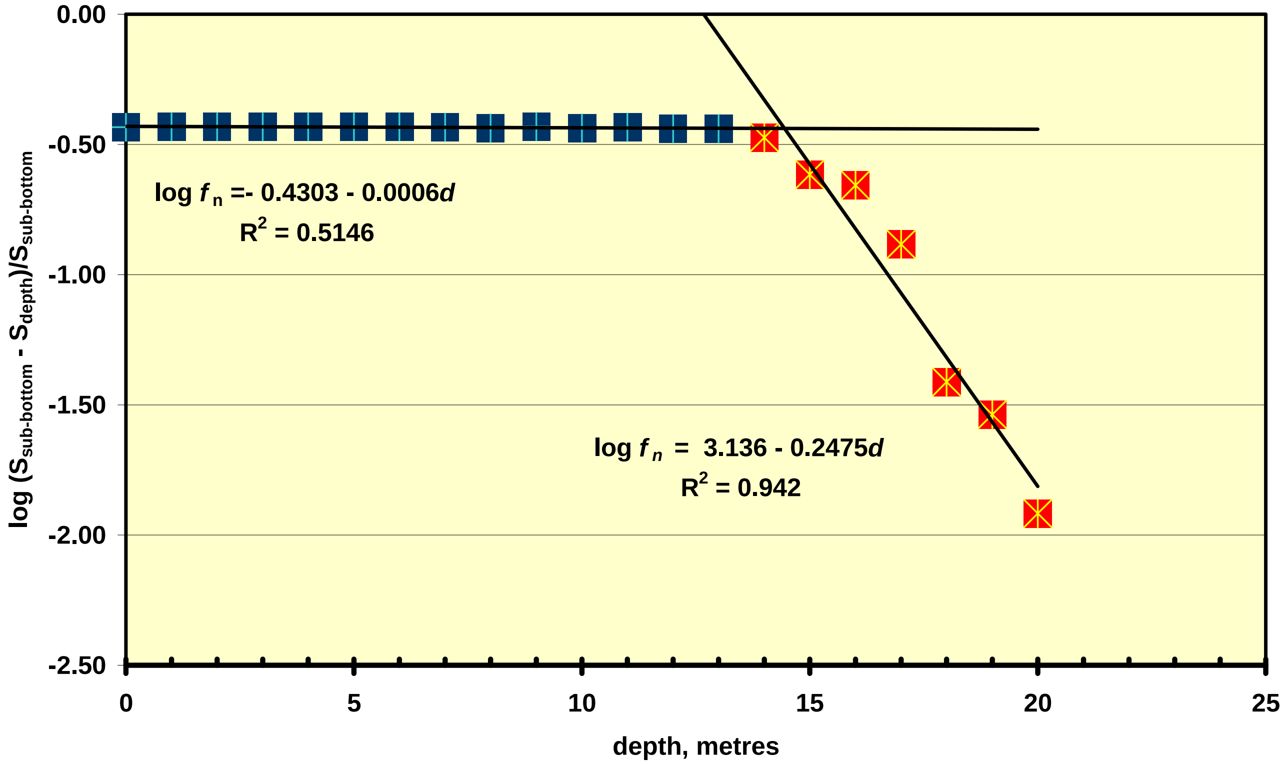

Figure 3: Plot of logarithmic difference function for salinity of the upper waters, Sea of Marmara

The turning point for the upper waters was found at a depth of 14.8 metres, as shown in Figure 3 by solving the simultaneous equations for the lower and upper parts of the sigmoidal curve. The reverse profile for salinity on the bottom of the AE2 site shows slightly lower values at depths of 68-73 metres and this is likely due to mud contamination on the bottom of the sensing probe after the initial excursion into the sediment. The data at the bottom of the site was also reproducible in terms of a slightly lower salinity in the sediment layers. In order to determine the reproducibility of the data a second set of readings were taken in the afternoon, but with the recordings limited to 5 metre intervals owing to limited operational time on the support vessel. Inspection of the data in Figure 2 shows that the salinity readings have a high degree of reproducibility. The mean salinity for the deeper waters on the AE2 site was 41.3±0.8 ‰ for depths between 20-74 metres and these values reflect the influx of more saline waters from the Aegean Sea which floods in from the Dardanelles. There was only one halocline observed over the whole range of depths on the site of the wreck. If the probe did penetrate part of the silt mound then this area has a mean salinity of 39.3±0.12 ppt which is statistically significant. The lower sediment salinity reflects limited exchange with the surface waters. Observations made through the ROV camera at the halocline noted the difference in light scattering over the depth range where the waters changed from lower to higher salinity. A similar optical presentation was recorded inside the submarine using the drop camera that had been inserted into the partly opened hatch inside the conning tower. Attempts to get the salinity probe inside the vessel were hampered by the increased distance from the submarine after winds had shifted the *Detek Salvor*. It is possible that a halocline does exist inside the submarine. Once the sea cocks had been opened the vessel would have begun to fill with the lower salinity upper waters and once past the thermocline, the pressure of the submarine descending through the water column may have been sufficient to flood the lower levels with the more saline waters that characterise the water column from 20 metres to the seabed. Owing to the limited amount of water movement inside the submarine it is not unexpected that these two layers of sea water have not mixed to any great extent over the past 92 years.

Temperature profile

The temperature profile across the site was recorded on the TPI WD30 instrument before being manually downloaded into Excel spreadsheets. The temperature measurements were calibrated with a digital thermometer that was accurate to ±0.1°C. Plots of the temperature and water depth show classic sigmoidal curves with turning points (inflexion points where the gradient of the temperature vs. depth changes sign) as shown in Figure 4. The surface waters were approximately 26°C and the sub-bottom temperature used in the analysis was 18°C since this reflected the steady temperature once the first thermocline had been penetrated.

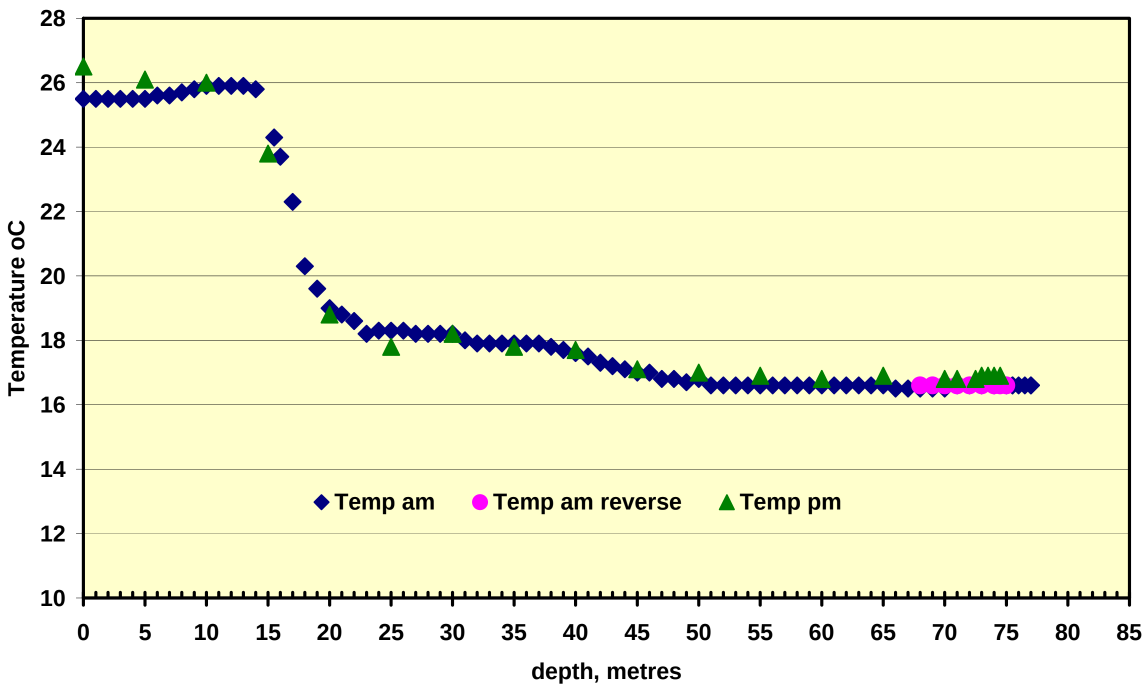

Figure 4 Temperature profile with depth on the AE2 site 14 September 2007

Through analysis of the simultaneous equations established by calculation of the ratios of temperature at known depth vs. sub-bottom temperatures plotted as a function of water depth it was possible to determine the turning point of the first halocline at 15.2 metres with top temperatures. The turning point of the salinity profile was 14.8 metres and given the uncertainties associated with ensuring that the cable was vertical in the water column, it can be stated that the temperature and salinity curves had the same turning point at 15 metres. It should be noted that there was no apparent hysteresis with the temperature profiles when the probe penetrated the marine sediments surrounding AE2. Given that the temperature probe is a modified thermocouple it is not surprising that the presence or absence of sediment on the tip of the probe or lying within the protective sheath had no discernible affect. The smaller thermocline had a turning point at 39.6 metres with the temperature maximum being 18°C and the minimum being approximately 16°C. Communications with the divers confirmed that the first thermocline was very strongly felt and they were also aware of the second but less pronounced thermocline. The coincidence of the turning point for the salinity and temperature profiles in the upper waters is perhaps a reflection of the small amount of mixing of the two water columns in the Sea of Marmara. The afternoon temperature profile was essentially identical to the morning profile, which indicates that in both cases the orientation of the probes in the water columns was reproducible.

Dissolved oxygen

The dissolved oxygen measurements recorded on the TPS combined salinity, temperature and dissolved oxygen meter. Calibration of the oxygen sensor was made using a two point calibration method based on both the value that the electrode had in air at a given temperature and the value it recorded in a borate buffer solution containing 20 grams per litre of sodium sulphite, which reacts with the dissolved oxygen to create a standard zero oxygen solution.

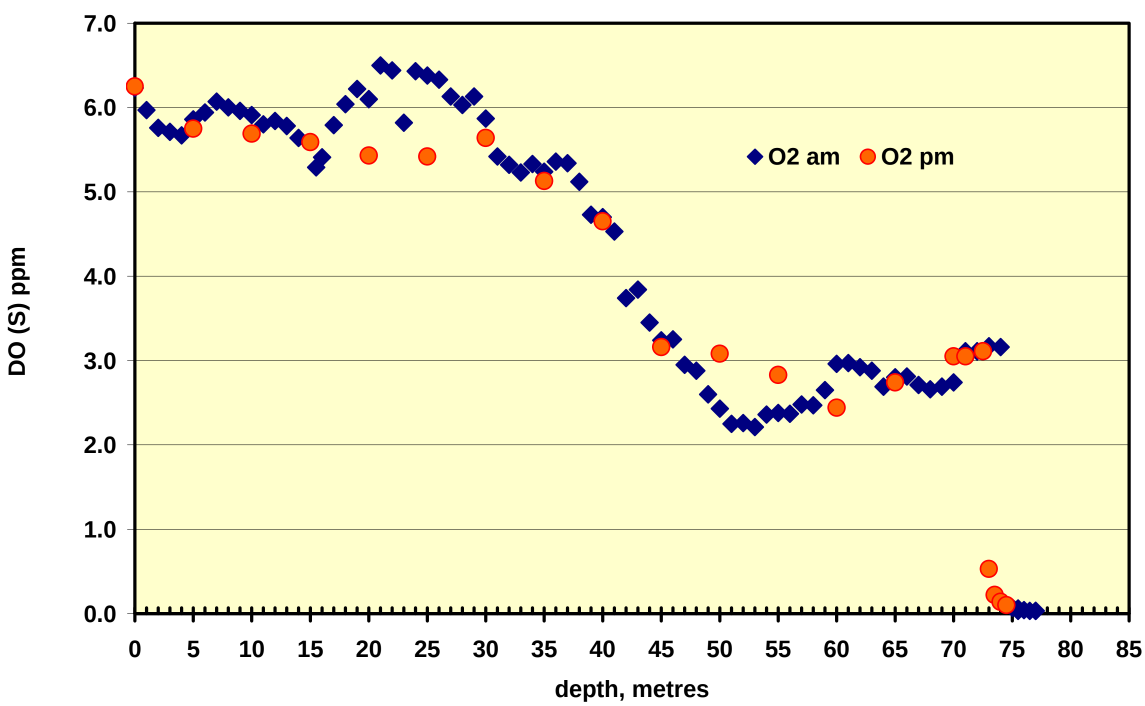

Figure 5: Plot of dissolved oxygen (salinity corrected) as a function of water depth, metres

Since determination of oxygen in seawater involves diffusion of molecular oxygen across a thin membrane, where it is consumed at an internal metal electrode, the values are not as reproducible as temperature and salinity, as the movement of the cable as the support vessel moves in response to wave chop causes localised eddies around the sensing head. The data obtained from the morning and afternoon measurements shows that the surface water is well oxygenated at between 7 and 5.5 parts per million and that the values fall from 5 to 3 ppm as the depth increases from 35 to 50 metres. At depths equivalent to the top of the fin and the upper works of the submarine the dissolved oxygen was recorded at 2.8±0.2 ppm which represents 36% saturation of the seawater for a salinity of 41.3‰ at 16°C (Riley and Skirrow, 1975). The degree of saturation is not unexpected as the amount of water movement on the site is generally very low, as attested by the divers who regularly disappeared in a cloud of fine silt that took many minutes to disperse. Inspection of the dissolved oxygen profiles shows that once the seabed is reached there is a dramatic drop off in oxygen as the sediment and silt layers are penetrated. Within the experimental error of the YSI dissolved oxygen probe it can be stated that he sediments and silt layers surrounding AE2 are essentially fully anaerobic. Corrosion due to differential aeration is a serious management problem for the submarine as the half buried in silt-half submerged environment is ideal for setting up differential corrosion cells.

Corrosion potential measurements

The voltage of the corroding hull of AE2 was recorded on the casing 5.74 metres after of the leading edge of the casing aft of the fin. The E_{corr} value was -0.619 volts vs. Ag/AgCl$_{sea}$ which had been calibrated with a saturated quinhydrone solution at pH 4.0 using a standard platinum electrode in order to provide an absolute value of the E_{corr} related the Normal Hydrogen Electrode. The calibration resulted in the determination of the absolute voltage as -0.391 volts vs. NHE which is not dissimilar to the E_{corr} values recorded on the J5 submarine which had a mean E_{corr} of -0.382±0.005 vs. NHE after 78 years of immersion at a depth of 32.4±1.0 metres. The pH of the metal corresponding to the E_{corr} value recorded on site was 7.27 which may be indicative of a relatively slow rate of corrosion but without additional comparative data it is difficult to be more precise. Since flooding of the drill hole by the surrounding seawater would result in more alkaline values, it is likely that the underlying acidity was greater than measured by the divers. Corrosion data on the turret and armour plating of the USS *Monitor* (1862) provides a very useful comparison since the *Monitor* is at the same depth as AE2. During the 1987 survey of the vessel off Cape Hatteras, North Carolina a number of E_{corr} measurements were made on the turret, the armour plating on the hull and on recently damaged sections of the hull that had broken away, thus losing the protective nature of the concretion cover.

On the USS *Monitor* site the mean corrosion potential (E_{corr}) of sound metal on the turret and armour belt was -0.600 ± 0.016 volts vs. Ag/AgCl but it was not possible to establish the absolute value of the voltage of their reference electrode. If it is assumed that the reference electrode used in the *in-situ* corrosion survey on the *Monitor* site is within ± 0.005 volts of the reference used in Turkey, the AE2 site is slightly less corrosive than the *Monitor*. Given that the Cape Hatteras site is subject to periodic massive storms, such as the one that sank the *Monitor* on 31st December 1862, and has a high frequency of strong currents running across the site, at speeds of up to 2 knots, it should be corroding at a faster rate than the submarine in the Sea of Marmara. The turret on the *Monitor* site was partially exposed to flowing sea water and part was covered by the upturned hull of the iron warship. Previous studies on the wreck of the *Yubae Maru* in Chuuk (Truk) lagoon in the Federated States of Micronesia has shown that by placing a vessel upside down on the sea bed it will corrode at 3-5% higher than a non-stressed vessel lying proud and upright on the floor of the lagoon.

The corrosion survey on the *Monitor* site was done using direct E_{corr} measurements but the majority of the readings were made on the electric field gradient associated with the corroding metals underneath the protective concretion layers. This technology is used for surveying undersea pipelines which leads to maps of relative corrosion intensity. It was found that the mud-line on the lower armour belt was more corrosive and the mean E_{corr} values for active corrosion sites was -0.549 ± 0.005 volts while the most aggressive microenvironment had mean voltages of -0.449 ± 0.036 volts. When there is little or no solid metal present the voltages reflect a redox cell and the mean potential of -0.333±0.007 volts was recorded for very badly corroded materials (Arnold et. al. 1991). Of direct relevance to the interpretation of the data on the decay of AE2, is the observation that corrosion was worst in the areas above the mud-line on the *Monitor*, which in the AE2 situation would amount to the areas of the casing, which have been shown to suffer from severe corrosion to the point where the there has been total metal loss. Visual images from the ROV confirm that significant areas of the casing have suffered total metal loss. Corrosion of an iron wreck in a partly buried, partly exposed microenvironment is going to be dominated by differential corrosion phenomena since the concentration gradient of dissolved oxygen across the partly buried submarine is extreme. In such environments the corrosion at or near the sediment line is two to three times greater than that at other locations.

Accidental site damage and potential impact on AE2

During the fieldwork on site in the Sea of Marmara the support vessel *Detek Salvor* was moored with a set of four anchors to locate the diving platform in close proximity to the submarine. This arrangement was essential to maximise safe deployment of divers and sensing devices such as the Remote Observation Vehicle (ROV) and physical environment measuring devices associated with determining the temperature, salinity and dissolved oxygen on the site. During the night of 13 September a storm caused the support vessel to drag its moorings and the 2-tonne shot line weight, which was secured to the support vessel, moved and “bounced” across the submarine. The percussive action of the weight caused mechanical removal of a large section of concretion from the surface of the submarine and also caused some of the rivets to spring. This accidental damage allowed divers to measure the metal thickness of the submarine in this location, using a hand held ultrasonic device as well a series of ultrasonic measurements were made by the ROV unit. Owing to difficulties in relocating the vessel and due to changes in the turbidity of the site, it was not possible to obtain any corrosion potential measurements on the metal in the immediate or general vicinity of the areas that had been deconcreted.

Damage to the protective concretion results in direct access of the dissolved oxygen, measured at 2.7 ppm at 16.5°C on site, to the corroding metal and this in effect amounts to a short circuit in the corrosion cell. After years of immersion in seawater, marine iron becomes covered with an intimate mixture of corrosion products and marine growth and debris. This concretion layer causes physical isolation of the anodic and cathodic parts of the corrosion cell, with oxygen reduction occurring on the outside of the concretion seawater interface and metallic corrosion or anodic reactions taking place in an essentially anaerobic microenvironment underneath the concretion. The circuit is completed by electronic conduction of the current through the corrosion and concretion matrix. Once the concretion has been breached, the acidic liquid iron corrosion products interact with the surrounding seawater and voluminous amounts of red-brown iron oxy-hydroxides begin to cover the surface and provide some protection until the marine organisms can once again colonise and begin the encapsulation process. This stage of the process can take several years and during this period the object suffers from accelerated corrosion, which naturally leads to loss of archaeological values.

Quantification of the damage

Without the post disturbance data it is difficult to assess the impact of the deconcretion of the section of the submarine. However, it is possible to use data from other wreck sites that have sustained accidental damage to get an estimate of the impact of this accidental partial deconcretion event. When the shank of the best bower anchor from HMS *Sirius* (1790) had a 500 cm^2 section of concretion removed the monitoring of the voltage showed that the E_{corr} had become more anodic by 220 mV which meant that the rate of decay had increased by a factor of 4.7 times during the 72 hour monitoring period after it had been relocated to the Kingston Jetty. Application of an aluminium alloy engine block, a cheap and locally available anode, brought the voltage down by 184 mV within a few hours and by 304 mV at the end of the treatment. An estimate of the final corrosion rate was that it was $^1/_6$ of the original in-situ rate of decay. It should be noted that the Sirius anchor was in turbulent water at a depth of only 1.5 metres. Based on the site conditions in the Sea of Marmara, a 220 mV anodic shift in the E_{corr} of AE2 would have resulted in an increased corrosion rate of 4.4 times.

Localised damage on the wreck of the Fujikawa Maru (1944) in the Federated States of Micronesia, Chuuk (Truk) Lagoon caused by “dynamite fishing” activities resulted in areas of the concretion spalling and this has resulted in accelerated corrosion of the wreck and loss of archaeological values. Assessment of the impact is difficult to gauge without direct access to metal thickness measurements over time. However it is possible to look at the changes in the mean corrosion voltages of the wreck and also of the pH values, which also reflect the local corrosion rate. Changes in the mean pH between April 2002 and July 2006 indicate that the reported “dynamite fishing” that had impacted on less than 1% of the surface area had resulted in an overall increase of 69% in the corrosion rate. Following this damage, the marine organisms began to colonise the wreck, which is located in equatorial waters at average temperatures of 29.3 ±1.3°C, and the corrosion rate had fallen by 51% of its elevated level within six months as a result of partial re-concretion of the damaged zones. Further “dynamite fishing” activities in early July 2007 resulted in a swing of a 95% increase in corrosion rate. The mean water depth at which the measurements were recorded on the Fujikawa Maru was 18.3±2.8 metres, which is significantly shallower than the AE2 site.

Part of the severity of the corrosion impact of accidental concretion damage also depends on the ratio of the anodic to cathodic areas of the metal. Given that the bulk of the submarine is buried in deeply anaerobic sediment, the relatively large surface of exposed metal will result in significant accelerated decay of the boat. Since the damaged area of AE2 is significantly more than 1% of the surface, it is essential to undertake some form of in-situ protection to correct the accidental damage and stabilise the site. Measurements on the *Monitor* site showed that a section of partly deconcreted marine iron, accidentally damaged during relocation on the wreck site, exhibited a maximum corrosion rate of 0.277 mm/year, compared with the average corrosion rate of 0.1mm/year (La Que, 1975) on the material that had been damaged while relocating it to another part of the site to enable work to proceed on the turret.

Remediation recommendation

It is imperative that sacrificial anodes are attached to the submarine AE2 in minimise the damage that has been caused by the accidental deconcretion process. Measurements on anchors and cannon that have been treated by anodes in-situ on the Sirius on Norfolk Island and on the *Xantho* (1872) iron steamship at Port Gregory in Western Australia and on the *Zanoni* (1867) composite ship in Gulf St Vincent in South Australia have established the method of site stabilisation as being very effective. It is recommended that a set of anodes be attached to the bow, the stern and amidships of the vessel to begin the process of in-situ conservation and to overcome the damaging impact of the loss of the protective concretion layer. Placement of 100 kg zinc anodes at the bow, stern and two anodes on each of the port and starboard sides of the ship in locations that will be determined by corrosion modelling of the internal and external elements of the vessel. Treatment of a series of mid 19^{th} century iron deck knees from the *James Matthews* (1841) showed that major changes in the pH of the corroding iron was observed within two weeks of attaching zinc anodes in this sandy burial anaerobic microenvironment (Heldtberg etal. 2004)

Concretion analysis and site history of AE2

During site inspections following from the accidental damage to the submarine by the shot line anchor divers were able to recover some samples of concretion for preliminary analysis before being handed over to Turkish officials. The concretions showed a primary concretion layer roughly 1.6 mm thick, which was followed by a secondary layer 8.8 mm thick and a third layer to the outer zone of the concretion which was 3.9 mm thick. Pitting corrosion beneath the original surface layer produced an inward growing mound of 3 mm of corrosion products. Since the corrosion processes on the submarine began in an anaerobic microenvironment and the original surface of the iron hull can be seen in cross-section, it is likely that examination of the underside of the concretion will find residual elements of the lead based primer that had been applied to the submarine during its construction phase. During the *in-situ* corrosion measurements the divers reported a thin but rock hard concretion layer of 3 mm located some 5.74 metres aft of the casing behind the fin.

Figure 6: Concretion sample from AE2 showing scrupled worm casts and small oyster shells

If AE2 has corroded according to the normal fashion of marine iron, there is an initial period of intense corrosion as paint layers are penetrated and after 4-5 years a steady corrosion rate is established. When this model is applied to the concretion layers the primary corrosion layer in the concretion could correspond to the first 13±2 years of immersion i.e. from 1915 to 1928 and the main thickness would correspond to a period of 79 years leading up to the present day.

Details of Ring Bolt Bracket

During the movement of the shot line anchor across the submarine a ring bolt bracket was dislodged from the vessel and recovered by divers who handed the object to the care of Turkish authorities once it had received emergency first aid treatment of being soaked in an alkaline carbonate solution. Examination of the bolt showed that it suffered normal wrought iron degradation in that the metal was torn rather than being fractured like a cast iron fitting would have been – see Figure 7. There was very active corrosion around the tear line on the bracket and within minutes of recovery the normal weeping patterns of a clear liquid transforming into a red-brown akaganeite crusty growths. The amount of residual solid metal in several parts of the bracket was very small.

Figure 7: Details of the ring and sheared off bolt fitting from the side of the submarine

Deep grooves were found on the inside of the ring which is consistent with it having been cold worked with a coarse file. All over the surface the general corrosion pattern is characteristic of anaerobic bacteria which caused the metal to have a mottled or pock marked appearance. The shallow pits are believed to be associated with localised increased populations of anaerobic sulphate reducing bacteria. Part of the original attachment of the ring bolt bracket was a bolt from which the head had been sheared. The bolt shows clear lines of mechanical working and not unexpectedly the extent of corrosion is more intense along these lines. The apparent bolt diameter is 15.25 mm while the inside diameter of the thread is 13.3 mm. Approximate pitch of thread is 2.2 mm. Without more accurate measurements of the bolt and determination of the thread pitch and the number of threads per inch it is not possible to determine the original size of the bolt but during the period of construction of AE2 bolt sizes went up in increments of $^{1}/_{16}$".

Assessment of the rate of deterioration of AE2

Owing to the very limited nature of empirical data obtained from the site in the Sea of Marmara it is necessary to drawn on data from other shipwreck sites to provide some method of internal calibration and validation of the few thickness measurements that were recorded on the AE2 site. Data from the *Monitor* report showed that the vessel and turret had a mean corrosion rate of 0.016 mm/year, if the two extreme values associated with damaged and partly deconcreted materials are ignored. Given that the *Monitor* and the AE2 are at the same depth, the long term corrosion rate for the *Monitor* applied to the Australian wreck would give an average corrosion loss of 1.47 mm from the outward surface. Estimates of the internal corrosion rate show that these values range from 20-30% of the external value, which would give a combined metal loss on structural elements of 1.77 – 1.91 mm after 92 years of immersion of AE2 (Arnold et. al. 1991). If the measurements conducted by the divers relate to the combing and other areas where the original metal was 6.35 mm thick the mean thickness of 4.80 ± 0.86 mm corresponds to a loss of 1.55 mm since the vessel was scuttled. Given that the amount of water movement across the AE2 site is much less than the microenvironment associated with the *Monitor* the observed values for the Australian submarine site reflect the anticipated lower corrosion rates.

It is also useful to calculate the apparent loss of metal thickness in more sheltered waters associated with the wrecks of a number of Second World War vessels associated with the Imperial Japanese Navy in Chuuk Lagoon, Federated States of Micronesia. The impact of periodic deep storms and the diurnal grind of time and tide and the colonisation of the wrecks by the surrounding milieu of marine organisms lead to a chronology that is faithfully recorded by the corrosion profiles recorded in graphitised cast iron. For open-ocean wrecks and those in the sheltered waters of Chuuk lagoon, it was found that the logarithm of the corrosion rate was linearly dependent on water depth. One problem of the open ocean data is that it is limited to depths of 30 metres, since this depth was the operational limit of the author diving on air, but when the AE2 site depth of 73 metres is used in the equation,

$\log i_{\text{open-ocean}} = -0.630 - 0.0156\, d$,

Where d is the mean water depth across the wreck site the calculated corrosion rate for AE2 is 0.0183 mm/year which is significantly higher than the observed value of 0.0168 ± 0.0030 mm/year which is to be expected since the AE2 has been subjected to periodic burial and exposure events. Recently published data from the wreck of the USS *Arizona* (1941) provided corrosion rates over the past 61 years, where the corrosion data was based on cores that were drilled through the remaining metal. The authors of the *Arizona* reported a linear dependence of corrosion rate on water depth, but when the data is analysed in the same fashion as the information on open ocean wrecks using a logarithmic plot of corrosion rate, the equation,

$\log i_{\text{Arizona}} = -0.7629 - 0.0743\, d$,

Which implies a surface corrosion rate of 0.173 mm/year compared with the open ocean value of 0.234 mm/year? The differences in the calculations of surface corrosion rate are due to the sheltered nature of the heavily polluted waters in Pearl Harbour compared with open ocean wreck sites (Johnson et.al.2006). Residual metal thickness measurements indicate that AE2 has a lower than expected rate of decay, based on the water depth and dissolved oxygen levels and the higher than average salinity. *In-situ* corrosion potential and surface pH measurements also indicated that the submarine was corroding in a relatively benign microenvironment. Examination of a sample of marine concretion recovered from the submarine showed clear evidence of multiple burial and exposure events, which explains why the combing was in relatively good condition. Silt levels appear to have come up to the base of the fin and down to the middle level of the ballast tanks, as currently observed in the conditions on site in September 2007.

The different type of colonisation on the fin will in part be due to the higher profile it has on the wreck but the complexity indicates that this area of the vessel has not been subjected to burial and exposure events to the same extent as the main sections of the boat. Preliminary analysis of the footage from the drop camera indicates that there is a further halocline inside the submarine. Such a halocline would result in a microenvironment that would inhibit normal marine biological activity by any wood boring organisms and by bacteria that eat cellulose. There appears to be a unique combination of diffusion parameters that has resulted in remarkable preservation of organic materials inside the submarine. If the submarine is in a quasi stable state, the pH value of 7.27 corresponds to a hydrogen pressure of 0.05 atmosphere of hydrogen which explains why no gas evolution was observed during penetration drilling of the concretion since the ambient external pressure was of the order of 8 atmospheres.

Sediment cores

The first partial core of the sediment surrounding the boat was done on 14 September 2007 and was recovered in a vertical position by support divers after being collected at the 20 metre decompression stage. In order to determine the dissolved oxygen content of the core it was necessary to pre-equilibrate the dissolved oxygen electrode by bubbling air through surface seawater which had been collected from a depth of 1 metre below the surface at the rear of the support vessel. A series of specialised micro-electrodes had been brought to the site to enable the microenvironment within the core samples to be determined. Prior to operational use the polycarbonate core sample holders had been pre-drilled to provide 3 mm diameter holes into which the electrodes can be inserted. The holes were covered with polyvinylchloride tape to seal in the sediment matrix.

The mean redox potential of the sediment core adjacent to AE2 was +0.119 ± 0.044 volts vs. NHE while the mean value for the core obtained 20 metres from the site was +0.157 ± 0.038 volts – see Figure 8 for a plot of the redox potential vs. depth of the sediment core. These data sets include all the values of the redox potential, measured at a rhodium electrode (0.5mm wire, 2 cm long sealed into a Vycor® seal into a Pyrex glass and silver soldered to a 0.5 mm hard pitched copper wire) in conjunction with a Ag/AgCl double junction reference electrode which had been calibrated against a platinum electrode in a pH 4.0 buffered solution of saturated quinhydrone (a 1:4 adduct of quinone and hydroquinone) and had a voltage of +0.228 volt vs. NHE.

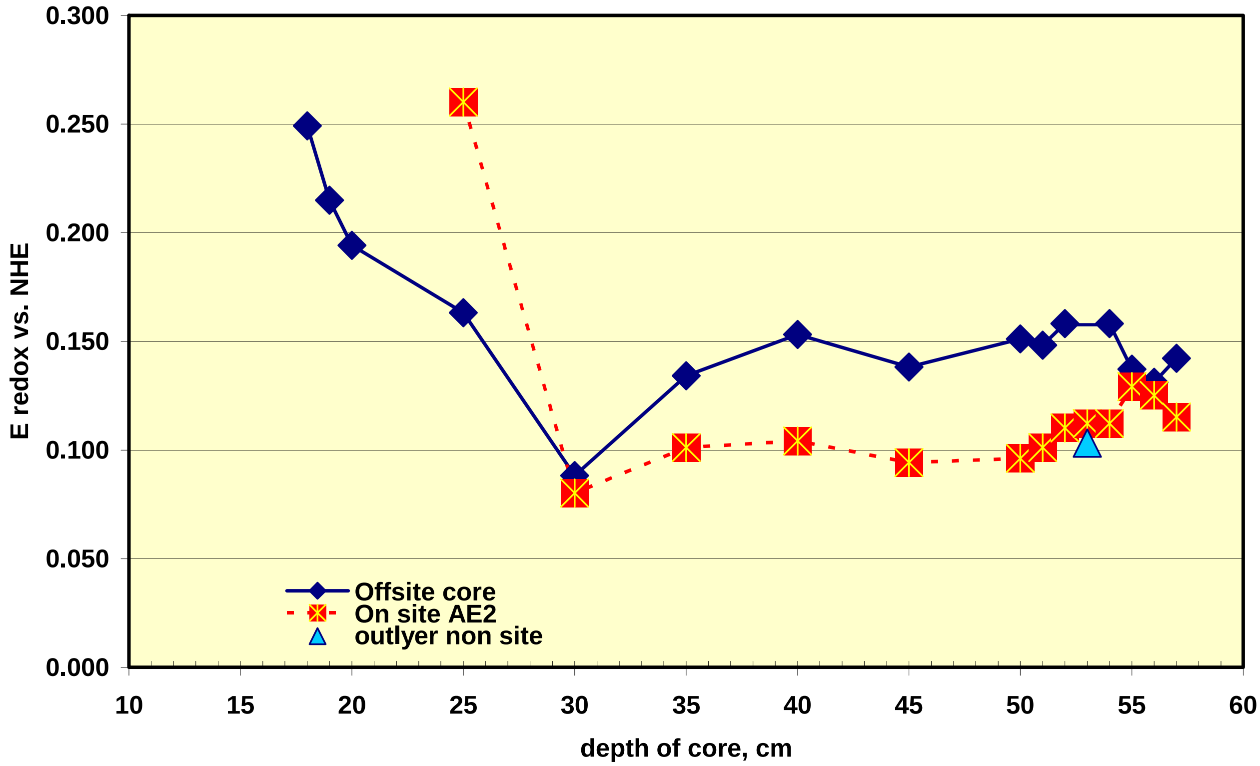

Figure 8: Redox potential of the sediment cores as a function of distance from surface

When the more oxidising values in the upper layers of the sediment core are excluded, the differences between the two cores became more apparent, as seen in Figure 8. The more oxidising values represent the changing amount of dissolved oxygen in the interstitial waters and in the upper layers of the sediment core. The AE2 core in the deoxygenated zone had a mean redox potential of +0.107 ± 0.014 volts, whilst the corresponding section of the core obtained away from the influence of the submarine had a value of +0.142 ± 0.020. The difference between the mean values of the cores is 35 mV and the sum of the standard deviations is 34 mV, which indicates that the differences are just statistically significant, to a 92.5% confidence level. If the outlier value in the off-site sediment core is included the mean value increases to +0.154 ± 0.039 volts.

When the off site core E_{corr} was plotted as a function of the pH it was found that there was no systematic relationship between the two variables which is consistent with there being no dominant chemical solution processes taking place within the sediment. Changes in activity of the microbiological populations can lead to production of acidic metabolites which then exert a major influence on the local pH. The data from the sediment core obtained adjacent to the AE2 site had very different properties to the redox data collected closer to the support vessel. Although the correlation coefficient is not high, the slope of -66±11 mV per unit change in pH is consistent with the voltage being controlled by the reduction of the interstitial water in an essentially anaerobic microenvironment which consumes one hydrogen ion per electron and has a slope of -0.059 millivolts – see Figure 9.

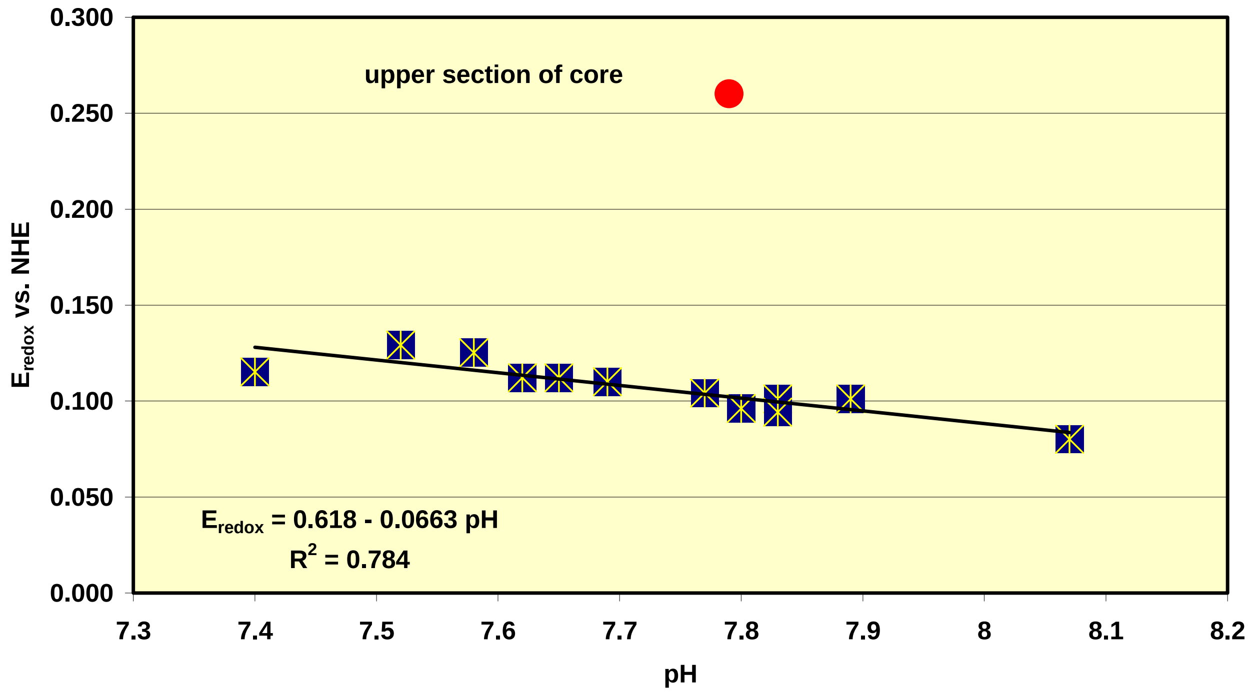

Figure 9: Plot of the redox potential E_h for the AE2 site core as a function of sediment pH

When the pH data from both the on-site and off-site core are plotted as a function of the sediment depth the differences between the two cores is quite apparent and is seen in Figure 10. The pH values of the core close by the submarine shows a steady alkaline microenvironment of approximately pH 7.8 before moving to less alkaline values over the last 7 cm of the core at a rate of -0.05 pH per centimetre distance down the core. The off-site core had a similar starting point to the AE2 core but the pH rapidly fell in the first 10 cm to 7.1±0.1 until both cores obtained similar pH values at the bottom of the profiles. Without access to data on the microbiological populations in the cores it is difficult to determine the underlying causes that give rise to the observed patterns of acidity across the sediment cores.

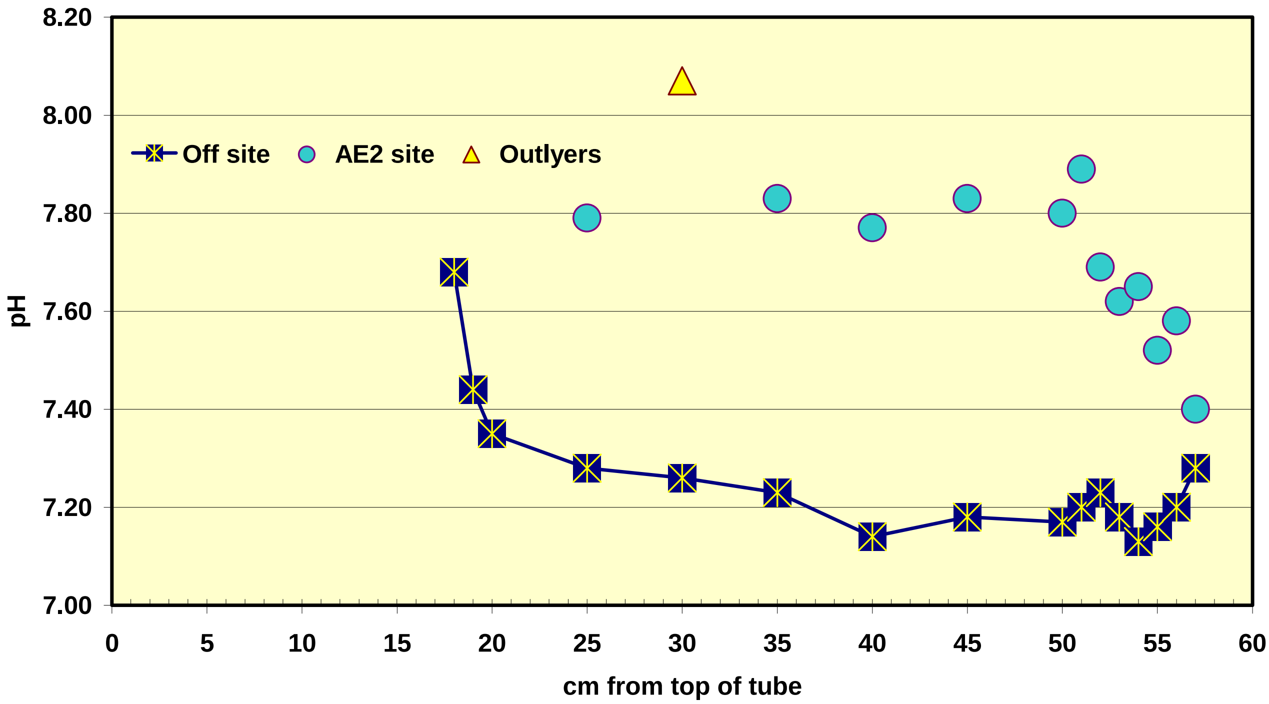

Figure 10: Plot of pH values of the AE2 site and off site cores as a function of sediment depth.

Measurement of the dissolved oxygen in the cores involves careful insertion of the microelectrode into the silty sediment layer through the pre-drilled hole and waiting for the reading to equilibrate. The basic characteristic of the two cores is that they are essentially anaerobic after the first few centimetres of sediment, which is not surprising since the seabed is composed of a very dense grey clay-like mineral deposit. The off-site core had increasing dissolved oxygen content from zero to 0.2 ppm in the last 7 cm of core which may be a reflection of reduced microbiological activity in this zone or it could be due to systematic errors introduced in the sampling and measuring processes. It is likely that the very low levels of dissolved oxygen in the AE2 core, as seen in Figure 11, are the result of experimental and operator error since the majority of the readings within the core reflect zero dissolved oxygen concentration.

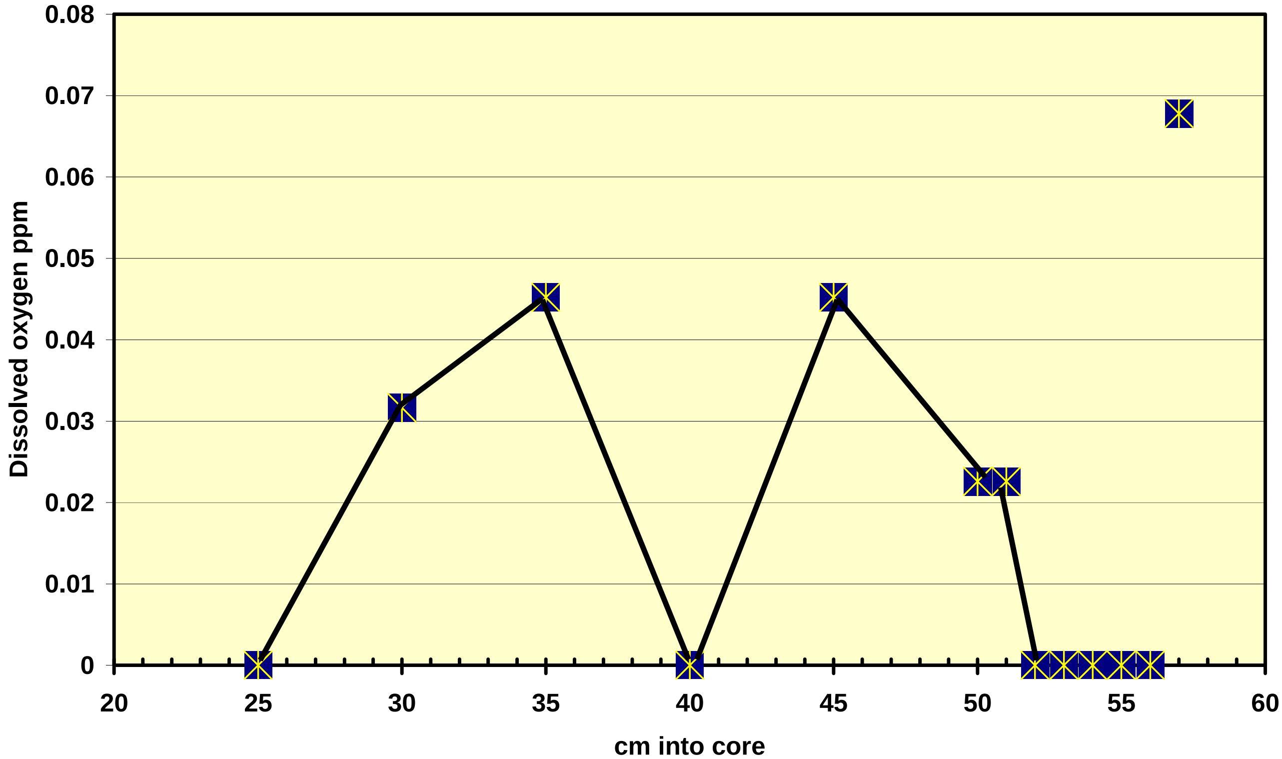

Figure 11: Plot of dissolved oxygen concentrations in the core from the AE2 site

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Appendix 1 to ANNEX E - Physical Oceanography 10SEP07

depth, metres	DO ppm	Salinity	Temperature	DO ppm	Salinity	Temperature
morning				afternoon		
0.0	6.23	26.1	25.5	6.3	26.20	26.5
1.0	5.97	26.0	25.5			
2.0	5.76	26.0	25.5			
3.0	5.71	26.0	25.5			
4.0	5.67	26.0	25.5			
5.0	5.86	26.0	25.5	5.8	26.40	26.1
6.0	5.94	26.0	25.6			
7.0	6.07	26.1	25.6			
8.0	6.00	26.2	25.7			
9.0	5.96	26.0	25.8			
10.0	5.91	26.2	25.9	5.7	26.40	26.0
11.0	5.80	26.1	25.9			
12.0	5.84	26.3	25.9			
13.0	5.78	26.3	25.9			
14.0	5.64	27.4	25.8			
15.0				5.6	32.90	23.8
15.5	5.29	31.3	24.3			
16.0	5.41	32.2	23.7			
17.0	5.79	35.9	22.3			
18.0	6.04	39.7	20.3			
19.0	6.22	40.1	19.6			
20.0	6.10	40.8	19.0	5.4	40.60	18.8
21.0	6.50	41.3	18.8			
22.0	6.44	41.1	18.6			
23.0	5.82	41.1	18.2			
24.0	6.43	41.3	18.3			
25.0	6.38	41.3	18.3	5.4	41.10	17.8
26.0	6.33	41.3	18.3			
27.0	6.13	41.3	18.2			
28.0	6.03	41.3	18.2			
29.0	6.13	41.3	18.2			
30.0	5.87	41.3	18.2	5.6	41.50	18.2
31.0	5.42	41.3	18.0			
32.0	5.32	41.3	17.9			
33.0	5.23	41.3	17.9			
34.0	5.33	41.3	17.9			
35.0	5.24	41.3	17.9	5.1	41.40	17.8

36.0	5.36	41.3	17.9			
37.0	5.34	41.3	17.9			
38.0	5.12	41.3	17.8			
39.0	4.73	41.3	17.7			
40.0	4.70	41.3	17.6	4.7	41.50	17.7
41.0	4.53	41.3	17.5			
42.0	3.74	41.3	17.3			
43.0	3.84	41.3	17.2			
44.0	3.45	41.3	17.1			
45.0	3.24	41.3	17.0	3.2	41.50	17.1
46.0	3.25	41.3	17.0			
47.0	2.95	41.3	16.8			
48.0	2.88	41.3	16.8			
49.0	2.60	41.3	16.7			
50.0	2.43	41.3	16.8	3.1	41.50	17.0
51.0	2.25	41.3	16.6			
52.0	2.26	41.3	16.6			
53.0	2.21	41.3	16.6			
54.0	2.36	41.3	16.6			
55.0	2.38	41.3	16.6	2.8	41.50	16.9
56.0	2.37	41.3	16.6			
57.0	2.48	41.3	16.6			
58.0	2.47	41.3	16.6			
59.0	2.65	41.3	16.6			
60.0	2.96	41.3	16.6	2.4	41.50	16.8
61.0	2.97	41.3	16.6			
62.0	2.92	41.3	16.6			
63.0	2.88	41.3	16.6			
64.0	2.69	41.3	16.6			
65.0	2.80	41.3	16.6	2.7	41.50	16.9
66.0	2.81	41.3	16.5			
67.0	2.71	41.3	16.5			
68.0	2.66	41.3	16.5			
69.0	2.69	41.3	16.5			
70.0	2.74	41.4	16.5	3.1	41.60	16.8
71.0	3.11	41.3	16.6	3.1	41.60	16.8
72.0	3.11	41.2	16.6			
72.5				3.1	41.40	16.8
73.0	3.17	41.4	16.6	0.5	39.70	16.9
73.5				0.2	39.70	16.9
74.0	3.16	41.4	16.6	0.1	39.70	16.9
74.5				0.1	39.80	16.9

75.0	0.07	39.5	16.6			
75.5	0.06	39.6	16.6			
76.0	0.04	39.6	16.6			
76.5	0.03	39.6	16.6			
77.0	0.03	39.5	16.6			
76.5	0.03	39.5	16.6			
76.0	0.03	39.6	16.6			
75.5	0.03	39.5	16.6			
75.0	3.11	39.7	16.6			
74.5	3.07	39.8	16.6			
74.0	3.11	39.8	16.6			
73.0	3.10	39.8	16.6			
72.0	3.10	39.8	16.6			
71.0	3.08	40.1	16.6			
70.0	2.76	40.6	16.6			
69.0	2.83	40.8	16.6			

Appendix 2 to ANNEX E - Site stabilisation post MAA

Background

During the Maritime Archaeological Assessment of the submarine AE2 and its immediate environs, the support vessel *Detek Salvor* was moored with a set of four anchors to locate the diving platform in close proximity to the submarine. This arrangement was essential to maximise safe deployment of divers and sensing devices such as the Remote Observation Vehicle (ROV) and physical environment measuring devices associated with determining the temperature, salinity and dissolved oxygen on the site. During the night of 13 September a storm caused the *Detek Salvor* to drag its moorings and the 2-tonne concrete anchor block for the shot line, which was attached to the support vessel, moved and “bounced” across the submarine. The percussive action of the weight caused mechanical removal of a large section of concretion from the surface of the submarine and also caused some of the rivets to spring. This accidental damage allowed divers to measure the metal thickness of the submarine in this location, using a hand held ultrasonic device as well a series of ultrasonic measurements were made by the ROV unit. Owing to difficulties in relocating the vessel and due to changes in the turbidity of the site, it was not possible to obtain any corrosion potential measurements on the metal in the immediate or general vicinity of the areas that had been deconcreted. Concluding operations involved a return of the site to its pre-disturbance condition and all markers and other devices associated with the survey were removed.

Issue

Damage to the protective concretion results in direct access of the dissolved oxygen, measured at 2.7 ppm at 16.5°C on site, to the corroding metal and this in effect amounts to a short circuit in the corrosion cell. After years of immersion in seawater, marine iron becomes covered with an intimate mixture of corrosion products and marine growth and debris. This concretion layer causes physical isolation of the anodic and cathodic parts of the corrosion cell, with oxygen reduction occurring on the outside of the concretion seawater interface and metallic corrosion or anodic reactions taking place in an essentially anaerobic microenvironment underneath the concretion. The circuit is completed by electronic conduction of the current through the corrosion and concretion matrix. Once the concretion has been breached, the acidic liquid iron corrosion products interact with the surrounding seawater and voluminous amounts of red-brown iron oxy-hydroxides begin to cover the surface and provide some protection until the marine organisms can once again colonise and begin the encapsulation process. This stage of the process can take several years and during this period the object suffers from accelerated corrosion, which naturally leads to loss of archaeological values.

Quantification of the damage

Without the post disturbance data it is difficult to assess the impact of the deconcretion of the section of the submarine. Relevant observations can be made by looking at data from a number of other shipwrecks and sites. When the shank of the best bower anchor from HMS *Sirius* (1790) had a 500 cm^2 section of concretion removed the monitoring of the voltage showed that the E_{corr} or corrosion potential had become more anodic by 220 mV which meant that the rate of decay had increased by a factor of 4.7 times during the 72 hour monitoring period after it had been relocated to the Kingston Jetty. Application of an aluminium alloy engine block, a cheap and locally available anode, brought the voltage down by 184 mV within a few hours and by 304 mV at the end of the treatment. An estimate of the final corrosion rate was that it was $^{1}/_{6}$ of the original *in-situ* rate of decay. It should be noted that the *Sirius* anchor was in turbulent water at a depth of only 1.5 metres. Based on the site conditions in the Sea of Marmara, a 220 mV anodic shift in the E_{corr} of AE2 would have resulted in an increased corrosion rate of 4.4 times.

Localised damage on the wreck of the *Fujikawa Maru* (1944) in the Federated States of Micronesia, Chuuk (Truk) Lagoon caused by “dynamite fishing” activities resulted in areas of the concretion spalling and this has resulted in accelerated corrosion of the wreck and loss of archaeological values. Assessment of the impact is difficult to gauge without direct access to metal thickness measurements over time. However it is possible to look at the changes in the mean corrosion voltages of the wreck and also of the pH values, which also reflect the local corrosion rate. Changes in the mean pH between April 2002 and July 2006 indicate that the reported “dynamite fishing” that had impacted on less than 1% of the surface area had resulted in an overall increase of 69% in the corrosion rate. Following this damage, the marine organisms began to colonise the wreck, which is located in equatorial waters at average temperatures of 29.3 ±1.3°C, and the corrosion rate had fallen by 51% of its elevated level within six months as a result of partial re-concretion of the damaged zones. Further “dynamite fishing” activities in early July 2007 resulted in a swing of 95% in corrosion rate. The mean water depth at which the measurements were recorded on the *Fujikawa Maru* was 18.3±2.8 metres, which is significantly shallower than the AE2 site.

Part of the severity of the corrosion impact of accidental concretion damage also depends on the ratio of the anodic to cathodic areas of the metal. Given that the bulk of the submarine is buried in deeply anaerobic sediment, the relatively large surface of exposed metal will result in significant accelerated decay of the boat. Given that the damaged area of AE2 is significantly more than 1% of the surface, it is essential to undertake some form of *in-situ* protection to correct the accidental damage and stabilise the site.

Remediation recommendation

It is imperative that sacrificial anodes are attached to the submarine AE2 in minimise the damage that has been caused by the accidental deconcretion process. Measurements on anchors and cannon that have been treated by anodes *in-situ* on the *Sirius* on Norfolk Island and on the *Xantho* (1872) iron steamship at Port Gregory in Western Australia and on the *Zanoni* (1867) composite ship in Gulf St Vincent in South Australia have established the method of site stabilisation as being very effective. It is recommended that a set of anodes be attached to the bow, the stern and amidships of the vessel to begin the process of *in-situ* conservation and to overcome the damaging impact of the loss of the protective concretion layer. Details of the attachment methods and size of anodes can be developed in consultation with appropriately experienced corrosion protection engineers and naval architects.

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ANNEX F REPORT OF OPERATION SILENT ANZAC ROV OPERATIONS, DROP CAMERA & SEABED BEARING-STRENGTH CHARACTERISTICS

	Name	Position
Prepared By:	Roger Neill & Peter Graham	Marine Science, Data Management & ROV
Reviewed By:	Stuart Cannon	Defence Scientific & Technical Organisation
Authorised By:	Terence Roach	Director of Operations

ANNEX F – ROV, DROP CAMERA & SEABED PENETROMETER

Abstract

In September 2007 the Australian Defence Science and Technology Organisation (DSTO) participated in a maritime archaeological assessment (MAA) of the World War One submarine HMAS AE2. A number of tasks were undertaken by the DSTO team, using a mix of commercially available hardware and in-house-developed equipment. A small remotely operated vehicle was used to undertake a comprehensive visual survey of the submarine and its surroundings. The ROV was also used to deploy an ultrasonic thickness gauge, allowing assessments to be made of the residual condition of AE2. A unique system was developed to enable the state of siltation inside the vessel to be assessed, and to allow judgements to be made of the general condition of AE2’s internal structure. It was found that, internally, the vessel is remarkably clear of sedimentary material, and it is in a remarkable state of preservation. Finally measurements were made of the bearing strength of the seabed upon which AE2 lays. The predicted depth of burial, derived from these measurements, matched the observed state of the vessel very closely. Data derived from DSTO’s contribution to the MAA will play a critical role in the development of a strategy for the long-term management and conservation of AE2.

Introduction

The Operation Silent ANZAC survey expedition had a number of deliverables for which DSTO personnel were assigned responsibility. This is a report of the primary findings and conclusions arising from each of the objectives identified in the Operation Order, issued 30 August 2007. This report specifically relates to operations undertaken by the DSTO Remotely Operated Vehicle, the Drop Camera and a penetrometer-based seabed bearing strength measurement instrument. In the following discussion, where positions are specified relative to frame numbers, these are the frame number for the main pressure hull, even if the object being described is on or under the casing or some other external part of AE2.

Remotely Operated Vehicle Operations

The Remotely Operated Vehicle (ROV) provided by DSTO for the purpose of this survey was a small, hand-deployable unit produced by Seabotix – the LBV150L. The unit was equipped with two cameras (colour and black and white), a mechanical scanning sonar (Tritech Micron, visible on top of the vehicle in Figure One), and external LED lights (mounted high-up on the skids) and, optionally deployed in place of the sonar, a Cygnus ultrasonic thickness measurement unit. Power and communications were transferred between the surface and the vehicle via a lightweight, 250 metre long tether. This tether was paid out and recovered by hand. Because of the light weight and relative simplicity of the vehicle, a two-person team was able to operate it throughout the expedition. Mr Peter Graham fulfilled the role of ROV Pilot and Dr Roger Neill doubled as deck hand and task overseer.

The initial plan was for the ROV and the divers to be deployed in isolation from each other, under the control of the dive supervisor (Dr Stuart Cannon). In practice it was found that the vehicle and the divers could operate simultaneously in relative harmony, although from time to time the ROV was withdrawn from the water to enable suspended matter thrown up by its jet wash to settle. The initial plan was for the ROV to operate for two days only – in practice it was in the water practically every day and ultimately over 12 hours of video footage was recorded off the vehicle's cameras.

Figure 1. The Seabotix ROV on board the Detek Salvor.

The vehicle proved to be quite reliable, and it was generally able to cope well with the conditions. On the last day, however, a strong surface current caused some difficulties by dragging the umbilical and, as a consequence, the vehicle down current. This was ultimately overcome by decoupling the vehicle from the surface with weights attached to the umbilical, approximately 50 metres along its length, allowing an operating area of 100m diameter. This method, illustrated in Figure 2, could prove very useful if future deployments are undertaken.

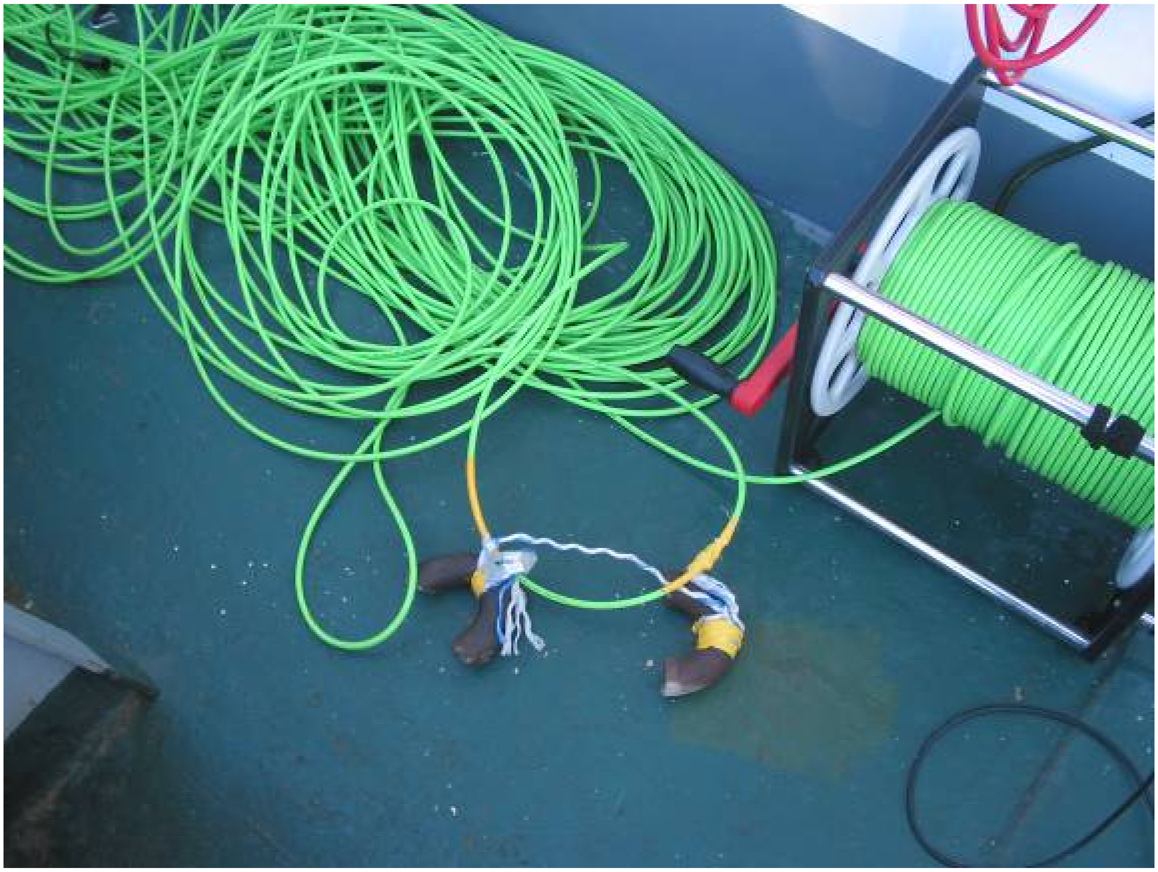

Figure 2. A pair of chain half links was used to carry the umbilical directly to the seabed.

Video-based Survey Tasks Undertaken by the ROV

The ROV was used to undertake detailed visual inspection of the submarine's external structure, to survey the surroundings of the submarine to establish if there is an extended debris field, and to establish the general morphology of the surrounding seabed. The ROV was also used to look for evidence of battle damage, both in the vicinity of the starboard side engine room and around the propellers.

Results of general investigation of the structure of the submarine

The exposed parts of the vessel were visually inspected in their entirety by the ROV. As has been previously reported, the submarine appears to be sitting virtually level, but perhaps slightly bow-down. The sediment in the vicinity of the midships is built up to within a metre of the top of the saddle tanks, and there is less sedimentation towards bow and stern. The forward hydroplanes are just clear of the seafloor, as is the forward torpedo tube door. There is a fair amount of scour around the aft end of the vessel, with the consequence that the rudder and at least one propeller blade are visible. Figure Three is a representation of the level of the build-up of seabed material along the length of the submarine (starboard side, AE2 presented in its nominal 1915 condition).

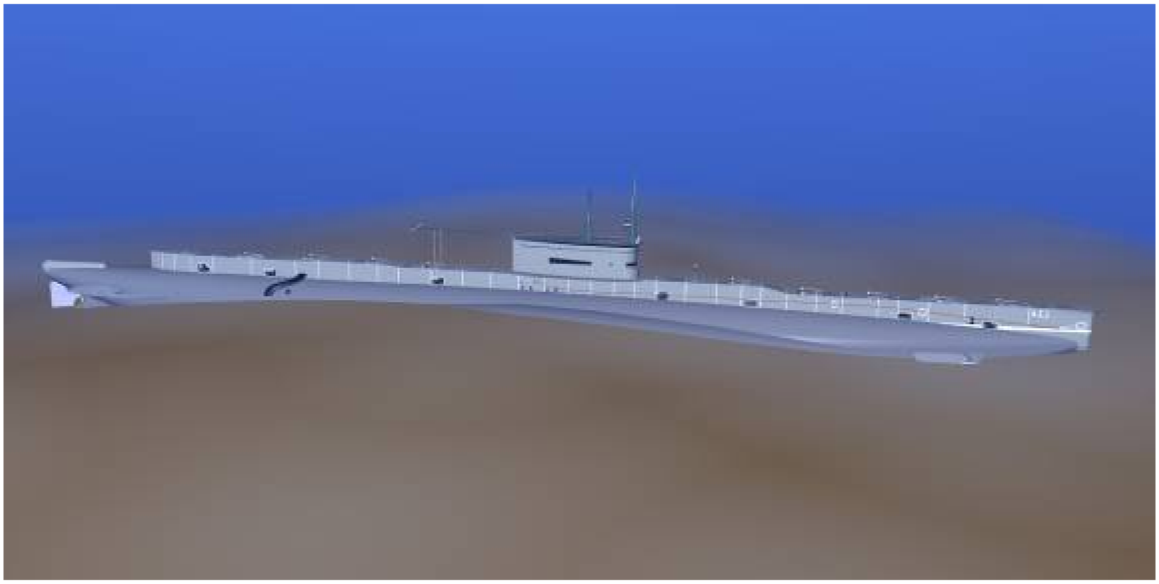

Figure 3. A representation of AE2 as she is lying on the seabed.

Pressure Hull and Saddle Tanks

The fabric of the pressure hull and saddle tanks appears to be substantially intact. There is no evidence of gross damage or significant discontinuities due to corrosion in either. Due to an unplanned impact of a concrete block on one area of the hull, on the port side in the vicinity of frame 41, the concretion was removed from a portion of the ballast tank. This revealed that there are localized, small (in the vicinity 25-50 mm diameter) corrosion holes. An example is shown in Figure 4.

Figure 4. Showing a hole through to the portside saddle tank, in vicinity of Frame 41. Note also the overlay of the plating, and rivets.

Casing

In contrast to the relatively good condition of the main hull and saddle tanks, the casing has sustained significant damage, apparently as a result of either fishing activity or an anchor dragging across the site. This, damage, accompanied by the loss of sections of the casing as a result of corrosion of its relatively light plating, has resulted in the profile of the submarine being largely lost for a substantial proportion of its length. At some time between the initial, 1998 dives on the vessel and 2007, the portside towing pennant has been fouled by either fishing equipment or an anchor and dragged across to the starboard side of the hull. This resulted in a substantial section of the casing being broken away and deposited on the starboard side of the vessel (approximately between frame 72 and 83), and the fairwater at the bow being split and 'peeled back', with destruction of approximately the first five metres of the casing (estimated to be from frame 93 forward).

Figure 5. Shows how the portside towing pennant has 'peeled back' the plating of the casing at the bow.

This has exposed gear and equipment that resided under the casing in the vicinity of the bow. The opening gear for the outer torpedo door is intact, and the anchor is lying in its stowed position on the anchor bed, with chain still in position leading back to the anchor winch.

Figure 6. At lower left is the bow cap of the forward torpedo tube, and its associated opening mechanism. The worm gear is visible as is the support frame and bearing and shaft. The quadrant gear, not visible in this image, is intact and correctly engaged with the worm gear.

The following image shows the towing pennant lying across the top of the hull in the vicinity of frame 75. The pennant has actually parted, but only after causing this significant amount of destruction. Interestingly, it was the fact that biological concretion had bonded the pennant to the hull that enabled the equipment which fouled the pennant to gain such destructive purchase.

Figure 7. Showing the portside towing pennant lying across the hull. Left of image is forward.

The removal of this section of casing has exposed the torpedo loading hatch opening, anchor winch and the windlass, all of which appear to be in a good state of preservation. The following illustrate the two winches.

Figure 8. Anchor Winch, looking from the port side. The rope lying over is fishing debris.

Figure 9. Windlass*.*

Moving aft from the break in the casing in vicinity of frame 72 the casing is substantially complete until the vicinity of the aft torpedo loading derrick at frame 42. In this vicinity the casing has been substantially compromised between frames 40-43, as can be seen in Figure 10

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Figure 10. Damage to the aft casing in the vicinity of the torpedo loading derrick.

There is one final area of substantial damage to the casing, in the vicinity of the main exhaust muffler (around frame 30). There is a semi-circular opening, plus two smaller holes, with an underlying structure evident under the aft-most holes. While the holes could be a result of strikes from fishing equipment, in this case a more likely cause is that this simply represents localized higher levels of corrosion, resulting from the heat-cycling effects of the underlying exhaust system, on both steel and paints. This is consistent with observations by Ian MacLeod (Personal Communication) of accelerated corrosion, in the vicinity of their exhaust stacks, on the former HMAS Swan and Perth [now sunk as dive wrecks off the West Australian coast] as illustrated in Figure 11 below.

Figure 11. Substantial corrosion holes in the aft casing in the vicinity of the exhaust system.

The following image shows a section of intact casing, which includes very cleanly preserved vent holes.

Figure 12. An intact portion of casing.

Exhaust Outlets

Both exhaust outlet pipes are in place and substantially intact. The portside pipe has a large hole, which is probably simply attributable to corrosion. This is to be expected, considering its previous employment carrying hot gasses internally while having its outside surface intermittently quenched by cold water.

Figure 13. Portside exhaust pipe.

Figure 13 illustrates the portside exhaust. Also visible in the background of the figure is an opening in the casing. This is not damage – it is, in fact, an access hole for a cleat.

The Telegraphy Post and Fin

The telegraphy post is still in place and, despite being festooned with fishing equipment, appears to be structurally intact.

Figure 14. Telegraphy post.

The forward end of the fin, which was constructed out of non-ferrous materials including naval brass and gunmetal, is complete. It still has its navigation lights in place, as are all of the viewing ports. The periscope standards are still in place and the jumping wire between these is intact. The periscopes themselves have been sheered off at some stage.

Figure 15. Starboard forward viewport on conning tower.

Figure 16. Forward periscope standard and jumping wire.

While the deck of the fin is still complete, the remainder of the steel aft end of the fin has corroded away. The reasons for this are:

- the relative absence of silt inside the submarine (see below) indicates that, unlike the remainder of the submarine, the fin has never been buried;

- corrosion processes in the more exposed location of the fin will be different than other parts of the vessel (MacLeod, 2007);

- the aft end of the fin was the location of the battery tank and fuel tank vent outlets, hence in service the structure would have been subject to chemical attack; and

- the effect of the adjoining non-ferrous components of the fin may have contributed to the corrosion processes.

Figure 17. A view looking up at the aft end of the fin, showing that the rear portion of the structure has completely corroded away.

Hydroplanes

The hydroplanes have proven to be remarkably effective capture devices for fishing gear, as they are all fouled to a greater or lesser extent. The planes are complete and appear to be in very good condition.

The forward hydroplanes are just clear of the seabed. They are angled slightly up, probably at about 5 degrees. Because the drive train for the hydroplanes was a worm gear-and-quadrant setup, it is not possible for the attitude of the planes to be significantly altered as a result of external forces (they would break before they could be rotated against the worm gear); this must be the angle at which the planes were set when the vessel was scuttled.

Figure 18. Forward Port hydroplane and plane guard. Note fishing nets caught between the two.

The aft hydroplanes are set horizontal. These are well clear of the seabed, so it was possible to undertake detailed inspection of both surfaces. Both port and starboard units appear to be in good condition, as evidenced by the following images.

Figure 19. Portside aft hydroplane.

Figure 20. Starboard aft hydroplane, with fishing nets hanging below it and lines above.

Rudder

The rudder is substantially clear of the seabed. It is heavily encrusted, but appears to be complete. It is canted to starboard, perhaps at fifteen degrees, indicating that the vessel was still actively manoeuvring until the decision was made to abandon ship.

Figure 21. The rudder

Propellers

A single blade of the starboard propeller is clear of the seabed. One of the aims of the Battle Damage Survey was to inspect the propellers for damage that may have been caused when the submarine grounded in the Dardanelles Straight. The single blade that is visible appears to be in excellent condition, with no signs of damage.

Figure 22. Starboard propeller blade

Aft Torpedo Door and Opening Mechanism

The aft torpedo door is very heavily encrusted with marine growth, so it is not possible to make judgements on its condition. The cover for the opening mechanism was relatively lightweight construction, so has suffered quite significant corrosion damage. As has been the observation elsewhere on the vessel, however, the underlying machinery appears to be in a good state of preservation.

Figure 23. The aft torpedo door.

Figure 24. Torpedo door opening shaft.

Battle Damage Inspection of the Hull

Because of the lay of the submarine and the position of the Detek Salvor, it was quite difficult to undertake repeat survey runs along the starboard aft end of the AE2. The approach to the submarine was from the port side, with the consequence that the ROV umbilical tended to foul on the superstructure of AE2. Despite this, the entire exposed surface of the hull was visualized at least once. While no obvious shell holes were identified, this is not particularly surprising. The experience of 'cleaning' the hull with the concrete block showed that holes of 50 mm diameter or so can be completely hidden by concretion. Hence if the 37mm shells punched cleanly through the pressure hull, the probability is that the holes won't be found unless the concretion layer is removed.

Survey of the Surrounding Seabed

The aim of this serial was to visually survey the seabed in the vicinity of the submarine to determine if there is any surrounding debris (for example the missing upper portions of the periscopes) and to establish whether any significant local environmental features may impact on the long-term management of the vessel.

The general approach was to establish a series of survey lines parallel to the hull of the submarine, at offset distances of 3, 6, 9, 12, 15, 18, 21 metres on the portside and a subset of those lines on the starboard side. The scanning sonar was used to navigate the ROV to the respective offset distances, and the survey lines extended approximately 5 metres beyond the line of the bow and stern of the submarine at each end. In addition, a couple of sample, oblique-orientation runs were undertaken to identify whether there were any significant differences in the benthic environment further away from AE2.

General observations

There is a build-up of sediment amidships on both sides of the vessel, but slightly higher on the port side. This probably amounts to a peak height of 1-2 metres and the build-up begins about 4 metres from the side of the submarine. Because the ROV pilot maintained a relatively consistent altitude during these runs, if priorities warrant, it will ultimately be possible to build a reasonable seabed profile from the ROV depth records;

Figure 25. This shows the sediment profile in the vicinity of frame 41. The profile was exposed unintentionally during a storm event, resulting from sediment removal by a concrete block that was dragged across the seabed and impacted the portside saddle tank.

The general terrain is relatively featureless, except for the proliferation of conical hillocks that are apparently generated by the local marine life;

Figure 26. An accommodation block for the local populace.

In the regions where scouring takes place, particularly near the stern of the vessel, there is a greater proliferation of shell-fish debris.

Debris surrounding the vessel is confined to fishing gear. There is an accumulation of fishing gear on the seabed at either side of the bow, and along the forward half of the vessel on the starboard side, plus there is fishing gear hanging off the submarine near the stern. Except for broken pieces of casing, there is no sign of debris belonging to AE2. The missing periscopes were not found.

There are also a number of red-coloured ropes lying across the seabed, laying approximately 90 degrees to the submarine. The mechanism that causes these to remain unburied is not clear.

Additional runs, undertaken at oblique angles to the submarine, on both port and starboard sides of the vessel, revealed that the local benthic environment is relatively uniform.

Ultrasonic Thickness Measurements

Prior to dispatch to Turkey the 5 MHz Cygnus ultrasonic thickness unit was calibrated against a standard thickness block, and it was tested against the 10 mm thick side of a partially-flooded steel barge at DSTO's test facility. In both cases the gauge was found to be accurate to better than 0.1 mm.

Attempts were made to use the ROV to take ultrasonic thickness measurements at three locations on AE2, two of which were not cleaned and one that had the biological concretion removed. The uncleaned sites were on the casing, on the starboard side immediately aft of the break in the casing that occurs midway between frame 71 and 72; and on the fin. The thickness gauge was set on its 'mild steel' setting while working on AE2.

At the measurement site on the casing, only one reading was recorded as being stable. This was 8.55 mm. Figure 27 shows the final approach of the ROV prior to taking the measurement. The site at which the reading was taken is approximately 60 mm from the break in the casing, which means that the position of the location site almost certainly overlay a casing frame. Hence the recorded thickness may be of combined casing material and frame. The original specified thickness of the 5 lb plating was 3.1 mm and the underlying angle-section frames had wall thickness of 4.8 mm. Hence the combined, specified thickness was 7.9 mm. This represents a difference between measured and specified thickness of 8%, which would be quite acceptable if the metals were new. The reality, of course, is that there is considerable corrosion evident in the casing. The MacLeod (2007) report discusses the nature of the corrosion processes in low-oxygen environments. Specifically, it appears that the corrosion process may not have produced the usual, relatively defined interface between the base metal and the overlying primary corrosion layer and as a result the ultrasonic system may have failed to measure the thickness of the underlying base steel. This could result in a thickness measurement that is rather high. It will be seen below that the measurements taken on the cleaned site also appear to be high. A method, described below, has been proposed to cross-check and validates these measurements and perhaps to develop a model that may allow some conclusions to be drawn of the actual nature of the residual material of the submarine.

Figure 27. The final approach by the ROV prior to taking thickness measurement. The Break in the casing can be seen at right of view.

An attempt was made to make a measurement on the non-ferrous structure of the fin. The reason was that it was known from the drop camera investigation that the structure is in good condition and that its rear surface is relatively clear of fouling, hence this would have been a good calibration site. Unfortunately the nature and thickness of the concretion rendered it impossible to take a stable reading.

Figure 28. Preparing to take a thickness measurement in a ‘cleaned’ area. Note the row of rivets overlying a rib is flush and well seated. To the left of the field of view is a joint between plates, which had an underlying butt strap.

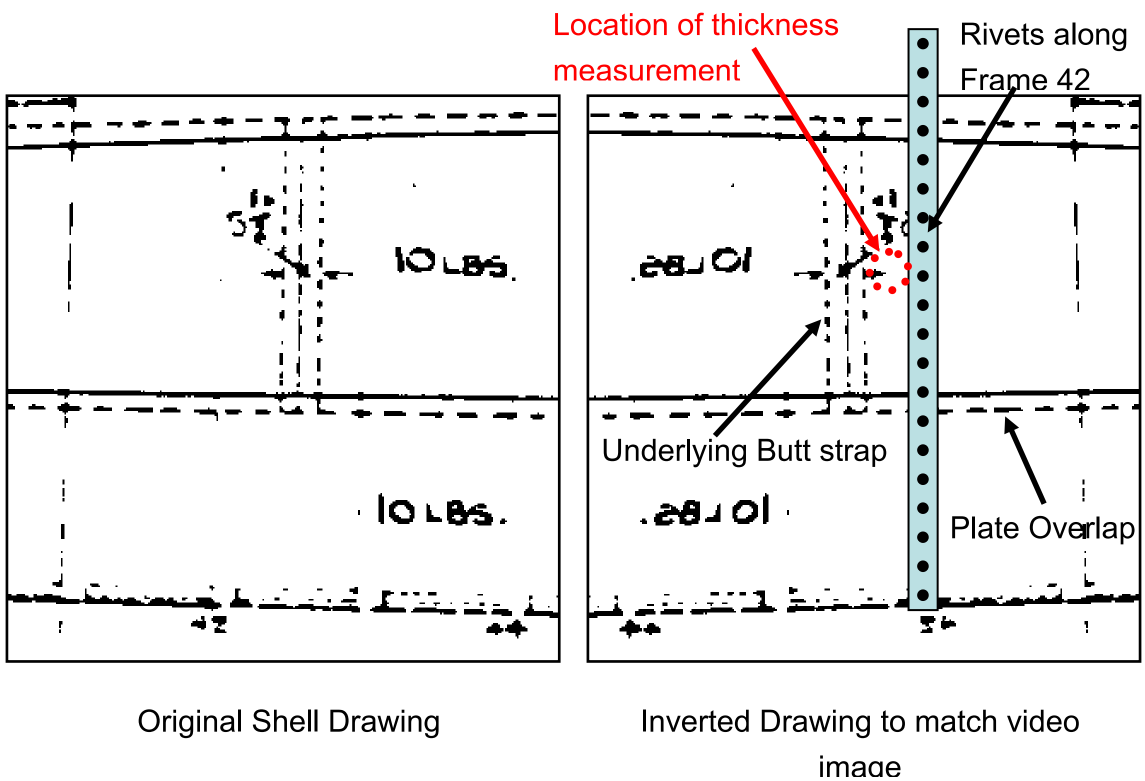

Figure 29. Showing the corresponding site for the measurement taken in Figure 29.

Finally a series of measurements were taken at the site where the concrete block had cleared the concretion off the surface of the saddle tank. It was not possible to exactly map the location of each measurement, and it will be seen in Figures 28 and 29 that this is an environment which was rich in plate overlaps, frames, butt straps etc. Consequently several of the measurements *could* have been taken over the top of double thickness plates, or even double thickness plates with underlying angle frames. After sorting into thickness order, a grouping appears to form as follows:

Sample Number	Group	Thickness Reading (mm)
4	1	6.4
1	1	9.15
5	2	12.65
13	2	14.1
14	2	14.1
12	2	14.5
11	2	15.0

3	2	16.85
2	3	22.5
7	3	24.4
8	3	24.8
9	3	26
10	3	26
6	4	37.2

Table 1 Thickness readings taken in the vicinity of portside, frame 41.

The two measurements in Group One are reflective of measurements taken over single-thickness plating, the specified thickness of which was 6.4 mm. For Group 2 the mean and standard deviation thickness measurement is 14.5 $\pm$ 1.4 mm. As the thickness of the frames was 6.35 mm, the combined thickness, as specified, would be just short of 13 mm. Hence Group 2 could be representative of measurements taken over a plate/frame combination. Group 3, with mean and standard deviation readings of 24.7 $\pm$ 1.4 mm *could* reflect readings taken over a frame in an area where the plates overlapped each other. Tempting as it is to draw this conclusion, it doesn't really stand up to critical appraisal. For one thing, the measurement assigned to Group 4 can not be easily explained in this manner. Except for the webbing in the frames, the plans show no thicker structural materials in this vicinity of the boat. Given that:

- the ROV pilot was specifically aiming to avoid double-thickness areas and visual inspection of the video records indicate that he generally achieved that aim,
- there are so many of the higher readings,
- they were interspersed in the midst of the other measurements, and
- only stable thickness gauge outputs were recorded, it is unlikely that any or many of the readings were recorded over multi-layer sites.

It would be prudent to seek a possible alternative explanation. The thickness gauge works by identifying the successive reflections from the front and rear surfaces of the base metal layer, and calculating the thickness from the time of flight of the acoustic signals through the metal. One possibility is that conditions existed such that the gauge failed to identify every reflection, but rather it picked up the peaks arising from multiple reflections (perhaps due to a kind of 'beating' effect). In this instance, the thickness measurements would be multiples of the actual thickness. The readings in Table 1 were reprocessed by dividing Group 2 readings by 2, Group 3 readings by 3 and Group 4 readings by 5. Treating the data in this way resulted in a mean thickness reading of 7.7 $\pm$ 0.9 mm.

No matter which of the above interpretations are correct (if any), there is a problem with all of the thickness measurements – they are all too high. The consistency of the measurements was good, however, which implies that the gauge was actually measuring something 'real'. One mechanism has already been discussed (non-layered nature of the corrosion products due to the anaerobic environment). Alternatively it is possible (if unlikely) that AE2 was built out of heavier plating than specified – there have been reports that some steelworks in the early 20th century made sure plating wasn't rejected by adding a fairly significant percentage over-thickness.

A suggestion has been made that may help us clarify the situation. The proposal is to use the thickness gauge to make a series of measurements on the former Victorian naval vessel HMVS CERBERUS, and then to validate those readings by taking direct measurements in situ. This would be possible because there are parts of the CERBERUS where it will be possible to access both sides of the plating. The attraction of using CERBERUS is that it is possible to access locations that have been subjected to relatively anaerobic conditions similar to those AE2 has experienced.

Incidental observation arising from the thickness measurement serials

Figure 30 is an image recorded just above the midline of the saddle tank in the region in which the concrete block impacted it. It is apparent that the rivets have been 'started' at this location. This is a matter of some concern, because loose rivets can act as seed sites for development of corrosion holes.

Figure 30. 'Started' rivets on portside saddle tank.

Deployment of Drop Camera into interior of hull

A drop camera system was developed to enable video imagery to be recorded from inside the conning tower and the aft end of the control room and midships torpedo space. The primary deliverables of the serial was to determine the level of siltation inside the vessel and to ascertain its general internal condition. The DSTO team was working under a number of constraints, with the consequence that the camera system was not as capable as we would have wished:

- The permit issued by the Turkish government specifically prohibited us from 'materially interfering with' AE2. This meant that it was not possible to open the upper hatch, which had swung virtually shut during AE2's final descent. Consequently all equipment had to be small enough to be inserted through the 100 mm opening at the leading edge of the hatch;

- The camera system had to be sufficiently simple that it could be delivered, installed, adjusted if necessary and manipulated by divers who would have relatively limited opportunity to train with the equipment;

- There were only three dive teams available for the serial, each of which was limited to approximately 30 minutes on the seabed – once again simplicity and ease of use was the driving imperative.

- There were other factors which had to be addressed when designing the camera rig:

- The lower hatch is approximately 2.5 metres below the main hatch, and immediately below it was the main access ladder. Provision had to be made for the camera to be manoeuvred through the hatch and clear of the ladder;

- The total drop from the upper hatch to the floor of the battery tank is over 4.5 metres (nineteen feet) – a means had to be developed to enable the camera to be lowered through this range and still rotated;

- Video data was transferred to the surface so that the technical team could review the data 'live'. A means had to be provided to enable instructions to be passed to the dive teams.

- Protection of the video / power cable as it is passed through the conning tower and past 'Bunts' the Conger eel.

The final solution is shown in Figure 31. The camera is a relatively simple PAL colour camera (SeaViewer Sea Drop). The end of the 150 metre-long umbilical was fed through a flexible, stainless steel conduit. The conduit, in turn was fed through a PVC guide tube which incorporated a right-angle bend. The guide tube allowed the camera to be moved in two dimensions anywhere within the 23 inch diameter opening of the upper hatch. This allowed the camera to be aligned with the lower hatch. The conduit allowed the camera to be lowered to any desired position within the submarine, and it also allowed the camera to be rotated by the divers. The locking mechanism for height, and the rotating handle was simply a pair of 'vice grip' pliers locked onto the conduit. These proved to be extremely effective. The conduit also proved effective in protecting the cable from Bunts. At one stage during handover between the dive teams, in which the camera was left in position in the control room, the video image started moving and there was a shower of debris passing the camera lens indicating that the camera was being disturbed by movement in the conning tower. On retrieval of the system scratches were observed on the flexible stainless steel conduit at a level which would have been in the conning tower and within range of being bitten by Bunts.

Figure 31. Showing the general arrangement of the drop camera with Mr Peter Graham DSTO ROV pilot left and Dr Roger Neill Task Overseer.

The camera has inbuilt LED lights, but these were found to generate an unacceptable amount of noise on the video output, so a high-intensity torch was strapped to the base of the camera rig. Two arrangements were tried. Tank tests undertaken in the laboratory prior to departure had indicated that the pencil beam of the standard torch generated an unacceptable spot. The concave reflector was replaced with a flat one and, in tests undertaken at night in a six metre square tank acceptable video imagery was achieved. In the actual deployment it was found that the suspended matter in the water inside AE2 absorbed too much of this diffused light, so the reflector was replaced. The resulting pencil beam of the torch is evident in many of the following images. An alternative lighting rig was developed while the team was in Turkey, but bad weather prevented this from being deployed.

A two-way through-water communications system was used to transfer instructions to the divers and to receive updates from them. This proved to be absolutely essential to the operation. The system failed on the third dive, resulting in a great deal of frustration for the team. On that dive the camera fouled the main ladder. The surface team could see how to clear the problem, but were unable to pass instructions to the divers. Consequently data quality was compromised for that dive.

The following photographs show the divers deploying the camera rig on AE2.

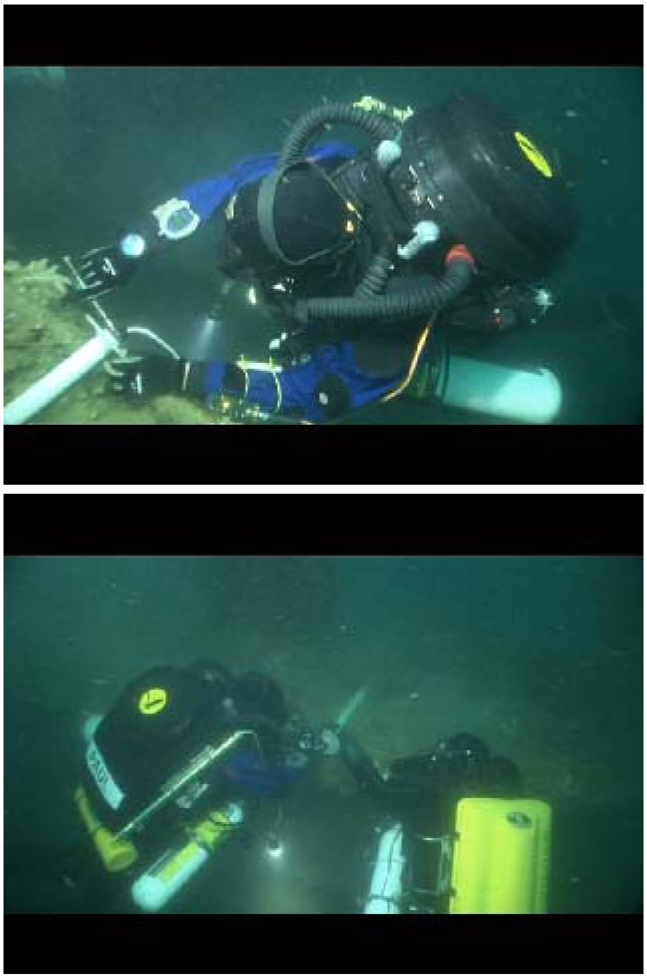

Figure 32. Divers deploying camera on AE2.

Inside the conning tower

The conning tower proved to be a surprising source of a wealth of information. It was a matter of great frustration to the team that the driving imperative of this serial was to get inside the main pressure hull, so only passing attention could be paid to the conning tower. Any return visit *must* include a detailed assessment of the internal state of the conning tower.

The conning tower is constructed out of non-magnetic materials such as bronze, gunmetal and copper. It is generally in excellent condition and had virtually no marine encrustation. The following stills show some of the features of the conning tower.

Figure 33. The first view inside the submarine – the access ladder at aft end of the conning tower.

Figure 34. ‘Bunts’ the conger eel lives inside the submarine.

Figure 35. The aft, portside scuttle is open – a last look before abandoning ship?

Figure 36. Locking lever for upper hatch.

Figure 37. Telegraph in the foreground and the steering wheel in background.

Figure 38. A lagged pipe on the starboard side of the conning tower, shows lagging – presumably asbestos - in excellent state of preservation.

Figure 39. A tantalising, but frustrating view of the steering right angle drive.

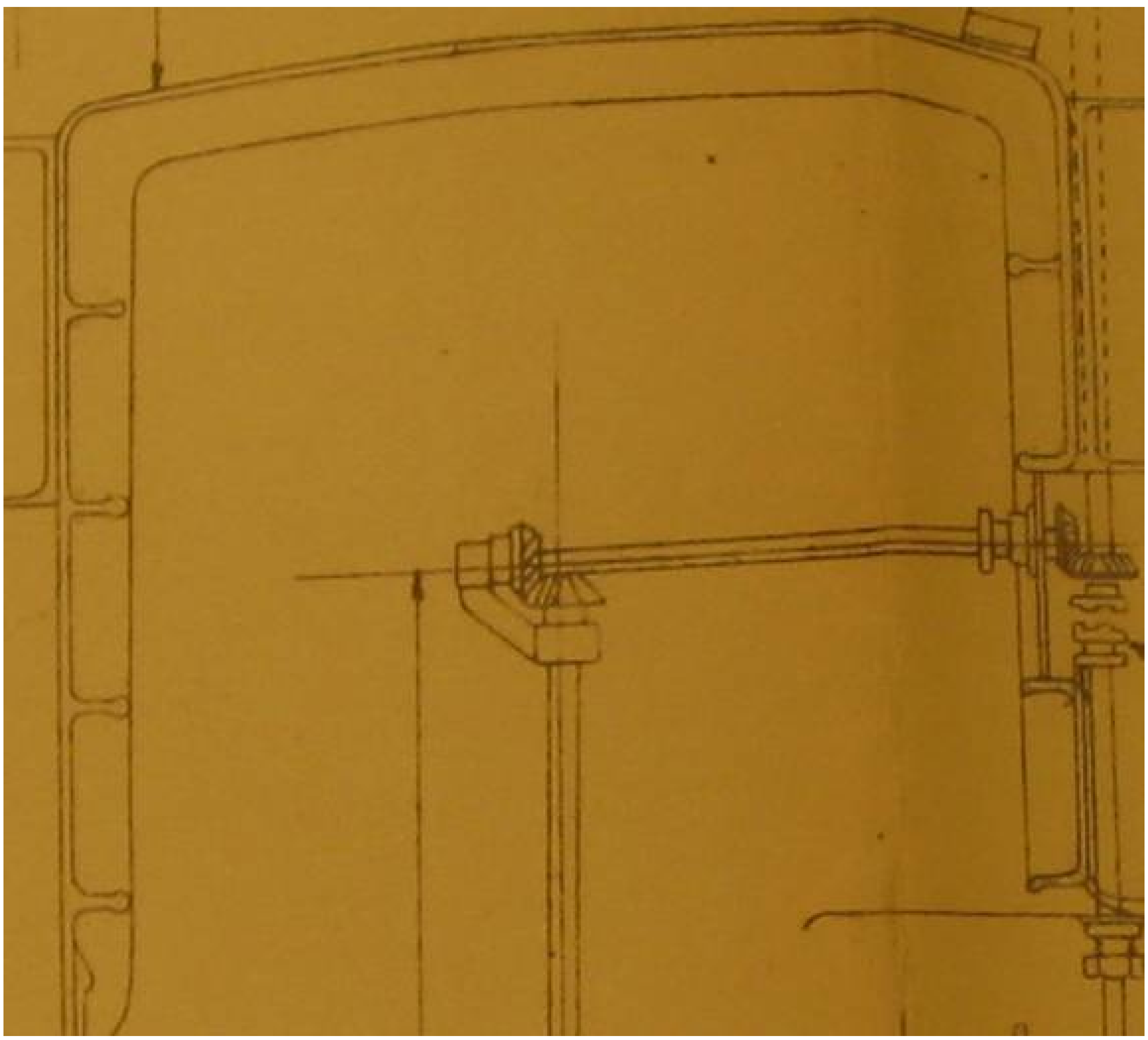

Figure 40. The position and arrangement of the above steering drive train in the conning tower (portside)

The Control Room

Perhaps the most surprising finding of the expedition was that the control room is relatively clear of siltation. There is a pile of material, 30-50 cm high, at the base of the access ladder. Other than that there is very little sedimentary material evident inside the submarine.

Another unexpected finding was that the submarine appears to have its own internal halocline. This had a clearly defined profile and had a distinctive; 'foggy' layer approximately one metre below the top of the hull. As a result of this finding the team developed a plan to insert a dissolved oxygen sensor into the hull, but unfortunately poor weather prevented this being done. An important objective of any subsequent expedition should be to further investigate this phenomenon.

Figure 41. The lower surface of the internal 'halocline' is clearly visible in this image.

The ability of the camera rig to penetrate this fog was somewhat limited, which limited the range of visibility to about two metres. While this significantly restricted the number of objects that could be inspected, a number of items were successfully imaged and a number of conclusions could be drawn. The following are examples of control room objects that were inspected.

Aft Periscope

The aft periscope has dropped at some stage, and its training controller is level with the floor of the battery tank. The training ring is visible, as are the lifting wires. The eyepiece and training handles have dropped into the periscope well. It is of interest that these submarines actually included periscope wells, because it would have been virtually impossible to lower the periscopes that far without unrigging the training mechanism.

High up in the control room the periscope shaft is very clean, and also visible is the limit switch (an automatic cut-off that prevented the periscope being raised too high) and the training gear-train also appears to be visible, although this seems to be heavily corroded.

Very high up in the control room, immediately below the level of the hatch is the topside of the periscope support housing. This appears to carry a fair amount of additional hardware over and above what is shown in the plans.

Figure 42. The aft periscope, showing (top to bottom) views above the support mount, the periscope shaft and the training ring immediately above the eyepiece and training hand*les.*

Steering Engine

The steering engine sits slightly forward of the main hatch opening, and to the port side. It was an electro-mechanical unit which drove a shaft, via a series of universal joints, leading to the tiller flat at the stern of the vessel. There was also a shaft leading through to the upper steering positions in the conning tower, as shown in Figures 39 & 40. The original paint finish of the machinery was white (painted in the 'best oil paint' comprising white lead paint (Vickers Sons and Maxim, 1914). A good indication of the condition of the interior is that there is still white paint visible on the steering engine.

Figure 43. Showing details of the steering engine (a) main shaft (b) main electromechanical unit and (c) mounting and gearbox leading to conning tower. Note the small amount of sediment sitting on the flat surface of this unit.

Possible trunk for the venting ballast tanks or ventilation systems

The ballast tank vent system is something of a mystery, as it is specified in relatively vague manner in the specifications document ('For each compartment of the external main ballast a vent valve of approved pattern, …,is to be fitted as high as possible on the inner hull with a pipe led inside the boat to the highest point, or such other point as may be approved…'(Vickers Sons and Maxim, 1914, Section 59)), and it is not shown on any of the plans to which DSTO has access. Likewise the specification for the ship's ventilation system is vague ('A watertight branch is to be fitted to one of the main (battery tank ventilation system) supply trunks to each battery tank, and is to be taken to such points as may be approved with a view to thoroughly ventilating all compartments of the boat.' (ibid, Section 52). A trunk was visible, high up in the hull on the starboard side, as shown on Figure 44. This appears to have some form of lagging surrounding it and a pair of branches leading down to the starboard side of the boat. The purpose of this trunk has not yet been ascertained, but its position in the boat and its size implies that it would carry air, rather than water.

Figure 44. Detail of an as-yet unidentified trunking system.

Also visible at top left of Figure 44 (c) is the universal joint attached to the shaft which leads through to the telegraph in the conning tower.

Even with the limited range of visibility of the drop camera, many items have been identified and some unknowns have been confirmed. (For example, the early group of E-boats were reported to have a different periscope setup than the later vessels. This has been confirmed). It was not possible to confirm the vexing question regarding the presence or otherwise of a gyro compass on board the submarine. It is apparent that there is much more to be learnt and the overall good state of preservation inside the hull should provide strong justification for re-entering the boat with a more sophisticated visualization system.

Surface-deployed assessment of surrounding seafloor characteristics

It is possible that proposals could be made for the long term management of AE2 which require some form of disturbance to the seabed upon which she lies. It is important to have a good understanding of the physical properties of the seabed to be sure that any disturbance will not have catastrophic effects on the vessel. (The most extreme example would be excavating under the vessel to pass lifting slings, but care would need to be taken even if it was simply proposed to undertake test excavations to confirm the condition of hull under the sediment layer.) One of the test serials involved measurement of the bearing strength of the seabed. To enable the measurements to be taken, the Royal Australian Navy loaned DSTO a Sting MK II Underwater Bearing Strength Probe. This 10.1 kg probe, shown in Figure Forty Five, comprises a faired instrument housing, containing accelerometers and data recording electronics, and a long stainless steel probe rod. At the tip of the rod is installed a 70 mm diameter flat disc. The probed is dropped from a height of approximately 10 metres above the seabed and the disk impacts the seabed. As the probe penetrates the seabed material, it decelerates, and from the rate of deceleration it is possible to calculate the relationship between bearing strength and depth.

The probe is deployed off a surface craft, and is essentially allowed to freefall during the final 5-10 metres of its descent. In this trial the probe was set to begin recording at a depth of 55 metres. Once the probe has been triggered it records continuously for a period of just over 2 minutes. During this interval the probe can be recovered from the seabed several times, as shown in Figure 46, and re-released so that multiple impacts can be recorded. Post processing software then automatically identifies the start and stop times for suggested impact events, which the operator can accept, fine-tune, or reject. From these events a series of impact curves are generated, which can subsequently be averaged.

Figure 45. The Sting Mk II Penetrometer held by Mr Peter Graham [DSTO ROV pilot] centre and Mr Mike Wynd [Diver] right and Mr Ahmet Tacsi [Boat Captain].

Figure 46. Rapid recovery and re-release maximises the number of impacts that can be recorded. Dr Roger Neill DSTO Task Overseer doubles as ROV handler.

The recordings were undertaken on 18th September, 2007. In the event, seven impacts were recorded and the bearing strength data derived from these are shown in Figure 47. The position at which the readings were taken was 50 metres North East of the centre of AE2.

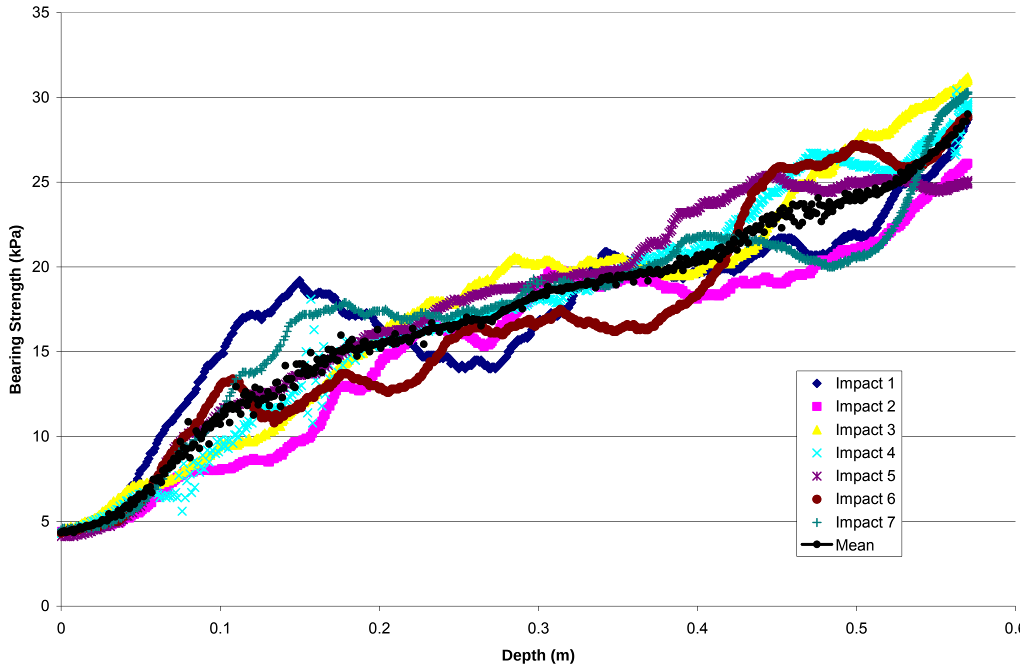

Figure 47. Bearing strength versus depth below the seafloor, 70 mm probe used.

The relationship between bearing strength and depth appears to be quite linear. A linear regression was performed on the mean impact data. This resulted in a slope of 36.5 kPa/m, intercept value of 6.7 kPa and a correlation coefficient (R^2) of 0.96, which is highly significant. With the 70 mm tip maximum penetration was just under 0.6 metres. To confirm the linear trend, the tip was replaced with a nominal 25 mm probe end and the test repeated. This yielded a maximum penetration of 1 metre, and the graph was linear throughout its full range. The bearing strength values derived from this trial are not included because Mulhearn (2002) has warned the 25 mm tip produces measures requiring correction in absolute terms, but he confirms that the trends revealed with the 25 mm tip geometry are very representative. Hence it can be concluded that the seabed is quite uniform up to a depth of at least 1 metre.

The above linear regression equation was used to extrapolate the predicted bearing strength data to a depth of three metres, using 0.1 metre increments. These data were then used to predict the depth of burial for AE2. The consulting naval architect and marine engineer, Mr Michael Rickard-Bell undertook a draught calculation using repeated iterations of increments of 27 waterplane area sections. His predicted depth of burial is 2.7 metres, as shown in Figure 48. The silt-line representation shown in Figure 3 was prepared prior to this analysis being undertaken, but a comparison of the two figures shows there is excellent consistency between the observed level of burial and the prediction. This gives a good level of confidence that, if proposals are raised requiring interference with the underlying seabed, valid assessments can be made of the likely impact such interference will have on the ability of the remaining material to continue supporting AE2 in her present attitude.

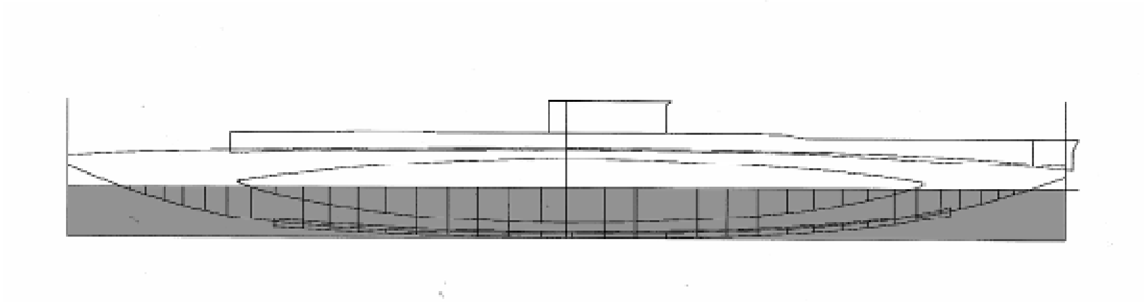

Figure 48. Predicted burial level in silt using bearing strength data. Burial indicated by grey shading.

Conclusions

DSTO agreed to undertake a set of tasks as its contribution to the 2007 maritime archaeological assessment of AE2. It was successful in meeting virtually all of its commitments. From a long list, there were just two deliverables that were not able to be adequately addressed:

- Provide a backup to the diver-based, 2-dimensional photomosaic of the wreck site by overlapping vertically-directed imagery; and
- Generate a graphic rendition of AE2 using a scanning sonar as the source of the imagery.

The backup photomosaic was not generated due to time lost as a result of bad weather. In the case of the sonar-derived mosaic the Micron sonar developed an intermittent fault which rendered it very difficult to use. The fault necessitated the sonar being reset on regular intervals, which imposed significant time delays on operations. Given the time lost due to bad weather, attempt to undertake the sonar-based survey would not have been a viable option. The main conclusions that can be drawn from the DSTO activities were:

The main structural fabric of AE2 appears to be intact. Thickness measurements derived from the ultrasonic gauge raised a number of questions regarding how much residual material remains in the structural elements of the vessel. Despite the uncertainties raised by the thickness measurements, visual inspection of the hull revealed that a significant proportion of the rivets appear to still be firmly in place. The exposed portions of the submarine have suffered considerable damage due to fishing activities. The vessel appears to have very little internal saltation. The ship's machinery, both internal and underlying the (broken) casing, is in a remarkable state of repair. No evidence could be found of battle damage, either incurred during the passage through the Dardanelle straights or during the final encounter. The level of burial of the submarine is consistent with what is predicted as a result of measurements of the bearing strength of the seabed. It is difficult to explain the results of the ultrasonic thickness measurements, but a suggestion has been made by Dr Ian MacLeod to undertake measurements on a wreck located near Melbourne, HMVS

CERBERUS. These measurements will be able to be validated and should enable a model to be developed to explain the readings taken on AE2.

The remarkable state of preservation of the internal structures of AE2, and its relative freedom from siltation, make it an almost unique time capsule dating back to the time of the Gallipoli campaign. The expedition's marine archaeologist, Mr Tim Smith, estimates there are at least 3000 individual items inside the submarine (personal communication). Now is the right time to re-enter the submarine and more comprehensively study her internal state. It would be disastrous to wait until the hull is breached before attempting to do so.

Acknowledgements
The authors wish to acknowledge the kind assistance of Dr Ian MacLeod who has been a technical 'sounding board' regarding many issues, and Mr Michael Rickard-Bell who has also provided a wealth of information regarding the structural details of AE2. The ongoing interest and support of Mr Tim Smith and Dr Mark Spencer are also acknowledged – but for them we would not have been involved in this project.

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AE2: The Silent ANZAC
AE2 Commemorative Foundation

TÜRKİYE SUALTI ARKEOLOJİSİ VAKFI
TINA

APPENDIX F1

Appendix 1 ANNEX F

INITIAL ARCHAEOLOGICAL FINDINGS DROP CAMERA INSPECTION 11SEP07

	Name	Position
Prepared By:	Tim Smith	Maritime Archaeologist

Appendix 1 to ANNEX F - Drop Camera Inspection

Introduction

Entry into the long lost hull of the submarine HMAS AE2 was momentous. This dark enclosed space had not witnessed human visitation for 92 years. The scene was eerie as the camera light penetrated the blackness, only the fine sediments captured in the glare showed any sign of movement. All else was still – a space captured in time, preserved.

Where spray from the conning tower once showered down onto the control room floor and its occupants, now lay a soft carpet of sediment.

This first vision of the space, the nerve centre of the old Australian E-class submarine, has proved invaluable. The Australian-Turkish, Operation Silent ANZAC expedition to document the archaeological wreck site had previously been limited to the external skin of the site. Today, for the first time, an appreciation of the interior could be made – critical to evaluate the likely state of the submarine, its degree of internal corrosion, sedimentation and general appearance.

Figure 1. Interior access ladder within conning tower. Seen for the first time in 92 years.

Drop camera

These are insights that could only be made by seeing the internal hull, a feat made possible by the Defence Science & Technology Organisation (DSTO), Melbourne. A simple yet effective drop camera was devised that would be inserted into the conning tower through the narrow entry point. LCDR Stoker was the last to escape the hatch before the submarine sank under fire on 30 April 1915. When leaving the boat, Stoker appears to have set the hatch in a position to keep it open.

Opening the submarine ballast tanks main vents ensured that AE2 would flood through the conning tower and sink to the depths of the Turkish Sea of Marmara. By setting the hatch in this way, he caused a problem to the expedition divers who have been carefully inspecting the hatch mechanism since the site's first discovery in 1998.

The hatch remained in this position when the submarine settled on the sea bed, leaving only a ten centimetre space in which to glimpse the interior of the conning tower which provided access into the interior. A ladder was visible disappearing tantalisingly into the depths. It was vital that any inspection of the archaeological site did not disturb the important marine coverings and corrosion products that help preserve the buried hull. The site is also protected by the controls of Turkish cultural heritage legislation.

Therefore a camera system was designed that could enter the small opening left by Stoker, but still be manoeuvred down into the hull's interior. Another obstacle was known to the team – a second hatch below which sealed the pressure hull from the conning tower. Its state could not be known until the camera and lights were deployed. If this hatch was shut, the mission would terminate abruptly. The team watched their monitors with steeled anticipation.

Figure 2. An engine telegraph repeater, auxiliary steering wheel and possible voice pipe in upper conning tower.

First glimpse

The first glimpse of the interior walls of the upper section of the conning tower was remarkable. First impressions were how clean the sides were, how still and clear the water. The operations room aboard the survey vessel Detek Salvor resembled Mission Control at NASA as the first film came back from AE2. The archaeological team were exuberant – this had been an expedition dream since the submarine was first found in 1998. Every second of footage as the camera gently lowered revealed new structure and new groans from the team. This detail could never be gleaned from the archival plans and photographs alone. E-class submarines were not well documented in their working life, so today, near pristine sites like the AE2, offer an unparalleled opportunity to see how they were actually formed and fitted out. A true appreciation of the internal spaces could only be obtained through imagery of E-class shipwrecks or through museum replicas. None of which had yet been accomplished.

Last glimpse?

The camera passed down the side of the tower and an object suddenly jumped into view – it was an inspection port, a thick glass window in the wall of the conning tower. The port, or 'scuttle' allowed the crew to peer outside the submarine as it surfaced or descended. One of AE2's ports was open, with the hinged brass 'deadlight' that sealed the window hanging down and unlocked.

Had an officer of the watch last glanced out this port as Stoker barked orders to surface? Able Seaman Edward Knaggs recalled that the First Lieutenant, Lieutenant Geoffrey Haggard, reported on surfacing that the torpedo boat (Sultan Hissar) "*appeared to be making ready to ram*". Was it he who opened the scuttle and failed to close it as AE2 fought to evade capture?

AE2 had been in a hurry – the Turkish gunboat Sultan Hissar had struck the engine room with three 37 mm shells from a deck gun. "*BANG? … A cloud of smoke in the engine room. We were hit and holed*! (Stoker, Straws in the Wind 1925). Any future attempts to dive were fruitless as water poured in through these openings. Stoker ordered all tanks blown and AE2 was forced, unwillingly, back to the surface.

Figure 3. Through the lower hatch and into the control room. Camera captures universal joint in steering rod, as generated in a computer generated view of the control room space.

Ladder to the depths

The upper ladder in the control room now acted as a guide to the camera as it gently lowered further. Teams of heavily-kitted technical divers using rebreather equipment hovered around the outer lid carefully feeding it via voice command from the surface communications team. Four two-person teams would be used through the day-long operation. The diver's squeaky voices returning from seventy-two metres depth were a bi-product of breathing helium at depth.

On passing, the camera revealed more surprises. A cross-brace that does not appear on historic AE2 plans but noted only in later E-class boats; suddenly a coaming, or ledge, was passed. This created immediate excitement as the team glued to the monitors. It could mean only one thing – the lower hatch was open! Access to the internal pressure hull of the submarine was assured if the camera could be guided still further. The divers manipulated the camera through another 360-degree sweep – there it was – the lower hatch resting vertically against the side of the chute, just as Stoker and the crew had passed it in their frantic escape from the doomed submarine.

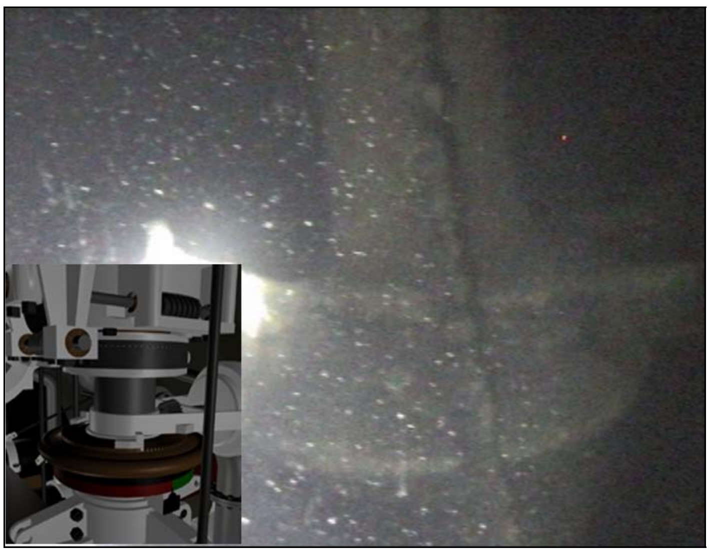

Figure 4. The aft periscope appears from the dark.

This hatch and the upper one had last been opened by Able Seaman William Cheater frantically as AE2 broke surface, still under fire from the approaching Turkish torpedo boat and gun boats. Cheater, an Englishman then thirty-two years old, was the officers' steward who looked after LCDR Stoker.

Still more forms are identified: a telegraph repeater for directing engine settings to the engine room. A possible voice pipe protruding nearby through which crew would have shouted commands above the din of the engines and noise of operations below. Nearby one of the submarine's secondary steering wheels retains its stark circular form and gearing.

Time capsule explored

Now a suspenseful wait as the dive team left the bottom for their two-and-a-half hour ascent, until the next team entered the water for their five minute travel time to the depths. Again the camera was moving, after a new light was attached. Through the hatch and suddenly concern – the camera was caught on some unseen obstruction. Anxious minutes passed as the divers re-positioned the camera's support frame, and then it was off again. The main steering pedestal located in the central floor below the hatch appeared to be the obstruction.

The scene unfolding before the camera was startling – the control room was a 'time capsule'. The camera passed down the lower ladder onto the floor of the room, beneath which lay the main batteries. It was like walking down onto a forgotten stage. The drama that had once unfolded here was palpable.

But all around was darkness punctured only by the camera's stark beam. Here an object came into view, piping and trunking passed fore, aft and across the room, a possible light and its caged fitting appeared, next large wheels that once opened valves were glimpsed.

As the camera turned in its wide arc, objects appeared all around swamping the Project Team far above with unparalleled data. The submarine's aft periscope retracted into its well – the side handles exposed as if ready for use and its guide wires running alongside.

Captain's station

The curved, almost oppressive, roof of the control room was plain and the anticipated mass of intricate machinery clearly visible. Detail was exceptional, nuts and bolts, flanges and piping, all largely unadorned by marine growth or corrosion products. In fact the control room surfaces and fittings were remarkably fresh looking. The much anticipated layer of sediment on the hull floor largely non-existent at this particular point. A gentle mound of fine sediment appeared immediately under the hatch area but appeared to taper off beyond. The prospect of imaging over 90% of the structure of this critical cavity was suddenly realised.

Along the walls lay the rods and universal linkages that once drove the forward hydroplanes that gave the boat lift and diving control. Above hangs a steel box which may have served to house a compass repeater station. But all consuming was the stillness, a silence that gave time for reflection amidst the drama of discovery.

'It's no use stopping here!'

At this point on 30 April 1915 Stoker had ordered all 32 crew, except the officers up these very ladders, through the chute and onto the submarine's casing. Only two other Chief Engine Room Artificers (CERA.) remained below controlling the submarine's surfacing. CERA Stephen Bell, 35-years old and hailing from London, recalled the captain's last words, "C*ome on then, it's no use stopping here*!" The remaining men prepared to scamper up the very ladder now illuminated by the camera's lights. Lieutenant Geoffrey Haggard, another Londoner and second in command, and Irishman Lieutenant John Cary, Third Hand, waited their turn.

Now on the bridge it was Cary's job to yell to Stoker and those still below to escape once the water level outside became critical. "*Hurry Sir, she's going down*! was enough for the last to leave the boat. But Stoker later recalled in *Straws in the Wind*, recalling his private dispatch case which contained some money. He raced back to the wardroom, grabbed it and scrambled hurriedly up through the tower. Twenty-four year-old Petty Officer Henry Kinder from Kogarah in Sydney recalled a slightly different scenario. Kinder wrote in a personal diary that he went back down in the dying minutes and extracted some papers for the captain, for which heroism he was later recognised by the award of a 'Mentioned in Despatches'.

Suspended in time

Imagery of this lower ladder was breathtaking. Its vertical frames and horizontal rungs appeared 'new' and totally unencumbered by marine growth. Fine sediment had instead settled onto the rungs and accumulated in piles. It was an unexpected insight – so still has been the internal flooded cavity of AE2 since 1915. Fine sediment passing through the slightly opened conning tower's upper hatch had gently accreted onto the ladder below. Captured now by film, it represented the stillness of time. More startling was the apparent difference between the interior of AE2 and the external surfaces which have witnessed significant damage from contact with fishing nets, and enhanced corrosion processes. The internal state of AE2 bodes well for quite significant retention of structural elements such as timber cupboards and benches, items of clothing and other organics, and for perhaps a remarkable state of preservation.

Archaeological layers?

In 1915 the scene below had been pandemonium – the submarine was now filled with water and every object that could float was in suspension. Following AE2's previous steep angles and surfacing, all heavy loose objects had previously crashed towards the bow and forward bulkheads. The cook Lionel Churcher was just preparing dinners which "*flew here and there mingling with other various articles*".

The Team's archaeological experts hoped that the first vision into *AE2's* hull would provide a clue to the state of these individual archaeological relics. Presently no confirmed items have been detected, perhaps a result of material being carried further past into the forward section of the submarine's hull. Other items are possibly just buried under the fine sediments that appear to have settled over the internal floor. It is anticipated that further inspection of the control room will reveal evidence of these very personal items.

Conclusion

The unique opportunity to enter the long forgotten recesses of the AE2 was not lost on the SILENT ANZAC team. The drama, excitement and uproar throughout the day-long camera inspection were real. It was always anticipated that the opportunity to view this personal space would be special. It was also understood that the operation had to be conducted scientifically and with proper archaeological controls, and within the terms of the expedition's Turkish Archaeological Work Permit approvals. No physical disturbance was made to the submarine's structure or protective corrosion products. The only impact was on the serenity of "Bunts' the Conger Eel who had made AE2 his home, and seemed nonplussed with the lights and intrusion. As he swam past, a light puff of sediment temporarily shielded the camera's view – perhaps a passing gesture. AE2's crew had left this boat and its spaces but now their presence could once again be felt through the blackness of the hull – a space in which they had lived and breathed for thirteen months since the vessel's commissioning in England.

Future archaeological goals

The drop camera deployment had several aims:

- to image the internal space of the submarine to appreciate its layout and form
- to identify key components an fittings
- to examine the level of sediment that may have entered the hull with impact on preservation of internal components and relics
- to determine the physical condition of the inside of AE2 and to identify probable structural condition
- to gather graphic imagery of the internal spaces of AE2 for interpretation and public education uses.

The September 2007 inspection of AE2 had several constraints: the short survey period available, diver support limits due to water depths, the limitations of the semi-closed upper conning tower hatch, restricting access to a single drop camera, limited lighting capability and therefore restricted arc of view. The dramatic vision gained from this deployment however has identified the potential for additional planned surveys.

The visual inspection has enabled for the first time a considered interpretation of the internal complexity of the submarine, its probable conservation status, and the ability to accurately document key features, including possible relic scatters. This data has led to a re-evaluation of survey priorities. It is now considered that the next team will seek to:

- initiate a second repeat drop camera deployment with greater lighting capacity;
- deploy the environmental corrosion meter into the conning tower space to assess quality;
- consider the possibility of deploying a ROV further into AE2 to extend the survey.

Additional imagery planned

To enable additional data collection, a planned further inspection will be made with an enhanced drop camera system. The deployment of an ROV will be considered pending an assessment of the condition of the upper hatch and its ability to be opened sufficiently without compromising the integrity of the hatch and stabilised marine concretions that act to preserve the hatch. ROV deployment would enable far greater lighting capabilities and the potential to traverse the inner reaches of the hull beyond the central control room. This has been a survey priority of the SILENT ANZAC expedition and a sophisticated three-dimensional computer generated image of the interior spaces has been completed by the DSTO project team for this purpose.

Environmental sampling

The current inspection has identified the nature of the ambient water state within the control room. Current indications are that the internal space is largely devoid of any water movement or destabilisation, increasing the potential for the physical remains to have retained significant form. A future task will include a water quality analysis via deployment of a water quality instrument. This will allow the internal water temperature, salinity and level of dissolved oxygen to be analysed and to see if the internal water analysis differs from the external water. The data will assist the predictive analysis of the corrosion state of the steel and other dissimilar metals contained in the submarine hull, fixtures and fittings.

The drop camera vision provided another unique insight – an apparent halocline, or level of different water density within the confined space. This could indicate a more complex localised environment than previously anticipated, with potential to assist different corrosion contexts within the hull.

ANNEX G
STRUCTURAL ANALYSIS

	Name	Position
Prepared By:	Michael Rikard-Bell	Naval Architecture & Engineering Adviser
Reviewed By:	Lance Marshall	SKM Naval Architect
Authorised By:	Terence Roach	Director of Operations

ANNEX G – STRUCTURAL ANALYSIS

Background

The writer of this section of the report of the findings of the Maritime Architectural Assessment (MAA) joined the AE2 project in early 2006 and subsequently attended the MAA in Turkey in September 2007. Prior to the MAA, the writer had investigated the risk of structural damage to the AE2 associated with a broad range of options for its future management. The range of these management options initially extended from preservation in situ to lifting the 92 year old relic from a depth of 73m for transfer ashore to a dedicated display site.

A theoretical analysis of structural damage associated with the option of preservation in situ due to corrosion and/or damage due to fishing or other similar operations was not included. Subsequent discussions with both conservators and with fellow ex-submariner acquaintances involved in similar submarine projects worldwide have been most useful in defining the practical difficulties associated with the removal of the submarine from the water and its subsequent preservation. Consequently, the option of the relocation of the wreck to a secure shallow water site close to facilities enabling 'in water' conservation and providing easier access for conservators and archaeologists was added.

The option of relocation would be a natural precursor to any effort to remove the submarine from the water as it would then enable a more detailed structural inspection than that which could be achieved by divers at a depth of 73 m. Accordingly, the investigation of the risk of associated structural damage associated with management options was focussed on:

- Relocation to a secure shallow water site as described above, and
- Lifting the submarine for transport ashore to a dedicated display site.

Preliminary Investigation prior to the MAA

This report discusses a Structural Analysis and the assessment of the ability of the hull to withstand forces associated with either relocating the submarine or lifting it from the water for transport ashore.

Preliminary Structural Analysis

The first stage of the structural analysis involved the preparation of a computer based 3-dimensional surface model of the hull, conning tower and ballast tanks to enable subsequent calculations in relation to longitudinal strength. The original model was prepared using hull shape dimensions derived from several sources. Unfortunately, each set of hull shape dimensions proved to be incorrect when the surface models were 'floated' and the resulting hydrostatic data compared with the trial data of AE1&2. Mr Tim Smith, the Director of Archaeology, was eventually able to source the original dimensional data from the lofting floor from which the hull frames were developed. The final model was developed from these dimensions and the resulting hydrostatic data now matches the original trial data.

Estimated structural weights and weights of machinery and equipment were then superimposed on the model which was then subjected to a ‘grounding’ analysis to simulate the lifting of the hull using two sets of slings. The decision to use two sets of slings as the ‘worst case scenario’ for the ‘grounding’ analysis was made after discussions with divers from the first expedition to AE2 in 1998 who remarked on the extremely soft nature of the bottom and the fact that the ‘ends’ of the submarine were basically clear of the silt.

This analysis demonstrated that the theoretical shear stresses in the pressure hull due to lifting the hull from the bottom in the ‘as built’ condition were significantly less than acceptable levels in the same condition when the submarine was lifted clear of the water. This analysis assumed that the interior of the submarine would be emptied of water prior to lifting however all internal tanks were assumed to be full.

The contribution to hull girder strength from both the ballast tanks and the superstructure were ignored in this analysis. It did however identify areas of localised maximum stresses and/or structural discontinuity; from which 16 sites were identified for the subsequent measurement of the thickness of pressure hull and ballast tank plating as part of the MAA. The location of these measurement sites was subsequently revised after it had been established that the warhead of an unexpended torpedo on board could be in a highly explosive state. The final locations were as depicted in Figure 1 at Appendix 1. The actual reading locations differ from these (see below).

Structural Measurements at the MAA

Thickness measurement methodology. A Cygnus Multiple Echo Ultrasonic Digital Thickness Gauge was chosen for the measurement of plating thickness. The unit was tested during the training exercise conducted prior to the MAA. Two of the divers nominated for the MAA became quite proficient in the use of the hand held instrument that required the orientation of the transducer be rotated until a steady reading was registered. The divers were also advised of the thickness readings likely to be registered at each of the nominated sites. Sites on both the pressure hull and the ballast tanks were specified as shown in Figure 1 at Appendix 1. A similar unit was fitted to the ROV and this was also tested prior to the MAA. The thickness gauge functions by identifying the successive reflections from the near and remote surfaces of the base metal layer, and calculating the thickness from the average transmission time of the acoustic signals through the metal.

Thickness Measurement Results

The number of readings taken with the hand held instrument was restricted to 6 because of the lack of visibility and the reduction of dive serials allocated to this task. The divers found it extremely difficult to get steady readings due to the presence of both silt and a layer of extremely tough concretion. Only two of these readings were taken on the previously specified sites on the ballast tank and the remaining four taken on the vertical side of the casing. No readings were taken on the pressure hull. The readings on the ballast tank averaged 10.7mm in an area in way of frame #27 where the only possible combination of frame and plating would be 9.6mm. The readings on the casing plating averaged 4.8mm in an area where the nominated plating thickness was 3.1mm.

Interpretation of Thickness Measurements

The interpretation of the measurements taken with the hand held instrument was considered in conjunction with those readings taken by the unit mounted on the ROV. All readings were consistently higher than had been expected. It was fortuitous that a documentary team diver recovered a piece of concretion from the vicinity of the submarine. With the approval of the Turkish Liaison officer the dimensions of the specimen were noted as well as ultrasonic thickness readings. The specimen was irregular in shape and measured approximately 13mm at its thickest point while the Cygnus unit only recorded approximately 6mm at the same point. The conclusion reached was that the Cygnus units were measuring the total thickness of plate plus concretion and that any reliance on these readings in relation to actual steel thickness would be invalid. The interpretation of the measurements taken with the hand held instrument was considered in conjunction with those readings taken by the unit mounted on the ROV. All readings were consistently higher than had been expected.

Analysis of Calculated Hull Thicknesses Subsequent to the MAA

This analysis repeated that undertaken prior to the MAA with the pressure hull thickness of 11.8 mm reduced by a corrosion rate of 0.03mm/annum based on the observation that the forward casing of 3.1mm plate at least was in a fully corroded condition with only concretion remaining. Note that this latter assessment was made on the basis that the generally brittle mode of failure evident from the excellent ROV video footage was not typical of steel plate failure regardless of its thickness. This analysis assumed that the reduction in pressure hull plate thickness would be at the same rate and would be uniform throughout with no concession being made for those parts of the pressure hull below the silt line whose condition could reasonably be assumed to be better than those above.

A Cygnus Multiple Echo Ultrasonic Digital Thickness Gauge was chosen for the measurement of plating thickness. The thickness gauge functions by identifying the successive reflections from the near and remote surfaces of the base metal layer, and calculating the thickness from the average transmission time of the acoustic signals through the metal. The unit was tested during the training exercise conducted prior to the MAA. Two of the divers nominated for the MAA became quite proficient in the use of the hand held instrument that required the orientation of the transducer be rotated until a steady reading was registered. The divers were also advised of the thickness readings likely to be registered at each of the nominated sites. Sites on both the pressure hull and the ballast tanks were specified as shown in Figure 1 at Appendix 1

Structural Analysis of Stresses Imposed by Lifting Subsequent to the MAA

Structural analyses of the stresses imposed by lifting on the pressure hull of reduced thickness were then carried out to assess the global as opposed to the local strength:

- Due to lifting the fully flooded hull clear of the bottom, or

- Due to lifting the hull clear of the water with the interior of the hull empty but with all internal and external tanks flooded.

The latter condition was believed to be realistic as there are tanks that might not be able to be emptied before the lifting operation commenced. This analysis also assumed in both conditions that the hull was still only being lifted with two sets of slings.

The results indicated that the difference in global stresses imposed on the hull when being lifted clear of the water were 50% higher than those imposed when only lifting the hull clear of the bottom. A further analysis convincingly demonstrated that any attempt to lift the fully flooded hull from the water could result in the failure of the hull girder unless the hull was to be fully supported throughout its length.[2]

Analysis of Penetrometer Testing of the Bottom

A prediction of the burial depth of the hull in the bottom sediment was carried out using the bearing strength data provided by DSTO from the Sting Mk II Underwater Bearing Strength Probe using repeated iterations of 27 water-plane areas. This prediction of a burial depth of 2.7m was remarkably close to the actual burial depth of the submarine. It could also indicate that the submarine is not resting on a 'hard' layer and that it is totally 'floating' in the silt. The prediction also validates the decision to use only two sets of slings at the 'ends' of the submarine as previously described in the Preliminary Structural Analysis above.
The potentially unstable state of the submarine also imposes a requirement on the equipment used for lifting including the following capabilities:

- Separate pairs of ganged captive wire winches on each set of slings,
- Winches capable of operating either in a self tensioning or adjustable tension mode, and
- Centralised controls with independent 'read outs' of wire tension and length of wire streamed.

The lifting vessel would have to be moored directly over the submarine with the moorings configured such that the position of the lifting vessel can be adjusted.

Review of the ROV Video Footage

The major achievement of the MAA in terms of data collection has been the incredible range of footage provided by the DSTO team using the ROV video camera as discussed in the excellent Report of ROV Operations (Annex F). The thickness readings using the Cygnus instrument attached to the ROV have also been of value.

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[2]The analogy of the bucket on a string may be of assistance in understanding the above results viz

- The weight of the bucket full of water when fully immersed = the weight of the bucket in air less the weight of water displaced by the bucket
- The weight of the bucket full of water when lifted clear of the surface = the weight of the bucket in air plus the weight of the contents of the bucket.

Suitability of the AE2 to be lifted from its present site

The calculations made so far as a part of the structural investigation, support the notion that the AE2 is "lift able" for movement to a new underwater site. These calculations have been based on a number of assumptions including, most notably, that the corrosion of the pressure hull has led to a 25% reduction in the metal thickness uniformly across all pressure hull surfaces. These calculations also excluded any contribution to the strength of the pressure hull by either the ballast tanks or the cast iron ballast keel. Unfortunately the MAA was unable to obtain any thickness measurements of the pressure hull; however, the damage caused during the shot line incident did reveal plating and riveting under the concretion which appeared to show that the pressure hull's structural integrity has been retained. Before lifting further investigation will be required including:

- Accurate thickness measurements made of the pressure hull, particularly in those areas close to holes and structural discontinuities, such as the structure close to the 'midship torpedo tubes where stress concentrations are likely to occur.
- Assessment made of the pressure hull and saddle ballast tank structure in way of the lifting slings as these areas stand to be damaged by the slings as the AE2's hull is lifted.
- Estimation of the force required to break the AE2 free from the silt.
- Penetrometer tests will be required to confirm as opposed to predict if the boat is actually 'floating' on silt that can be 'blown' clear after the forward and aft lifting slings have been rigged.
- Determination of the material properties of the pressure hull's steel (Presently assumed to be mild steel with a yield stress of 230 MPa yet some sources have indicated that a "special steel" was used which had a higher yield stress.
- Investigation into whether the corrosion rate will be accelerated when the AE2 is moved to shallower water with higher oxygen content.
- Investigation in to any requirements for modification to the proposed Impressed Current Cathodic Protection System in view of increased oxygen and reduced salinity in the shallower water.
- Location and extent of trapped water deleted and liquids added.
- Extent of corrosion following the period of holding the AE2 in shallow water with higher oxygen content.
- Extent and location of any damage or corrosion wastage presently hidden by silt

Conclusion

Careful review of the ROV video footage and underwater photography show that the visible ballast tank and pressure hull plating is basically intact. The condition of the ballast tank plating and fastenings revealed following the inadvertent exposure of the hull as a result of the impact of the shot line weight leads to the conclusion that the submarine is capable of being lifted from the bottom and being moved to a shallow water location. It is also concluded that the submarine should not be lifted clear of the water during the lifting and moving operation without further data gathering and analysis as discussed earlier.

Relocation of the submarine to a secure shallow water location within the Sea of Marmara would permit commencement of the in water conservation process due to the significant reduction in salinity likely in the shallower water of a depth of less than 20m as reported in the report of the Conservation Assessment of the Microenvironment of AE2 (Annex E). Relocation would also provide ample opportunity for the conduct of a more comprehensive investigation of suitable management options for the ongoing preservation of the submarine. This could include an option whereby the submarine would be on submerged display.

Qualifications

The above conclusion is qualified by the prior requirement to render safe the warhead of the unexpended torpedo. The above conclusion is also qualified by the requirement for a highly specialised vessel for the lifting of the submarine in view of the extremely low bearing pressure of the silt in which the submarine is now virtually ‘floating’ and the need to be able to either adjust or regulate lifting sling warp tensions.

Acknowledgements

The writer acknowledges the valued advice received during the proceedings prior to the compilation of this report from both Dr Ian MacLeod of the WA Museum and Mr Paul Mardikian, the Conservator of the HUNLEY project in South Carolina, USA. This report would not have been possible to compile without the enthusiastic support of our Archaeological Director, Mr Tim Smith and the naval architectural support and valued advice of Lance Marshall and John Manning of Sinclair Knight Merz and Dr Stuart Cannon of the DSTO. Finally, I acknowledge the highly professional participation and support of both the Senior Defence Scientist Dr Roger Neill and his highly competent Assistant Scientist and ROV pilot Mr Peter Graham.

Michael Rikard-Bell CEng, CMarEng, FIMarEST, FRINA

Appendix 1 to ANNEX G - Sample Sites

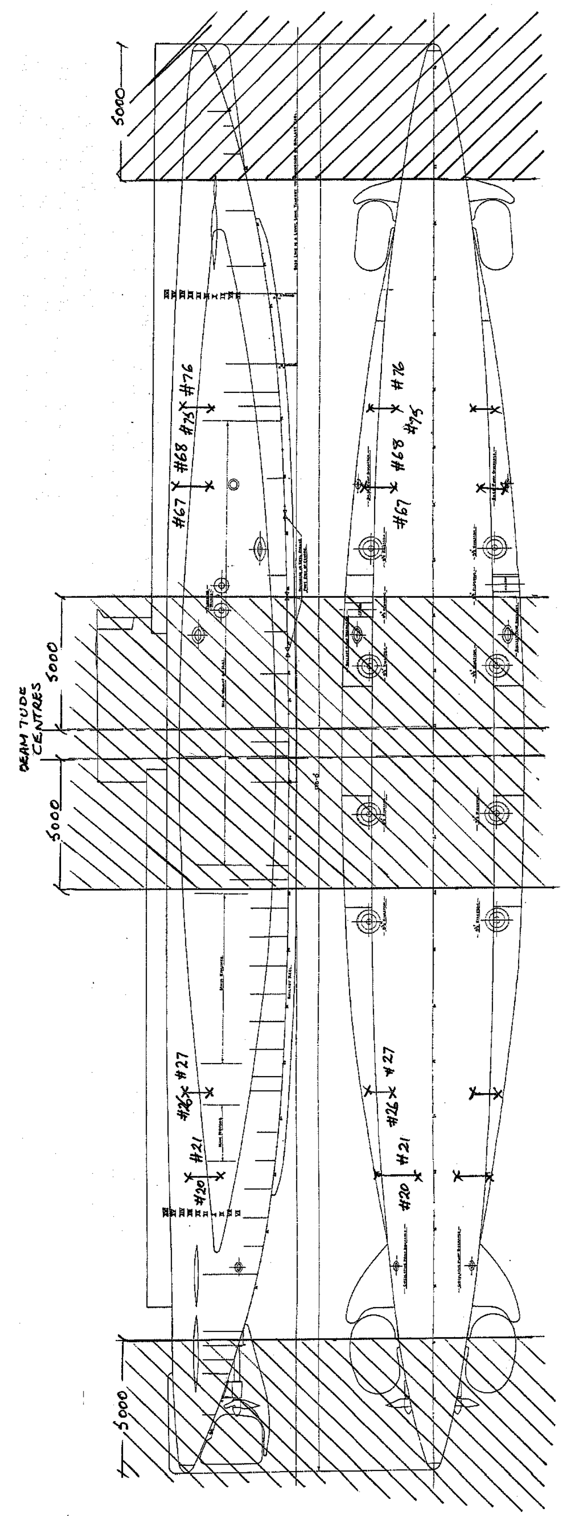

Figure 1 Measurement Points

Notes: 1. Thickness measurements were unable to be made at these locations.

2. Cross hatched areas indicate explosive risk areas which were avoided.

ANNEX H

ANNEX H AN UPDATE TO THE SUMMARY OF THE RISK TO FUTURE OPERATIONS ASSOCIATED WITH THE UNEXPENDED TORPEDO IN HMAS AE2

	Name	Position
Prepared By:	Roger Turner	Torpedo Risk & MoD UK Liaison
Reviewed By:	Ken Greig	Project Manager
Authorised By:	Terence Roach	Director of Operations

ANNEX H - UPDATE TO THE RISK – UNEXPLODED TORPEDO

Preamble

A paper summarising the risks to a dived survey associated with the torpedo believed to be remaining aboard HMAS AE2 was produced in advance of conducting a Marine Archaeological Assessment on the wreck in September 2007[3]. The aim of that paper was to bring together the knowledge associated with the remaining torpedo in order that the risks to the MAA could be minimised. That paper concluded that:

- There is a torpedo on board (99%)
- It is in the stern tube (95%), bow tube (2%), stern rack (2%) bow rack (1%), midships tubes (less than 1%)
- The possibility that a low energy event in the vicinity of the warhead could stimulate a detonation is too great to be ignored.
- Such detonation would be catastrophic.

Further, the paper recommended that the MAA plans be subjected to scrutiny to ensure that:

- No planned event includes
- any high energy event anywhere on the hull and
- no low energy event within 5m of any of the torpedo tubes.

No single unplanned occurrence could lead to the low energy disturbing event needed to detonate the warhead or one of its components. These conclusions are offered for scrutiny to all participants of the MAA and to such external authorities as the project considers appropriate.

The MAA has concluded with much knowledge gained from the experience. It is now the intention to combine that knowledge in order to scope in full the options for the future of the wreck. These options will range from “do nothing’, through “preserve and protect in situ” to “raise and land to form part of a shore side museum”. In any such event, the presence of the torpedo will affect how those options could be pursued. It is the purpose of this paper to use the experience of the MAA to update the risk which the torpedo may pose to the options being scoped for the wreck of the AE2.

Aim

It is the aim of this paper to update the knowledge associated with the remaining AE2 torpedo in order that appropriate action can be taken to mitigate the risk and minimise the possibility of an unplanned event occurring as a consequence of any of the options being scoped for the future of the wreck.

The MAA

The MAA was conducted with knowledge of the torpedo and all activity was planned and undertaken following the recommendations noted above. The exception to this was the

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[3] A Summary of the Risk to a Dived Survey Associated with the Torpedo remaining aboard HMAS AE2 by Capt Roger Turner BSc CEng FIMarEST RN rtd dated 21 June 2007

‘Shot-Line Weight’ incident described below. The evidence gathered during the MAA allows a number of conclusions to be drawn as follows.

State of preservation

The MAA made extensive video recordings of the hull (including some from within the conning tower). It gathered concretion samples and took ultra-sonic thickness readings of the hull. The findings are examined in great detail by Dr Macleod in[4] Annex E which describes the environment and draws conclusions with regards the effect this has had on corrosion rates. It concludes that the environment is surprisingly benign and hence the wreck is in remarkably good condition. The visual evidence supports this and it can be seen that, for example, bronze worm and gear wheels in the bow-tube operating gear retain their original shape with very little marine growth or encrustation. Similarly, the bronze fittings seen immediately inside the conning tower are well preserved with little corrosion or loss of shape. Dr Macleod concludes that the non-ferrous fittings have developed a “thin, adherent white calcareous concretion” which assists in their preservation.

Following the earlier assumption that the torpedo is most probably (95%) in the stern tube we can assume that it is enjoying an environment which is still more benign than that of the open submarine. If the tube were dry at the time the AE2 was scuttled, it is quite possible that it is still dry. If the tube were wet, there being no flow, the oxygen would have long been depleted and the corrosion rates slowed or even halted. While it is difficult to quantify this we can conclude that if the non-ferrous fittings in the hull are well preserved, those in the tube will be still better preserved.

The warhead casing or shell is of phosphor-bronze. The firing pistol is of gunmetal. Whilst it is difficult to assess all the options for corrosion paths within these components we can conclude that the probability of the metal having deteriorated sufficiently to allow the free passage of sea water into the warhead such as to cause the gun cotton to have become innocuous slurry is low.

On this basis we must re-examine the affect of time on gun-cotton which has been left undisturbed for over 90 years.

Time and Gun Cotton

The affect of time on the explosive material has been summed thus - ‘Guncotton of this type and vintage was probably Lyddite based. This was a 'dirty' explosive and the cotton was a carrying medium for a picrate based chemical. This is fairly unpleasant stuff in that it becomes unstable with time especially in proximity to metals. If some moisture has

[4] Conservation assessment of the microenvironment of AE2 Oceanography and site assessment of the wreck in the Sea of Marmara, November 2007, Dr Ian D. MacLeod Executive Director Collections Management and Conservation,Western Australian Museum

penetrated the head it will tend to dissolve the picrates and the inherent acidity of the medium will lead to corrosion of the surrounding metal'[5].

As the gun cotton was kept wetted (25lbs of water to the 200lbs of guncotton) there would be sufficient medium for the migration to have occurred and picrates to have formed. While there is a possibility that the warhead is unarmed and stable, the evidence drawn from the MAA indicates that the probability that it has become unstable and that detonation could be caused by a low energy event is greater than we assumed prior to the MAA.

That argument can be quantified using the risk tree developed prior to the MAA. The probabilities assigned in this exercise are somewhat arbitrary and very much open to discussion. However, amending the wet/dry probabilities by an order of magnitude leads to a risk conclusion as shown in Appendix 1. This demonstrates that the probability of an unplanned detonation has risen from 2% to 16%. Admittedly there is considerable supposition involved in reaching this conclusion but it serves to reinforce the previous position that:

- The possibility of occurrence of a low probability, high consequence event cannot be ignored.

Unplanned blows to the hull

While this same risk was very much in mind in the planning and conduct of the MAA, regrettably there was one unplanned occurrence which fell outside of the planned operating limits. On that occasion, the Diving Support Vessel dragged its moorings in unexpectedly heavy weather. This would not have been of concern to the wreck except that the divers' shot line weight (comprising a 2 tonnes concrete block and secured to the DSV) was dragged across the wreck. The divers subsequently observed that the block had passed up the port side of the wreck just aft of the fin and then fallen clear of the starboard side. It had caused some damage to the wreck in the form of a number of 2-3cm dents in the casing which had caused up to five rivets to spring and scraped the metal clean of marine growth. This description is included principally to allow an assessment of the effect the impact may have had on the torpedo.

It is hard to quantify the strength of the blows. The pitching motion of the DSV would have caused the clump to move mostly in the vertical plane thus the blows to the wreck would have been largely oblique. It is probable, however that blows of significant energy would have occurred on at least one occasion sufficient to cause the dent.

How much of that energy would have been transmitted to a torpedo resting in the stern or bow tubes is again difficult to estimate. The distance from the damaged area to the stern

[5] Conservation and Corrosion Issues on AE2: Assessment of water penetration into the unspent torpedo and risks associated with underwater activity during the Maritime Archaeological Assessment Phase, Ian D. MacLeod, Western Australian Museum (22 March 07)

tube is approximately 18m; to the forward tube 26m and the midships tubes, 4m. These distances are not great but the critical issue is how much energy would have been transmitted. The transmission path is likely to be broken up by the reduced integrity of the riveted hull structure. The damping effect of the hull in the silt would also reduce the energy transmitted. Certainly the energy of the impulse would have been significantly less at the bow and stern than amidships. We can also conclude that such a blow if applied in close proximity to an unstable explosive could have caused detonation. That it did not might lead us to conclude that either the torpedo is not in either of the midships tubes or that it is stable. While of academic interest, this conclusion does not assist in mitigating the risk to any future operations.

It is more prudent to conclude that although the impulse did not cause a detonation on that occasion it cannot be assumed that a similar impulse will not cause a detonation in the future. Suffice to say that it should not be repeated.

Other hull damage

The video footage shows that extensive damage has occurred to the forward casing. The damage is consistent with the possibility that the port towing bridle has been snagged and considerable force applied sufficient to tear the bridle from its hawse-hole and to remove a 2-3m section of casing. The extent of the marine growth in the damaged area would suggest that the damage occurred some years ago. There was no evidence of the damage at the time of the initial 1998 survey. Hence we might conclude that this event took place between 2 and 9 years old.

The force which would have been required to do this would have to be excessive and the resultant impulse to the hull (and the torpedo) would be some orders of magnitude greater than that inflicted by the shot line weight incident. Again that it did not cause a detonation of the torpedo is fortunate but does not allow us to rule out the possibility that a similar impulse would now cause a detonation.

Future Options

A range of six options has been identified for the future of the AE2[6]. Of these Options 1 and 2 involve limited interference with the wreck. The detailed planning will need to be mindful of the basic requirement to avoid impulse to the wreck with no operations to take place within 5 metres of the tubes.

Options 3 to 5 all involve interfering with the hull with, in each case, an intention to conduct an internal survey, prepare the hull for lifting and then lifting the hull for the purpose of relocation to a permanent, either wet or dry, berth. Clearly even the preparation for any of these options will involve contact with the hull with the inevitability of certainly low and probably high energy impulses being administered. The outcome of not neutralising the torpedo risk would at best case be nothing, with the option of recovering the torpedo itself

[6] AE2 Future Options Matrix V3 dated 17 Dec, AE2 Foundation, Capt Ken Greig RAN

from the wreck once it has been lifted. However, we have above established that there is a 16% chance that a low energy event will cause a detonation of the warhead and with that a certain loss of the wreck and a probable loss of life. This outcome is not acceptable hence we are obliged to eliminate fully the risk from the torpedo prior to embarking on any of Options 3 to 5.

Eliminating the Risk from the Torpedo

The options for eliminating the risk of an unplanned detonation of the torpedo are either its removal or flooding. Removal of the torpedo is not a practical option whereas flooding the warhead would render the gun cotton charge inert.

The torpedo is probably in a tube behind an outer door and a sluice valve with a top-stop latching device to prevent its movement. It is unrealistic to think that these could be operated sufficient to remove the torpedo. The doors could probably be cut but it is hard to visualise removing the top-stop without major surgery which is likely to introduce the trauma which this operation is intended to avoid. However, having said that, the option should not be ruled out until the torpedo has been positively located and its condition verified.

Assuming that the torpedo is in the stern tube, this could be achieved by trepanning through the starboard pressure hull at a point some 3.8 m forward of the stern tube outer door apex and some 0.31m above the (horizontal) after planes. This would give access between frames 5 and 6 to the side of the stern tube. Trepanning through the stern tube itself would then give access to the warhead. Drilling through the warhead shell would expose the gun cotton to sea water. Drilling a second hole would allow water to be sucked through the warhead and thus flush out the gun cotton charge or render it inert.

Clearly this is an extremely hazardous operation which will require extensive planning and exposure for critical scrutiny to all the expertise that can be identified. For execution it will require expertise and technology which is well outside the immediate grasp of the AE2 Foundation. To pursue this option, will require identification of advice first to scope fully the practicalities of the proposed operation together with the associated hazards and then form a plan which also mitigates the risks at each stage.

While the plan should focus firstly on the stern tube there exists the possibility that the torpedo is in the bow tube or one of the reload racks. Prior to commencing the operation, arrangements should be made to conduct an internal survey to eliminate the possibility of the torpedo being in the reload racks. A contingency plan should also be in place to conduct a similar operation to enter the bow tube between frames 93 and 94 on the starboard side.

Should the torpedo not be found in either of these tubes or the reload racks it must then be in the midships tubes or no longer on board. The probability of these options is low but to be certain a contingency for drilling into the midships tubes should be developed. The most practical way to attempt this will be to drill through the outer doors and then through the sluice valves. This can expect to meet complications and will require careful planning.

Whilst at this stage the routes into each tube has been identified as being the most likely lines of approach, it should not be assumed that they are without other impediment (eg internal stowage racks, hull stiffeners, etc) and should be subjected to full scrutiny prior to firming the plan.

Primer

The torpedo primer comprises 7oz (200gm) gun cotton which could still detonate if impacted/shocked. Configured as it is the possibility of an unstable detonation is low. This probability is reduced further if the primer has become wet. From this it is concluded that the primer does not present a hazard once the main charge has been neutralised. This assumption should be scrutinised by an appropriate explosives expert before it is accepted.

Detonator

The detonator comprises 77 grains (5gm) of fulminate of mercury located in a closed copper tube. It is possible that this could still detonate if impacted. The consequence of this event is reduced significantly if the main charge has been neutralised. However, the possibility of the detonator causing detonation of the primer should not be overlooked. The outcome of this event should be considered in greater detail in conjunction with planning for neutralising the main charge.

Conclusions

It is concluded that:

- The torpedo presents a risk to any of the Options currently being planned for the AE2.
- The extent of that risk should as a consequence of the MAA findings be considered as being in the order of 16% chance that an energy event to the AE2 will lead to a > 95% chance of catastrophic detonation of the torpedo main charge.
- The impact caused by the shot-line weight does not allow that risk to be lowered.
- The risk to Options 1 and 2 can be managed by taking due precautions to avoid energy events on the wreck.
- The risk to Options 3 to 5 can only be mitigated by neutralising any risk that the torpedo main charge will detonate.
- The only practical option identified for neutralising the main charge is to drill into the warhead and flush the gun cotton.
- That operation is extremely hazardous and should not be attempted without having explored all other options and completing due planning.
- The plan for drilling into the warhead should also include a plan to survey the submarine internally to eliminate the possibility of the torpedo being in the reload racks.
- The plan for drilling into the warhead should include a contingency for drilling the bow tube for the event that the torpedo is found not to be in the stern tube.

- A further contingency should be considered for the event that the torpedo is found not to be in either the stern or bow tubes.
- All of these plans should be subjected to scrutiny by as many experts as can be identified. These should at a minimum include:
    - Representatives of the ADF
    - Representatives of the Turkish Naval Staff
    - Representatives of other allied nations if possible.

Recommendations

It is recommended that the conclusions of this paper be considered in depth to develop a step by step plan for eliminating the risk from the torpedo commensurate with the Options to be pursued for the AE2's future.

Capt Roger Turner BSc CEng FIMarEST RN Rtd
20 December 2007

Appendix 1 to ANNEX H - Risk Tree

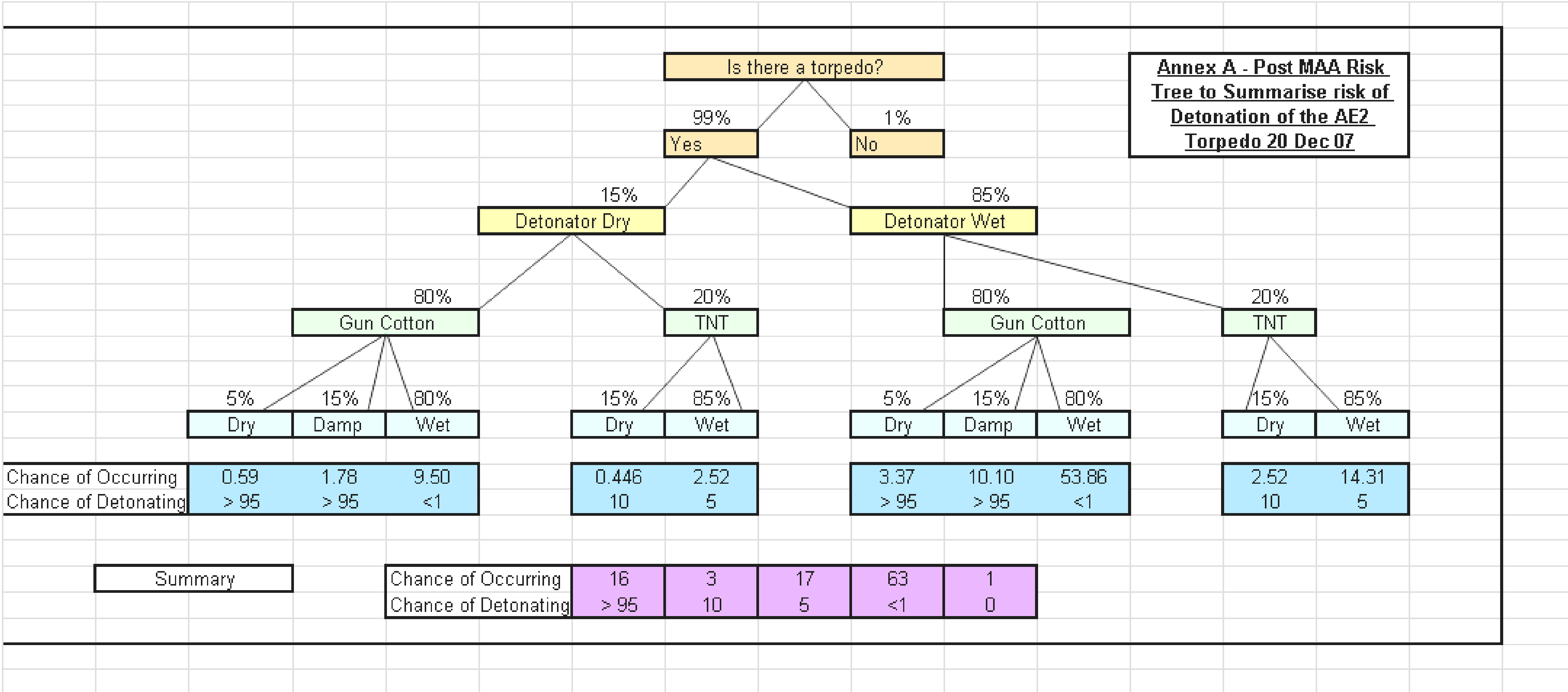

Figure 1 Post MAA Risk Tree to summarise risk of detonation of the AE2 torpedo

Appendix 2 to ANNEX H - Water Penetration into the Torpedo

Background

Historical reports provide compelling evidence of there being an unexpended torpedo on board the historic submarine AE2, which lies in approximately 73 metres of water in the Sea of Marmara, Turkey. Although the precise nature of the torpedo cannot be determined from archival sources, there is strong evidence that a Mark III torpedo is either in the forward torpedo tubes, in the mid-ships or in the aft torpedo tubes.

Issues

- Will the detonator containing mercury fulminate be dry or wet?
- Will the main explosive charge be active and in a firing condition?
- Will “shock waves” associated with the normal operations of a diver collecting concretion samples in the vicinity of the charge are sufficient to set off detonation?
- Will the rubber seals around the doors of the torpedo tubes be functional after 92 years and have kept the tubes dry and thus allowed retention of the explosive charge?
- What happens to explosives such as guncotton and mercury fulminate in a marine environment and what implications does this have on the viability of the MAA?

Comparative studies

What is mercury fulminate and how will it react in seawater?

The detonator is likely to be charged with mercury fulminate, which is very sensitive to shock and rapidly decomposes, according to the equation shown below, to produce the gases which provide sufficient energy to initiate the decomposition of the primary and secondary charges.

$$(C{=}NO)_2Hg \rightarrow 2\ CO + N_2 + Hg$$

One gram of mercury fulminate will undergo a volume expansion of more than 4500 times in converting to its gaseous decomposition products. Mercury fulminate was analysed by Liebig in 1823 and is made by reacting mercuric nitrate with alcohol in nitric acid. If seawater penetrates the detonator casing the salt can be biologically reduced back to the original mercury nitrate, which is water soluble. However, it is likely that the alkalinity and the high amount of chloride in the sea water would precipitate the mercury as a mercury (II) chloride. Reports of Dunbar-Nasmith in *Dardanelles Patrol*, where Nasmith removed the detonator from an unexploded torpedo that had been fired and failed to detonate, notes that the torpedos had a typical gun cotton warhead that was charged with 320 pounds of trotyl or TNT. (Shankland & Hunter, 1964) Bullets recovered from the wreck of the *Mira Flores* (1886) off Rottenest Island, Western Australia were examined under a Scanning Electron Microscope (SEM) and the mercury from the percussion cap had migrated into the marine concretion that had formed as a cathodic deposit, which resulted from the lead bullet head preferentially corroding to protect the brass cartridge cases. Despite the galvanic protection of the brass cap, mercury chlorides and sulphates had precipitated out as the mercury fulminate leached from the percussion cap (MacLeod, 2007). The implication is that in the event that water has penetrated the torpedo tubes, the mixed metal composition of the torpedo will have exacerbated localised corrosion processes while the metal was in an aerobic situation. Once the available supply of oxygen was consumed, iron is not able to cathodically protect copper alloys and so any brass vessel holding the detonator will have suffered bacterially induced corrosion, which would facilitate penetration of salt water into the detonator. Anaerobic sulphate reducing bacteria are very common in seawater and become active when the dissolved oxygen levels fall to zero. As they consume the oxygen from the sulphate ions, their metabolic by-product is sulphide ions (smell of rotten eggs is due to hydrogen sulphide, H_2S) which will be much less soluble than the mercury picrate salt and so the detonator will be neutered.

What happens to the rubber seals around the torpedo tubes?
Experience with conservation of a brass porthole from the SS *Xantho* (1872) and from the *Georgette* (1876) has shown that the rubber gaskets were extensively degraded in that they were crumbly to touch and had lost most of their elasticity. Both these wrecks are in shallow aerobic seawater and it is likely that the degradation of the rubber was catalysed by the presence of iron chloride corrosion products, since iron(III) compounds are known to catalyse the breakdown of many natural polymers. Recent literature reports on the 42-year exposure of vulcanized natural rubber to seawater (Ab-Malek and Stevenson) showed very little degradation, with the rubber absorbing only 5wt% of water, and that the general elasticity was not significantly changed over that period. However, it is likely that a combination of anaerobic and aerobic degradation processes, in conjunctions with chemical attack by iron (III) corrosion products will have caused sufficient degradation to occur that would have resulted in the 7 atmosphere pressure gradient and the associated crevice corrosion around the rubber to have effected seawater penetration into the torpedo tubes.

What happens to explosives such as TNT in seawater?
A good guide as to the fate of 2, 4, 6 trinitrotoluene (TNT) in seawater can be obtained by looking at its interaction in the animal and human gut, following a series of either accidental or deliberate dosage experiments. The main change detected in the urine of animals and people is that the nitro group in the 4-substituent position is reduced in an anaerobic environment, by bacteria and enzymes in the gut, to a less reactive form which also has much higher water solubility. A scheme for some of the typical reactions is shown in Figures 1-3. It should be noted that TNT is not very soluble in water at only 0.13 grams per litre or 5.7 x 10^{-4}M.

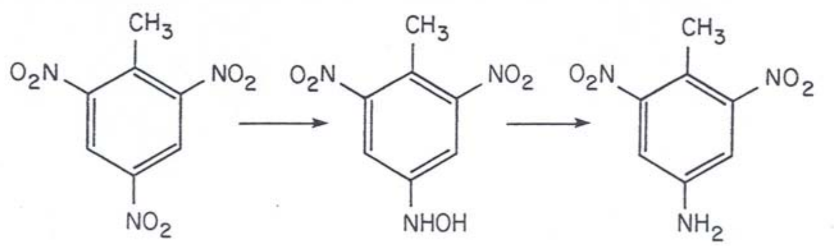

Figure 1: Typical reductive pathway for conversion of TNT into 4-amino-2, 6 dinitrotoluene.

Perhaps more relevant to the issue of the degradation of explosive on board the vessel, assuming that water has penetrated the charge on the torpedo and in the detonator area, is the issue of how such materials degrade in the presence of micro-organisms. Whilst many yeasts were found to be able to biodegrade TNT they were only able to reduce the nitro-group at the 4 position, as shown in Figure 1 and feeding bacteria with the addition of glucose increased the rate of degradation of the explosive. Since most studies of the biological degradation of TNT from waste streams relates to soil bacteria and micro-organisms, it is recommended that TINA undertake microbiological assay of the water in the immediate vicinity of the vessel and from samples of the sediment to isolate and identify micro-organisms present in the marine environment. Once the nature of the bacteria has been quantified, it would be possible to cross-reference the literature to gauge what impact such activity would have on the explosive charges, should they be exposed to water.

How can we assess the amount of TNT in the marine environment?
Literature reports of analysis of TNT and its degradation products in sea water from sites where munitions have been dumped shows that benzene extracts can be analysed by gas chromatography with electron capture detection (Hoffsommer and Rosen, 1972). The method is very sensitive and is reported being able to detect TNT at the level of 10^{-12} grams per millilitre of sea water. Thus samples of seawater collected in the vicinity of the aft, stern and mid-ships should be analysed for TNT and its biological by-products as a safe method of assessing if there is leakage of seawater into the explosive head of the un-spent torpedo. The presence of TNT and related compounds in seawater would prove that the water-tight doors had been breached and that the risk from detonation of explosives was extremely low. If additional diving time is available, owing to freakish combinations of logistical activities and continued good diving conditions, it may be worthwhile considering attempting to penetrate the doors covering the tubes with a steel hypodermic syringe to see if any water samples can be drawn from the interior and used for explosive residue analysis. If the needle penetrates the cavity and gas escapes the conclusion of water-tightness cannot be assumed. Previous experience of gently tapping such instruments into sealed gun barrels on the HMS *Sirius* (1790) carronade and a *Zuytdorp* (1712) cannon allowed the entrained gases to be analysed and these were confirmed as a mixture of carbon dioxide, hydrogen and methane. The carbon dioxide resulted from the reaction of acidic corrosion hydrolysis products with marine organisms, the hydrogen was from electrochemical reduction of water during anaerobic corrosion and the methane came from chemical reduction of the cementite, Fe_3C, in the cast iron.

What about other explosives having been used?
Other nitrated aromatic compounds include Tetryl or N-2, 4, 6-tetranitro-*N*-methylaniline, has been used as a booster explosive and as a base charge in detonators and blasting caps. It was first synthesised in 1877 and is much more sensitive to impact and friction than TNT. Extraction of sea water samples showed that the detection limit of Tetryl was 20 parts per trillion or ppt. (Hoffsommer and Rosen, 1972).

Why not try the acoustic coupling method of rivet integrity?
It is recommended that stripping of rivet heads of the protective concretion on AE2 would amount to a major form of intervention on the vessel and thus it should not be supported during the initial visit to the site by the team. Given that the whole tenor of the MAA is to minimise the disturbance of the vessel, while doing the best to gauge its current state of degradation/preservation, the

“pinging” of the rivets with a heavy dumpy hammer could be left to a second season of assessment, should the first results indicate that the steel has sufficient integrity that consideration of the technical aspects of a possible lift is considered to be a major priority of the team managing the site for both the Turkish and Australian governments. If such testing was done during the initial survey the data may not necessarily lead to information that cannot be obtained from other methods that are less invasive. It is recommended that field testing of the approach be conducted on a vessel such as J5 in Bass Strait, since the amount of deterioration of the rivets in such boats is going to be much greater than on AE2. If solid rivet “ring signatures” can be detected underwater by the divers, then the methodology can be developed and refined and given due consideration for stage 2 of the assessment. Naturally, any such testing program should be conducted in conjunction with permission from Heritage Victoria and from Peter Harvey, the Manager of the Maritime Heritage Unit. Some form of hydraulic cement or underwater epoxy should be applied to “pinged” rivet heads on J5 in order to minimise any localised differential corrosion resulting from exposure of the corroded iron to direct contact with oxygenated seawater.

Relative impact of dumpy hammer and chisel versus the needle gun for ultrasonic measurements

Although there is a small chance that the fish is in a dry environment the issues associated with accidental shock setting off the warhead of the torpedo have to be considered. Given that the whole concept of the MAA is to gently discern the nature of the physical and chemical state of AE2, with minimal intervention, it is proposed that use of the needle guns to clean away marine concretion on selected areas of the hull will cause less shock to the structure than sharp blows with a dumpy hammer and a chisel. Thus it is strongly recommended that any metal thickness measurements involving direct contact with the corroded hull should use the needle gun in areas near the tubes (aft, bow and amidships) and that the use of the dumpy hammer method should be restricted to the half dozen points where concretion sampling is to be conducted.

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