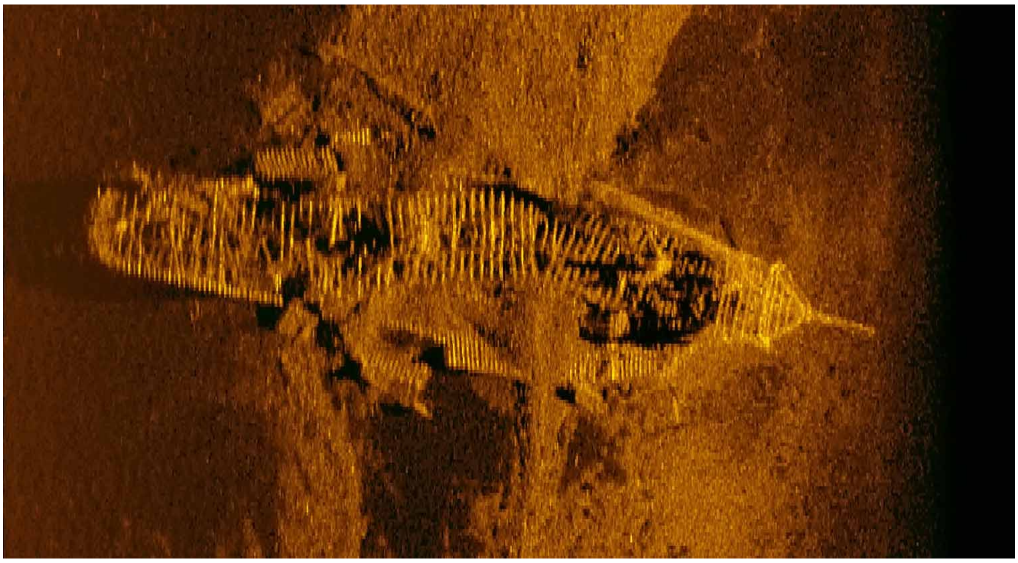
Maritime archaeological analysis of two historic shipwrecks located during the MH370 aircraft search



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Western Australian Museum

Cover images:
Top: Anchor 2 on wooden sailing shipwreck site IOS-001 in 3900m depth (Fugro/ATSB).
Bottom: Side scan sonar image of iron sailing shipwreck site IOS-002 in 3700m depth (Fugro/ATSB).

Abbreviations

ATSB	Australian Transport Safety Bureau
AUV	Autonomous Underwater Vehicle
cwt	hundredweight (20 cwt = 1 imperial ton/ 2240 lbs)
E	east
ft	feet
GIS	Geographic Information System
Hz	Hertz
in	inches
IOS	Indian Ocean Shipwreck
kg	kilograms
m	metres
mm	millimetres
N	north
ROV	Remote Operated Vehicle
S	south
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNESCO	United Nations Educational Scientific and Cultural Organisation
W	west
WA	Western Australia

Acknowledgements

The author thanks the following people and organisations who generously contributed data, advice and research that made the compilation of this report possible. Peter Foley, Director ATSB, Daniel O'Malley, Communications Officer ATSB; Duncan Bosworth, ATSB; Andy Sherrell, Quality Assurance Manager, MH370 search; Fugro; John Pugh, Geoscience Australia; Dr Michael MacPhail, Consultant Palynology Services/ Australian National University; Dr Michael McCarthy, Curator, Department of Maritime Archaeology, WA Museum; Dr Jane Fromont, Head, Department of Aquatic Zoology, WA Museum; Michael Gregg, Curator, Department of Maritime History, WA Museum; Kevin Edwards, Tempus Archaeology; Australian Centre for Field Robotics, University of Sydney; Mr Tom Bennett; Mr Ian Wiese; State Library of South Australia.

Table of contents

Table of figures

Tables

Background

In June 2014 the Australian Transport Safety Bureau (ATSB) contracted survey company Fugro to undertake a wide-area bathymetric search for the missing Malaysian Airlines Boeing 777 aircraft (flight number MH370) aircraft. In the course of undertaking the search lasting until 17 January 2017, four sonar contacts were identified as shipwreck sites. The ATSB sought advice from the WA Museum's Department of Maritime Archaeology which identified two of the wrecks as mid to late 19th century historic sailing shipwrecks, designated Indian Ocean Shipwreck (IOS)-001 (located May 2015) and IOS-002 (located December 2015). This report summarises the historical research and maritime archaeological analyses that have been undertaken in an attempt to identify these sites. The other two shipwrecks, located in March 2016 and October 2016 respectively, were identified as late 20th century motorised fishing trawlers, and are not included in this report.

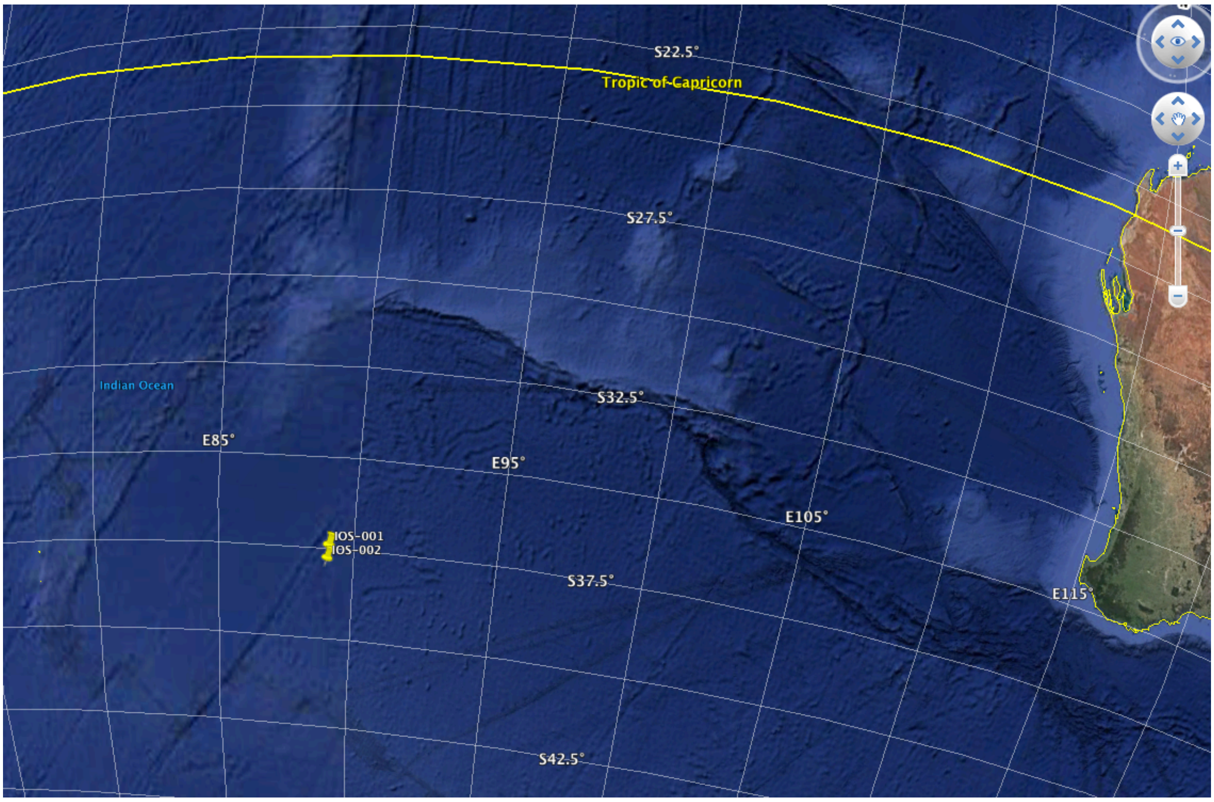

Figure 1 Location of IOS-001 and IOS-002 sites (Google Earth).

Survey equipment

Wide area bathymetric surveys utilised Fugro's Edgetech 2400 Series deep-towed vehicle with the ability to operate at up to 6000m depth. The vehicles are equipped with a multi-beam echo sounder (MBES) with a 200-400kHz frequency and Edgetech side-scan sonar with 75kHz and 410kHz frequencies, and a maximum 2500m swathe width. Close-range surveys were undertaken using Fugro's Echo Surveyor VII AUV equipped with multi-beam echo sounder (MBES) with a 200-400kHz frequency and an Edgetech side-scan sonar with 75kHz and 410kHz frequencies, and a Kongsberg NEO 11 megapixel 35mm monochrome camera with LED lighting.

IOS-001

Site discovery and location

On 19 May 2015, while using a deep tow side scan sonar *Fugro Equator* detected a cluster of small sonar targets in the southern part of the MH370 aircraft search area, 12 nautical miles east of the 7th arc, at coordinates 37°40'18"S and 89°23'5"E in 3900 metres depth (Figure **1**).

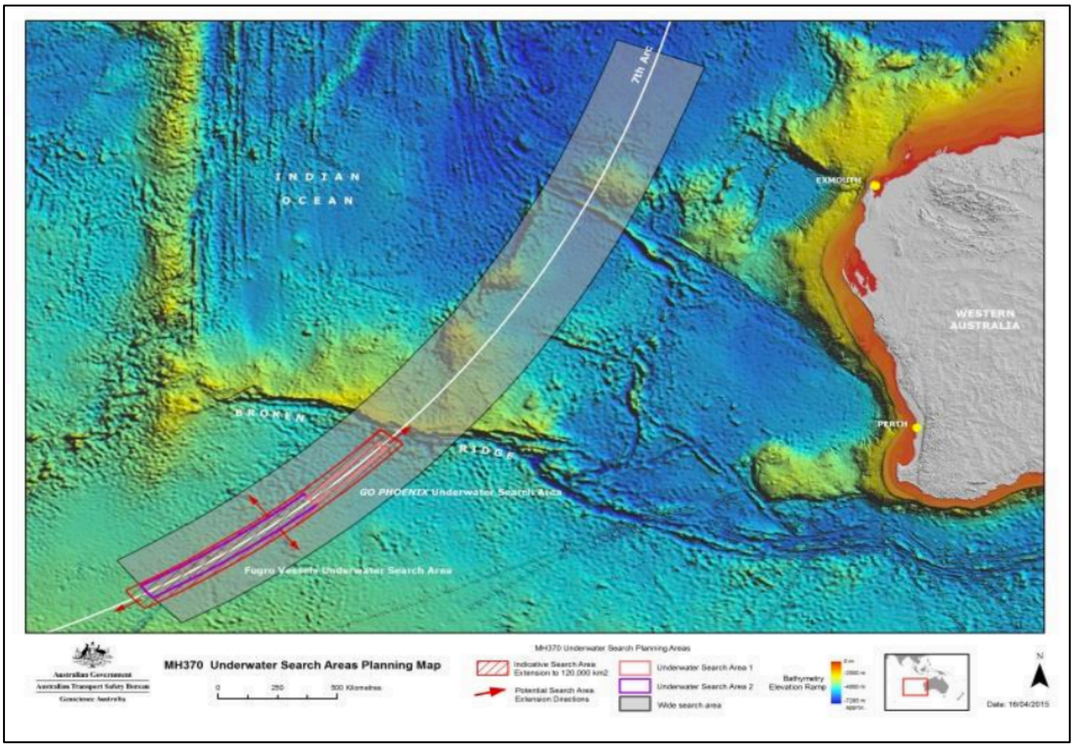

Figure 2 MH370 underwater search area planning map showing the search area adjacent to the 7th Arc (white line) (ATSB).

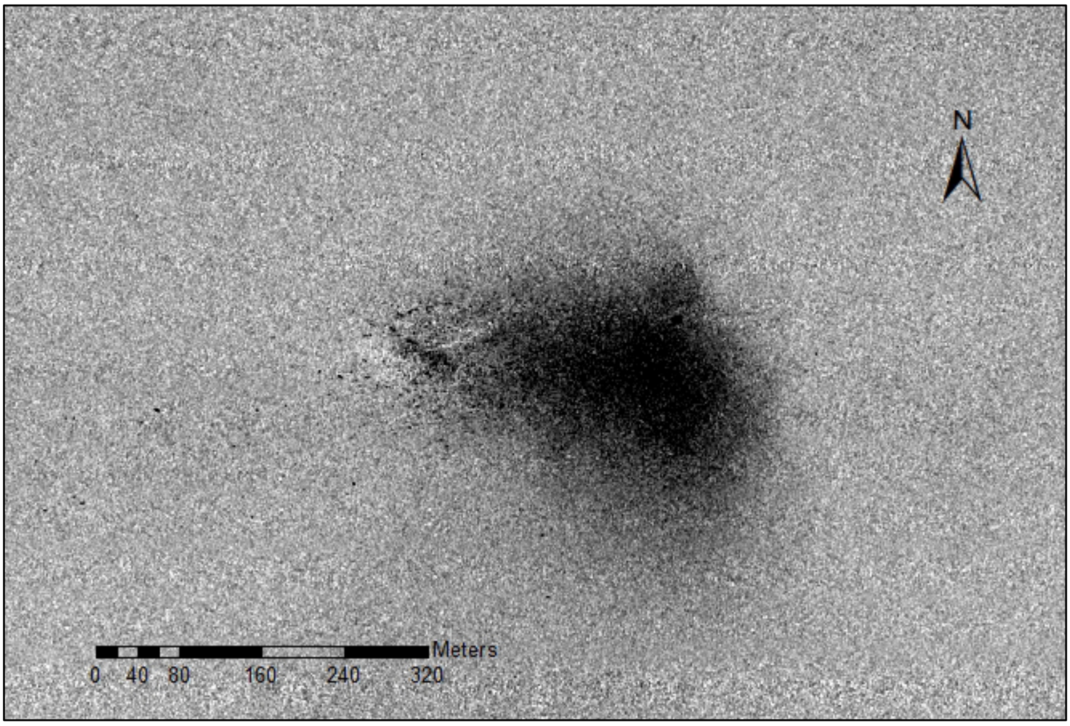

Figure 3 GIS map showing sonar image of IOS-001 shipwreck site scattered over a wide area of seabed in 3900 m depth (Fugro/ATSB/ WA Museum).

Fugro Supporter was tasked with performing a high-resolution sonar scan using the Autonomous Underwater Vehicle (AUV) *Echo Surveyor VII* to investigate the sonar targets. An additional low-altitude AUV mission was undertaken to photograph the site (Fugro locates uncharted shipwreck 19/5/2015).

Site recording

About 12,000 geo-referenced, black and white photographs were taken over an approximately 30,000 metre square area that take into account the pitch, roll, altitude and heading of the AUV. The flying height of the AUV was approximately 10m above the seabed. Images had about 30-40% overlap on run lines, with between 0-50% overlap on adjacent run lines due to positioning inaccuracies in 3900m depth. Due to some navigational irregularities an entire photomosaic could not be automatically generated from the georeferenced photographs using traditional sonar software. The WA Museum attempted to reconstruct a three-dimensional model of the site by processing the photographs using the Agisoft Photoscan™ 3D modelling program, but this only worked for individual runs and did not generate an entire 3D model, probably due to a combination of issues related to lighting and image overlap. The ATSB subsequently provided a subset of the data (410 images) to the Sydney Centre for Field Robotics at the University of Sydney, who were able to correct for lighting effects and generate a 3D model and orthographic projection of a photomosaic of part of the site using their proprietary software (Figure 4, Figure 5).

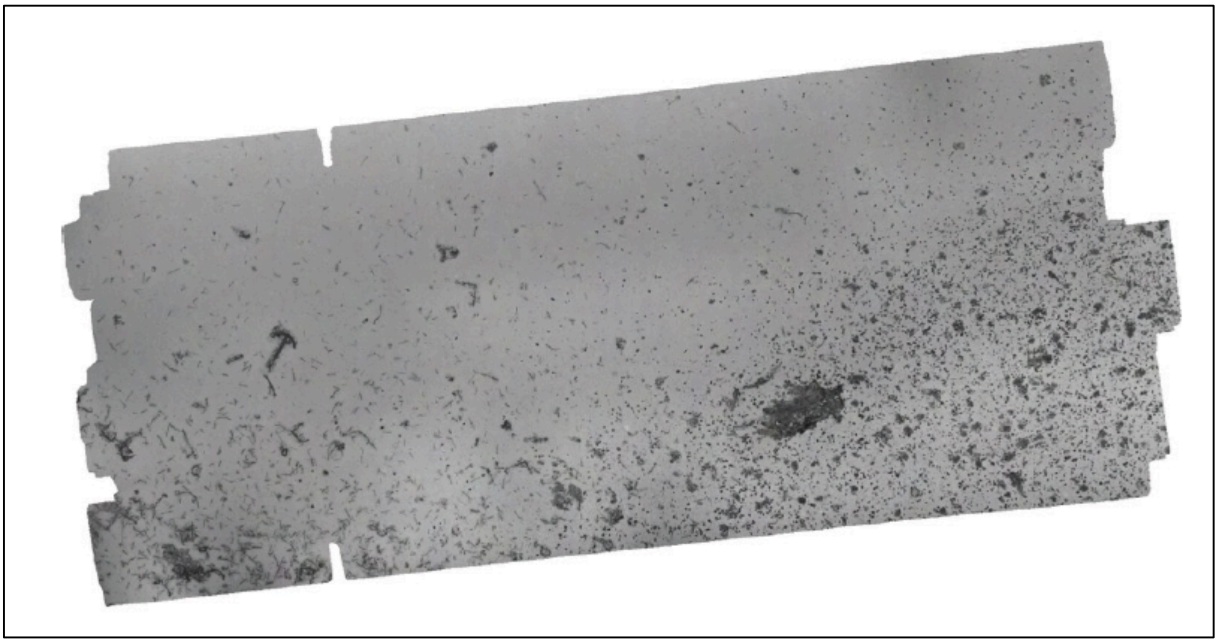

Figure 4 Orthographic projection of 3D mosaic showing part of IOS-001 site, with Anchor 1 and water tank visible along with coal and scattered fastenings (Australian Centre for Field Robotics, University of Sydney).

Figure 5 Three-dimensional model of part of IOS-001 site showing Anchor 1 (Australian Centre for Field Robotics, University of Sydney)

Site environment

The site is lying widely scattered over a 630 by 460m area on a flat, sloping seabed with evidence of bioturbation. The photographs appear to show some light sedimentation occurring, possibly as a result of decaying organic matter falling from the upper ocean waters onto the seabed. This matter known as 'marine snow' is estimated to cover about three-quarters of the world's deep ocean floor, adding to bottom ooze and accumulating at a rate of as much as 6 metres every million years (Marine snow, n.d. 20/8/15). The bathymetric data appears to show the beginning of a large mound that may indicate the presence of buried lower hull remains, that may in turn be overlain by collapsed structure and cargo (Figure 6).

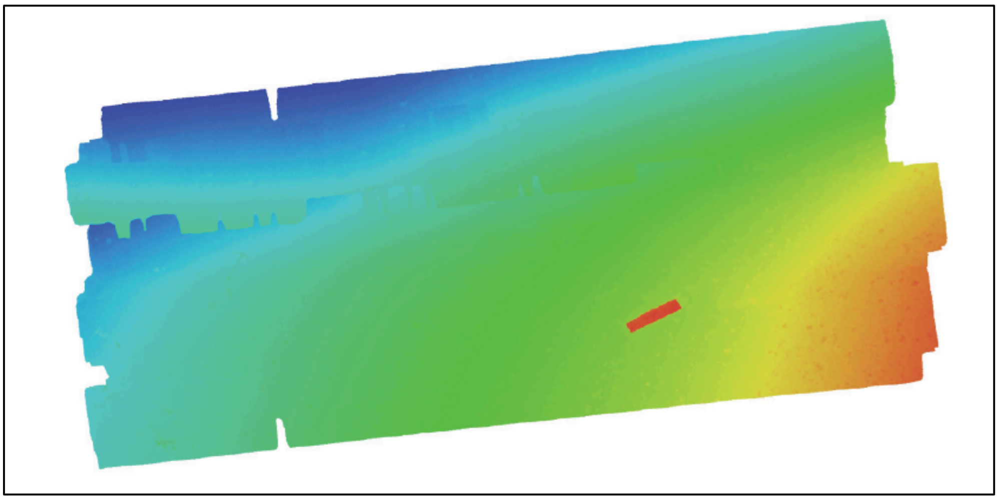

Figure 6 Bathymetry showing part of IOS-001 site with rectangular water tank visible, and possible circular edge of a wreck mound at lower right. Dark blue corresponds to -3791 m and red to 3784.2 m. An elevation offset visible in upper left of model is due to a lack of photographic matches in this area (Australian Centre for Field Robotics, University of Sydney).

Site plan

A GIS site plan was created using geo-referenced images of key features overlying the side scan sonar image of the site (Figure **7**).

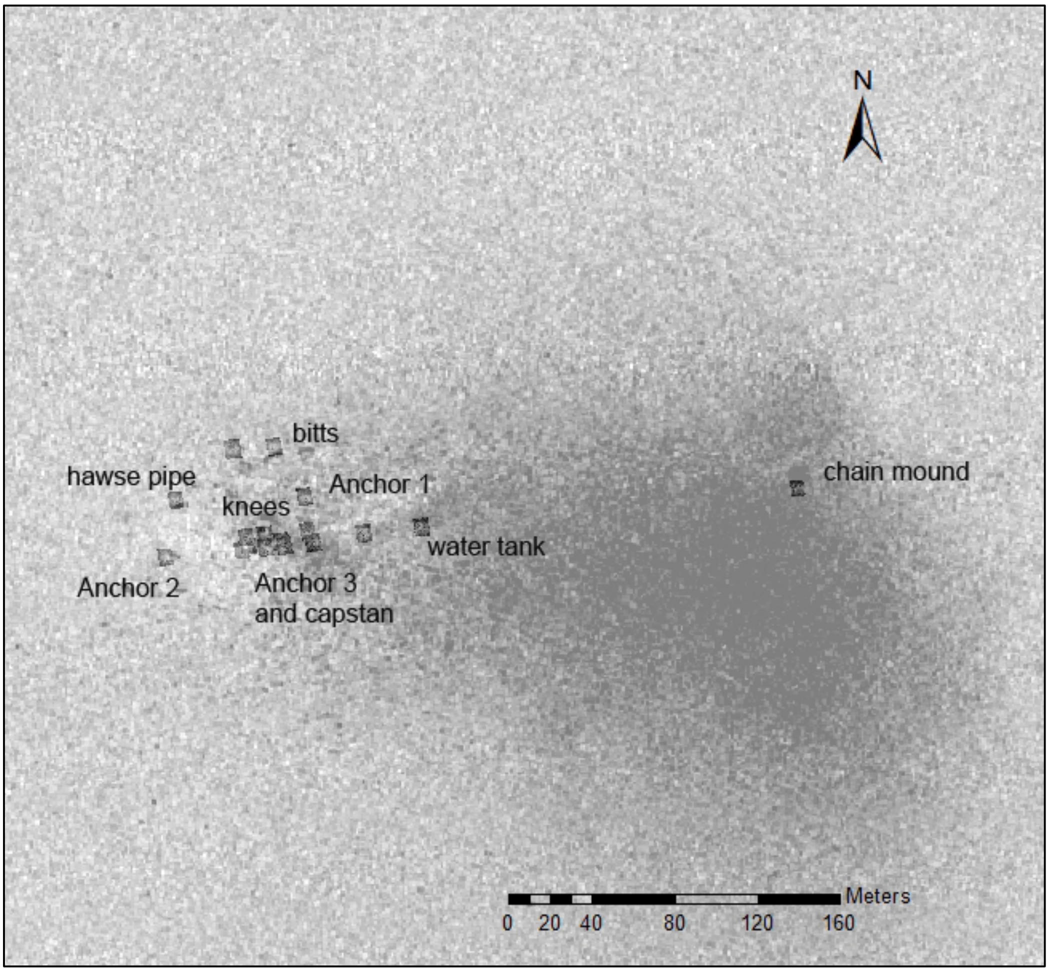

Figure 7 GIS site plan of IOS-001 site showing key features overlying side scan sonar image of wreck site area (Fugro/ATSB/ WA Museum).

The main concentration of wreckage is located to the northwest of the site. These include three anchors, mooring bitts, a hawse pipe and capstan. Most of these items would have been located on, or close to, the main deck level at the bow of the vessel. The water tank is likely to have been located in the lower forward or aft part of the vessel. The largest anchors, Anchors 1 and 2, are separated by 60m, while Anchor 2 lies 245m from a large mound of stud link anchor chain towards the east of the site. Most of the material scattered on the seabed consists of the remains of the vessel's cargo of coal that has spilled out of the hull prior to it striking the seabed.

Ship construction

The vessel was of wooden construction with iron supporting knees and fastenings dating it to the 19th century. No major remaining hull structure or loose ship's timbers are observed on the site, and they appear to have been entirely degraded leaving only metal objects such as fastenings, anchors and fittings, and the coal cargo.

Iron knees

Knees are supporting brackets made of timber or bent iron used to connect deck beams to the vessel's hull (Figure **8**). Introduced in the mid 18th century and commonly used throughout the 19th century into the 20th century, iron knees were fashioned in a number of ways such as right-angled, staple, rider and crutch knees. French and British shipbuilders were early users of iron knees due to shortages of suitable timber to make traditionally grown wooden knees, while American shipbuilders with vast reserves of timber at their disposal continued to use wooden grown knees until the mid-19th century at least (Stammers 2001: 115-116).

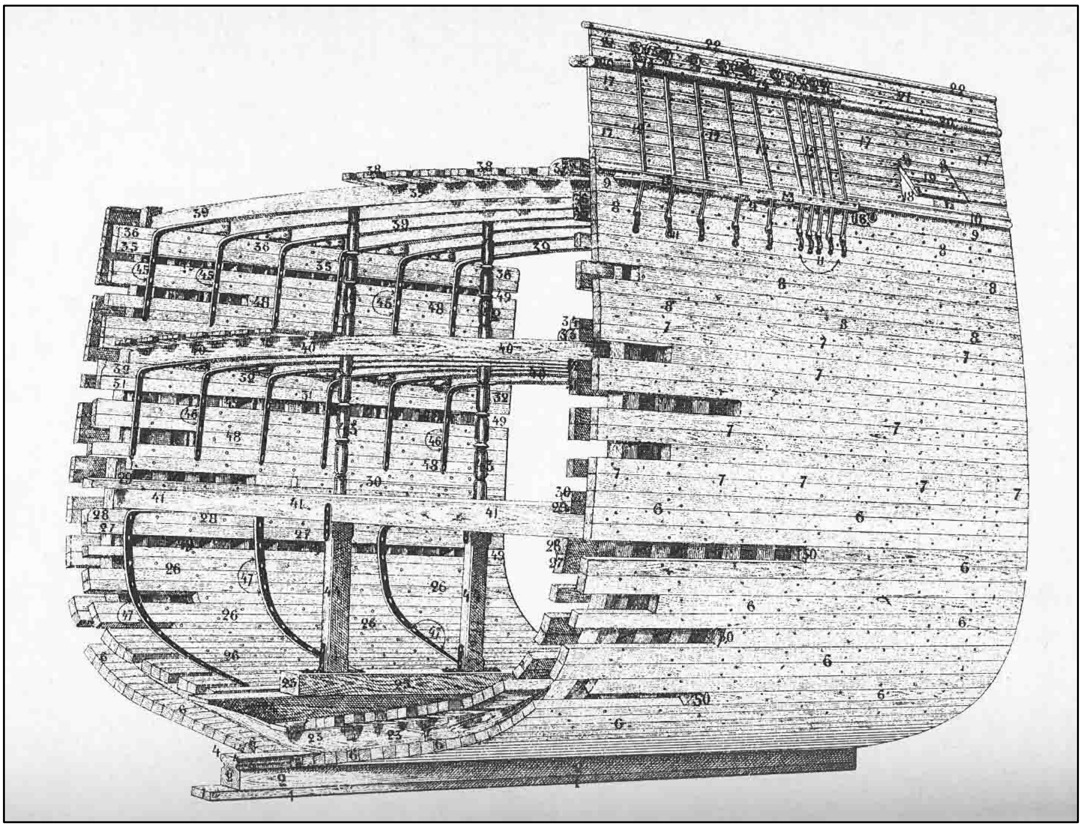

Figure 8 Amidships section of a large wooden three-decked ship showing arrangement of right-angled iron knees joining deck beams to hull (Paasch 1890).

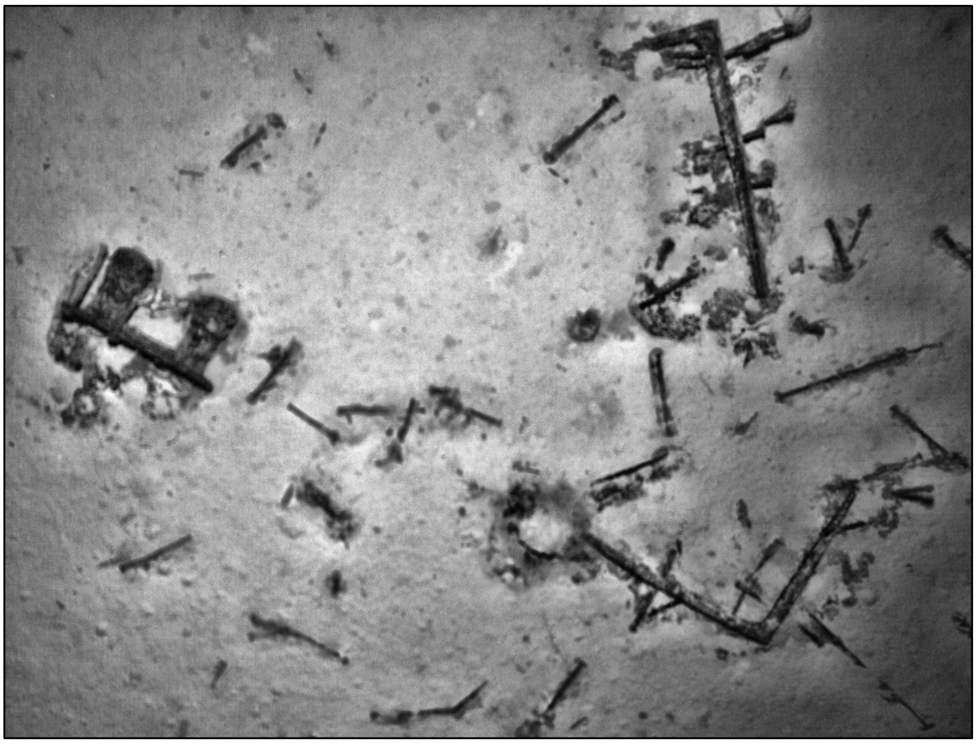

Figure 9 Detail of two right-angled iron knees with scattered fastenings and mooring bitts (Fugro/ATSB).

Figure 10 Detail of a smaller, curved between-deck staple knee (Fugro/ATSB).

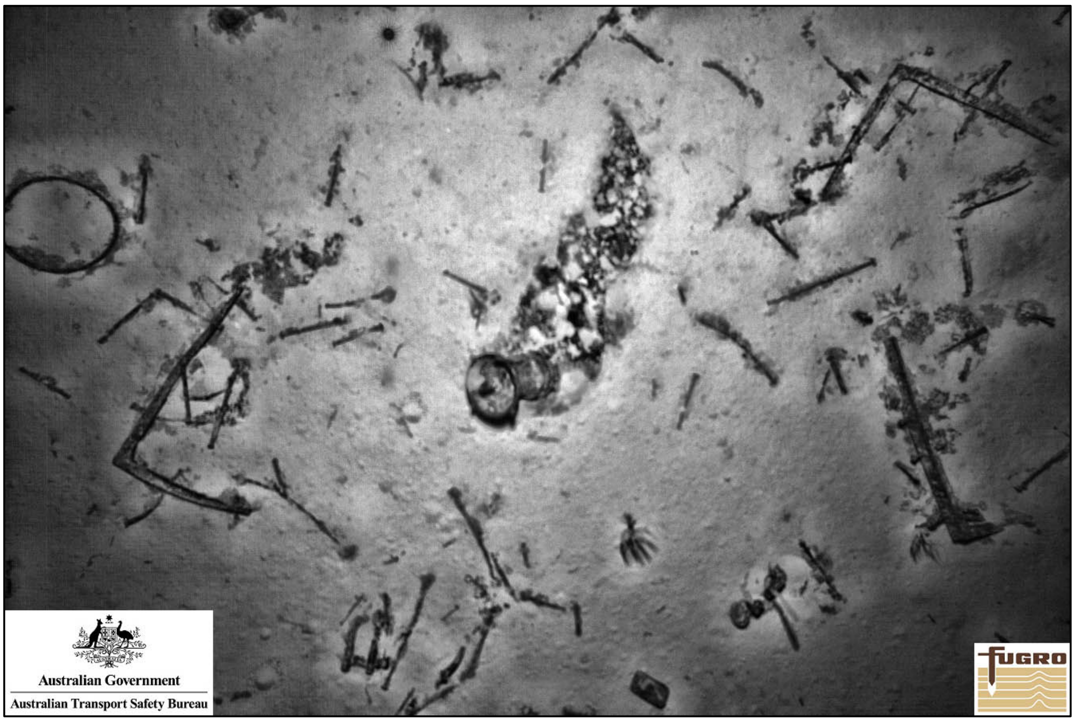

Figure 11 Concentration of three iron knees, fastenings, and an upside-down capstan in centre of image (Fugro/ATSB).

Copper sheathing

While copper sheathing has not been directly observed on IOS-001 its apparent absence requires some explanation. Large rectangular sheets of copper, and copper-alloy sheathing were typically used to protect the exterior of ocean-going, wooden-hulled vessels below the waterline to reduce marine fouling and attack by the common shipworm, *teredo navalis*, the properties of copper being toxic to marine biota. While upper timbers can be completely biologically degraded the remaining lower, sheathed hulls of wooden vessels are often found intact. For example, the wreck of an early 19th century schooner discovered in in 2001 in 807m depth in the Gulf of Mexico still had extensive remains of the lower part of its wooden hull, with copper sheathing visible above the seabed (Anautz *et al*, 2006; Deepwater shipwrecks n.d.). However other wooden shipwrecks such as HMS *Pandora* (1791, 33m depth, Queensland) and *Cheviot* (1856, 26m depth, Victoria) have their lower hulls buried in flat, sandy sea beds close to their waterline, corresponding with their sheathing line. Bathymetric data on IOS-001 provides some evidence for the beginnings of a wreck mound, which may indicate the presence of buried wooden hull remains, and hence explain the lack of any visible hull or copper sheathing.

Fastenings

Hundreds of hull fastenings are visible scattered over the site ranging between 36 and 75cm in length. It is not clear if they are of ferrous or of copper/ copper alloy composition, or both. Most of the larger fastenings appear to be drift bolts or through bolts that were clenched (McCarthy 2005: 69-85) with at least one eyebolt visible. Some bolts appear to have remnant wood around their circumference, which is a typical feature of copper alloy bolts as copper corrosion products penetrating the surrounding timber provides a toxic barrier to organisms.

Site Features

Anchors

Three anchors of different sizes have been identified on the site (Figure **12**). All anchors are Admiralty type anchors with a curved crown, consistent with a post-1830s date. Pering's Improved Anchor patented in 1835 featured a curved crown (Curryer 1999: 76), while the Board of Admiralty 1841 Pattern anchor features a 'graceful elliptical curve' (ibid: 83-84). Anchors 1 and 3 have folding iron stocks. Wooden stocks were still used on vessels up until the 1850-60s, gradually being phased out by the use of iron stocks, including folding stocked anchors. A distance of 60m separates Anchor 1 and Anchor 2. Anchor 3 lies approximately in between with Anchor 1 and Anchor 2 lying 31m and 27m from Anchor 3, respectively (Figure **12**).

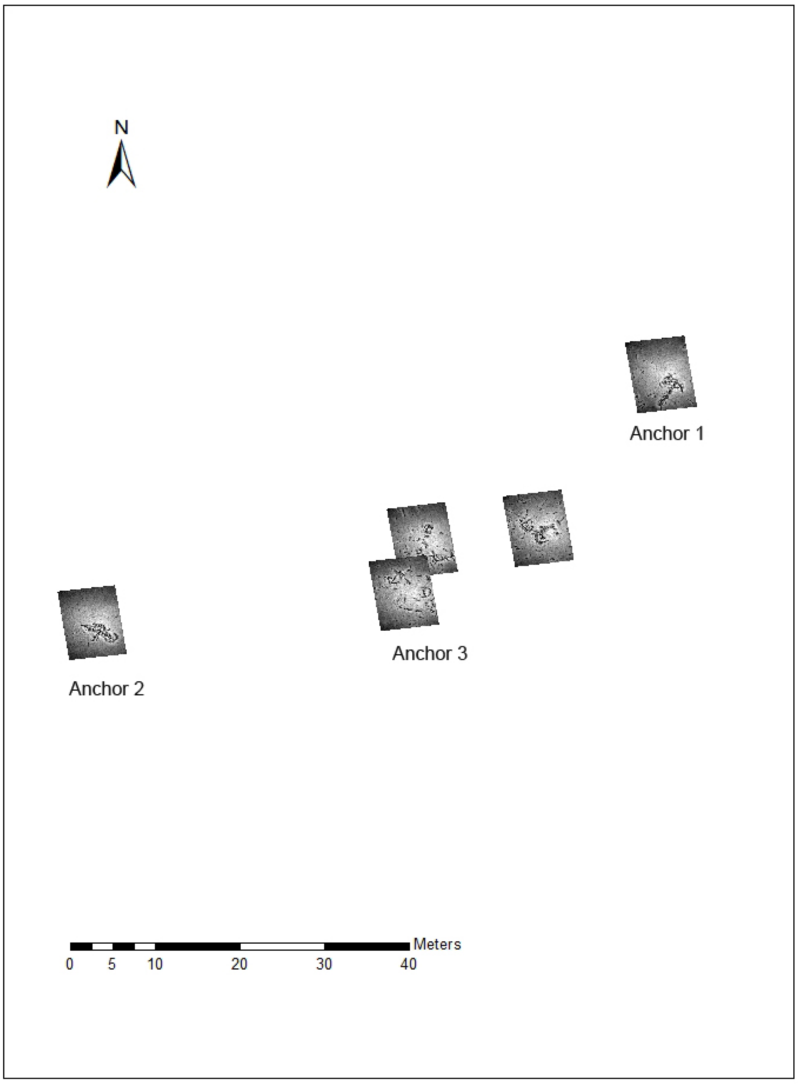

Figure 12 Georeferenced photographs showing relative positions of anchors on IOS-001 site (Fugro/ATSB/ WA Museum).

Measurements taken from georeferenced photographs provide the following dimensions for the anchors.

Table 1 Dimensions of anchors on IOS-001 site

Anchor description	Length of shank (m)	Length of stock (m)	Width of crown (bill to bill) (m)
Anchor 1	3.18 (10 ft 5 in)	N/A	2.71
Anchor 2	2.1 (6 ft 10 ½ in)	1.77	N/A
Anchor 3	1.73 (5 ft 8 in)	0.9m (may not be complete, obscured)	1.11

Anchors 1 and 2 are larger bower anchors, with Anchor 3 a lighter kedge or stream-type anchor. One bower anchor was always kept ready for emergencies, as is the case with Anchor 2 that has its stock set. Stream or kedge anchors specified for use in inland waters were 7/8 the size of bower anchors (Curryer 1999: 43-44).

The measurement of 3.18 m (10 ft 5 in) of the largest bower anchor can be used to help determine the vessel's original dimensions, using Sutherland's rule where the length of the shank equates approximately to 2/5's of the vessel's maximum width (Evans and Nutley 1991: 42), equating to 7.95m (26 ft 1 in) breadth. An approximation of the anchor's cubic weight based on its shank length is about 11cwt (559 kg), in turn equating to a vessel of about 225 tons.

For comparison the Ningaloo Reef Unidentified shipwreck near Point Cloates, Western Australia–identified as possibly a non-British wooden sailing coal trader of between 300-700 tons–was carrying four Admiralty type anchors with shanks ranging in length between 1.53 and 2.98m (Anderson 2011: 103). The two largest examples of three anchors found on the 858 ton wooden barque *Stefano* (also a non-British coal trader) had shanks measuring 2.80 and 3.08m (Anderson 2009: 130). From this information it is broadly estimated that the anchors used on IOS-001 could be carried aboard a vessel ranging from 225 to 850 tons.

Anchor 1

Anchor 1 is a large, Admiralty-type best bower anchor, with an iron folding stock lying detached nearby, an iron shackle, with stud link chain visible attached to the shackle.

Figure 13 Anchor 1, Admiralty type anchor with detached folding iron stock (Fugro/ATSB).

Anchor 2

Anchor 2 is another large Admiralty-type, iron stocked anchor with stud link chain attached (Figure **14**). The stock appears to be a folding type that has been rigged. As the stock is rigged for deployment, this is identified as the sheet anchor.

Figure 14 Anchor 2, Admiralty type anchor with iron stock (Fugro/ATSB).

Anchor 3

Anchor 3 is an Admiralty-type bower or kedge anchor of lighter size and construction to a best bower and sheet anchor, with a folding iron stock (Figure **15**). A ring or shackle is visible though it is not clear if there is chain cable attached. A possible apron knee lying nearby may be an indication that part of the stempost, or sternpost is lying nearby.

Figure 15 Anchor 3 stream or kedge anchor with folding stock, possible apron knee at top right (Fugro/ATSB).

It is notable that only three anchors have been so far identified, as by at least 1890 all deep sea merchant sailing ships over 200 tons were required to carry at least five anchors namely three bowers, one stream and one kedge anchor (Lloyds Rules and Regulations 1913-14: Table 30; Paasch 1890: 149). An exception to this was vessels used 'for Channel purposes'—short voyages across the English Channel—that were only required to carry 'not more than two bower anchors and one stream anchor' (Lloyds Rules and Regulations 1913-14: 60). This may be some further evidence for the wreck not being a British registered, and Lloyds insured vessel.

Windlass

A significant feature on the site is the remains of a common wooden windlass. Wooden windlasses contained iron elements including the axle and toothed gear rings known as pawls and purchase rims. The axle length of the common wooden windlass on the Ningaloo Reef Unidentified site measured 4.23m (Anderson 2011: 103), giving an approximate indication of scale for the IOS-001 shipwreck.

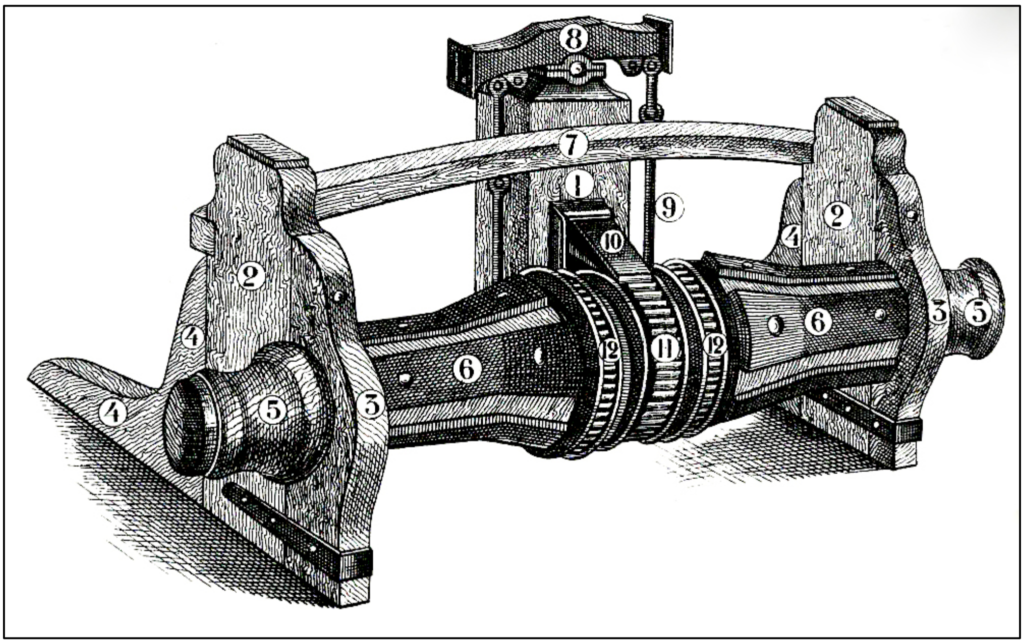

Figure 16 Common wooden windlass showing pawl bitt (1), wooden carrick bitts (2), cheeks (3) and whelps (6), iron pawl rim (11) and purchase rims (12) (Paasch 1890).

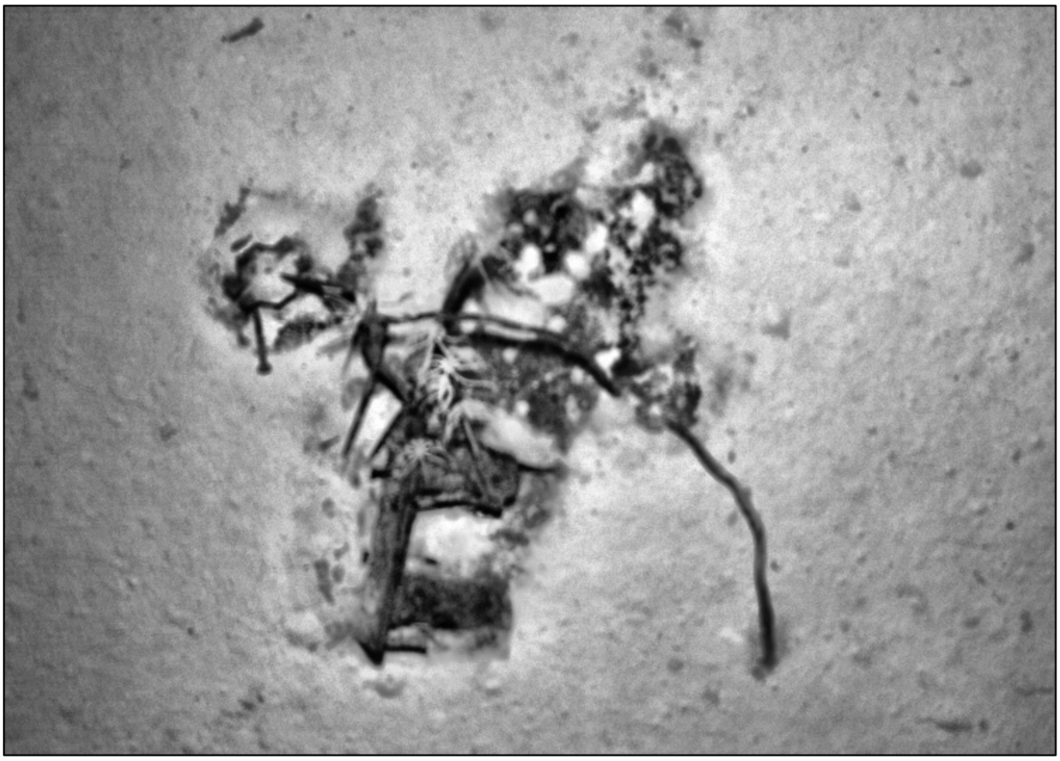

Figure 17 Windlass on IOS-001 site. A hexagonal-shaped bolted fitting is also apparent which may be for the pawl bitt that has deteriorated (Fugro/ATSB).

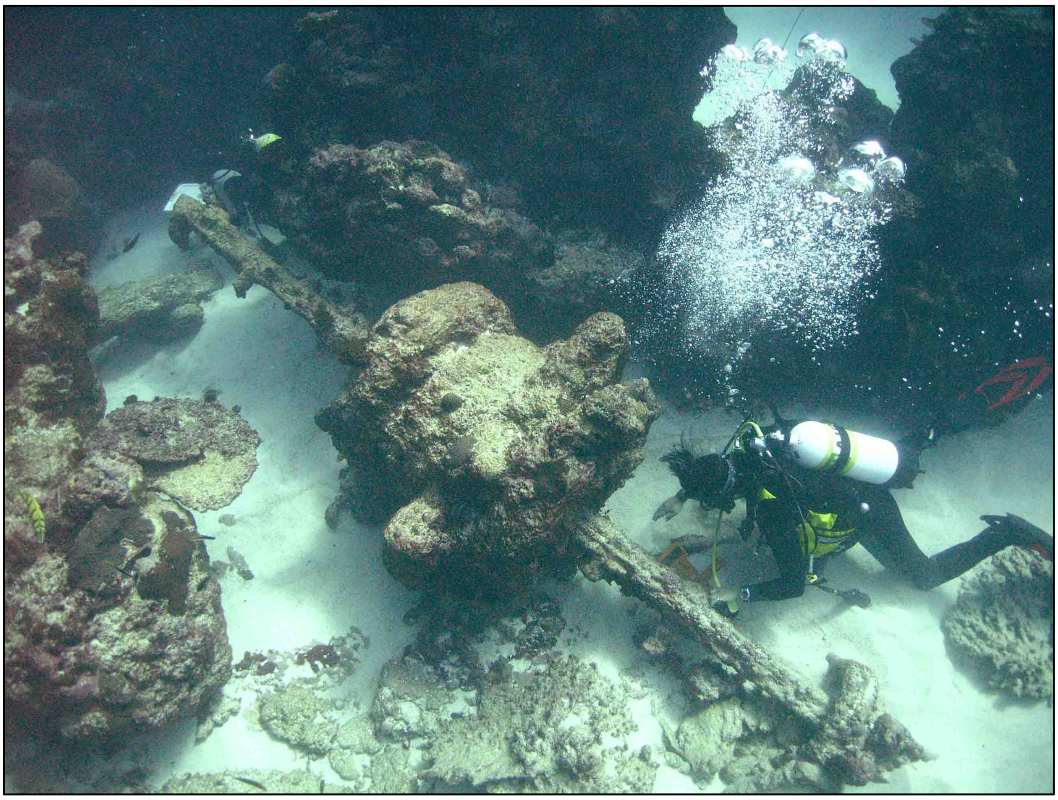

Figure 18 Remaining iron elements of a large wooden windlass on *Stefano* (1875) site. The wooden whelps, carrick bitts, pawl bitt and cheeks have disappeared leaving only the iron axle, pawl-rim and purchase-rims. (Patrick Baker/ WA Museum).

Chain mound

A mound of stud link chain cable lies 245m east from Anchor 2 (Figure **19**). Chain mounds are typically found on late 19th century shipwrecks, with stud link chain used on merchant ships from as early as 1815 (Curryer 1999: 100). Chain mounds are a good indication of the bow/ forepeak of the vessel where chain cables for the anchors were stored below deck. That the chain mound is intact is a strong indication that the lower fore part of the vessel also sank intact in this area. The gauge of stud link chain is a more reliable method of estimating a shipwreck's tonnage than anchor size. However the small, sub-inch, differences in gauge are not considered to be reliable in this case, without the ability to take precise, manual measurements from original surfaces. As the anchors—normally stowed above deck in the bow area—and the majority of other structural parts of the vessel lie between 145 and 245m west of the chain mound, this is further evidence that the vessel did not sink to the bottom intact, and appears to have suffered some catastrophic event.

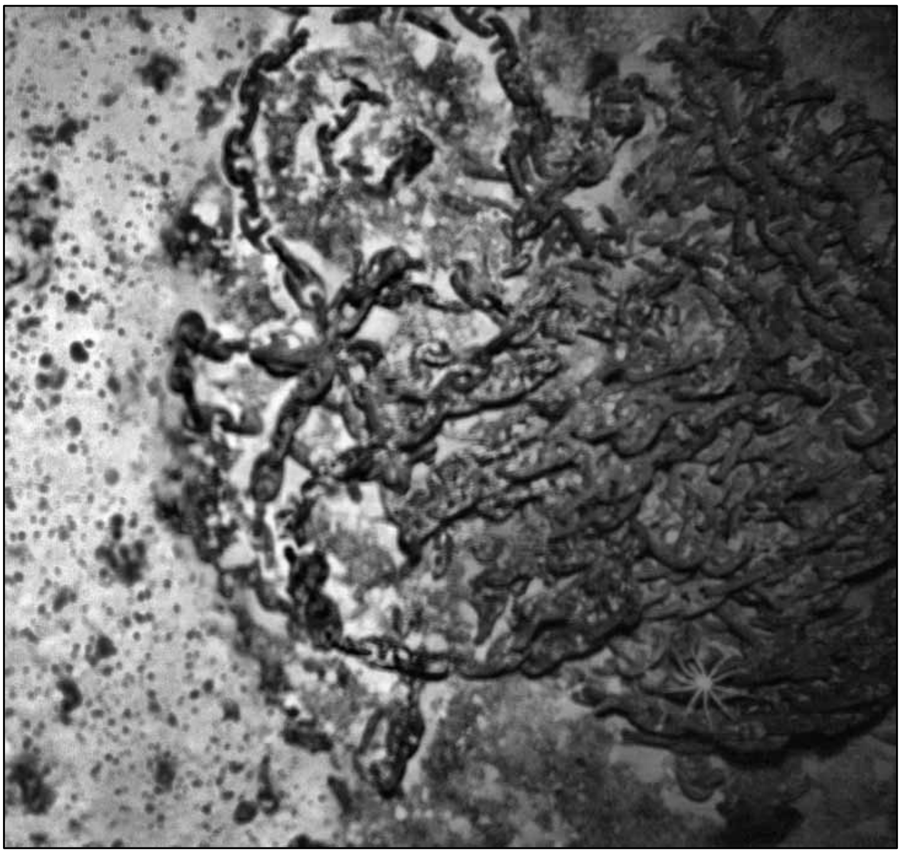

Figure 19 Detail of chain mound with stud links visible (Fugro/ATSB).

Rigging

Although wooden materials exposed above the seabed have disappeared, wooden masts and yards would have included iron elements such as mast hoops (used to prevent splitting of the wooden mast and to attach rigging), truss hoops (to support yards), rigging chains and topmast caps (Figure **20**). At least one possible truss hoop with chain attached is identified (Figure **21**). There are other elements of rigging including mast bands present, indicating the ship sank with some of its standing rigging not having been detached.

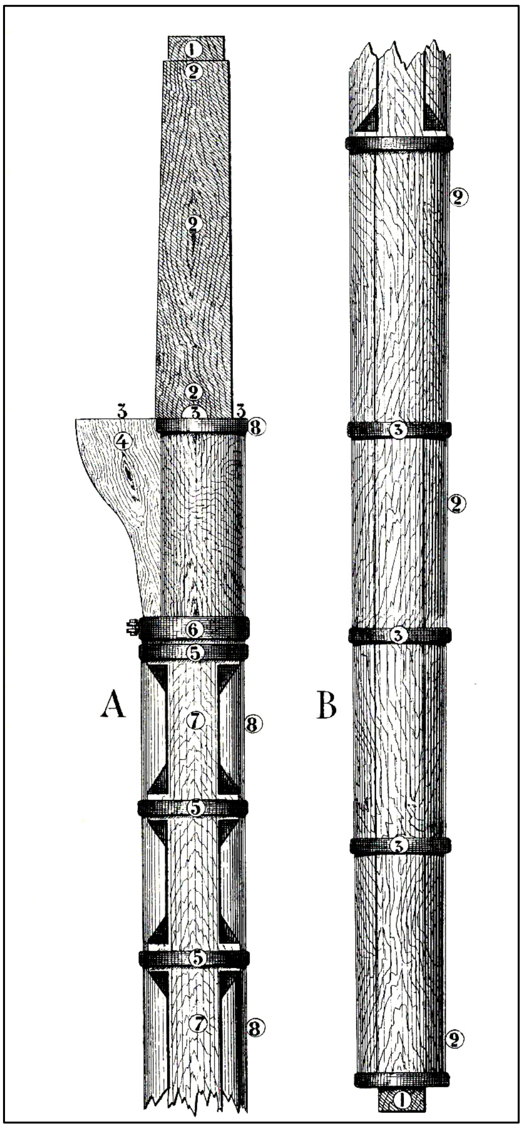

Figure 20 Diagram showing layout of the upper and lower parts of a wooden mast showing iron mast hoops (A5 and B3) and truss hoop (A6) (Paasch 1890).

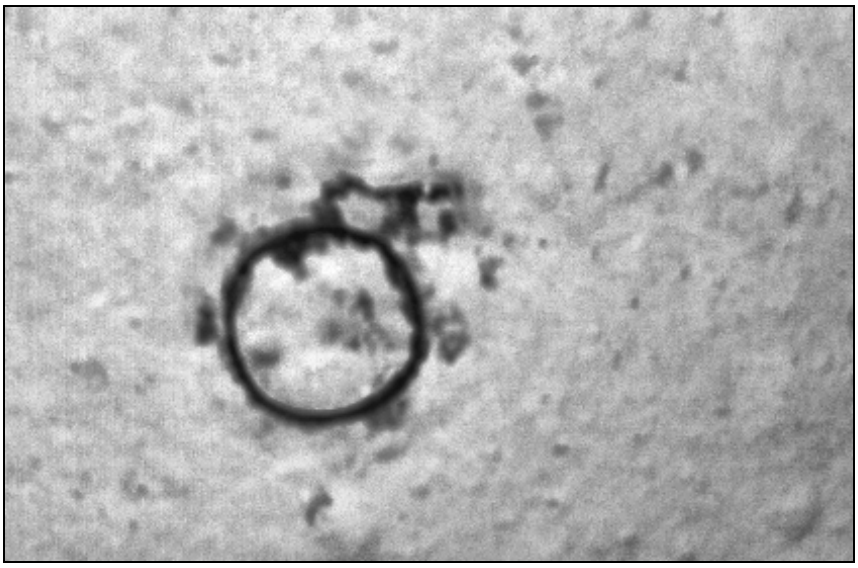

Figure 21 Possible iron truss hoop with chain attached (Fugro Survey/ ATSB).

Water tank

A large rectangular metal object of 6m length is the largest feature on the site (Figure 6, Figure **22**), and is identified as a ship's iron water tank. Metal tanks were increasingly fitted to ships from around 1811 to store water, as well as perishable goods such as bread (Pearson 1992: 25). Remains of a similar large rectangular tank have been identified on the wreck of the 858 ton wooden barque *Stefano*, wrecked in 1875 near Point Cloates, Western Australia (Figure **23**).

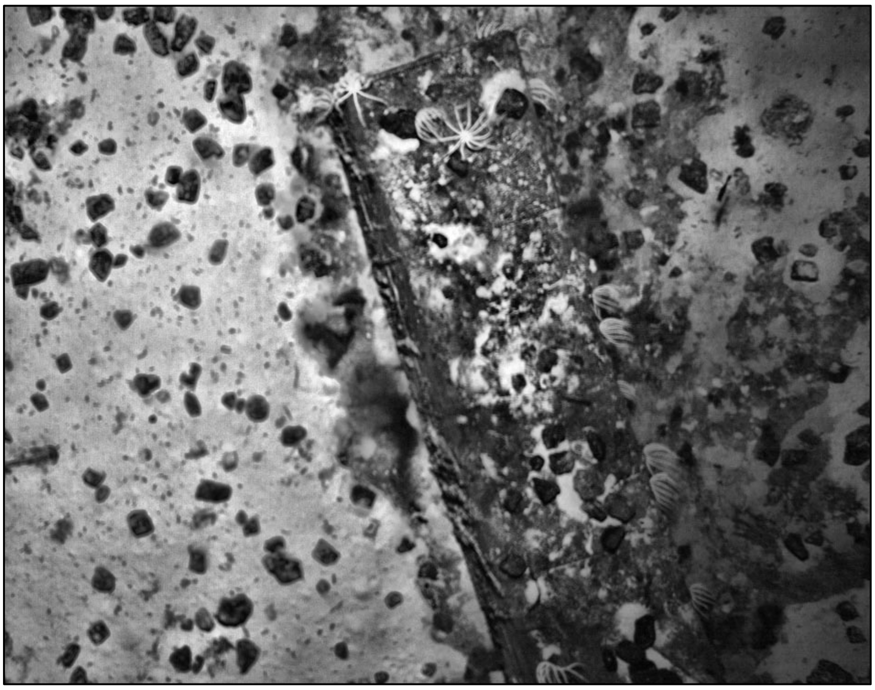

Figure 22 Rectangular iron water tank on IOS-001 site, with coal scattered around (Fugro/ATSB).

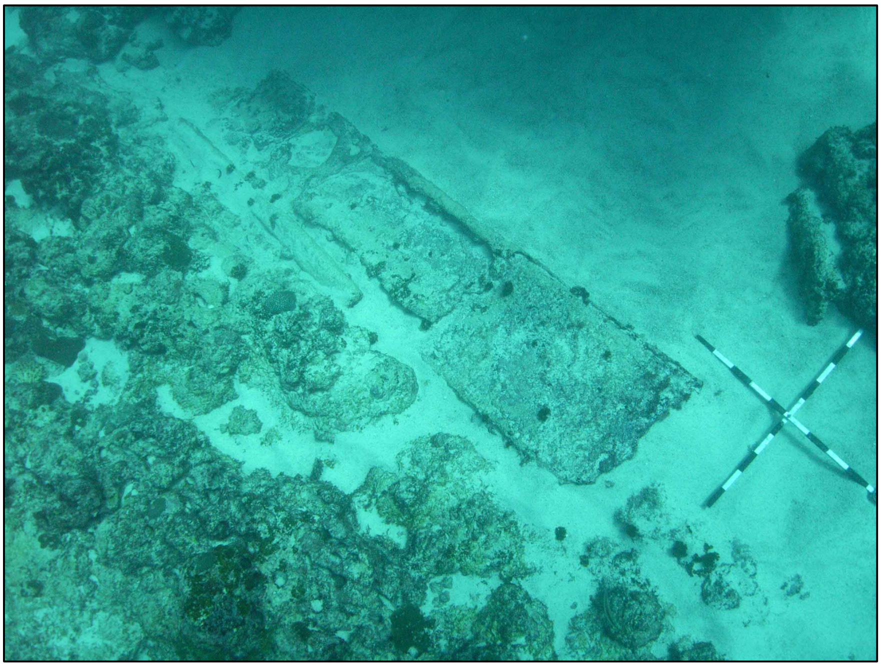

Figure 23 Remains of an iron water tank on the *Stefano* (1875) wrecked Point Cloates, Western Australia. Scale bar is 1m across. (Patrick Baker/ WA Museum).

Ballast

A small concentration of stone may be remains of ballast, or alternatively is a geological feature (Figure **24**).

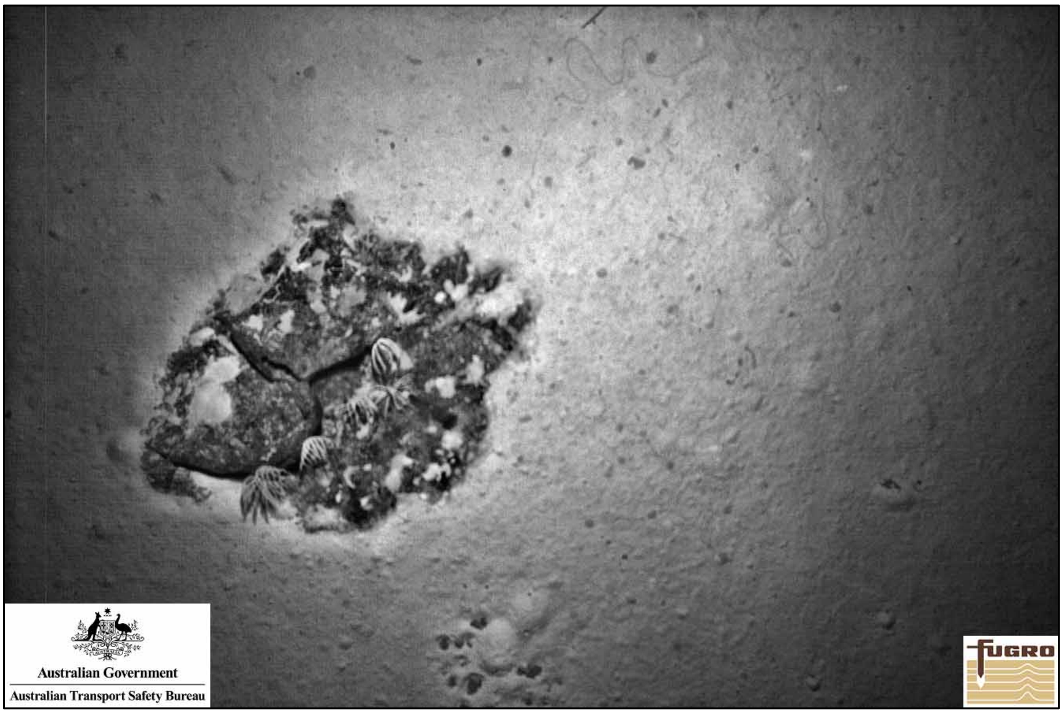

Figure 24 Possible stone ballast (Fugro/ATSB).

Coal

A large amount of coal is widely scattered over a 340 x 270m area of seabed, the extensive quantity indicating it is remains of the vessel's cargo.

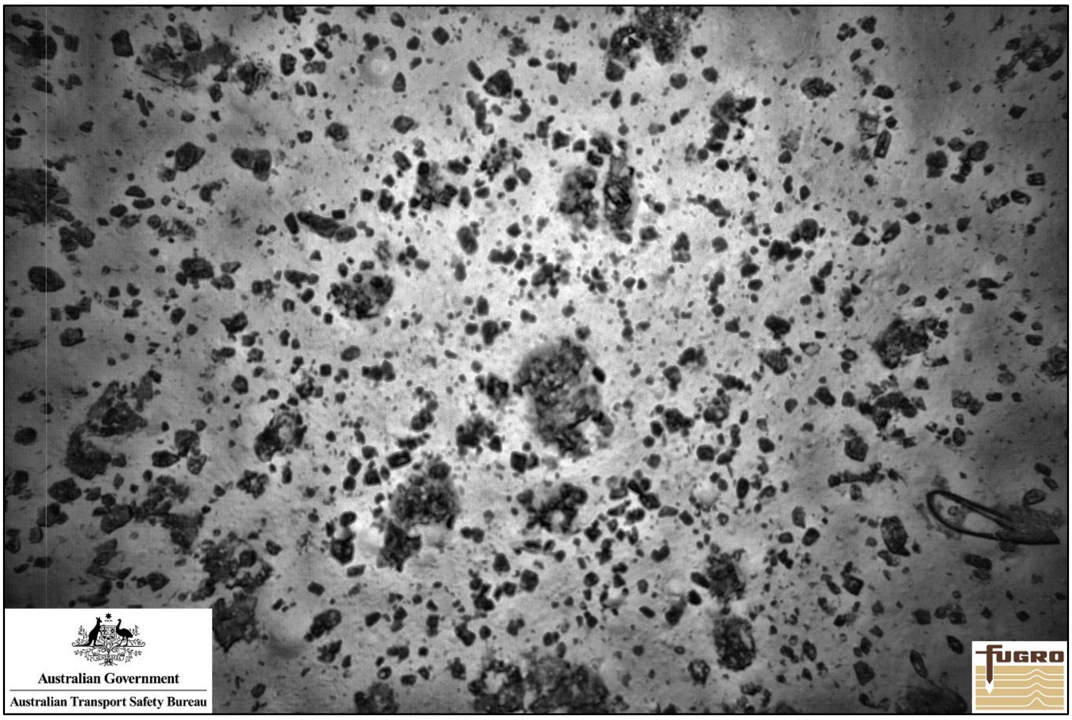

Figure 25 Scattered remains of coal cargo on IOS-001 site (Fugro/ATSB).

The mid to late 19th century industrial revolution saw a massive increase in the use and construction of steam engines, steamships and steam railways throughout the world, particularly in Europe and North America, and in European colonies in Africa, South America, Australia and Asia. The opening of the Suez Canal in 1869 reduced the distance for passenger, mail and cargo steamers travelling between Europe and India by 7,000km. Slower sailing ships carrying bulk cargoes including coal, lumber, grain and nitrates continued to ply the world's sailing trade routes. High quality steaming coal that burned efficiently was much in demand for use on steam ships, and high quality steaming coal was exported from European coalfields to Southeast Asia and China where there were no developed sources of quality steaming coal.

Of the coal shipped from the 19th into the 20th century the main commercial sources were America, Japan, Australia (Newcastle, New South Wales) and the United Kingdom (Lancashire, North Country, Scotland, Wales) (Thomas 1943: 123-124). Wales was regarded as having the best quality steaming coal, and development of the Welsh coalfields proceeded actively from 1850 when high quality steaming coals located in the Rhondda Valley in the Southern Welsh Coalfields were transported to docks at Cardiff, Swansea, Newport, Llanelli and Barry for export (South Wales coalfield n.d. [5/8/2015]).

As an inflammable fuel 'the carriage of coal is attended with risk both of fire and explosion, the loss of many lives and fine vessels being due to these causes' (Thomas 1943: 122). Coal releases 'marsh gas' (methane) that can ignite on contact with a spark, or it could spontaneously combust due to overheating. Surface ventilation was important to air out ships' cargo holds and other confined compartments into which inflammable gas could collect (*ibid*). The necessity of bunkering down cargo hatches in heavy weather such as experienced in the Roaring Forties meant there was less opportunity for ventilating the cargo, thereby increasing the risk of both methane build-up and over-heating, that could lead to spontaneous combustion.

Oil-fired boilers became increasingly common in both merchant and naval vessels from the early 20th century, diminishing the importance of coal as a fuel, and the associated coal shipping trade.

Marine biota

Marine biota is evident in many of the photographs including unidentified species of fish, jellyfish and sea cucumbers (Dr. Jane Fromont, pers. comm., 13/8/2015). Bioturbation is also evident on the seabed in the vicinity of the wreck. As there have been no scientific studies in this part of the Indian Ocean it is not known whether the presence of marine biota is directly related to the wreck site as both providing a habitat and a source of nutrients.

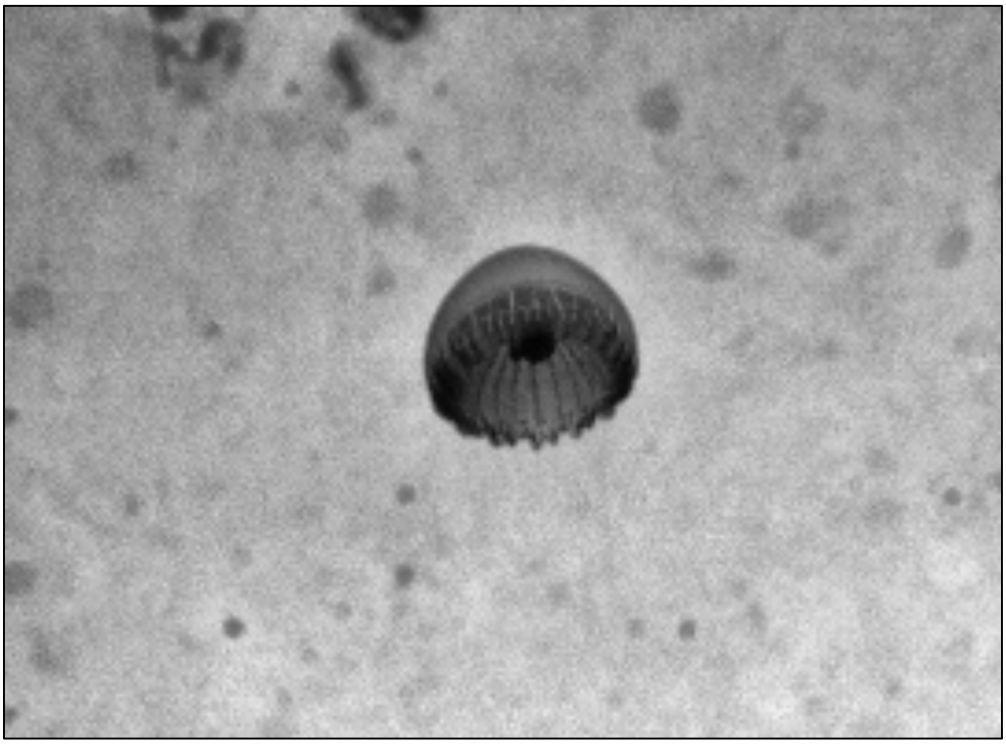

Figure 26 Unidentified jellyfish (Fugro/ATSB).

Figure 27 Unidentified fish (Fugro/ATSB).

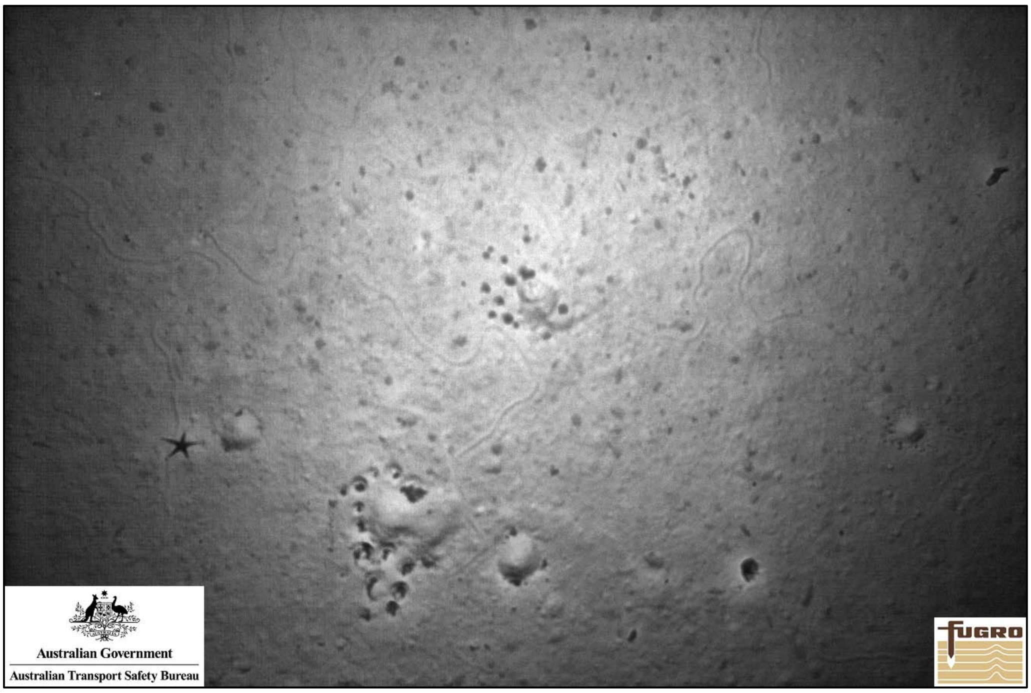

Figure 28 Bioturbation and starfish on seabed (Fugro/ATSB).

Site formation

The IOS-001 site is scattered over an approximately 460m by 630m area, with the main concentration of structural elements in an area of about 350m by 250m. The location of the chain mound in relation to other heavy iron components 245 m distant, the wide distribution of other heavy elements of the vessel such as anchors, and the widely scattered cargo of coal, indicate that the ship broke up prior to striking the seabed. The intact chain mound is an indication that at least the lower forepart of the vessel remained intact, and likely landed further east on the seabed than the main wreckage concentration as a result of hydrodynamic effects during the sinking process. Heavy iron objects remain proud of the seabed, indicating the seabed is likely to be a compacted sediment surface. The iron water tank made of relatively thin plate is still intact. While still likely to be suffering from corrosion, the low energy at this depth has allowed the structure to retain its intact form.

Biological degradation processes in the deep-sea environment are not well understood. As one of the deepest wooden wrecks yet located in the southern Indian Ocean the site offers significant information on long-term, deep-sea deterioration processes on wooden shipwrecks. Despite cold-water temperatures, no ultraviolet light and low oxygen levels, the ship's timbers have completely degraded as a result of biological and microbiological activity. Similar degradation processes have been observed resulting in the disappearance of timber deck planking, and disintegration of wooden ships' boats found on the wreck site of HMAS *Sydney* II (1941), in the eastern Indian Ocean in 2500m depth (McCarthy 2016: 194, 316).

Historical research

Wooden sailing ships continued to be used for deep-sea trades into the 20th century for transporting bulk cargoes such as lumber, coal, wheat and nitrates. While slow, they were cheap to buy and operate. The increasing prevalence of iron and steel steamships and more efficient steam engines led to the decline of wooden ships in deep-sea trades. Most vessels still remaining in the global deep-sea merchant sailing fleet were destroyed during World War 1, while the last commercial, deep-sea sailing trade carrying wheat between South Australia and Europe died out in the 1930s. The Norwegian merchant marine used ageing wooden, iron and steel sailing ships into the 20th century to carry bulk cargoes such as coal, timber, wheat and guano (Derry 1973: 118).

The IOS-001 site is located in 37° 40'S and 89° 02'E, northward of the track of the Roaring Forties, an important sailing route from the northern hemisphere to Southeast Asia, China, Japan, Australia and New Zealand. Detailed instructions for sailing the route from Cape Town for Singapore recommend:

> … from May to September take route across Indian Ocean…along the parallel of 39°S or 40°S, as far as about 75°E. From thence edge away to the NE crossing 30°S in about 100°E; and 20°S in 105°E, passing close W of Christmas Island, and up to Tandjung Gedeh (the E entrance point of Sunda Strait from the Indian Ocean). From October to March, take the trans-ocean route, as above, as far as about 75°E, thence steer to pass through 25°S, 98°E, and thence directly N for Sunda Strait, passing midway between Christmas Island and Cocos or Keeling Islands, and steering for Balimbing Pamantjasa on the W side of Sunda Strait, as in this season the E-going current is strong, and W'ly winds blow at times with considerable strength. During changes of monsoon, March, April and September-October, it is advisable to make easting until due S of the entrance to Sunda Strait, and then steer directly for it.
> (RAN Hydrographic Department, 1973,10.02.02)

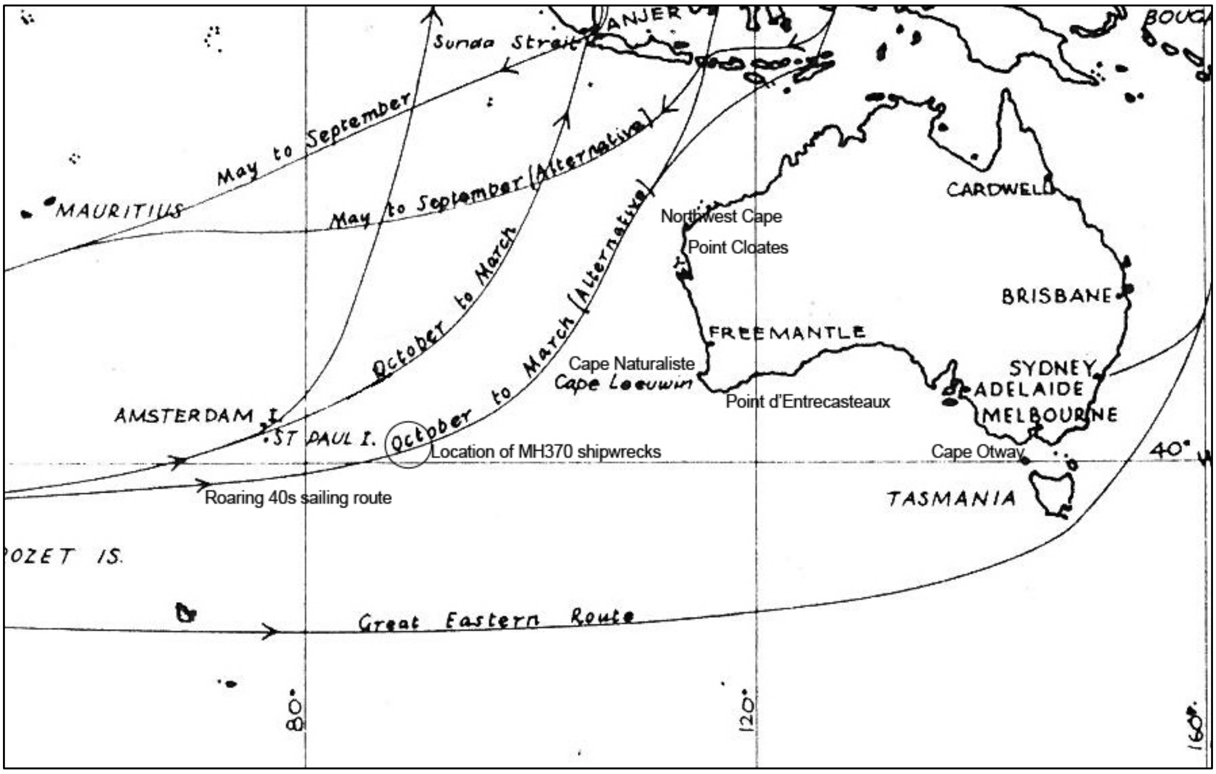

Figure 29 Location of MH370 shipwrecks circled in relation to major Indian Ocean sailing routes, with other locations mentioned in text. The wrecks lie along the recommended Europe to Southeast Asia/ China route between October and March ('Sailing ship routes to and from Eastern ports typical of those followed by Killick Martin & Co's ships'/ WA Museum).

Horsburgh (1841: 141) similarly states that ships bound from England for China passed via St Paul Island (Île Saint-Paul, 38°43'48"S, 77°31'20"E) in the Southern

Ocean then headed for the straits east of Java. If IOS-001 was heading from Europe to Southeast Asia or China, it would have only just departed from 39° or 40°S, and was on track intending to make passage for a port such as Singapore or Hong Kong. However the location leaves open the possibility that the vessel was making passage to an Australian destination such as Fremantle or Adelaide.

The Point Cloates area 130km south of Northwest Cape, Western Australian coast is a 'ship trap'. Its submerged reefs have claimed a number of European-Southeast Asia coal trade shipwrecks that were perhaps following the same Indian Ocean trade route as IOS-001. These include the wrecks of the 858-ton Austro-Hungarian wooden barque *Stefano* (1878) with a cargo of coal from Cardiff, Wales to Hong Kong; the 1415 ton British iron sailing ship *Benan* (1888), also with a cargo of coal from Cardiff to Hong Kong; and the Ningaloo Reef Unidentified (NRU) wreck, believed to be a mid-late 19th century wooden sailing ship carrying coal (McCarthy 2011, Souter 2011, Anderson 2011).

One possible candidate for identification of IOS-001 is the partly iron-fastened, 286-ton wooden brig *W. Gordon* with dimensions of 118 x 28 x 11.8 ft (Lloyds Register 1875-75). While on a voyage from the Clyde, Glasgow to Adelaide in 1876 with ten crew, it disappeared after departing Cape Town in June 1876. While its cargo is not confirmed, during the 19th century coal was one of Glasgow's major exports (The Glasgow Story 2004). The name board of *W. Gordon* was found washed up at Cape Otway, Victoria in September 1876, where it is likely to have drifted from some distance away given the absence of any other related wreckage (Loney 1982: 55; Anderson 2003: 247).

Table 2 Coal-laden wooden sailing ships reported missing to the UK Board of Trade between 1878 and 1886, possibly lost in Indian Ocean

Name	Rig	Tonnage	Year missing	Voyage	Dimensions	Persons
Stratford	Ship	1389	1878	Dundee-Bombay	Not in 1878 Lloyds	25
Alpine	Barque	1108	1878	Cardiff–Singapore	200 x 35 x 22.9 ft	19
Magdala	Barque	395	1882	Penarth–Ternate, Moluccas	120.4 x 27.4 x 16.8 ft	11
Rajmahal	Ship	1302	1883	Liverpool–Bombay	224.5 x 36.9 x 22.8 ft	25

References: Board of Trade 1886; Lloyds Registers 1874-75, 1878-79; http://www.clydeships.co.uk/

Table 2 lists four coal-carrying shipwrecks reported missing between 1878 and 1886, which by their destination could have ended up in the southern Indian Ocean. Of these the barque *Magdala*, 395 tons, breadth 27.4 ft is the only candidate close to matching the size of the IOS-001.

In 1887 there were a number of reports of floating wreckage from a large wooden ship in the southern Indian Ocean along the Roaring Forties track. One of the reports read:

> "Captain Wilson, of the barque *Horsa*, which arrived in the Bay on Tuesday night from London, reports that when in 41°40 S., and 80°30 E., on May 4, he

passed within two ships' lengths of a large mass of wreckage. This happened on a very dark night with the ship going at about four knots per hour, and he is therefore unable to furnish any details. From what, however, could be seen, the wreckage appeared to be about 6 feet out of water and about 120 feet long. This might be the deck of a large iron ship, but what is more probable, part of a wooden ship. It would, perhaps not be the same as that sighted by the yacht *Sunbeam* and the ship *Glenesk*. As there are no ships now overdue to any alarming extent, it would be unwise to hazard an opinion as to the name of the ill-fated ship."
(*The Armidale Express and New England General Advertiser* 31/5/1887: 4)

A few months later between September and December 1887 two large sections of wreckage from a large, unidentified ship washed up on Western Australia's southwest coast between Cape Naturaliste and Cape Leeuwin. One section half a mile north of Calgardup Creek (Redgate Beach) was described as 'about one quarter a section of the bottom of a wooden vessel of apparently over 500 tons, lying bottom upwards'. The wreckage appeared to have been of recent origin, though as no rigging and spars had come ashore the wreck was considered to have occurred some distance away (Worsley, Worsley and Green 2012: 199).

Another drift wreckage site at Sandpatch Beach near Cape Naturaliste consists of four or five iron beams, and iron bolts concreted into rocks (Figure **30**). It is possible the Calgardup Creek and Cape Naturaliste drift wreckage is related to the unidentified floating wreckage seen in the Southern Ocean by Captain Wilson of the *Horsa* in 41°40 S., and 80°30 E four to eight months previously. Alternatively, the wreckage may be related to the shipwreck IOS-001, wrecked some 700km further east in 37° 40'S and 89° 02'E.

Figure 30 Iron bolts concreted into rocks at Sandpatch Beach just south of Cape Naturaliste, Western Australia, believed to be drift wreckage from an unidentified wooden shipwreck (Mr Ian Wiese/ WA Museum).

As seen from the above references, prevailing westerly winds and currents of the Indian Ocean have caused materials related to events occurring thousands of miles away to drift onto the western and southern Australian coasts. Other examples include a figurehead from the clipper ship *Blue Jacket,* destroyed by fire off the Falkland Islands in March 1869, that washed ashore on Rottnest Island in 1871 (*The West Australian*: 14/12/1933:15). In August 1881 a portion of a ship's bulwarks with the letters 'Know' and 's' painted on them were discovered at Point D'Entrecasteaux, south-west Western Australia, identified as being from the missing iron sailing ship *Knowsley Hall* (*Evening Post* 22/11/1879: 2; *The Age* 9/5/1880). When the Pacific and Orient Line (P&O) ship *Heythrop* caught fire off South Africa in November 1971, its Number 4 lifeboat was abandoned. In February 1973 the lifeboat floated into King George Sound, Western Australia after drifting an estimated 7000km (Mystery Bay 2006).

With thought to the crewmembers that lost their lives on the wreck, there were generally between 10 and 30 crew carried aboard merchant sailing ships. For example *Stefano* carried 17 crew, while *Benan* carried 28 crew. During voyages in the high latitudes ships' boats were often stored or lashed down to avoid their being swept away in high seas and gales, making their retrieval difficult or impossible in case of emergency. Even if the crew were able to launch and escape into the ship's boats the vastness of the ocean, exposure to harsh weather conditions, cold-water temperatures and their location far from land were factors working against their survival.

Discussion

Based on feature identification, IOS-001 is typical of a mid to late 19th century wooden sailing ship in the 225-800 ton range. Taking into account the evidence for the vessel breaking up prior to striking the seabed, and the susceptibility of coal cargoes to explode or catch fire, an explosion causing the catastrophic destruction and sinking of the vessel appears to be the most likely explanation for this vessel's loss.

On the basis of the coal cargo and the site's location along the Roaring Forties trade route to Southeast Asia, there is a high probability that the vessel was voyaging from Europe to a major Asian or Chinese port such as Singapore, Macassar, Batavia, Macau, or Hong Kong, or possibly to an Australian port such as Fremantle or Adelaide. The wooden barque *Magdala*, 395 tons, lost in 1882 while on a voyage from Penarth to Ternate with a cargo of coal, and wooden brig *W. Gordon*, 286 tons, lost in 1876 on a voyage from Glasgow to Adelaide (cargo not confirmed but may have been coal) are two possible candidates for identification. Further attempts at positive identification of this site are hindered by the lack of samples and artefacts that could confirm the likely location of construction of the vessel, provenance of domestic and cargo items, and its likely port of origin.

There is a potential link between unidentified floating wooden ship wreckage seen in position 41°40 S and 80°30 E in the Southern Ocean in May 1887, and drift wreckage belonging to a large unidentified wooden ship washed up at two places on the south-western Western Australian coast between September and December 1887. Alternatively, it may also be possible that the drift wreckage may be related to the wreck of IOS-001, wrecked further southeast in 37° 40'S and 89° 02'E.

IOS-002

Site discovery and location

On 19 December 2015 the MH370 search team located a second shipwreck (MH370 Operational Update, 13/1/2016) at coordinates 37°53'28"S, 88°59'14"E, lying 36 km SSW from the IOS-001 site.

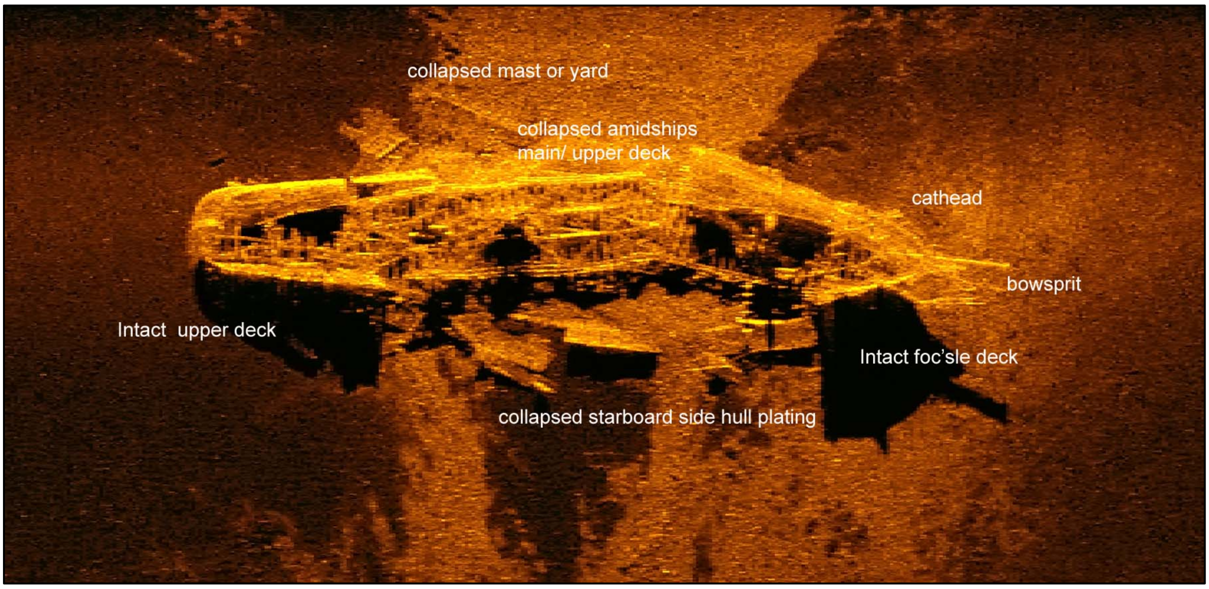

Figure 31 High-resolution sonar image showing key features (Fugro/ATSB/ WAM).

Site recording

Fugro's survey vessel *Havilah Harmony* deployed an AUV to capture high-resolution sonar imagery flying over the wreck site at 30m above seabed level (Figure **31**). Due to the height of the wreck above the seabed posing a risk to AUV navigation, and other operational MH370 search priorities, a high-resolution photography mission that would require the AUV to navigate at 10m flying height above the seabed was not undertaken.

Subsequently, on 19 November 2016, the Chinese MH370 search vessel *Dong Hai Jiu 101* returned to the site to undertake an ROV mission using a Remora III ROV, which provided video footage and enabled the recovery of coal samples. This provided valuable additional data to further attempts to identify the wreck.

Site environment

The vessel is lying upright on a flat or slightly undulating seabed, in 3732m depth. The sonar data exhibited some reflectivity from the environment surrounding the site that appears to be connected to the breaking up of the wreck and its contents, which the ROV survey subsequently confirmed to be remains of the coal cargo. The side scan sonar data showed two major areas, HH0009–identified as an iron sailing shipwreck–and HH0009A, which an ROV survey undertaken on 19 November 2016 confirmed to be a widely scattered (approximately 700 x 350m) area of coal, along with a ship's deck ventilator and an 4 ft cubic (1.22 m cubic) iron ship's water tank (Pearson 1992) (Figure 32). The two sites are clearly related to the same wrecking event.

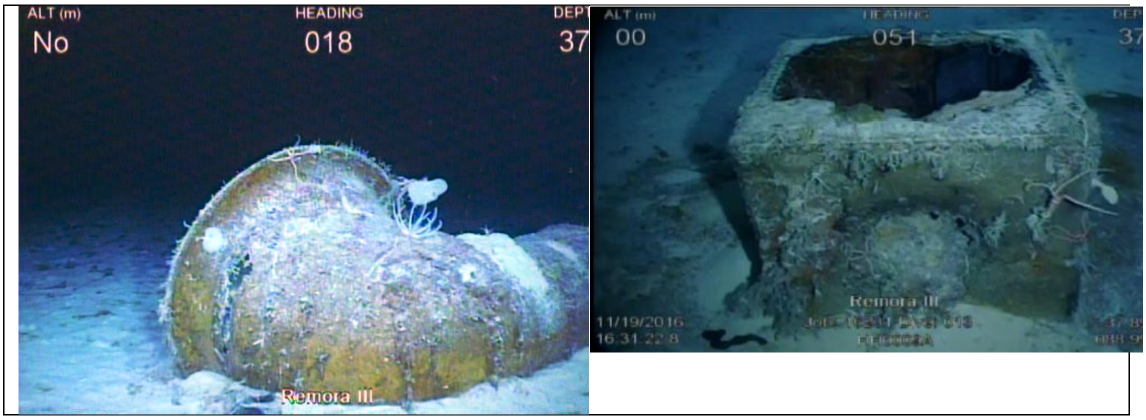

Figure 32 Ship's ventilator and iron tank in Area HH0009A (ATSB)

Figure 33 Side scan sonar record showing IOS-002 shipwreck (contact HH0009) lying 700m northwest of contact HH0009A (Fugro/ ATSB)

Site description and features

The sonar data depicts features typical of a large 1860-1890s iron, two-decked sailing ship in the range of 1000-1500 tons. The sonar images were of good quality allowing identification of key structural features. The different sonar runs show different aspects and details of the features, due to acoustic shadowing.

Features identified include deck beams, longitudinal tie plates, what appears to be at least two levels of deck stringer plates (supporting its identification as a two-decked vessel), an intact forecastle (foc'sle) deck, a beak-head structure protruding below the bowsprit, rudder quadrant and rudder quadrant, anchor catheads, and an elliptic counter stern. The beak-head feature is typical of earlier iron sailing ships constructed prior to 1880.

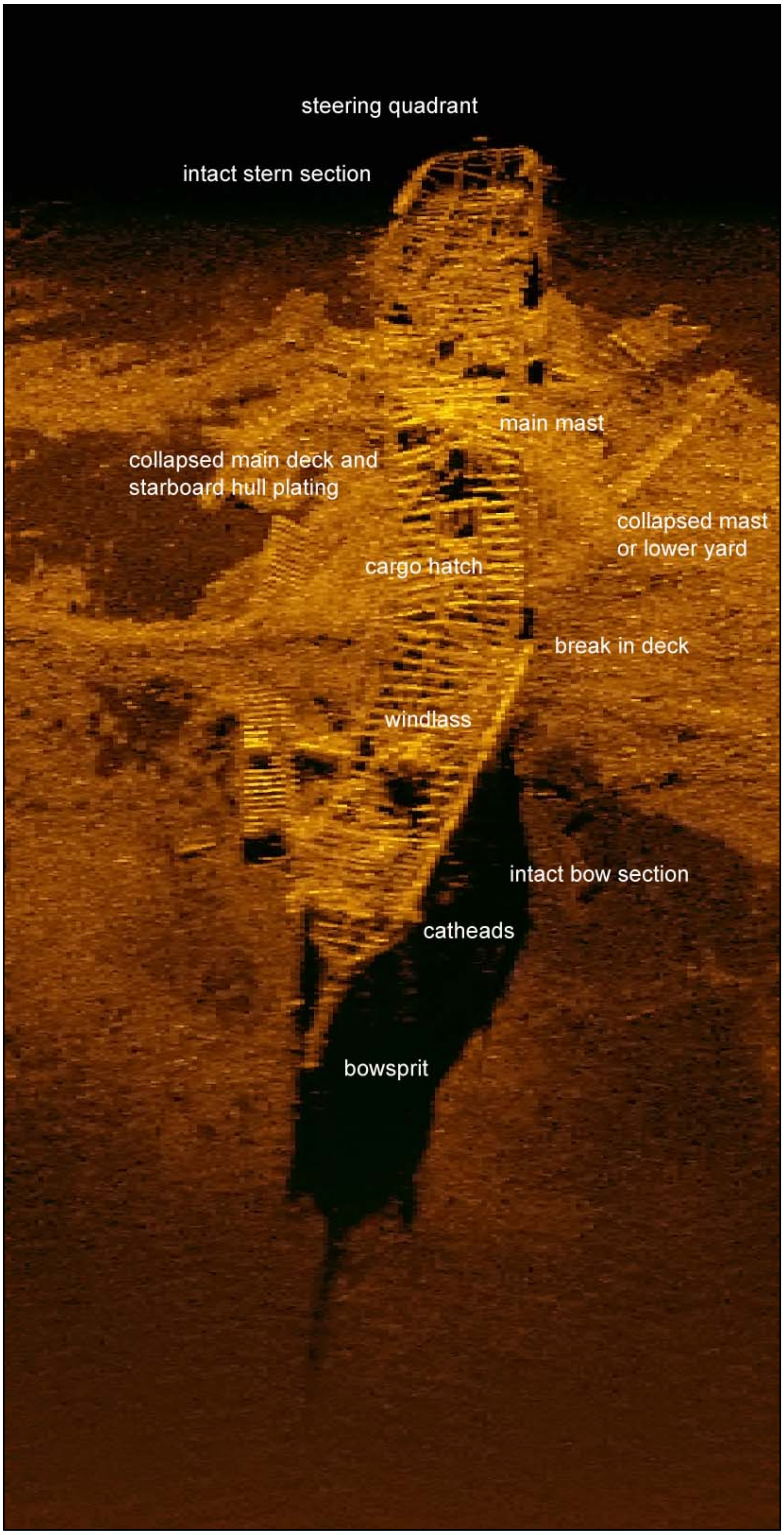

Figure 34 High resolution sonar image showing key features (Fugro/ATSB/ WAM).

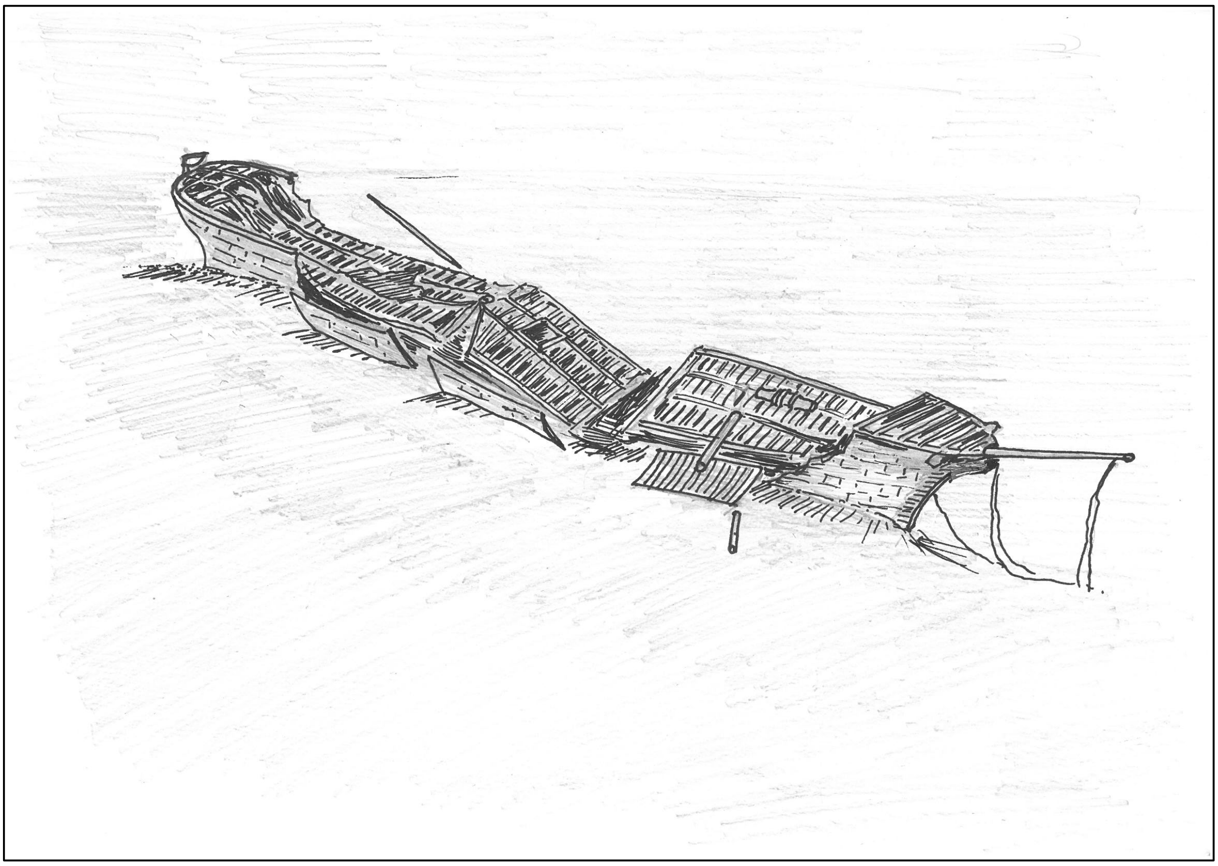

Figure 35 Impression of IOS-002 shipwreck site (R. Anderson/ WA Museum).

Vessel measurements

As the flying height of the AUV above the seabed is known, sonar geometry can be used to calculate measurements of the structure, that may in turn be correlated with historically known measurements for iron ships known to have been lost, or possibly lost, in the Indian Ocean (Figure **36**, Table 3).

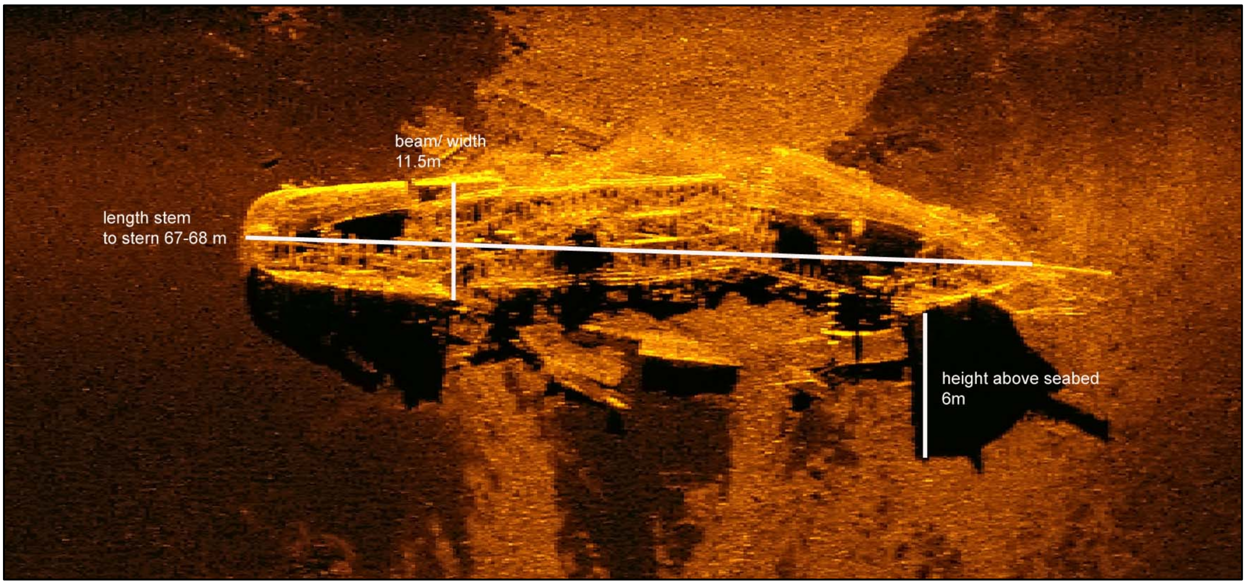

Figure 36 Key measurements from sonar data (Fugro/ATSB/ WA Museum).

Table 3 IOS-002 measurements obtained from sonar data

Description	Measurement	Notes
Orientation	295°	Bow heading WNW
Length overall including bowsprit:	75m / 246 ft	
Length from bow to stern at deck level (not including bowsprit)	67-68m/ 219.8-223.09 ft	Waterline length is likely to be slightly less
Forecastle (foc'sle) deck length	5m / 16.4 ft	Could be broken-may not be total original length
Bowsprit length:	7m/ 22.96 ft	
Fore main deck – starboard side	11m/ 36.09 ft	
Fore main deck – port side	21m/ 68.9 ft	May be erroneous – difficult to tell if foc'sle or main deck
Intact deck structure at stern	19m/ 62.34 ft	Difficult to tell if main or poop deck, probably main deck
Maximum beam at break in aft main deck	11.5m/ 37.7 ft	No intact deck to take amidships measurement, maximum beam likely to be slightly larger
Height of main deck at stern from seabed	4m/ 13.12 ft	
Maximum height from seabed at bow	6m/ 19.7 ft	

Official survey measurements for vessels were taken by measuring the length of hull from the sternpost to the forepart of the stem, usually at waterline level. Small discrepancies in overall measurement taken from the sonar data may arise as the length of the shipwreck's deck extends beyond the sternpost and forepart of the stem. Other small differences in measurement may result from the process of taking manual measurements from the sonar record, and the collapsing structure of the wreck. Therefore the shipwreck measurements may be slightly different to the hull measurements as surveyed and recorded in Lloyds Registers. Based on the sonar measurements, ships that are candidates for identification should have a maximum length of between 67m and 68m (219–223 ft) and therefore be in the range of 1000-1500 tons, allowing for some discrepancies as discussed above.

Features identified in ROV survey

A number of key features were identified from the ROV survey. These included deck rails and stanchions on the bow confirming that the uppermost bow/forecastle deck is intact (Figure 37), with two Admiralty type anchors stowed flat on the deck (Figure 38). The bow also has a beak-head typical of earlier-built iron ships (1850-70s) with what appears to be decorative scrollwork and either be a metal figurehead, or mounting point for a wooden figurehead. Scuttles (portholes) and steering gear machinery on the stern show that the upper stern is also intact (Figure 40), although it remains unclear if the vessel is flush-decked, or has a poop deck. At the stern the lower hull is buried almost to the top of the rudder, probably as a result of impact, and indicating the sediment is likely to be a moderately soft sand, mud or clay. The vessel is of riveted iron construction, with at least two decks (Figure 41, Figure 43).

Figure 37 Starboard side of bow buried in seabed, with intact deck railings, clipper bow, beak-head and bowsprit (ATSB)

Figure 38 Two Admiralty anchors and chain stowed on the intact foc'sle deck (ATSB)

Figure 39 Spare folding stocked Admiralty anchor with chain on main deck, and foremast stump (ATSB)

Figure 40 Intact counter stern with intact portholes and anenomes (ATSB)

Figure 41 Iron hull plating showing riveted iron frames and hull plating, with remains of coal cargo visible in foreground (ATSB)

Figure 42 Hull buried in seabed, collapsed outer hull plating (left), collapsed deck (top right) and a bulkhead in the foreground (ATSB)

In the amidships area of the vessel the deck beams and stringers have collapsed almost exactly on top of each other, with the thinner hull plating entirely corroded away and missing (Figure 43).

Figure 43 Two decks collapsed on top of each other, with hull plating missing (ATSB)

Machinery visible includes an iron windlass (Figure 44), bilge pump (Figure 45), worm-drive steering gear, a donkey boiler (Figure 46) and possible crane or winch.

Figure 44 Collapsed iron windlass with chain connected to iron capstan on forecastle deck (ATSB)

Figure 45 Manual bilge pump with lead piping visible (ATSB)

Figure 46 Donkey boiler and machinery (ATSB)

Figure 47 Intact hull with iron rigging chainplates for shrouds, with wooden deadeyes missing. A spider crab and anemone are visible (ATSB)

All timber has completely disappeared including timber deck planking and deadeyes (wooden pulley blocks usually made of *lignum vitae* and having a higher resistance to biological degradation) from the chain-plates (hull-mounted supports for the standing rigging/ shrouds) (. While much intact hull plating appears to be sound, in one area the hull plating shows evidence of ragged edges and extensive surface corrosion products, which may be an indication of heat or fire damage (Figure 48). This phenomenon has been observed on the HMAS *Sydney II* shipwreck relating to fires as a result of battle damage (McCarthy 2016: 209; Anderson & Bigourdan in McCarthy 2016: 316), and is relevant to discussion as to the possible cause of wrecking being a fire or explosion in the coal cargo.

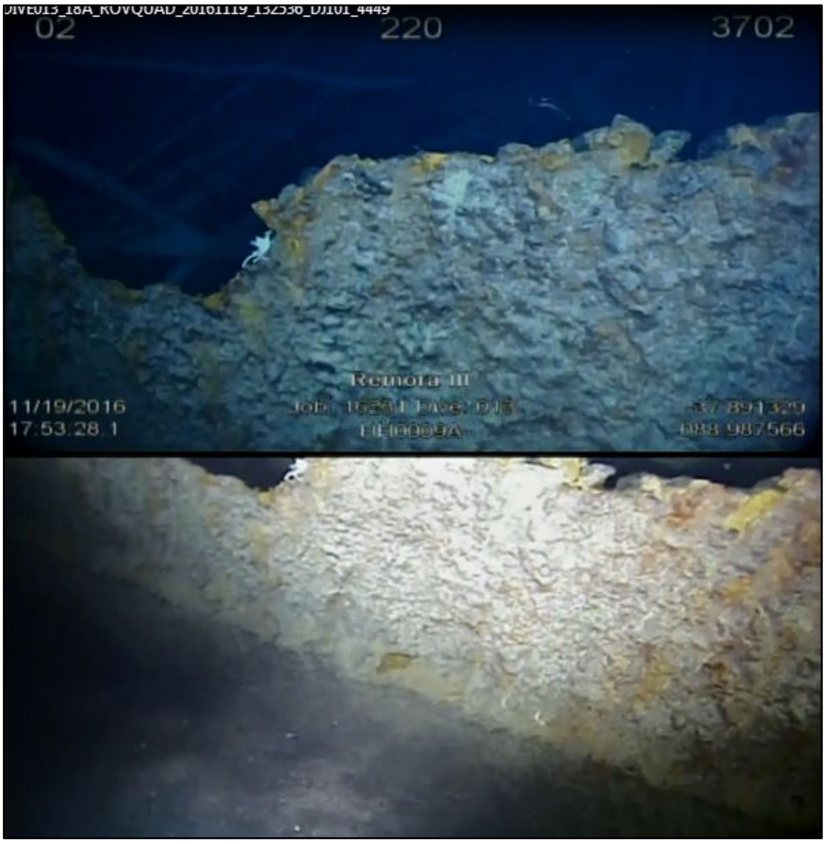

Figure 48 Hull plating surfaces showing extensive corrosion products, possibly related to heat/ fire damage (ATSB)

Coal cargo

The Remora III ROV manipulator arm was used to obtain a sample of coal for analysis (Figure 49). The sample was sent to Geoscience Australia in Canberra with palynological analysis undertaken by Honorary Associate Professor Michael McPhail at the Australian National University's Department of Archaeology and Natural History. McPhail confirmed the coal to be Late Carboniferous [age limits 318-299 million (Ma) years] and probably British in origin, supporting a port of departure in the United Kingdom (McPhail 2017).

Figure 49 Remora III ROV manipulator arm recovering coal sample (ATSB)

Site formation

The wreck is breaking up according to the 'Waterline Theory' of site formation where iron vessels lying upright on soft sediment sink to their approximate waterline (Riley 1985), with the less well-supported hull plating and deck in the amidships area of the wreck collapsing first, leaving the more structurally rigid bow and stern triangles intact. The fact that only iron deck beams are visible on the sonar images indicates that the ship had a wooden deck that has since completely deteriorated. With the exception of the bowsprit and a collapsed mast section or lower yard off the port stern, there are few visible remains of standing rigging elements such as iron mast and yard sections, typically found on iron sailing shipwrecks in shallower waters. This could indicate that the ship was either dismasted prior to sinking, or alternatively that the standing lower masts broke off from the ship's hull during the dynamic forces of the sinking process. The coal cargo appears to have spilled out

Historical research

Available secondary sources were consulted for information on iron sailing ships that had disappeared between the United Kingdom and Australia/ New Zealand (Table 4). Due to a lack of published research on vessels that have disappeared between American/ European ports and Australian/ Asian ports, this research is not comprehensive. The vessels *Inca* (1911) and *København* (1928) are included for comparison as there has been speculation in the media about these ships being possible candidates for identification, however neither are considered possible candidates as the *Inca* most likely disappeared in the Pacific Ocean and is too small, while the *København* is too large.

Table 4 Large iron sailing ships recorded to have disappeared on voyages to or from Australia

Name and date lost	Dimensions (length x breadth x depth) and voyage	Comments
***Assaye* (1868-1890)**	227.4 x 35.9 x 24 ft, 1351 tons, voyage London to Wellington, New Zealand	close to right size – but believed to have struck the Snares off south coast NZ
***Culzean Castle* (1875-75)**	259.3 x 40.5 x 23 ft, 1818 tons, Voyage Liverpool, UK to Melbourne with 40 emigrants and crew	too large
***Inca* (1889-1911)**	212.5 x 34.6 x 20.1 ft, 1058 tons, voyage Callao, Peru to Newcastle, New South Wales	too small – Pacific voyage - unlikely to be in Indian Ocean
***Knowsley Hall* (1873-79)**	260 x 42.3 x 23.9, poop 56ft, foc'sle 40 ft, 2 decks, voyage London to Lyttleton, New Zealand with 55 passengers and 35 crew	too large – part of wooden name board found washed up at Point d'Entrecasteaux, Western Australia
København (1921-1928)	430 ft (130m), 3965 tons, Danish sail training vessel on voyage Buenos Aires, Argentina to Australia with 75 crew and sailing cadets	too large
***Kooringa* (1874-94)**	226 x 35.2 x 21.6 ft, 2 decks 1206/1175 tons, voyage London to Brisbane	close to right size – last spoken to in South Atlantic 8 April 1894 – candidate for identification
***Lake Ontario* (1868-97)**	217.7 x 34.7 x 21 ft, 1096 tons, 2 decks, b. 1868, disappeared voyage Liverpool to Wellington, New Zealand	close to right size – candidate for identification
***Loch Laggan* (1872-75)**	243.1 x 37.8 x 22.8 ft, 1504 tons, voyage Liverpool UK to Melbourne with general cargo	too large -possibly wrecked in extensive iceberg field reported near Crozet Islands in 42° south
***Marlborough* (1876-90)**	228 x 35 x 21 ft, 1191 tons b.1876, disappeared on voyage Lyttleton, New Zealand to London in 1890	close to right size – but outward voyage, believed to have struck iceberg near Cape Horn
***Miltonpark* (1882-1903)**	255.7 x 38.3 x 20.6 ft, 1520 tons, 2 decks, poop deck 25 ft, voyage Liverpool, UK to Fremantle with machinery for Midland railway workshops	too large
***Rodenbeck* (1892-1906)**	251.8 x 39.7 x 21.8 ft, 1736 ton steel German barque, voyage Liverpool, UK to Sydney and Newcastle	too large
***Savoir Faire* (1863-94)**	216.8 x 36 x 25 ft, 1454 tons, voyage Geelong to UK	Close to right size – but on outward voyage and believed likely to have wrecked at Cape Horn
***Strathnaver* (1865-75)**	200 x 34 x 21 ft, 1017 tons	too small – outward voyage from Sydney to UK

***West Riding* (1875-95)**	203.9 x 33.6 x 19.9 ft, voyage London to Fremantle	too small

Sources: Shipwrecks on the UK-Australia run n.d.; Lloyds Register of Shipping 1874-1905; Australian National Historic Shipwrecks Database.

Table 5 Coal-laden iron sailing ships reported missing between 1878 and 1886, possibly in southern Indian Ocean

Name	Rig	Tonnage	Year missing	Voyage	Dimensions	Persons
Roopareil	Ship	1044	1878	Grimsby–Negapatam	207 x 34.3 x 21.1 ft	25
St Enoch	Ship	1853	1878	Dundee–Bombay	Not in Lloyds 1874-75, 1878	37
Dunscore	Ship	1640	1878	Sunderland–Singapore	Not in Lloyds 1874-75, 1878	33
Carradale	Ship	1242	1879	North Shields–Bombay	Not in Lloyds 1874-75, 1878	23
Rozelle	Ship	1286	1879	Newcastle-on-Tyne–Bombay	231.5 x 36.5 x 22.7 ft	27
Cape Sable	Ship	1416	1880	Sunderland–Singapore	239.4 x 37.2 x 22.5 ft	28
Ghazeepore	Ship	1496	1882	Shields–Calcutta	236.4 x 38 x 23.7 ft	34
Darjiling	Ship	1043	1883	Cardiff–Calcutta	Not in Lloyds 1874-75, 1878	35
West Ridge	Ship	1405	1883	Liverpool–Bombay	220.2 x 36.1 x 25 ft	28
Buckinghamshire	Ship	1466	1883	Shields–Rangoon	238.2 x 37.5 x 23.1	28
County of Aberdeen	Ship, 4 masted	1865	1884	Cardiff–Bombay	281 x 40.4 x 24.1 ft	30

References: Board of Trade 1886; Lloyds Registers 1874-75, 1878-79; http://www.clydeships.co.uk/

Table 5 lists ten coal-laden iron sailing ships reported missing between 1878 and 1886 that could have disappeared in the southern Indian Ocean, while following the Roaring Forties sailing route to reach Indian or Asian ports.

Vessels were assessed as candidates for identification based on their recorded dimensions fitting the wreck dimensions, and if they were on an inward-bound voyage (i.e. carrying British coal to an Indian, Australasian or Asian port. All dimensions provided in secondary sources were checked with Lloyds Shipping Registers where possible. Sailing ships on outward-bound voyages to the United Kingdom from Australia or New Zealand either headed east across the southern Pacific Ocean with prevailing trade winds via Cape Horn, or took a more northerly route in the Indian Ocean following the easterly tradewinds, and were therefore not included as candidates for identification.

Discussion

Candidates for identification

From the information available from primarily British sources, the vessels that most closely match the dimensions of IOS-002 on outward voyages from Europe to Australasia/ India/ Southeast Asia are *Kooringa* (1894), *Lake Ontario* (1897) and *West Ridge* (1883). *Kooringa*'s length measurement of 226 ft/ 68.8m is within 0.8m of the maximum size calculated from sonar measurements, while *Lake Ontario*'s length measurement of 217.7 ft/ 66.35m is within 0.65m of the minimum size. The

West Ridge's recorded length of 220.2 feet (67.12m) exactly matches the IOS-002 measurements.

The flush-decked iron barque *Kooringa* (Figure **50**) disappeared in 1894 during a voyage from London to Brisbane, Queensland with a general cargo, while *Lake Ontario* disappeared in 1897 on a voyage from Liverpool to Wellington, New Zealand. Of the above vessels only the *West Ridge* was recorded as carrying a cargo of coal, and is the favoured candidate for identification.

Figure 50 IOS-002 would have closely resembled the 3-masted iron barque *Kooringa*, which disappeared in the Indian Ocean in 1894 while on a voyage from London to Brisbane (A.D. Edwardes Collection/ State Library of South Australia, PRG 1373/7/16/).

The *West Ridge* was a 1,405 ton iron barque built in the Dobie & Co. shipyard in Glasgow in 1869 with dimensions of 220.2 x 36.1 x 25 ft (67.12 x 11 x 7.62m), registered to the port of Liverpool, owner Mr W. Sproule. It had two bulkheads, two decks, a raised quarterdeck and a foredeck 35 ft (10.6m) length (Lloyds Register 1878; *Liverpool Mercury* 1/2/1884). On its last voyage it was carrying a large cargo of British coal from the Brymbo and Broughton, New British, Plaskynaston, Black Park and Vron Collieries from Liverpool to Bombay (*UK Parliamentary Enquiry into missing coal ships 1878-1886*: 60-61), sailed by a multinational crew of 28 British, Scottish, Norwegian, Swedish, Canadian and Irish seamen, including its master, John Arthur from Shetland (*Liverpool Mercury* 1/2/1884). It was last spoken to in 44º North, 9º West on 12 July 1883 before disappearing. The Court of Inquiry into its loss found that the cargo was 'particularly well ventilated' and therefore that explosion or spontaneous combustion was not considered to be the cause of loss (*UK Parliamentary Enquiry into missing coal ships 1878-1886*: 74). The description of being 'particularly well ventilated' and the presence of a ventilator on the IOS-002 site is some supporting evidence for the identification of *West Ridge*.

There remains a lack of comprehensive research into all sailing ships reported missing between Europe and India/ Southeast Asia, that negates any attempt at conclusive identification of IOS-002. Based on all the available historical and archaeological evidence at time of writing, the *West Ridge* appears to be the most likely candidate for IOS-002. While the *West Ridge* appears to be further east from the normal sailing track to its destination of Bombay, if it had become dismasted, unmanageable, was on fire or damaged in a leaking condition it may also have been trying to reach the closest port of Fremantle to obtain assistance or undertake repairs. Alternatively IOS-002 is another vessel.

Cause of loss

What are the most likely reasons for the vessel's loss? Being caught in a combination of high seas and winds during a severe low-pressure storm has caused the disappearance of numerous large ships, and such storms commonly occur in the Roaring Forties. Unlike modern steamships, iron sailing ships only had a single collision bulkhead up forward. With no watertight compartments to maintain buoyancy, an uncontrolled leak in one part of the vessel could be lead to sinking. Another possible cause of loss is collision with an iceberg or floating wreckage, causing the vessel to sink either immediately, or some time afterwards if repairs at sea and/or the ship's pumps could not prevent water ingress into the hull.

For example a newspaper report relating to the *Lake Ontario* describes how storm conditions in the Southern Ocean could cause the disappearance of deeply-laden, large sailing ships:

> THE MISSING BARQUE LAKE ONTARIO
> In connection with the posting of this vessel as missing on a voyage from Liverpool to New Zealand a Wellington paper remarks:—The weather has been of a most tempestuous character this year, as all the vessels arriving in New Zealand and Australian ports during the past few months report trying times when crossing the Southern Ocean. The experiences of the *Akaroa* which left Liverpool for Wellington some seven weeks later point to the *Lake Ontario* having encountered similar weather, in which she had only too probably foundered with all hands. The *Turakina* left London at the same time as the *Lake Ontario* left Liverpool and had to put into Algoa Bay in a disabled state, while the experiences of the ship *Soukar*, which left London in June, are still fresh in the minds of our readers. The *Lake Ontario* would necessarily be very deeply laden, and would catch the full effects of adverse weather. Her crew with one exception—William J. Hiley—were all Germans, and Captain Prindt was in charge. The hopelessly overdue barque was posted at Lloyd's this month.
> (*The Sydney Morning Herald*, 3/12/1898)

For ships carrying cargoes of coal, explosion or spontaneous combustion was a constant danger. Over an eight year period between 14th August 1878 and 30th June 1886, 302 British-registered ships carrying coal cargoes disappeared at sea, although only some of these losses were considered to have been caused by coal fire or explosion, with other possible causes being overloading, collision, foundering in a gale or improper stowage. There were additionally 147 cases of gas explosions in coal cargoes causing total loss or partial damage; 23 cases of spontaneous combustion in coal carried for ships' use; and seven cases of gas explosions in coal carried for ship's use (*UK Parliamentary Enquiry into missing coal ships 1878-1886)*.

The ROV footage showing extensive corrosion patterns on the hull consistent with fire damage (whether as a result of spontaneous combustion or explosion) is one possible clue to the fate of IOS-002, though this is not conclusive.

Summary

Search efforts to locate the missing Malaysian Airlines Boeing 777 aircraft MH370 have so far located two shipwrecks dating from the mid to late 19th century in international waters. For IOS-001 the wooden brig *W. Gordon* and wooden barque *Magdala* are two possible candidates for identification. For IOS-002, the iron barques *Kooringa* (1894), *Lake Ontario* (1897) and *West Ridge* (1883) are possible candidates, with the *West Ridge* best fitting the archaeological evidence and available historical sources. It is important to note that these attempts at identification are based on incomplete historical information from predominantly British historical sources. Future research into British and foreign archives may identify other possible candidates–therefore identification remains speculative at this stage.

Both ships are likely to have carried crews of between 15 and 30 men, while it is known that captains sometimes travelled with their wives and children on international voyages. Both vessels may have carried additional passengers as well as cargo. Then, as now, the disappearance of so many lives in these shipwrecks would have had a devastating impact on 19th century families and maritime communities.

Being of wooden and iron construction respectively, the IOS-001 and IOS-002 shipwrecks provide valuable comparative information on long-term, deep-sea site formation and biological degradation processes. They are representative of the typical types of wooden and iron merchant sailing vessels used in international deep-sea trade during this time.

Both the sites also provide tangible archaeological evidence for use of the 'Roaring Forties' trade route utilised by sailing vessels making passages between Europe, North America, Australia, New Zealand, India, Southeast Asia, China and Japan.

Legal status and recommendations

While the shipwrecks have historic value, the discovery of unidentified shipwrecks of unknown nationality and ownership poses problems for their legal protection, as research cannot be carried out to confirm whether the ships' owners or insurance companies have maintained, or sold their ownership rights to the vessels' hulls and cargo over the years. Even if their nationality could be identified, being merchant vessels and not 'flag of state' vessels such as warships, sovereign ownership laws that automatically protect flag of state vessels would not protect them.

The location of both the IOS-001 and IOS-002 shipwrecks lie on the deep ocean seabed within an area defined as the 'High Seas' or 'the Area' (1958 UN Convention on the Law of the Sea (UNCLOS))—a zone beyond the limits of national jurisdiction. Thus the wrecks are currently not protected by any nation's historic shipwreck laws. As underwater cultural heritage over 100 years old in the Area, both IOS-001 and IOS-002 are protected under the *2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage. The 2001 UNESCO Convention* allows State Parties to effectively control intervention on historic shipwrecks in the Area, by managing vessels registered under their flag, or of vessels undertaking activities carried out from their ports. In relation to discoveries and reporting of underwater cultural heritage over 100 years old in the Area, Article 11 of the 2001 UNESCO Convention requires that:

Article 11 – Reporting and notification in the Area

> 1. States Parties have a responsibility to protect underwater cultural heritage in the Area in conformity with this Convention and Article 149 of the United Nations Convention on the Law of the Sea. Accordingly when a national, or a vessel flying the flag of a State Party, discovers or intends to engage in activities directed at underwater cultural heritage located in the Area, that State Party shall require its national, or the master of the vessel, to report such discovery or activity to it.
>
> 2. States Parties shall notify the Director-General and the Secretary-General of the International Seabed Authority of such discoveries or activities reported to them.
>
> 3. The Director-General shall promptly make available to all States Parties any such information supplied by States Parties.
>
> 4. Any State Party may declare to the Director-General its interest in being consulted on how to ensure the effective protection of that underwater cultural heritage. Such declaration shall be based on a verifiable link to the underwater cultural heritage concerned, particular regard being paid to the preferential rights of States of cultural, historical or archaeological origin.

At the time of writing Australia is not a signatory to the *2001 UNESCO Convention*, while Fugro vessels involved in the discovery of the shipwrecks were flagged according to their registry in the ports of Labuan, Malaysia (*Havilah Harmony*), Nassau, Bahamas (*Fugro Equator*) and Jakarta, Indonesia (*Fugro Supporter*)—countries that are also not currently signatories to the 2001 UNESCO Convention. In lieu of there being a State Party to the *2001 UNESCO Convention*, or vessel or master flying a flag of a State Party being clearly represented, as a State Party of the United Nations Convention of the Law of the Sea (UNCLOS) Australia can report the locations of the shipwrecks to the Director-General and the Secretary-General of the International Seabed Authority.

Recommendations

It is recommended that:

1) Further historical research to identify the wrecks should attempt to locate information on late 19th century wooden and iron merchant sailing ships recorded to have disappeared en route between Europe/ Americas and India/ Asia;
2) If an opportunity arises to undertake further scientific studies, underwater archaeological investigations to gather detailed data using ROVs and high-resolution close-up photography of the sites and any associated artefacts will further assist in identification of the sites;
3) That the Australian Government reports the location of the IOS-001 and IOS-002 shipwrecks to the Director-General and Secretary-General of the International Seabed Authority, as sites automatically protected under the *2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage*.

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