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German U-boats of the English Channel & Western Approaches: History, Site Formation & Impacts

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Of all the naval weapons of the early to mid-20th century, the German submarine, or *Unterseeboot*, was potentially decisive. Able to attack vital allied merchant shipping supply routes and enemy warships, the U-boat – as it was commonly known – was a major threat to the Allies. During both World Wars I and II the Western Approaches to the English Channel and the English Channel were important shipping routes and major areas of naval operations. As such, they became the final resting place of many U-boats and their crews.

Between 2005 and 2009 Odyssey Marine Exploration documented over 267 shipwrecks as part of its ongoing Atlas Shipwreck Survey project, including one World War I and eight World War II U-boat wrecks. In the summer of 2008 Odyssey invited U-boat expert Dr. Axel Niestlé to join its research vessel, *Odyssey Explorer*, in an expedition to survey and confirm positively the identity of five of these sites. Thereafter, the Odyssey team continued investigating the remaining four U-boat wrecks, studying and comparing site-formation processes and impacts of this interesting class of vessel.

This report presents an overview of submarine warfare before proceeding to examine each submarine's environmental condition, site formation, evidence of battle damage and post-depositional fishing impacts. Finally, the potential future preservation of the U-boats is discussed in relation to ongoing deterioration that may expose the interior hulls and their contents in the future.

1. Introduction: German Submarine Development

For centuries man has had the desire to explore the underwater world. Designs for submarines and breathing devices can be traced back to the 1500s. It was not until the 19th century that American and European inventors started building submarines that were true forerunners of modern boats. However, the first submarine ever sent into action against an enemy was the primitive American *Turtle,* built by David Bushnell to attack British warships in New York harbor, where several attacks failed in 1776 (Thacher, 1862: 62-63). Napoleon commissioned the first practical submarine, designed by the American inventor Robert Fulton. Testing of this craft, the *Nautilus*, was carried out successfully in France in 1800-01, when Fulton and three mechanics descended to a depth of 25 feet (Parsons, 1922: 33-38).

To understand the technology and significance of the U-boat it is necessary to look at its development. In Germany the first submersible and forerunner of the U-boat was Wilhelm Bauer's *Brandtaucher* (literally translated as 'Fire Diver') submarine of 1851. This three-man pedal-wheel propelled submarine was 8.07m long with a beam of 2.01m and draught of 2.63m. With a displacement of 20-30 tons the submarine was capable of 3 knots, but only for short bursts (Fig. 1). Unfortunately, the boat sank in

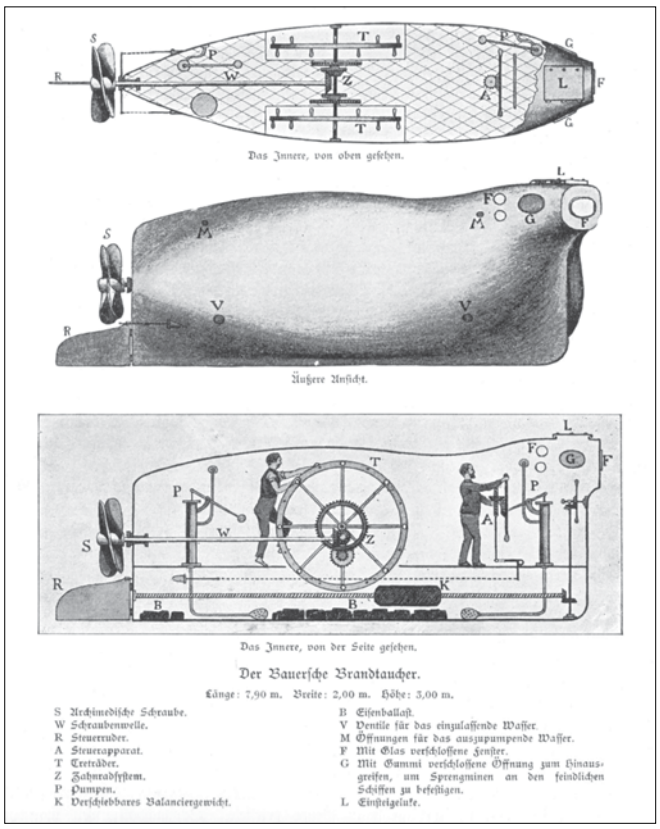

Fig. 1. Plan of the Brandtaucher submarine built by Wilhelm Bauer, which sank on acceptance trails in Kiel harbour, Germany, on 1 February 1851. From: Haas et al.*, 1896.*

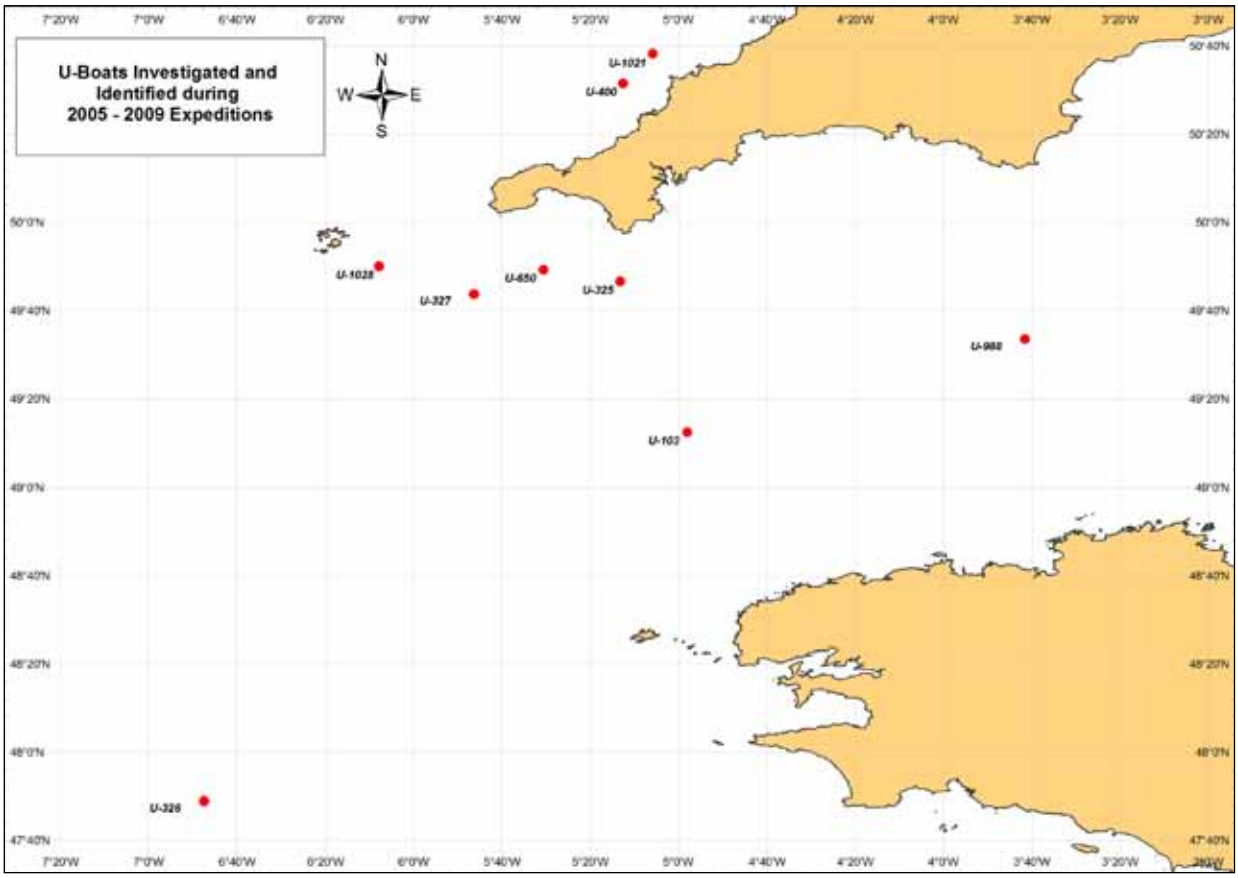

Fig. 2. Map of the locations of U-boat wreck sites investigated by Odyssey Marine Exploration, 2008-2009.

Fig. 3. U-2, the first totally German designed and built U-boat alongside the submarine tender Vulcan*, at Swine-münde, Germany, 1908. From: Mõller and Brack, 2004: 18.*

Kiel harbor on 1 February 1851 during acceptance trials (Mõller and Brack, 2004: 11-12).

The next attempt to craft a practical working submarine came in 1868 from Friedrich Otto Vogel, who built a 5.3m-long vessel with a specially-adapted steam engine (Rössler, 2001: 14). This submarine was broken up after trials as it was neither watertight nor built sufficiently strongly. Subsequent designs and funding were not granted, and Vogel eventually gave up to resume his teaching career in Saxony (Mõller and Brack, 2004: 12).

Interestingly, one strange event was the report of a 16m-long spindle-shaped submarine constructed of wood and copper/brass sheet plating, tested at Howaldt, Kiel, in 1891. Subsequent investigation by the German Inspectorate of Torpedoes in 1902 discovered that the submarine was actually in a dock in Hamburg and was of American design and build. Known as the Howaldt Diving-boat of 1891, the Inspectorate concluded that the vessel was not suitable for naval purposes (Rössler, 2001: 14).

The only other functional submarine built by the Germans before 1900 was the Howaldt Diving-boat, Construction Number 333, of 1897. An underwater torpedo boat of 15m in length and 2m diameter, built at the Howaldtswerke shipyard in Kiel, this vessel was fitted with an electrical propulsion system and torpedo armament (Mõller and Brack, 2004: 14). Designed by Karl Leps, a German torpedo engineer, this submarine survived its trials, but was ineffective and did not have much military

Country	Sunk	Damaged	Taken Prize	Total
British	228	26	--	254
Norwegian	66	2	1	69
Italian	48	1	--	49
Danish	29	4	3	36
French	32	--	--	32
Greek	17	1	--	18
American	9	1	--	10
Russian	9	--	--	9
Dutch	8	--	--	8
Spanish	3	2	--	5
Swedish	4	1	--	5
Belgian	4	--	--	4
Portuguese	4	--	--	4
Egyptian	2	--	--	2
Canadian	2	--	--	2
Argentinean	1	--	--	1
Brazilian	1	--	--	1
Turkish	1	--	--	1
Uruguayan	1	--	--	1
Finnish	1			1
Sub Totals	**470**	**38**	**4**	**512**

Table 1. Shipping losses to German U-boats for April 1917 (extracted from www.uboat.net).

potential. Although it played an important part in the continuing development of German submarines, the project was eventually scrapped (Williamson, 2002a: 4).

Using a French submarine design, in 1902 Spanish engineer Raymondo Lorenzo d'Equevilley-Montjustin submitted plans for a submarine to F.A. Krupp, a German armament manufacturer based in Essen, Germany. In 1903 the submarine named *Forelle* (*Trout*) was launched. This was the first truly successful German submarine. Spindle-shaped, 13.3m long with a displacement of 15.5 tons and powered by a 65hp shunt electric motor, this submarine carried two torpedoes, was capable of 5½ knots underwater with a range of 25 nautical miles at 4 knots (Rössler, 2001: 16). It performed well in trials, although because of its limited range it was proposed to be carried on the deck of a surface warship from which it would be launched when required (Williamson, 2002a: 4).

The German Imperial Navy was not fully committed to the concept of submarine warfare and as a result did not place any orders to build sister vessels to the *Forelle*. However, the Russians were impressed, and due to their war with Japan wanted to develop their navy with new technology and weapons. In 1904 they ordered three submarines to be built by Krupp (Rössler, 2001: 16).

German submarine development continued in 1904, when naval engineer Gustav Berling was tasked by the German Torpedo Inspectorate to oversee future submarine construction and development. Following three Russian submarine designs, U-1 was built at Krupp yard in Kiel and after many delays went into service in the German Imperial Navy in 1906. Admiral von Tirpitz was not fully convinced of a submarine's usefulness as a naval weapon and considered it as weakening his development of the German Fleet policy, and did not expect very much from U-1 (Rössler, 2001: 21).

It was not until 1908 that the first official totally German-designed and built U-boat was launched. U-2 was built at Kaiserliche Werft, Danzig. She was 45.42m long with a displacement of 341 tons and 430 tons submerged (Fig. 3). With a crew of 22 and two bow and two stern torpedo tubes, the submarine was capable of a surface speed of 13.2 knots and 9 knots submerged (Mŏller and Brack, 2004: 17). It served the war years in a training flotilla and was scrapped in 1920. Germany built a further two similar U-boats, which saw no active service.

It is worth noting that although Germany was cautious of its submarine development, this was not the case for the rest of the world in 1908. France possessed 60 submarines,

Function	No.	Type
Submarines built for export	6	Pre-war boat, Coastal
Gasoline-powered submarines	18	Pre-war boat
Ocean-going diesel-powered torpedo attack submarines	90	Pre-war boat, War Mobilization boat, U-ships
U-Cruisers & Merchant submarines	11	Modified Transport, U-Cruisers
UB Coastal torpedo attack submarines	136	UB I, UB II, UB III
UC Coastal mine-laying submarines	95	UC I, UC II, UC III
UE Ocean mine-laying submarines	19	UE 1, UE 2

Table 2. List of U-boats built by Germany in World War I (after Mõller & Brack, 2004: 16-63).

Great Britain had 68 and the United States of America had around 12. The bulk of these vessels were experimental, small and only fit for coastal defense, with a few unsuitable for any naval military purposes (Gibson and Prendergast, 2002: 346).

New specifications in military requirements for German submarine design led to the building of a further 14 U-boats, namely U-8 to U-18, between 1908 and 1910. It was not until 1913 that the first four diesel-powered submarines were built, leading to the development of successful ocean-going submarines. Up to the outbreak of the war the Germaniawerft (Krupp's shipbuilders) made great efforts to export their successful submarine technology. Russia, Austria, Norway, Italy and Turkey all placed orders for submarines (Rössler, 2001: 21). The Germans were certainly the world leaders in submarine construction and technology. However, it would take a war to realize the full potential of the submarine as a significant naval weapon.

Fig. 4. The M/V Odyssey Explorer *used as the research platform during the 2008-2009 U-boat expedition.*

2. The War Years

The following is a short summary highlighting significant factors in the history and evolution of German submarine warfare during World War I and World War II. This section provides a historical backdrop to the U-boat wrecks examined by Odyssey and discussed in this paper.

A. 1914-1918

In the build-up to World War I the German navy had not realized the significance and importance that submarines could exert on naval warfare. When war broke out in 1914 the navy only had 20 active U-boats and a further 25 in different stages of construction. In fact, the German navy had made no plans for the deployment of submarines against enemy ships and commerce. This was somewhat due to the fact that submarine attacks on merchant shipping would be at variance with German Naval Prize Regulations. These regulations, in unison with the international code of maritime law, and the 1909 Declaration of London, laid down the following principle (Gibson and Prendergast, 2002: 23):

> "The Declaration allowed belligerent warships to stop any merchant vessel at sea, board and inspect its registration and cargo documents, and search it for contraband. If such prohibited cargoes were found, the offending vessel could be seized and sent to port under a prize crew. In the event the warship could not do that, the vessel carrying contraband could be sunk, but only after 'all persons on board had been placed in safety'."

During the early period of the war both Germany and the Allies believed that the use of submarines would not contradict the Prize Regulations, since generally submarines were small, not well armed and handled badly at sea. However, the acceleration in submarine design and construction resulted in both sides accessing bigger and better-armed submarines that could operate over greater distances.

Both the Germans and the British realized that they would be under serious threat if the supply lines of food and goods into their respective countries were cut. By the end of 1914, the British had established a full blockade of merchant vessels proceeding to German ports. They also equipped various types of decoy vessels known as Q-ships.

Fig. 5. The ROV Zeus configured for Odyssey's U-boat expedition.

Fig. 6. U-boat expert Dr. Axel Niestlé conducting U-boat surveys from the Odyssey Explorer's *Offline Room.*

These apparently innocuous, neutral merchant vessels were fitted with concealed guns and some with depth charges and torpedoes. They posed a significant threat to any surfaced submarine (Gibson and Prendergast, 2002: 55). In retaliation, in February 1915 the Germans announced that they would conduct unrestricted submarine warfare around sea approaches to Britain and Ireland. However, after the sinking of the British passenger liner the *Lusitania* on 15 May 1915 by U-20, pressure from America and the Allies forced the Germans into following the Prize Regulations. By September 1915 the Germans had stopped submarine attacks on passenger ships and abandoned unrestricted attacks on merchant shipping (Williamson, 1999: 5).

Both the British and German navies chose to interpret the Prize Regulations to their own advantage. The United Kingdom openly mounted guns and, in some cases, placed trained naval gun crews on many of her merchant ships. In response, the Germans declared that they would sink, without warning, any merchant vessel equipped with guns. They also took the opportunity to move the bulk of the submarine fleet down to the Mediterranean, where the pickings were good and Allied warships were less experienced in anti-submarine warfare. It was indeed in this theater that German submarines recorded the greatest number of sinkings (Williamson, 1999: 5).

The year 1917 saw significant turns in the war. On 6 April America joined the Allies, bringing much needed military aid and personnel. The US entry had been provoked by the loss of 11 merchant ships in early 1917, all attributed to U-boat attacks.

The Germans re-introduced unrestricted submarine warfare and came very close to bringing Britain to its knees. To combat the ever-increasing loss of shipping, under pressure from the civilian government the British Admiralty reluctantly introduced the convoy system (the grouping of merchant ships under the protection of warships). The Admiralty's reluctance was due to the fact that insufficient cruisers were available for their protection. The first ocean convoy sailed at the end of April 1917. The success of the convoys greatly reduced the loss of merchant shipping and turned the tide of German attacks, eventually putting an end to the U-boat threat since the cruisers protecting the convoys could quickly confront any submarine if it attempted a surface attack or as soon as it fired a torpedo (Hague, 2000: 19).

The Germans developed larger cruiser type submarines, fitted with 6-inch guns, to attack convoys. These U-boats had some success. However, the use of hydrophones to detect submarines, depth charges and new mine technology all took their toll. Gradually Allied shipping production overtook the losses and more U-boats were being sunk (Williamson, 1999: 6).

The German high command lost faith in their U-boats as a weapon of victory, and in January 1918 only five of the 33 operational submarines were fit for service. By October 1918, peace negotiations were progressing and Germany halted attacks on merchant shipping. On 9 November 1918, all U-boats were ordered to return to home ports and prepare for surrender. The German nation was near a state of collapse, the blockade by Britain had worked and on 11 November 1918 the Germans signed the Armistice ending the war (Gibson and Prendergast, 2002: 331).

German submarine development had come a long way since the 19th century. The war had shown that the submarine was indeed a formidable weapon and as such changed the face of naval warfare. By the end of World War I the Germans had built 375 U-boats of 33 separate classes belonging to seven general types (Table 2). The German U-boats sank more than 11 million tons of shipping and damaged 7.5 million tons of shipping. However, this devastation came at a high cost, namely the loss of 178 U-boats and 5,364 men (Gibson and Prendergast, 2002: 352-64; Mŏller and Brack, 2004: 16-64).

B. 1918-1939

Although combat during World War I ended on 11 November 1918, the state of war did not end officially until 29 June 1919, when the Allies and Germany signed the Treaty of Versailles. Among the terms of truce was the requirement that Germany hand over all her U-boats and dismantle or destroy those under construction. The U-boats were distributed to Great Britain, USA, France, Italy and Japan. Of course, each of these countries fully studied the technology and construction for use in their own submarine programs (Williamson, 2002b: 3).

Although the treaty destroyed Germany's physical capacity, it did not take away its vast repository of knowledge and technical expertise in submarine development

Function	No.	Type
Coastal submarines	20	IIA, IIB, IIC, IID
Long-range submarines	186	IX, IXB, IXC, IXC/40, IXD
Atlantic submarines	673	VIIA, VIIB, VIIC, VIIC/41, VIIC/42
Mine-laying submarines	14	VIID, XB
Torpedo transport submarines	4	VIIF
Aircraft trap submarines	4	U-Flak
Supply submarines	10	XIV
Electro submarines	179	XXI, XXIII
Walter submarines	8	V 80, XVIIA, XVIIB, XVIII

Table 3. List of German U-boats in service in World War II (after Mǒller and Brack, 2004: 64-136).

and construction. In 1922 Germany began selling U-boat designs to Japan and cooperated with Argentina, Italy and Sweden on their submarine programs. At the same time, Admiral Paul Behncke, Commander-in-Chief of the German *Reichsmarine*, authorized secret construction of a new generation of U-boat. Under the cover of a fictitious Dutch shipbuilder and funded by the German navy, two submarines were built for Turkey and launched in 1927. The Germans were able to select crews and conduct trials on these submarines, thus gaining first-hand practical knowledge of their new design. They also set up a training program with a series of theoretical lectures on U-boat seamanship and warfare. All the time, Germany was keeping her hand in submarine development and training without breaking any of the terms of the Treaty of Versailles (Paterson, 2007: 15).

In 1933 the German defense minister established a submarine school. Named the Anti-Submarine School, or *Unterseebootsabwehrschule*, it provided theoretical training in all aspects of submarine operations using various simulators. Also during the 1930s Germany began building U-boat components, including frames secretly stored in warehouses in Kiel. In June 1935 U-1 was launched, a small Type IIA coastal submarine. At this time, Adolf Hitler formally declared that Germany would re-equip its army, establish an air force and build up a navy. Although this violated the Treaty of Versailles, Britain signed a Naval Agreement with Germany allowing them to develop a navy which would be less than half the size of Britain's (Paterson, 2007: 17).

As Germany once again headed towards war, the country wanted a navy that would be a force to be reckoned with. Key to this was the development of their U-boat service. This principle led to the formation of the U-boat School Flotilla, *Unterseebootsschulflottille*, and further development and construction of other U-boats (Paterson, 2007: 19). In charge of the U-boat service was Commander-in-Chief Karl Dönitz, who had served as a commander of a U-boat during World War I, was a very experienced submariner and who had fresh ideas on how to conduct submarine warfare in his new role. Dönitz believed that his submarines would be central to defeating the enemy, who he could starve of essential supplies just by attacking merchant shipping. Germany's U-boat building program continued and the Type IA and Type IIB U-boats were joined by the greatly improved Type VII, which became the mainstay of the German submarine fleet (Williamson, 2002b: 8). Dönitz pushed for the construction of a large force of 300 U-boats, but at the outbreak of war Germany only had 57 U-boats, many short-range, and only 22 ocean-going U-boats.

C. 1939-1945

At 11:00 hours on 3 September 1939, Britain declared war on Germany. At 22:00 hours on that day, U-30 torpedoed and sank the 13,581-ton Donaldson liner *Athenia* 400km north-west of Ireland. On the night of 7 May 1945, three days after the German forces had surrendered, U-2336 sank the small Canadian merchant ship *Avondale Park* off the Firth of Forth on the east coast of Scotland (Middlebrook, 2004: ix). These two chronological incidents demonstrate the significance of the U-boat as a primary naval weapon, showing that the World War II submarine campaign was the longest single battle of the war.

As an island nation, Great Britain imported all of her oil and most of her raw materials and food. The Germans knew they did not possess the naval strength to completely blockade the British Isles. They believed that attacking merchant shipping with their U-boats could bring Britain to its knees. Right from the start of the war the U-boats carried out a 'sink on sight' campaign against enemy merchant shipping. Germany was for the most part very careful to avoid attacking US ships. Also Germany wielded its *U-bootwaffe* against naval vessels – Günther Prien's daring attack on 14 October 1939 claimed the British battleship *Royal Oak* at anchor in her homeport of Scapa Flow (Middlebrook, 2004: 3).

Odyssey Target Name	U-Boat	Method of Discovery	Maritime Zone
T12n9e-1	U-326	Odyssey	French Economic
15wm2	U-988	UKHO 23021	International Waters
U-Unknown1	U-325	Sport divers 2007	UK Territorial
U-Unknown2	U-650	Salvage company 1976	UK Contiguous
U-Unknown3	U-1208	Sport divers 1997	UK Territorial
U-1021	U-1021	Sport divers 1990-2001	UK Territorial
U-400	U-400	Sport divers 1990-2006	UK Territorial
TRI-15a-39Wb-1	U-103	UKHO 22758	French Economic
T1a12a-6	U-327	UKHO 22326	UK Territorial

Table 4. The status of U-boats examined during Odyssey's Atlas expedition, 2008.

Odyssey Target Name	U-Boat	Depth (m)	Dive Nos.	Dive Dates	Dive Time	Stills	DVD	HD DVD
T12n9e-1	U-326	164	145 473	11.9.05 26.7.08	2hr 45min	150	3	2
15wm2	U-988	77	169 441 814	29.9.05 3.7.08 14.2.12	3hr 54min	168	3	2
U-Unknown1	U-325	84	449 451	17.7.08 17.7.08	4hr 38min	193	5	4
U-Unknown2	U-650	79	450	17.7.08	3hr 5min	95	3	3
U-Unknown3	U-1208	81	452	18.7.08	2hr 43min	75	3	3
U-1021	U-1021	53	453	19.7.08	1hr 35min	86	2	2
U-400	U- 400	56	454	19.7.08	1hr 38min	65	2	2
TRI-15a-39Wb-1	U-103	103	502	28.9.08	1hr 41min	109	2	2
T1a12a-6	U-327	88	571	13.6.09	2hr 43min	327	3	3

Table 5. Survey data for U-boats examined during Odyssey's Atlas expedition, 2008.

In September 1939, North Atlantic merchant vessel convoys formed to deliver crucial supplies to the United Kingdom. These early convoys, typically composed of 30 to 50 merchant ships (many fitted with medium-caliber guns), were normally protected by escort ships, mostly corvettes and destroyers (Hague, 2000: 26-28).

In 1940 the Germans marched through Europe, and by occupying France achieved the opportunity of setting up strategic airfields, torpedo boat and U-boat bases on the Atlantic coast. Germany effectively closed the Western Approaches to Britain and thus reduced the amount of shipping movements to London, Britain's major port (Williamson, 1999: 10). Germany's occupation of Norway saw the establishment of similar bases, making eastbound passage through the North Sea or the Kattegat into the Baltic perilous, if not impossible at times.

Until 1940 German U-boat tactics had been based on boats operating singly within assigned patrol areas and attacking targets with torpedoes or by surface gunfire. Both at this stage of the war and throughout its course, U-boats were always controlled via radio communications with headquarters. Using its mechanized coding equipment, Germany believed that the naval codes were virtually unbreakable (Paterson, 2007: 88). As will be seen, this was a fatal assumption of German U-boat command.

The single-boat assigned patrol sector all changed when Dönitz introduced what became known as *Die Rüdeltaktik,* the 'Wolf Pack'. Once a convoy had been spotted, a

group of U-boats would group together (like a wolf pack) and then attack the convoy (Middlebrook, 2004: 7). Normally ships on the outside of the convoy would be taken out first, so that when the escort ships went to their assistance and defense the other U-boats could slip into the midst of the convoy to unleash havoc on the vulnerable ships. Throughout 1940 a total of 500 allied vessels were sunk by U-boat attack (Williamson, 1999: 9). As a result of the German successes, the United States and Great Britain again launched an emergency shipbuilding program, with 50 ships ordered from US yards and with America initiating its 'Liberty' ship construction effort (Sawyer and Mitchell, 1985: 2). Through the Lend Lease pact of September 1940, the USA moved closer to the UK, giving Britain 50 World War I vintage destroyers to enhance convoy protection.

Meanwhile, German U-boat design and development was constantly improving and 1941 marked the introduction of the ocean-going Type VII and the later Type IX, which was capable of longer distance cruises into the South Atlantic (Williamson, 2007: 16). At this time U-boats also commenced operations in the Mediterranean.

Convoy organization was a difficult task for Britain and her Allies. The convoys had to cross the North Atlantic on the best routes to avoid U-boat attack, yet at the same time not deviating too far north or south on the Great Circle courses (the shortest distances across oceans) (Middlebrook, 2004: 91). Related complex issues were the organization of sufficient escort ships to protect convoys and the Convoy Sailing Conference, whereby masters of merchant ships were allocated a convoy and a position within it. One weakness in the early years of the war was the failure to provide full escort protection across the North Atlantic. It was not until May 1941 that the Royal Canadian Navy and the British Royal Navy were able to provide convoys with continuous protection (Middlebrook, 2004: 11).

The submarine war was also fought in the southeastern Atlantic, from the Straits of Gibraltar to the coast of South Africa. The Mediterranean was another important theater of operations – convoys were organized for all these routes. German U-boats eventually operated in the Indian Ocean and the Pacific in coordination with Japan (Williamson, 2010: 26-29).

Another weakness was air protection. Long-range aircraft were required to provide cover for the convoys and as a U-boat deterrent, but this depended on the range that the aircraft could fly, where the air base was situated and on which route the convoy navigated (Middlebrook, 2004: 50). Of course, the Germans were aware of these complexities and the U-boats generally operated on or near the edges of this 'air gap'.

Of great significance was the USA's entrance into the war. A few days after Japan attacked Pearl Harbor on 7 December 1941, Germany declared war on America on 11 December 1941. The involvement of America in the war brought essential reinforcements, weapons and supplies to Britain and her Allies and paved the way for ultimate victory (Middlebrook, 2004: 17). However, America was not part of the convoy system and her eastern seaboard was not protected or under any wartime restrictions. The Germans swiftly took advantage of this weakness and dispatched six long-range U-boats to attack the unprotected merchant shipping in a campaign code named *Paukenschlag,* 'Drumbeat' (Blair, 1996: 438-41). With the development of U-boat tankers, Dönitz was able to supply these long range U-boats with fuel and food from their bases in France (Williamson, 1999: 12).

In 1942 Germany built more Type VII U-boats, which enabled increased mass wolf pack attacks on Allied shipping. This was to be the best year for U-boats successes, with over 1,300 Allied vessels sunk (Williamson, 1999: 13). The U-Boats were now sinking more merchant ships than the rest of the German navy and the Luftwaffe combined, thus making their mark as a significant naval weapon (Middlebrook, 2004: 9). In February 1942, U-Boat Headquarters launched a new Caribbean offensive, Neuland, targeting tankers and merchant ships sailing into the Caribbean and the Gulf of Mexico (Kelshall, 1994: 19).

By the end of 1942 the German U-boat force consisted of 375 submarines with losses of 86 (ADM 239/388: *History of U-boat Policy 1939-1945*). This increase in loss was due to a few factors. The Americans had joined the convoy system, so their merchant ships received protection and a means of attacking U-boats and the Allies had more effective anti-submarine measures.

The beginning of the end of the German U-boat campaign for the promoted Grand Admiral Dönitz started in 1943. The Allies had launched huge successful attacks on U-boat bases and shipyards; the British had captured the Enigma Machine (the German cipher machine used to send orders and intelligence to U-boats), and so were able to intercept all messages (Hague, 2000: 52). The Enigma story proved pivotal: at the outset of the war Polish and Czech soldiers taking refuge in France were accompanied by one of the secret cipher machines and their code elements, but it took British code-breakers at Bletchley Park until early 1941 to work out how to use it. In February 1942 the Germans changed their machine code system and, until the capture of U-559 in October 1942, the Allies were unable to read the U-boats' coded radio signals (Paterson, 2007: 88-89). In this period the German submariners turned the ocean waves red with merchant seamen's blood –

the Germans called this the "happy time" (Gannon, 1998: 49-53). The tide turned, however, in May of 1943.

More escort vessels were made available for the Allied convoys. Ships were fitted with depth charges, radar, high-frequency direction finders (HF/DF), ASDIC/sonar (the main submerged submarine detection system) and sonobouys (underwater submarine sonar detection system). Increased flying range for aircraft meant that they could now cover a greater area, and attack surfaced submarines with rockets and acoustic torpedoes (Hague, 2000: 63-64, 73-75).

For the first time during the war the tonnage of new merchant vessel launchings overtook the tonnage of vessels sunk. The Germans only managed to sink half the number of vessels they had destroyed in 1942 (Middlebrook, 2004: 323). As a result of the growing U-boat losses and the successes of the Allies, Dönitz ordered the withdrawal of large numbers of U-boats from the North Atlantic (Williamson, 1999: 14). Attacks on the convoys still continued, but the tactics of the patrol line and the wolf pack attack were abandoned and U-boats were ordered instead to hunt singly in widely spaced patrol areas.

Germany continued its program of submarine development and construction during 1943 and 1944. Of great significance was the introduction of the snorkel fitting, which was based on a design found on Dutch submarines captured during the German occupation of the Netherlands. The Germans began converting their U-boats and adding snorkels in 1943. The snorkel consisted of two tubes, one to draw in air and the other to vent exhaust gases from the diesel engines while the submarine traveled at periscope depth (Mõller and Brack, 2004: 160). Previously, U-boats had to surface to carry out these procedures, but fitted with a snorkel they could remain beneath the surface, hidden from the enemy.

Under the threat of ever-advancing Allied technology, the Germans were forced to push the limits of submarine design. The first Type XXI U-boat was launched in May 1944. This design was much larger, had an extended underwater endurance and better torpedo systems than the Type VII or Type IX.[1] Its design and performance was so revolutionary that had it been in service a few years earlier the outcome of the Battle of the Atlantic may have been different

In June 1944 the Allies invaded Normandy to begin driving the Germans out of France and the Atlantic Ocean. This closed down all the U-boat bases along the French coast and forced the Germans instead to operate out of their bases in Norway. The Caribbean offensive was now playing out too far from North Sea bases and ended in August (Kelshall, 1994: 442). U-boat activity was greatly reduced and in September Germany withdrew U-boats from the Mediterranean and scuttled their submarines in the Black Sea (Williamson, 1999: 15). For the first time during the war U-boat losses exceeded the number being built.

Early in 1945 the U-boats concentrated their campaign around British coastal waters. The Allies with their advances in anti-submarine warfare, and further minefields placed around British waters, were making a difference. The Germans continued to suffer great U-boat losses, and by May 399 U-boats had been sunk (Williamson, 1999: 15).

On 4 May 1945 at 1:16am, Grand Admiral Dönitz sent a signal to all U-boats at sea to cease hostilities and return to base. Germany's capitulation was signed at Rheims on 6-7 May. At noon on 8 May the Admiralty announced that the German High Command had been ordered to give surrender orders to all U-boats at sea. They were to surface, hoist black flags, report in plain language their positions and numbers, and proceed by fixed routes to designated ports and anchorages (Paterson, 2007). The last U-boat sunk in hostile action was lost in a protracted battle in coastal waters off Rhode Island. Although U-boat headquarters had ordered an end to offensive actions as of 8am on 5 May 1945, at 5:40pm that evening U-853 torpedoed the SS *Black Point* just off Point Judith, Rhode Island. The ship sank shortly after 6pm, killing 12 men and with 34 survivors. The submarine was sunk in a protracted battle that finally ended with confirmation of its loss at 10:45am on 6 May. It is speculated that the submarine commander had not received the cease-fire message (Winckler and Cunningham Dobson, 2007: 27).

Prior to the start of the World War II, Germany had 57 U-boats in service. By the end of the war a further 1,098 U-boats had been built (this number excludes 1,476 manned torpedoes and midget submarines). Table 3 presents a breakdown of the U-boat types and numbers (Mõller and Brack, 2004: 64-136).

U-boat casualties were high. Allied attacks claimed 757 U-boats – of these 648 were lost during front-line service at sea. A third of these were lost during their first active patrols, the majority sank with all hands. Working on the average crew of 50 submariners on a typical Atlantic U-boat, the number of losses equates to over 30,000 men. Between 1943 and 1945, one out of every two boats on active service in the Atlantic did not survive (Niestlé, 1998: 4). The U-boat officers and crews were highly trained, skilled submariners. Despite these large losses, the camaraderie, pride, high morale and bravery of these men in a very challenging environment was second to none and similar to that of many of the world's elite military groups.

German submarine development played a significant part in the history of submarine warfare. The first

half of the 20th century established the submarine as an important strategic naval weapon. German submarine development was so advanced that many of the designs and prototypes were adopted by the Allies to become the basis of their own submarine programs. For example, the Type XXI U-boat hull design became the basis for the Russian Zulu and Whiskey-class submarines and influenced the US Navy Nautilus and Albacore-class submarines (Gardiner, 1995).

3. Odyssey Marine Exploration Atlas Project 2005-2009

Between May 2005 and November 2009, Odyssey Marine Exploration searched more than 4,725 square nautical miles of seabed in the Western English Channel and the Western Approaches to the English Channel, recording 267 shipwrecks of various types dating from the 17th century to the present day (Cunningham Dobson and Kingsley, 2010; Kingsley, 2010; Cunningham Dobson, 2011; Cunningham Dobson and Kingsley, 2011; Niestlé, 2011).

Six German U-boats were discovered in Odyssey's search areas and three other U-boat wrecks outside the search area, but were included in the 2008 expedition to ground-truth sites identified (Fig. 2). This expedition included the World War II German U-boat expert Dr. Axel Niestlé and led to the definitive identification of the sunken German submarines U-325, U-400, U-650, U-1021 and U-1208 (Niestlé, 2011). Of the nine U-boats investigated, four were the type VIIC, the workhorse of the U-boat fleet, four were the type VIIC/41, a much improved version of the type VIIC, which could dive deeper, and one was a Mittel U-type submarine from World War I.

Various official records and historical documentation exist with reference to U-boat losses during both world wars. The official post-war loss lists were often based on incomplete or dubious information. In the midst of a battle, documentation was often left incomplete. All these factors served to produce errors in the final positions and names of lost U-boats. The only way a U-boat wreck site can be definitively identified is for divers to photograph and record hull features that an expert can study to determine the submarine type and construction number.

Following advances in technology and equipment in technical diving (Tri-mix and re-breathers), divers can now reach depths of up to 300m. Around the waters of the UK, sport and technical divers have made a considerable contribution to the re-assessments of several U-boat losses. Dr. Axel Niestlé has worked with many dive groups who provided information to assist identifications. His expedition with Odyssey was his first employing a Remotely-Operated

Fig. 7. Side-scan sonar image of U-326 (site T12n9e-1), lost 30 April 1945 and located 142km south-west of Ushant, France.

Fig. 8. The bow of U-326 with snagged fishing net draped over the bow and towards the conning tower.

Fig. 9. The port side conning tower of U-326 draped in fishing net and lines.

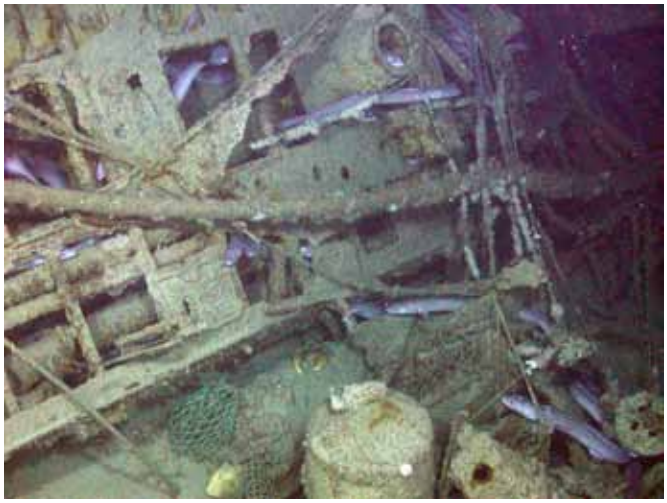

Fig. 10. The main deck of U-326 forward of the conning tower,with collapsed and deteriorated fittings and equipment on the seabed.

Fig. 11. The broken Schnorkel mast lying on the seabed close to the hull of U-326.

Fig. 12. The bent port propeller shaft of U-326.

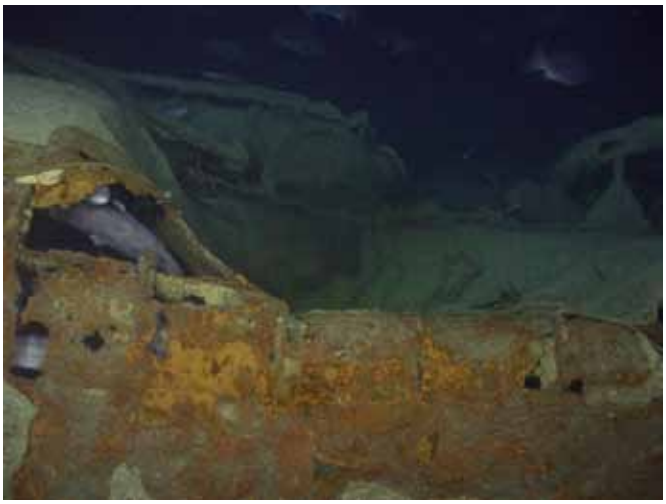

Fig. 13. Bomb damage above the forward section of the engine room and galley area of U-326.

Fig. 14. The port bow plane of U-326 in diving position.

Fig. 15. A Catalina PBY-5A aircraft showing the mounting of 12 Retrobombs under the wing. Similar aircraft and Retrobombs sank U-326. Photo: courtesy Captain Jerry Mason, USN.

Type VIIC	*In Service*	1940-1945
U-400	*Dimensions*	67.1 x 6.2 x 4.74m
U-650	*Type Displacement*	769 tonnes surfaced, 871 tonnes submerged
U-988	*Speed*	17.0-17.7 knots surfaced, 7.6 knots submerged
U-1208	*Range*	8,500nm at 10 knots surfaced, 80nm at 4 knots submerged
Type VIIC/41	*In Service*	1940-1945
U-325	*Dimensions*	67.1 x 6.2 x 4.74m
U-326	*Type Displacement*	769 tonnes surfaced, 871 tonnes submerged
U-327	*Speed*	17.0-17.7 knots surfaced, 7.6 knots submerged
U-1021	*Range*	8,500nm at 10 knots surfaced, 80nm at 4 knots submerged
Mittel U	*In Service*	1917
U-103	*Dimensions*	67.7 x 6.32 x 3.65m
	Type Displacement	750 tonnes surfaced, 952 tonnes submerged
	Speed	16.5 knots surfaced, 8.8 knots submerged
	Range	10,100nm at 8 knots surfaced, 45.4nm at 5 knots submerged

Table 6. Specifications of U-boats surveyed during the 2008 Atlas expedition.

Vehicle (ROV) as an efficient tool for gathering underwater video footage, photographs and data. A ROV is capable of operating at greater depths with longer underwater endurance than a diver, and can be equipped with all necessary survey and recording tools needed for an in-depth inspection of a target. The ability for experts aboard ship to observe and control the underwater surveys allows them to identify features and fittings in real time, thus reducing the need for further dives. High-resolution recorded data can be reviewed at leisure, shared with others, and form an archival record of the site, as well as a base survey with which future site monitoring may be cross-referenced.

Odyssey's research platform during the project was the 76m-long, 1,431-gross-ton *Odyssey Explorer* (Fig. 4). This ship is fully equipped to support deep-sea exploration and features a wide array of survey and recovery equipment suitable for the operation of a work-class ROV system, as well as a wide range of geophysical survey tools. Where required, high-resolution side-scan sonar passes were conducted over the targets. However, targets U-Unknown1, U-Unknown2, U-Unknown3, U-400 and U-1021 were not side-scanned because pre-determined accurate positions for these submarines were known. Odyssey's ROV Zeus was configured for site inspections with all camera and lighting systems fully functional (Fig. 5).

Data from the ROV was simultaneously transmitted to three separate on-board work areas: the ROV Control Van, which housed the ROV pilots; the Online Room, which housed the surveyor, navigator, and datalogger; and the Offline Room, the work area for the archaeologists, project manager and specialist observers. Large High-Definition plasma monitors in the Offline Room allowed every aspect of seabed operations to be observed, including close-up images of features only a few millimeters in size. In addition, four desktop computer screens set side-by-side displayed the results of navigation/survey activity, utilizing the WinFrog program, sonar images, the archaeological commentary, and a four-screen split image of ROV cameras and other screens required for observation during operations.

A ship-wide intercom communication system linked the archaeologist and project manager directly to the ROV pilot, the surveyor/navigator, the data loggers, the officers on watch and the ROV deck crew. During all operations involving survey and documentation of the wreck or its environment, the project archaeologist supervised all ROV tasks and was in constant contact with all stations.

Following the first U-boat discovery in 2005, Odyssey contacted U-boat expert Dr. Niestlé to assist in the identification of the wreck. In 2008, Dr. Niestlé accompanied Odyssey on an expedition to identify five U-boats (Fig. 6). His expertise, knowledge and identification methods were essential to the success of the expedition. Dr. Niestlé provided Odyssey with a U-boat survey recording form that aided in the gathering of critical data and features of a U-boat that ultimately identified individual submarines.

Operational procedures for the U-boat surveys consisted of the following:

- Positioning of the research vessel over the site;
- Locate and position the ROV in the vicinity, but off the wreck site to prevent disturbance;

- Fly ROV towards target constantly monitoring video, SONAR and survey data;
- Initial panoramic survey of the site to determine the extent and any potential snags or hazards to the ROV or the wreck;
- Plot waypoints of bow, stern and other critical features determined by the archaeologist, project manager and guest expert through video and SONAR images, along with a length and breadth of the site using WinFrog navigation software;
- Conduct a detailed and comprehensive visual survey of the target recording observations, images and data.
- This was complemented by a multibeam sonar of U-988 (site 15wm2).

A. Site Surveys

Of the nine surveys, five were conducted with Dr. Axel Niestlé observing onboard. Only one of the U-boats was a new discovery made by Odyssey. The others were all either known United Kingdom Hydrographic Office registered wreck sites, found previously by sport divers or by salvage companies (Table 4).

Surveys of all these sites followed the same procedures. A total of 13 ROV dives were conducted, 1,268 still photographs taken, 26 DVD's and 23 High-Definition tapes recorded during a total dive time of 24 hours and 42 minutes (Table 5). The archaeological survey results are presented below in terms of the chronological sequence of dives conducted and focus on site-formation process and impacts. A comprehensive forensic interpretation of the losses and processes of identification of five of these sites is published elsewhere (Niestlé, 2011). Table 6 lists the basic specifications of the surveyed U-boats (four Type VIIC, four Type VIIC/41 and one Mittel U).

B. U-326 (Site T12n9e-1)

U-326 was a Type VIIC/41 ocean-going attack submarine built at the Flender Werke AG shipyard in Lübeck. Launched on 22 April 1944, U-326 joined the training Fourth Flotilla base at Stettin, north-east Germany (modern Poland). From there it joined the combat Eleventh Flotilla based at Bergen, Norway, and under the command of Kapitänleutnant Peter Matthes commenced front line patrols. Unfortunately, it was sunk on its first war patrol west of Brest, France, in the Bay of Biscay with the loss of 43 men. U-326 was not credited with any successful enemy sinkings or attacks.[2] As was often the case during World War II, official records of U-boat sinkings were sometimes unreliable and the sinking of U-326 could be credited to two different aerial attacks. In consultation with Dr. Axel Niestlé, Odyssey determined that most likely the U-boat attack recorded nearest to the wreck site took place on 30 April 1945, carried out by the Catalina flying boat 'R' of VP-63 Squadron, United States Navy.

U-326 is located 142km south-west of Ushant, France, at a depth of 160m at position 47°51.17'N, 006°46.43'W. The wreck is intact, lying on a smooth hard sand bottom with a list to starboard of approximately 45° in a north-east to south-west orientation. From the side-scan data and ROV inspection, no debris field is associated with the wreck, thus indicating that it impacted the bottom essentially intact (Fig. 7). Features observed off the wreck appear to have fallen from the ship as it deteriorated or have been pulled off by fishing nets (Figs. 8-9). The external metal casing of the conning tower has collapsed and mostly lies on the sand to starboard (Fig. 10). The Schnorkel mast is broken off approximately one meter above the mast hinge, with the mast lying to the starboard side (Fig. 11). No remains of the wooden decking were noted. Parts of fishing nets are found snagged around the wreck, mostly on the bow.

Battle damage is limited to a depression and rupture of the pressure hull approximately above the forward section of the engine room and galley area, and 4m forward of the after torpedo loading hatch (Fig. 13). The extreme stern section is very degraded and for the most part missing, with at least one of the propeller shafts bent downward through 100-110° (Fig. 12).

The pressure hull damage is consistent with what would be expected from a direct hit of a Retrobomb. One problem an aircraft had attacking a submarine with conventional depth charges was that the aircraft had to be directly over the target. When the depth charge was dropped, the continuing forward flying motion of the aircraft resulted in the depth charge landing ahead of the target. To resolve this issue the National Defense Research Committee based at the California Institute of Technology developed in 1942 the Retrorocket or VAR (Vertical Antisubmarine Rocket).

Commonly known as the Retrobomb, it was effectively a rocket propelled depth charge. Fitted to multi-rail launchers on the underside of an aircraft's wing, Retrobombs were mounted with their rocket motors facing the direction of flight (Fig. 15). Once fired, the rocket effectively slowed down the forward airspeed, resulting in the Retrobomb falling vertically and thus striking the target. The multi-rail launchers enabled the aircraft to fire groups of Retrobombs and lay a rectangular pattern over the water, which increased the chances of a successful hit.[3]

This type of Torpex-filled depth charge (an explosive 50% more powerful than TNT and composed of 42% RDX, 40% TNT and 18% powdered aluminium, originally developed for torpedoes), weighing 16kg (35lbs) and only exploded on contact (Creed, 1985: 208-209). It would

be safe to conclude that the official records of such an attack by the Catalina flying boat match the observations of battle damage on the wreck.

The survey of U-326 also revealed that the Schnorkel and the attack periscope were in a raised position and the forward port diving plane appears to be set for a crash dive (Fig. 14). This most likely suggests that U-326 was operating with its Schnorkel mast and attack periscope extended and, therefore, that it was probably sailing submerged and at periscope depth. It would appear that patrolling Catalina flying boat 'R' of VP-63 Squadron, United States Navy, spotted the periscope and Schnorkel either visually or by radar and then executed a successful attack.

U-326 most probably sank stern first, bending the propeller shafts on striking the seabed and then settled on her starboard side as the rest of the pressure hull filled with water. Hence, the bow section is undamaged. U-326 was conclusively identified by the observed flooding-hole slot pattern and the presence of the Schnorkel mast.

C. U-988 (Site 15wm2)

U-988 was a Type VIIC ocean-going attack submarine built at the Blohm & Voss shipyard, Hamburg. Launched on 3 June 1943, the submarine joined the training Fifth Flotilla base at Kiel, North Germany. From there it joined the combat Seventh Flotilla based at St. Nazaire, western France, where under the command of Oberleutnant zur See Erich Dobberstein it commenced its war patrols. It was attacked on 29 June 1944 by four British frigates and a Liberator aircraft from 244/Lm Squadron while on patrol west of Guernsey in the English Channel, and sunk with the loss of 50 men. U-988 is credited with the sinking of one British warship, an auxiliary warship and a merchant ship (Niestlé, 1998: 95).

U-988 is located 64km south of Start Point, Devon, in 77m of water at position 49°35.72'N, 003°40.49'W. The wreck lies on a sand/shell flat seabed in a roughly north-east to south-west orientation with a list of 40-60° to starboard. From the side-scan data there is no apparent debris field and the wreck appears intact (Fig. 16). Unfortunately, during the two dives on this site the underwater visibility was very poor, while on the last dive it was made worse by large shoals of fish, which hindered observations. However, it was possible to confirm the type and identity of the U-boat based on features and fittings, thus validating the UKHO (United Kingdom Hydrographic Office) site record.

There is considerable damage to the bow and stern sections of the wreck and along the upper section of the pressure hull (Fig. 18). Most of the upper deck structure is missing. The conning tower is intact with the attack periscope upright and the main hatch was observed open.

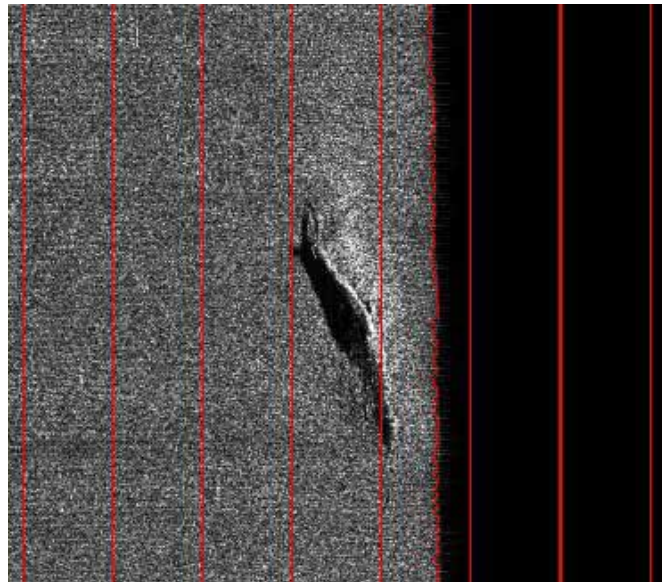

Fig. 16. Side-scan sonar image of U-988 (site 15wm2), lost 29 June 1944 and located 64km south of Start Point, Devon, England.

Fig. 17. The exposed top section of the engine room of U-988.

Fig. 18. The forward end of the pressure hull of U-988 alongside snagged fishing gear.

Fig. 19. The forward torpedo tubes of U-988.

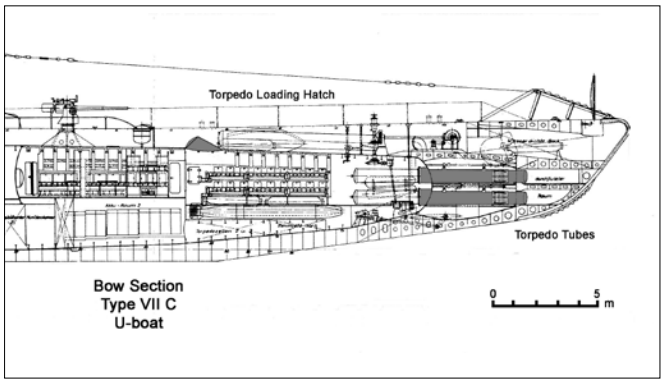

Fig. 20. Plan of forward loading torpedo hatch and torpedo tubes of U-988. After Köhl and Niestlé, 2006.

Fig. 21. A G7e torpedo being loaded onto the forward deck of a U-94, in service 1940-42. The same ordnance was recorded in the exposed torpedo tubes of U-988. From Dallies-Labourdette, 1996.

Remains of part of the Schnorkel system are visible. No remains of the guns or gun platforms were observed. There is considerable damage to the aft upper pressure hull and a large section of the top of the engine room is visible (Fig. 17). The forward torpedo-loading hatch is intact, but the hatch cover is missing. The forward section of the pressure hull where the torpedo tubes are fitted is exposed and most of the bow section is badly damaged (Figs. 19-20). The port dive plane is intact, but the hull superstructure and forward pressure hull section are open, exposing the two forward torpedo tubes which are lying with the forward sections broken and the aft sections pointing at an angle of 20-40° to the surface. It was observed that both these tubes still contain torpedoes (Fig. 19).

The most common type of torpedo used by the German navy was the wakeless electric powered T III (G7e), which had a range of 5,000m, a speed of 30 knots and carried 280kg of explosives (Fig. 21). The standard length for a torpedo was 7.16m and, on average, a torpedo weighed around 1.5 tons. It had issues with battery power and required maintenance every few days (Williamson, 2002b: 38-9). For a short period after March 1943 the G7e/T4 Falke torpedo was fielded. This ordnance was the world's first acoustic homing torpedo with a range of 7,500m, a speed of 20 knots, and a 200kg Hexanite warhead. This torpedo was ideal for the Type VIIC/41 submarines, which could dive deeper and stay submerged longer than the Type VIIC. It could be fired without the U-boat being at periscope depth (15m) as it could be aimed at a sound contact detected by the U-boat's hydrophones. It would travel straight for 400m, the acoustics would then activate and search for the target. Not in service long, it was replaced in September 1943 by the G7es/T5 Zaunkönig or GNAT (German Navy Acoustic Torpedo), as the Allies called it. It had a range of 5,700m, a speed of 25 knots, and carried a 200kg Hexanite warhead (Sternhell and Thorndike 1946: 161).

Two methods using a pistol device detonated the warhead of a torpedo. Generally torpedoes were fitted with both types and it was up to the U-boat captain to select his preference. One was contact-operated and the other was magnetic. The contact-operated pistols consisted of four whiskers mounted at the tip of the torpedo nose cone, and as soon as they made contact with anything it would detonate (Williamson, 2007: 37). The force of the explosion caused the hull plates to crack and to be forced outwards due to the expansion of the explosives gases. If the area hit was filled with a liquid, such as water, oil or other non-compressible materials, the effect would be the same. In some cases the torpedo penetrated the hull, causing the hull plates to point inwards and then explode. The magnetic

pistol devices were detonated by a target vessel's magnetic field, with the aim being for the torpedo to detonate just below the hull using the force of the explosion to bend and crack the hull.

Torpedoes were a technologically advanced and expensive weapon. However, they were not without problems. During the early stages of the war there were major issues with the malfunctioning of both pistol detonating device types, which were not resolved until late 1942. These were mainly development issues, faulty parts, and incompetence on the part of the designers and manufactures. The issue was so serious that the senior personnel involved were court-martialled and imprisoned (Williamson, 2007: 38). Many U-boat captains reported that they were robbed of a prize due to a torpedo not detonating.

Close study of the underwater video of the exposed torpedo tubes of U-988 and the end of the torpedoes suggests that the torpedoes contained within are T III (G7e). The T III (G7e) torpedo warhead had a particular priming device, a propeller driven device that, after enough rotations during the run of the torpedo, would release the bolt that kept the priming striker away from the exploder.[4] The marine growth-covered outline of such a device was seen on the front of the weapon contained within the lower exposed torpedo tube of U-988. This torpedo was introduced into service in 1942 to become the standard issue, and as such is a type that would be expected to be onboard U-988.

Battle damage to the submarine is extensive. The pressure hull damage is consistent with the documented attack by depth charges and aerial attack. Sections of the pressure hull show damage where the plates have been pushed inwards by an external force, as opposed to an internal explosion. The upper section of the engine room is exposed, suggesting an explosion or large rupture. It is most likely that U-988 sank quickly, landed on the seabed and then heeled over to starboard.

There is extensive trawl net damage on the site. Sections of net and footropes are snagged in the pressure hull. It is very likely that upper fittings and structures have been removed and displaced. The very large dense shoal of fish encountered on each dive confirms that the site is a good fishing area and damage to the site is likely to continue in the future.

One of the standard survey tools for seabed mapping, including shipwreck monitoring, is the multibeam swath bathymetry system. Developed from echo-sounder technology, a multibeam swath bathymetry system is able to produce much more seabed depth information than a single echo sounder. From an archaeological perspective, multibeam surveys are able to provide very detailed and accurate baseline surveys and repeatability in the future is easily conducted. Multibeam surveys have become a very useful tool in the initial non-disturbance surveys of wreck sites.

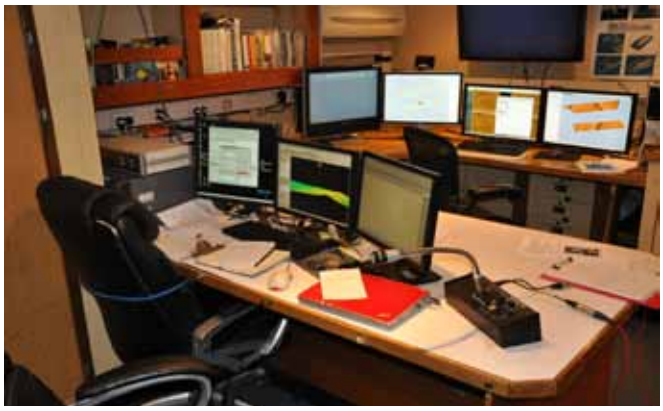

Fig. 22. The multibeam software and graphic display system in the Odyssey Explorer *Offline Room.*

Fig. 23. View of the black 'brick shaped' multibeam head attached to the center of the lower ROV frame between the skids.

In February 2012 Odyssey conducted a multibeam survey of the HMS *Victory* wreck site (sunk western English Channel, 1744: Cunningham Dobson and Kingsley, 2010; Seiffert *et al.*, 2013: 2-3). To test the system, an additional wreck located close to the *Victory* site was required. Since U-988 was also located in the Western English Channel and visual survey work had previously been conducted on the submarine, it was decided to conduct a multibeam survey of this site.

Mounted on the Zeus ROV for the 2012 survey was a RESON SeaBat 7125 ROV2 High-Resolution Multibeam Sonar System capable of measuring relative water depths over a 140° or 165° swath angle, perpendicular to the ROV's track (Fig. 23). With the addition of a second projector the system was able to operate in dual-frequency, providing both long-range functionality and high resolution. A surface processor and display screen enabled the operator to observe the seabed image as the ROV passed over the wreck

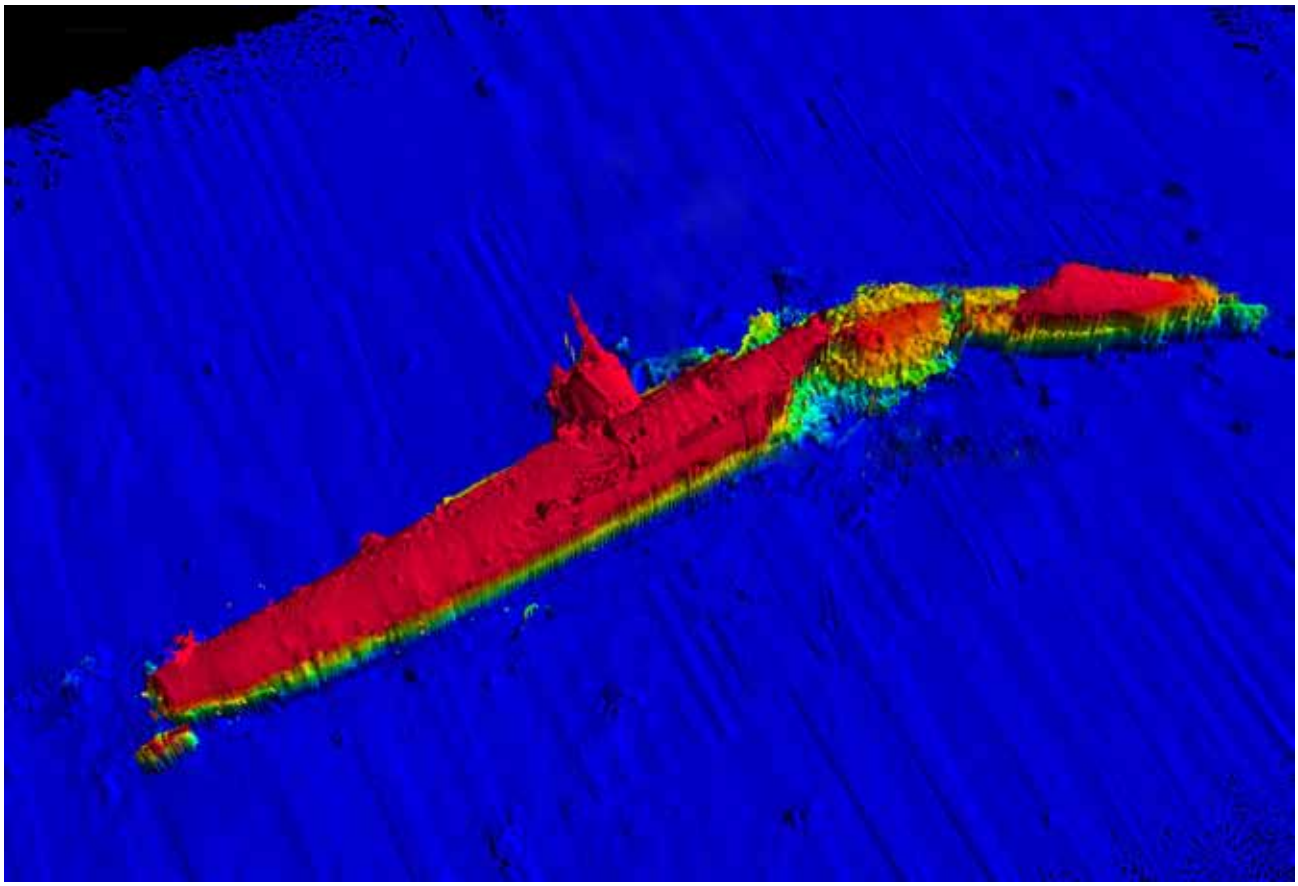

Fig. 24. Processed multibeam image of U-988.

site (Fig. 22). Further post-survey processing and image 'cleaning' and filtering can be conducted to remove wobbles in the data (known as 'artifacts').

From the *Odyssey Explorer* research platform, the ROV Zeus conducted a multibeam survey of site 15wm2 (U-988) on 14 February 2012 during Dive 814. The weather was wind from the north-west 18 knots, with a moderate sea and swell, an observed strong current and moderate visibility on the seabed. Using the WinFrog survey and navigation software a survey block of three lines, 130m-long and 10m spacing was designed. The ROV conducted two passes of each line over a total survey time of 45 minutes.

The results of the multibeam survey significantly enhanced the visual survey that was previously conducted, and a far clearer image of the submarine's orientation and layout on the seabed was obtained (Fig. 24). By contrast, the visual survey was affected by poor visibility and dense shoals of fish. Multibeam surveys are unaffected by such problems. The port forward dive plane, the forward torpedo loading hatch, the conning tower and periscope are all very clear on the resultant image. The damage to the stern section matches that of the visual survey, which highlighted the exposed engine room and broken stern.

D. U-325 (Site U-Unknown1)

U-325 was a Type VIIC/41 ocean-going attack submarine built at the Flender Werke AG shipyard in Lübeck. Launched on 25 March 1944, U-325 joined the training Fourth Flotilla base at Stettin, north-east Germany (now in Poland). It then joined the combat Eleventh Flotilla based at Bergen, Norway, on 1 December 1944. Under the command of Oberleutnant zur See Erwin Dohrn, from there the U-boat commenced its war patrols. It was sunk off Lizard Point in the Western English Channel in the British Minefield Artizan B3, Part 1, between 30 April and 9 May 1945, with the loss of 52 men (Niestlé, 2010: 7). It was not credited with any successful enemy sinkings or attacks.

The type of mine used would have been one of the standard British contact mines of World War II, either the Mark XVII or the Mark XIV. Both consisted of a metal container approximately 1m tall by 1.6m in diameter with 11 detonator horns on the top section. They could carry a charge of 320lbs (145kg) to 500lbs (227kg) and could be laid in water of up to 915m (Henry, 2005). Approximately 100 mines had been laid in this field.

U-325 is located 40km south of Lizard Point, Cornwall, in 84m of water at position 49°48.28'N, 005°12.38'W.

Fig. 25. The detached stern section and rudder of U-325, lost between 30 April and 9 May 1945 and located 40km south of Lizard Point, Cornwall, England.

Fig. 26. The aft end bandstand gun platform of U-325.

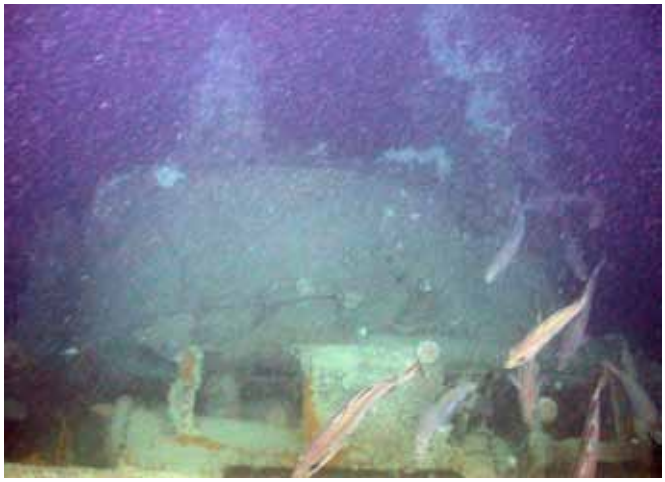

Fig. 27. The conning tower and round sponge encrusted Direction Finder loop of U-325.

Fig. 28. The stern torpedo tube of U-325 with the stern dive planes visible at right.

Fig. 29. The forward torpedo tubes of U-325, with the tube door on the right open.

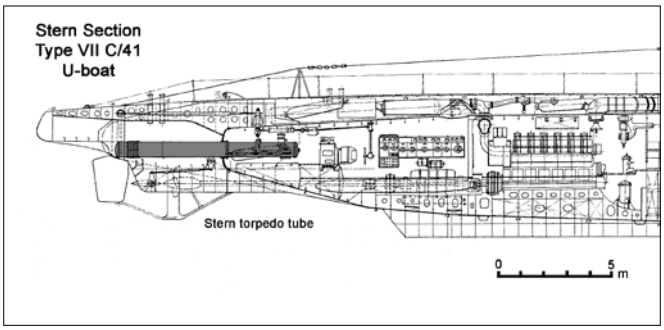

Fig. 30. Stern section diagram of U-325. After Köhl and Niestlé, 2006.

Odyssey Target Name	U-Boat	U-Boat Type	Launch Date	Date Lost	Mode of Loss
T12n9e-1	U-326	VIIC/41	22 April 1944	30 April to 9 May 1945	Aircraft retro-bomb
15wm2	U-988	VIIC	3 June 1943	29th June 1944	Depth charges
U-Unknown1	U-325	VIIC/41	25 March 1944	April 1945	Minefield
U-Unknown2	U-650	VIIC	1 October 1942	January 1945	Hedgehog bomb
U-Unknown3	U-1208	VIIC	6 April 1944	24 February 1945	Depth charges
U 400	U-400	VIIC	18 March 1944	14 December 1944	Minefield
U 1021	U-1021	VIIC/41	25 May 1944	14 March 1945	Minefield
TRI-15a-39Wb-1	U-103	Mittel U	9 June 1917	12 May 1918	Ramming by SS *Olympic*
T1a12a-6	U-327	VIIC/41	27 May 1944	27 February 1945	Depth charges

Table 7. Summary of Atlas survey zone U-boat types and fates.

The wreck lies on a sand/shell flat seabed in a north-south orientation with a list of 80° to port. The wreck is mostly intact apart from bow and stern damage. A 5m section of the stern, which includes the rudders, is completely detached from the main body of the U-boat, lying on its port side in a north-west to south-east direction a few meters away (Fig. 25). A section of the stern torpedo tube is exposed, with a badly crushed torpedo sticking out (Figs. 28-30). The starboard aft diving plane is intact in the neutral position, although the inside section of superstructure is badly damaged and exposed. The galley hatch and the end of the 'bandstand' (platform where the aft gun was mounted) are exposed with all the decking missing (Fig. 26). The conning tower is intact with both periscopes in the stowed position. The DF (Direction Finder) radio loop is intact and the main hatch is closed (Fig. 27). All the forward decking is missing, exposing the frames and two compressed air bottles fitted onto the pressure hull. Life-saving dinghy containers and the mount for the anti-aircraft gun were observed on the seabed among debris from the conning tower and deck area. The bow is damaged, exposing the top starboard torpedo tubes. The starboard anchor is visible, stowed in the hawse pipe.

Battle damage to U-325 is consistent with hitting a mine. There is a large hole in the aft end of the pressure hull, and the stern section is separated from the main body of the submarine. The position of the wreck is within a known British minefield. U-325 was engaged in normal submerged cruising, periscopes down and diving planes set for a level track through the water when she entered the minefield and struck a mine with her stern.

Fishing net snags were observed on the extreme stern section and draped over the stern dive planes. Draped sections of nets and lines were visible over sections of the remains of deck structure.

U-325 was identified conclusively by the Type 2 folding Schnorkel system and the Jaumann-type anti-radar coating above the exhaust outlet.

E. U-650 (Site U-Unknown2)

U-650 was a Type VIIC ocean-going attack submarine built at the Blohm & Voss shipyard, Hamburg. Launched on 1 October, 1942, the submarine joined the training Fifth Flotilla based at Kiel, North Germany. From there it deployed to the combat Seventh Flotilla based at St. Nazaire, western France, and finally with the combat Eleventh Flotilla based at Bergen, Norway, from where U-650 commenced its war patrols under the command of Oberleutnant zur See z.V. Rudolf Zorn. It was sunk by a Hedgehog depth charge attack from an unknown Allied ship sometime in January 1945 with the loss of 47 men (Niestlé, 2010: 10). It was not credited with any successful enemy sinkings or attacks.

U-650 is located 32km south of Penzance, Cornwall, in position 49°51.06'N, 005°29.97'W in 79m of water on a flat seabed consisting of a sand and shell matrix, lying on its port side at an angle of around 70-80° in an north-east/south-west orientation. While the pressure hull is mostly intact, it is heavily corroded in places along with parts of the superstructure missing or disintegrated (Fig. 31). All of the decking is gone, exposing the frames and other equipment fitted on the top of the pressure hull. The stern section aft of the rudders is badly damaged and not attached to the main body of the wreck (Fig. 33). Both aft diving planes are intact. The aft galley hatch was observed to be open and the engine exhaust piping was visible on the top aft section of the pressure hull (Fig. 32). The conning tower is intact, but the entire superstructure and aft 'bandstand' for the guns are missing, either fallen down onto the seabed or damaged and removed by fishing activities.

Fig. 31. Damage and fishing net snagged on the top outer plating of U-650, lost in January 1945 and located 32km south of Penzance, Cornwall, England.

Fig. 32. The open aft galley hatch of U-650.

Fig. 33. The triangular shaped stern section of U-650 lying on the seabed.

Fig. 34. Top view of the forward torpedo-loading hatch of U-650.

Fig. 35. The bullnose bow fitting of U-650 lying on the seabed.

Fig. 36. The forward torpedo tubes of U-650.

Fig. 37. Three cylindrical shaped life-raft containers from U-650 fallen out of the stowage area onto the seabed.

Fig. 38. Depth charge hull damage to U-650.

Fig. 39. A 24-barreled anti-submarine Hedgehog mortar mounted onto the forecastle of HMS Westcott, *28 November 1945. The same type of weapon was used by an unknown allied ship to attack U-650. Photo: Imperial War Museum (A-31000, collection No. 4700-01).*

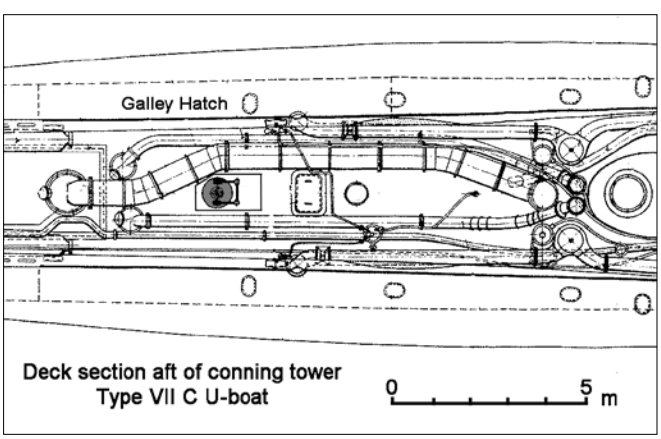

Fig. 40. Galley hatch location diagram of U-650. After Köhl and Niestlé, 2006.

The forward torpedo-loading hatch is open (Fig. 34). Just forward of this feature is damage to the starboard forward area of the pressure hull and to the bow section. The four torpedo tubes are visible through the debris and the 'bullnose' (a fairlead on the bow) sits on the seabed (Figs. 35-36). Directly below the pressure hull and keel is much debris consisting of sections of superstructure and other fittings and equipment. Near the forward end of the submarine are four life-saving dinghy canisters that have fallen out of their deck stowage area onto the seabed (Fig. 37).

Battle damage to U-650 is limited to a large irregular shaped hole a few meters forward of the forward torpedo-loading hatch on the starboard side of the pressure hull (Fig. 38). This type of damage can be accredited to a hit by a contact-fused projectile. Records and reports state that U-650 was sunk by such a projectile by an unidentified Allied vessel.

The most common type of contact-fused projectile used by the British navy was the 'Hedgehog multiple spigot mortar', adapted for naval use in 1942. It consisted of a 1.18m long, 18.2cm diameter, 9kg bomb carrying a 16kg Torpex or 15kg TNT explosive charge (Fitzsimons, 1977: 1283). It also contained a propellant within a hollow stem ending in stabilizing vanes, all placed on a spigot or spike. This weapon system consisted of four cradles each containing six launcher spigots (Fig. 39). These would be fired in a staggered sequence so that all the bombs would land in the sea at about the same time in a 30m-long elliptical area at a fixed point about 230m ahead of the attacking ship. The propellant for the bombs was electrically detonated. The bombs were contact fused and would only detonate if they struck a target (Hague, 2000: 68). Reloading of a launcher took three minutes.

Initially this weapon system had performance issues and for its first year of service it was ineffective. Improvements to the launching system and training of personnel gave this weapon system a better success rate than depth charges. As it only exploded on contact, if no explosion took place the submarine could still be tracked by sonar, contrasted with the 15 minutes or more for the disturbance of a depth charge to settle before sonar was effective. Unlike depth charges, which were pre-set to explode at a specific depth, the Hedgehog bomb was also effective at any depth as long as it struck the target. A direct hit by one or two Hedgehogs was sufficient to sink a submarine. Depth charges usually exploded away from the target, so that a cushion of water dissipated the explosive shock. With a Hedgehog strike, this cushion of water was behind the explosion and thus increased its effect (Fitzsimons, 1977: 1283).

The damage to this area of U-650 might certainly be accredited to a Hedgehog bomb. The section from the Control Room forward would have flooded rapidly, preventing any attempt to surface the U-boat. U-650 was obviously submerged at the time of the attack or may have been sitting on the bottom. The observed open galley hatch could indicate that some of the crew made an attempt to escape the stricken submarine or that it was blown open by the force of an explosion (Fig. 40).

Fishing net and line snags are evident all over this wreck (Figs. 31, 34, 37). The aft deck galley hatch has net and line snags. Trawl net remains were observed snagged on various parts of the debris lying on the seabed adjacent to the hull. Net and lines are caught on structures and fittings of the conning tower. Lengths of lines and floats were observed floating towards the surface from parts of the conning tower and other parts of the U-boat. At one stage of the survey one of the ROV's thrusters drew in a short length of this vertical line. Luckily, with use of the ROV manipulator arms, the line was freed from the thruster. A net and line snag was also observed at the bow section on the exposed torpedo tubes.

U-650 was conclusively identified by the Type 1 Schnorkel system and the presence of the original 8.8cm deck gun platform forward of the conning tower.

F. U-1208 (Site U-Unknown3)

U-1208 was a Type VIIC ocean-going attack submarine built at the F. Schichau GmbH shipyard Danzig, northeast Germany (now Gdańsk in Poland). Launched on 6 April 1944, the submarine joined the training Eighth Flotilla based at Danzig and then joined the combat Eleventh Flotilla based at Bergen, Norway. Under the command of Korvettenkapitän Georg Hagene, it commenced its war patrols. It was sunk by depth charge attacks by two British frigates south-east of the Isles of Scilly in the Western Approaches to the English Channel on 24 February 1945 with the loss of 49 men (Niestlé, 2010: 10). U-1208 is credited with the sinking of one British merchant vessel.

U-1208 is located 19km south-east of St. Mary's, Isles of Scilly, in position 49°51.78'N, 006°06.75'W in 81m of water on a flat seabed consisting of a sand and shell matrix, lying on its port side at an angle of around 40-50° with the bow pointing in a south-east direction (Fig. 42). The keel is intact, but the upper-section pressure hull and superstructure are badly damaged and corroded in places. It was only possible to survey the starboard side of the wreck because the port side was densely covered in trawl net and line and was a danger to ROV maneuvers (Figs. 43-44).

The starboard diving plane and bow were observed intact along with the towing eye for underwater refueling. The top section of the pressure hull between the bow and the conning tower is badly damaged. The entire superstructure is missing and only a few air bottles and piping remain. Missing sections of pressure hull have exposed the inside of the U-boat. Other sections are badly pushed in. The conning tower is intact and both periscopes are visible in the stowed position. Draped fishing nets and lines prevented the ROV from surveying the aft section of U-1208. The missing guns and their mounting platforms were most probably torn away by fishing activities.

The battle damage is consistent with heavy depth charge attacks. Although U-1208 was destroyed by the two British frigates, the battle damage to the pressure hull also indicates that further depth charge attacks known as 'tin can opener attacks' were carried out to confirm the kill, judging from evidence of debris spilled out from inside the submarine.

There has been extensive trawl net damage to this site. Due to the battle damage, fishing nets and gear have easily snagged on the ragged, damaged pressure hull. Of all the nine U-boats surveyed, this one was the worst for net hangs – so much so that a survey of the stern section was not possible.

U-1208 was conclusively identified by its 'Atlantic Bow' (Fig. 42), complete with the towing eye conversion to facilitate underwater refueling, and by the absence of the balcony array for the multi-unit listening equipment.

G. U-1021

U-1021 was a Type VIIC/41 ocean-going attack submarine built at the Blohm & Voss shipyard in Hamburg. Commissioned on 25 May 1944, the submarine joined the training Thirty-First Flotilla based at Hamburg, northern Germany, before joining the combat Eleventh Flotilla based at Bergen, Norway. Under the command of Oberleutnant zur See William Holpert, the submarine commenced war patrols.

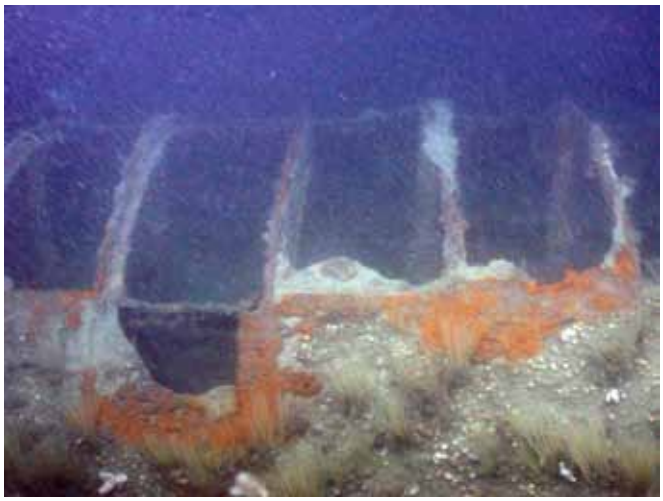

Fig. 41. Severe outer hull damage to U-1208, lost 24 February 1945 and located 19km south-east of St. Mary's, Isles of Scilly, England.

Fig. 42. The marine growth encrusted Atlantic bow and towing eye of U-1208.

It was reported sunk in the British minefield 'HY A1', some 16km off the north Devon coastline on 14 March 1945, with the loss of 43 men. Approximately 100 mines had been laid in this field (Niestlé, 2010: 15). U-1021 was not credited with any successful attacks.

Odyssey located U-1021 9.6km west of Trevose Head, Cornwall, in 52m of water in position 50°39.48'N, 005°05.04'W. The wreck sits on a hard sand/shell flat seabed with the bow pointing north-east. The wreck is mostly intact, although parts of the extreme stern and bow sections are broken off. U-1021 lies on her port side with a 70-80° list. Surveying the wreck from the stern along the port side, the superstructure is mostly intact with the wooden planking gone. Sections of the exhaust piping are visible on the seabed and on the top of the pressure hull (Fig. 45). The aft torpedo loading tube hatch and galley hatch were observed closed. The inverted Type LM43U aft gun mount and the remains of a 3.7cm M42U anti-aircraft gun were observed lying on the seabed alongside the hull (Fig. 46). The conning tower is intact, but some of the superstructure is missing.

Both periscopes are in the stowed position and the outer conning tower hatch cover is missing (Fig. 47). The DF Loop aerial is bent or broken and lying to one side. Forward of the conning tower exhaust piping and sections of the Schnorkel are visible (Fig. 48). The forward air bottles are intact and the forward torpedo loading tube hatch is exposed. A balcony array unit was observed at the forward end of the keel (Fig. 49). Of significance in the survey of this U-boat was the grating covering the original forward gun mounting (Fig. 50). This feature was intact with a section of the Schnorkel observed alongside. The starboard bow section is damaged, the diving plane intact and the

Fig. 43. The exposed engine exhaust trunking of U-1208 alongside snagged fishing gear.

Fig. 44. Cracked hull plating damage and snagged fishing gear on U-1208.

'bullnose' lies on the seabed. A survey of the stern section revealed that the starboard propeller assembly, shaft diving planes and rudder were intact, while the extreme end section of the stern was missing.

Battle damage is concentrated on a section just forward of the forward torpedo-loading hatch, where the Petty Officers' living quarters were situated. U-1021 was submerged when the bow touched a mine in the newly laid British minefield. So great was the blast that it cracked the pressure hull all the way around (Fig. 51).

Trawl nets and fishing lines are snagged across the wreck. Remains of the deck superstructure are draped with net and lines and sections of the conning tower are similarly festooned. Along the port side on the seabed are piles of bundled trawl net fragments and lengths of trawl footrope.

U-1021 was conclusively identified by the circular grating feature fitted in place of the deck gun plate (Fig. 50).

Fig. 45. Engine exhaust trunking remains on U-1021, lost mid-December 1944 and located 19km north-west of Newquay, Cornwall, England.

H. U-400

U-400 was a Type VIIC ocean-going attack submarine built at the Howaldtswerke AG shipyard Kiel, northern Germany. Commissioned on 18 March 1944, the submarine joined the training Fifth Flotilla base at Kiel, northern Germany, and subsequently joined the combat Eleventh Flotilla based at Bergen, Norway. Commanded by Kapitänleutnant Horst Creutz, it commenced war patrols. U-400 was reported sunk in the British minefield 'HW A', some 16km off the north Devon coastline in mid-December 1944 with the loss of 50 men. Approximately 156 mines had been laid in this field (Niestlé, 2010: 14). U-400 was not credited with any successful enemy sinkings or attacks.

Odyssey located U-400 19km north-west of Newquay, Cornwall, in 53m of water at position 50°33.16'N, 005°11.37'W. The wreck sits on an area of exposed flat rock outcrops and a sand/shell seabed in a north-east/south-west direction. The wreck is not intact and a large part of the bow has been blown apart, lying about 7m away from the main body of the submarine. The stern is intact, pointing in a south-east direction (Fig. 52). The submarine lies on its port side at an angle of 40-50°. Both rudders were observed intact. The aft deck superstructure is damaged in places and the wooden decking is gone. The aft torpedo-loading tube hatch is closed and the engine muffler tubes are visible along the stern section of the top of the pressure hull. The aft air-bottles are visible and intact (Figs. 53-55). The aft superstructure of the conning tower is missing, while the gun mounts and guns lie on the seabed next to the hull.

The conning tower is intact, with the periscopes in the stowed position. Forward of the conning tower the decking has gone, exposing the Schnorkel tube and a section of circular grating on the original forward gun mount.

Fig. 46. The aft deck gun mount of U-1021 (at right) on the seafloor.

Fig. 47. Stowed periscopes on the top of U-1021's conning tower. The outer conning tower hatch is missing.

Fig. 48. The forward torpedo hatch and Schnorkel head of U-1021.

Fig. 49. The balcony array, keel and dive plane of U-1021.

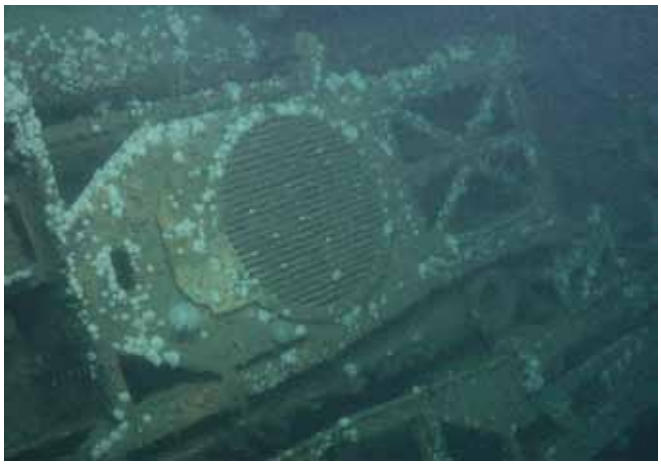

Fig. 50. The grating deck gun mount cover of U-1021.

Fig. 51. A crack through the hull and keel of U-1021.

The forward torpedo loading hatch is visible, the hatch missing. Just forward of this area is a crack in the hull (Fig. 56). A few meters away rests the displaced remains of the forward bow section (Fig. 58). Between the main hull and the forward bow section an air bottle lies on the seabed. The forward bow section has been rolled over and the port dive plane is intact in the neutral position (Fig. 57). The 'bullnose' is intact and remains of a starboard forward torpedo tube are exposed (Fig. 60).

Interestingly, approximately 10m off the starboard hull is a small, rectangular, metal-framed box sitting upright on the seabed (Fig. 61). Close inspection revealed this possibly to be the anchor frame of the mine that sank U-400.

Battle damage to U-400 consists of severe damage to the pressure hull forward of the conning tower. The torpedo-loading hatch has been displaced to one side and a large diagonal crack is visible in the pressure hull (Fig. 56). The forward bow section is damaged, with a section missing. This type of damage may be attributed to a mine. From observations of the wreck site U-400 appears to have been submerged, navigating the coastal waters of Cornwall, when she ran into a British Deep Trap minefield.

Trawl nets and fishing lines are snagged on sections of the U-boat, but the snagging is not as extensive as on the other submarines surveyed. Lines and floats were observed leading vertically upwards from parts of the conning tower. Lines are draped and snagged on various parts of the remains of the fore deck superstructure. The wreck site is situated close to shore, where lobster or crab fishing is common. Confirmation of that activity in proximity to or on the wreck takes the form of lobster or crab creels and lines snagged on debris on the seabed alongside the submarine hull.

U-400 was conclusively identified by the earlier Type 1 folding Schnorkel and by a modified balcony array for the multi-unit listening equipment.

Fig. 52. The end of the stern section of U-400, lost 14 March 1945 and located 9.6km west of Trevose Head, Cornwall, England.

Fig. 53. The closed aft torpedo hatch of U-400 (at right).

Fig. 54. Air bottles from U-400 exposed on the seabed.

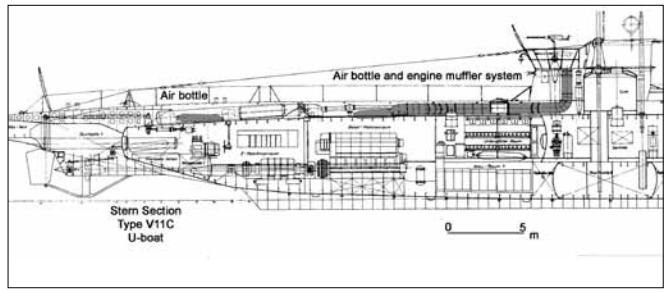

Fig. 55. Stern section diagram of U-400. After Köhl and Niestlé, 2006.

I. U-103 (Site TRI-15a-39Wb-1)

World War I U-boat U-103 was a Type Mittel-U ocean-going attack submarine built at the Flender Werke AG shipyard in Lübeck. Launched on 9 June 1914, it joined the combat II Flotilla based in North Belgium. U-103 had a colorful career and is credited with eight Allied merchant ship losses and one damaged under the command of Kapitänleutnant Claus Rucker. Rucker was one of the 20 most successful U-boat commanders of World War I, credited with a further 72 sinkings and two damaged vessels.[5]

U-103 was sunk during a failed attack on the White Star Line RMS *Olympic*, which served as a troopship during the war (Fig. 63). Sister ship to the famous White Star Line RMS *Titanic*, she was on her twenty-second voyage as a troopship en route to France with US troops when, in the early hours of 12 May 1918, her lookouts sighted a surfaced U-boat. The submarine fired two torpedoes at *Olympic*'s port bow. Having survived four previous U-boat attacks during the war, the *Olympic* was fitted with six-inch guns and did not hesitate to fire upon U-103, which immediately started a crash dive (Chirnside, 2004). To avoid being hit by the torpedoes, the *Olympic* carried out evasive maneuvers and decided to ram the diving submarine. U-103 was struck just aft of her conning tower and the *Olympic*'s huge port propeller sliced through the top surface of the submarine's pressure hull. With her prow twisted and some hull plates damaged, the *Olympic* did not stop but carried on her way as the crew of U-103 scuttled and abandoned the U-boat. Ten crewmembers died and 31 were rescued by a passing American destroyer (McCartney, 2002: 36).

U-103 is located 96km west of Falmouth, Cornwall, at position 49°16.48'N, 004°51.04'W in 103m of water. The wreck is intact, sitting upright with a 10-20° list to port on a flat sand/shell seabed in a north-west to south-east orientation (Fig. 62). The pressure hull is intact apart from a cut in the top section just aft of the conning tower. The wooden decking is gone and only a few sections of deck superstructure remain in place, some with holes where the plates have started to disintegrate (Fig. 64). Both the aft

Fig. 56. A crack through the hull of U-400 forward of the torpedo hatch.

Fig. 57. The port bow plane of U-400.

Fig. 58. The broken edge and keel of U-400's bow section.

Fig. 59. View of the broken interior hull of U-400.

Fig. 60. The bullnose and port bow section of U-400 exposed on the seabed.

Fig. 61. A British mine anchor in proximity to U-400.

and forward torpedo loading tubes are intact with hatches closed (Fig. 65). The aft superstructure is intact in places, the aft galley hatch is closed and four air bottles lie on the seabed along the port aft side of the U-boat (Figs. 66-67). The starboard propeller shaft is intact and has a four bladed propeller (Fig. 68). The aft 8.8cm deck gun is *in situ*, upright but snagged in trawl net (Fig. 69).

The conning tower is intact, although some of the superstructure is missing and the metal plates show signs of severe rusting (Figs. 70-71). The hatch was observed open and the periscopes in their stowed position. On the forward section of the conning tower the engine induction pipe was observed intact. The forward 8.8cm deck gun was also intact with the barrel at an angle of 50-60° (Fig. 72). On the forward deck area is what appears to be ammunition for the deck gun, spilled from the deck ammunition canister (Fig. 73). The damaged port bow area reveals the port torpedo tubes. The port anchor is stowed in the hawse pipe and the surrounding hull plates have broken away (Fig. 74).

Battle damage is visible to an area of pressure hull just aft of the conning tower, which has been dented and cut. There are no signs of damage caused by explosives. The damage is consistent with the historical record of the U-boat being rammed by a ship. The main hatch is open as most of the crew abandoned the stricken U-boat when she was scuttled.

Trawling has impacted the remains of U-103. Nets and lines are snagged around the conning tower and sections of bundled trawl net drape around the periscope and the aft deck gun. Net and lines are also caught on the remains of the deck superstructure and around the damaged bow section at the port anchor and hawse pipe.

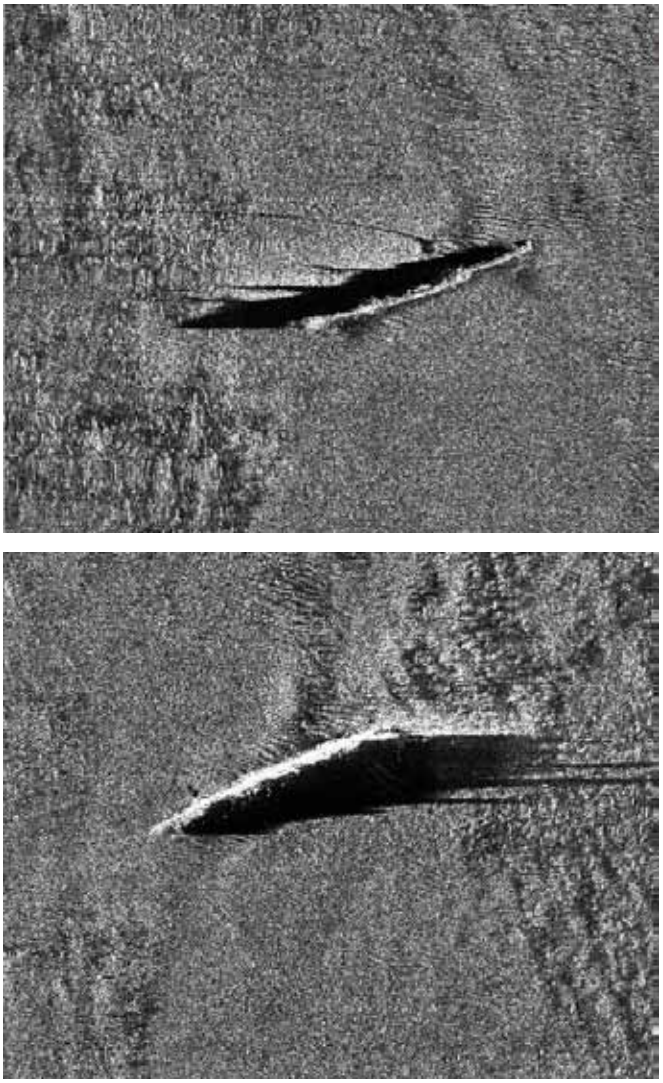

Fig. 62. Side-scan sonar images of U-103 (site TRI-15a-39Wb-1), lost 12 May 1918 and located 96km west of Falmouth, Cornwall, England.

J. U-327 (Site T1a12a-6)

U-327 was a Type VIIC/41 ocean-going attack submarine built at the Flender Werke AG shipyard in Lübeck. Launched on 27 May 1944, the submarine joined the training Fourth Flotilla base at Stettin, north-east Germany (now in Poland). Then the vessel joined the combat Eleventh Flotilla based at Bergen, Norway. Commanded by Kapitänleutnant Hans Lemcke, U-327 commenced its war patrols. U-327 was depth-charged from the British frigates HMS *Labuan*, HMS *Loch Fada* and the British sloop HMS *Wild Goose* in the western end of the English Channel on 27 February 1945, with the loss of 46 men. U-327 was not credited with any successful enemy sinkings or attacks.[6]

This target had the possibility of being two vessels, namely the American World War I merchant ship *Raven* or the World War II German submarine U-327. The side-scan sonar images verified that the target was most likely

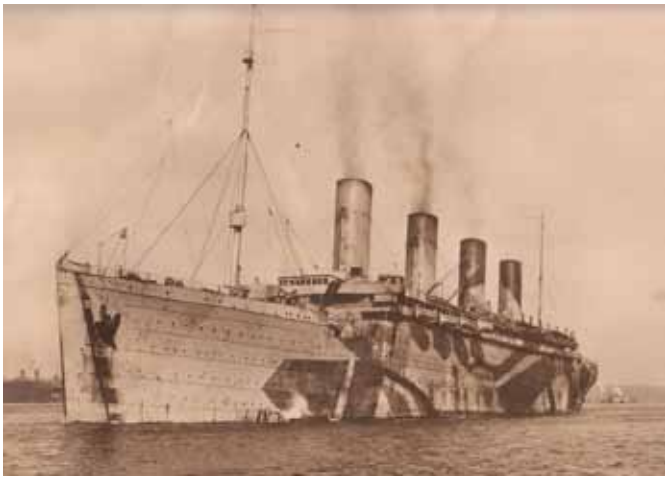

Fig. 63. RMS Olympic *fired on and then rammed U-103 on 12 May 1918.*

Fig. 64. The deck superstructure and hull of U-103.

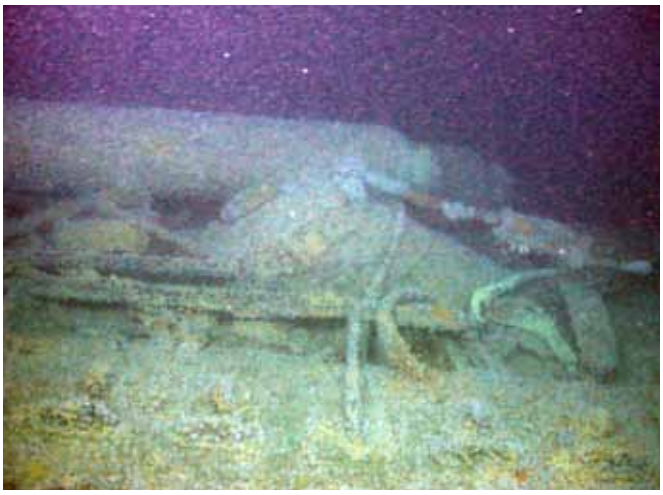

Fig. 65. The forward torpedo-loading hatch of U-103.

Fig. 66. The aft galley hatch of U-103.

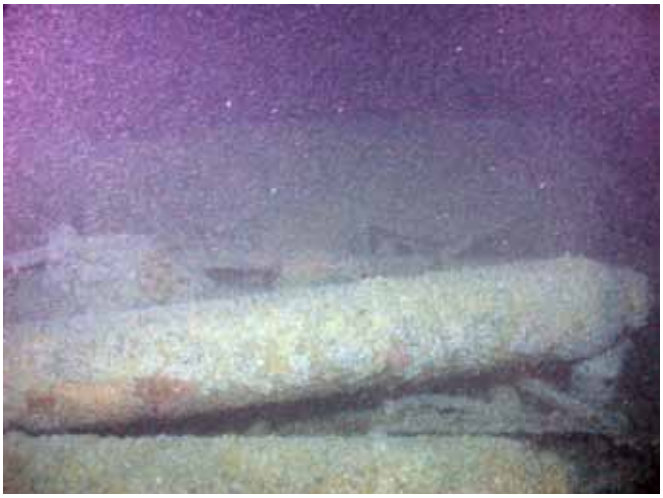

Fig. 67. Air bottles on U-103.

Fig. 68. The starboard propeller of U-103.

Fig. 69. The aft gun deck of U-103 and snagged fishing nets.

Fig. 70. The open conning tower hatch on U-103.

Fig. 71. The conning tower on U-103.

Fig. 72. The forward deck gun of U-103 alongside snagged fishing nets.

Fig. 73. Spilled deck gun ammunition from U-103.

Fig. 74. The port anchor and torpedo tubes of U-103.

a submarine. Designated as UKHO (United Kingdom Hydrographic Office) target number 22313, this site did not have any structures on the seabed and was classified as 'DEAD'. The UKHO has not located the wreck of U-327. UKHO target 22326 was classified as the American Auxiliary vessel *Raven* torpedoed by UB-55 on 14 March 1918. The side-scan sonar image of this site did not appear to match the *Raven* and it is likely that this casualty lies further north of the survey block within which this target lies.

Odyssey decided to dive this target to confirm its identity as a submarine (as the side-scan sonar imagery suggested). Other U-boats to be considered in the area were: U-650 a Type VII C, U-683 a Type VII C, U-740 a Type VII C, and U-1055 a Type VIIC.

U-327 is located 40km south-west of Penzance, Cornwall, at position 49°45.92'N, 005°45.27'W in 87m of

water. The wreck lies intact on a flat sand/shell seabed with an 80° list to starboard and the bow points in a south-east direction (Figs. 75-76). There is damage to the bow where the top deck section was dragged aft along the fore deck by trawl nets. The port torpedo tubes are visible through the damaged superstructure, as well as where they connect to the pressure hull (Fig. 77). The port dive plane is intact in the neutral position (Fig. 78). The intact keel is missing a few steel plates along the port side (Fig. 79). Of significance was the discovery of the intact balcony microphone array system on the keel, just below the forward dive planes (Fig. 80). This feature identified the U-boat as a Type VIIC/41 vessel.

The intact forward torpedo-loading hatch is closed (Fig. 81). Adjacent to that the Schnorkel head and tube are intact in the stowed position (Fig. 82). The midships pressure hull side structures have damage and holes in them (Fig. 83). The conning tower is intact, with some superstructure damage. The periscopes are in the stowed position and the DF loop and other features were missing. The main hatch opening lacks the hatch itself, which may have been broken off by nets (Fig. 84). No deck guns and platforms were observed. The port propeller shaft and propeller were intact, although covered in trawl net (Fig. 85). The extreme stern section is broken off, situated on its side on the seabed (Fig. 86). The aft air bottle has been displaced and is on the seabed along the bottom of the port side of the keel.

Battle damage is evident just forward of the aft dive planes. From observations of the conning tower, U-327 appears to have been rigged for diving, submerged and hiding from surface attack. Along the top and slightly down the sides of the pressure hull are cracks that breached the hull's watertight integrity (Fig. 87). Also missing are sections of the stern's superstructure, and the separated extreme stern section rests on the seabed. This damage is consistent with that caused by depth charges detonating near the stern to separate the stern section of the pressure hull. This fits the documented attack on U-327.

This site is heavily covered in snagged trawl net, floats and lines (Figs. 77, 81, 82, 88, 89). Along the port forward hull and forward deck are numerous bundled sections of net with lines and floats coming off it. From just aft of the port forward dive plane to the forward torpedo-loading hatch, draped bundles are caught on the hull. The nets snag the port propeller shaft and rudder. Along the keel line are further sections of net. From the quantity of net on this site it is obvious that a trawl net snagged the front section of U-327, dragged all the way to the stern, and, as a result, the trawler had to drop the snagged net. Just off the stern section a large pile of trawl net was observed, while 40m away to the north two smaller piles of net and fishing gear were located.

4. Site-Formation Processes

Every underwater wreck is unique in regard to the interplay between the wreck and its environment. The study of site-formation processes permits differences and patterns to be determined from interpretative studies. The sinking of a vessel is influenced by various factors and forces, some natural, such as weather and sea conditions, and some man-made, such as bad design, poor seamanship, fire and battle damage. The manner in which the vessel sinks before coming to rest on the seabed is also affected by environmental and anthropogenic forces. The environment the vessel settles into will shape the site-formation process. In turn, these may be affected by impacts like fishing activities and seabed development.

The nine U-boats surveyed in this paper span a time period of 96 years. U-103 sank in 1917 and the other eight U-boats were lost between 1944 and 1945, some 65 years ago. They all lie in depths ranging from 53-164m. The sinking of all these U-boats can be attributed primarily to damage inflicted to their pressure hulls, which allowed the ingress of sufficient quantities of seawater to prevent the submarines from surfacing or remaining on the surface. Eight of the nine U-boats were sunk by some type of explosive weapon (Table 7). The remaining World War I U-103 was badly damaged by a ramming incident, which forced its commander to scuttle the boat by opening sea valves to deliberately flood and sink the submarine.

Submarines are designed to operate within a certain depth limitation and, as such, the pressure hulls were made of a suitable thickness to withstand depth and pressure with an in-built safety margin. The hulls of World War I U-boats were constructed of carbon steel and could operate to a maximum depth of 100m, while the high-strength alloyed steel World War II versions allowed a greater operating depth (Fig. 90). The Type VIIC could operate to a maximum depth of 220m and the Type VIIC/41 to a maximum depth of 250m (Rössler, 2001).

U-boat pressure hulls are cigar-shaped with ends formed from dished plates, which carry the torpedo tubes' housings. Internally the pressure hulls were divided into several watertight compartments. In Type VIIC U-boats their plating thickness was 2.23cm, decreasing to 1.6cm towards the ends (Andrews and Showell, 2004: 37). The construction and shape, along with the compactness of all the internal machinery and equipment, made the U-boat a very strong structure. They thus tended to remain more intact on the bottom than iron/steel-surfaced vessels of the same age.

All the Atlas survey zone submarines remained relatively intact. All the conning towers are at least partially intact, although the armor plating is degraded or missing in some cases. The periscopes are either fully extended or fully stowed. All the wooden decking has degraded or is missing and sections of the streamlined external casing plating are badly damaged, missing or heavily degraded on the majority of the sites. This is to be expected because these structures were manufactured from thinner plating, which has been impacted by the initial brunt of the attack and is most vulnerable to post-depositional trawling activities and corrosion.

Various fittings and equipment originating inside the external casing fell onto the seabed once the external casing degraded, broke away or was damaged. None of the U-boats were upright, but were lying either on their port or starboard side. This pattern results from the design of the hull and the fact that the keel is not flat, but is rockered. On a Type VIIC submarine the keel is 0.54m high, 1.09m wide and 86m long. It is free flooding and iron ballast is carried at the ends (Andrews and Showell, 2004: 37).

Some of the U-boats are expected to still contain personal effects, movable equipment and fittings trapped within the pressure hull. Where large sections of the pressure hull are missing, exposing the interior to current motion, some material is likely to have been swept offsite. Human remains are also likely to survive, trapped between fittings, equipment and in compartments (see section 6 below).

All of the U-boats surveyed displayed damage to the bow and stern sections:

- Bow damage: U-988, U-325, U-327
- Stern damage: U-988, U-325
- Bow section missing: U-400, U-1021
- Stern section missing: U-326, U-325, U-650, U-400, U-1021
- Collision damage aft of her conning tower as the cause of sinking: U-103

The majority of this damage was caused by wartime explosives, but it is possible that some damage to the bow and stern was caused by impact with the seabed. Generally it was the rule for U-boats to dive deep to escape attack, which meant that U-boat dive planes would be expected to be found in the downward position.

Pressure hull damage to all but one of the surveyed U-boats was evidently caused by explosive forces. Three types of explosive weapons were used in the attacks, namely depth charges, mines and airborne homing torpedoes. The explosion from a depth charge occurs in two parts. First, the initial explosion and shock wave from the device detonating either by contact or at a pre-set depth is sufficient in strength to cause damage to the U-boat crew and internal equipment. However, it is the second shockwave, a result of the cyclical expansion and contraction of the gas bubble from the initial explosion that will inflict the most damage. If this is close enough to the U-boat it will attach itself to the hull, and this expansion and contraction will bend the submarine back and forth causing the U-boat pressure hull to crack and breach (Jones, 1978: 50-5). A mine works the same way. In the case of the aerial retro-bomb, the cone-shaped warhead would penetrate the pressure hull and then detonate, causing catastrophic damage from the explosion and subsequent shock waves.

Following these explosions, the U-boat pressure hulls would have been considerably weakened, having a direct bearing on the collapse of the submarines' structures over time. Odyssey's observations of the Atlas zone U-boats revealed cracks caused by the shock waves in the form of areas of plate blown inwards and large holes where the aerial bomb struck. The perceived damage to the majority of the stern and bow sections indicates that it was caused by the flexing of the U-boat from the shock waves of the explosive weapons and, as mentioned above, by the bow or stern striking the seabed first.

U-326 and U-103 were struck and damaged just below the surface, while attempting a crash dive to escape attack. A crash dive was the fastest procedure by which a U-boat could submerge. As soon as the conning tower hatch was closed, the order would be given to close the exhausts and blow the diving cells (Paterson, 2009: 106). The remaining seven U-boats were all damaged within a 100m water depth because they were trying to avoid depth charges and buoyed mine fields. If not badly damaged, the submarines would sit on the bottom and wait till the attacks stopped. If fatally damaged by depth charges or mines, escape was rare. If the hull was not crushed by water pressure when the submarine sank below its operational depth, most crewmen found themselves trapped inside the watertight compartments until the air ran out (Williamson, 2001: 51-2).

The only way of escape from a submerged U-boat was by using a German Tauchretter (diver rescuer) rebreathing set. This item of life-saving equipment had two functions as both a life-vest and a source for breathing air. The user inserted the mouthpiece and fitted a nose clip. By breathing into the unit the exhaled carbon dioxide would be chemically scrubbed and oxygen released for rebreathing. During the escape to the surface a crewman needed to breathe continually in order to avoid pulmonary barotrauma (burst lung). Depending on depth, the set had a working duration of 15-45 minutes (Stelzner, 1943). The most common type used by the Germans was the Dräger apparatus (Fig. 91).

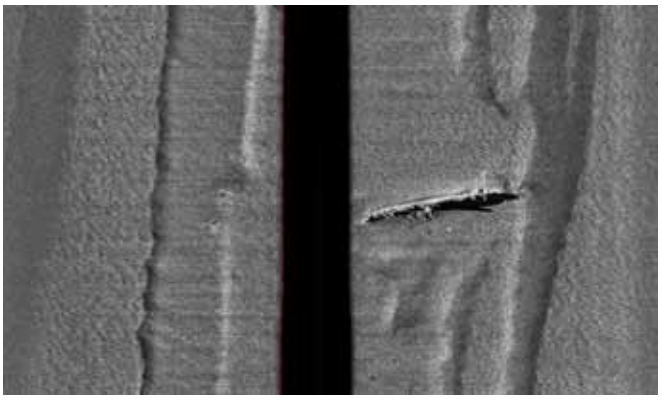

Fig. 75. Side-scan sonar image of U-327 (site T1a12a-6), lost 27 February 1945 and located 40km south-west of Penzance, Cornwall, England.

Fig. 76. The bow of U-327.

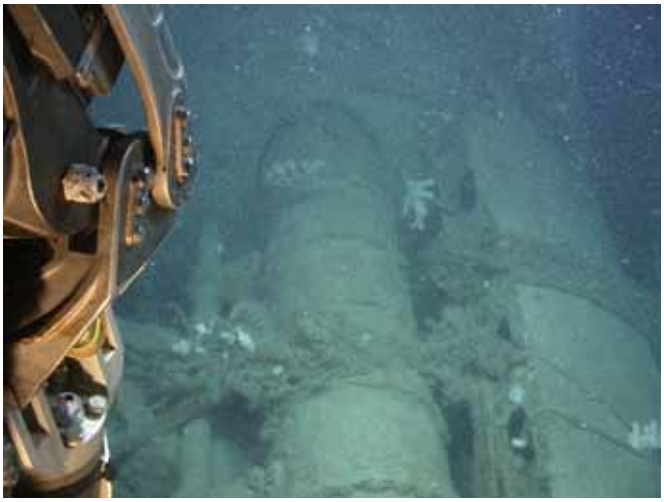

Fig. 77. The port torpedo tube of U-327.

Fig. 78. The port dive plane of U-327.

Fig. 79. A section of U-327's keel with missing plates.

Fig. 80. The balcony microphone array from U-327.

Fig. 81. The forward torpedo-loading hatch of U-327, alongside snagged fishing net and rope lines.

Fig. 82. The Schnorkel head and tube of U-327 alongside snagged fishing net.

Fig. 83. Pressure hull damage on U-327.

Fig. 84. The conning tower, periscope and open hatch of U-327.

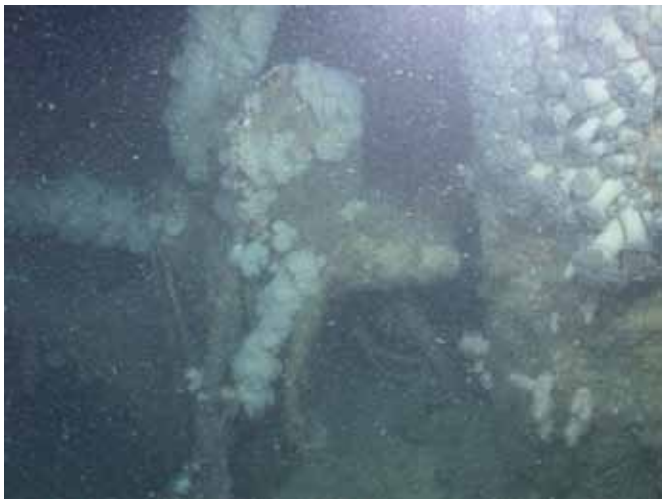

Fig. 85. The port propeller and shaft of U-327.

Fig. 86. The stern section of U-327.

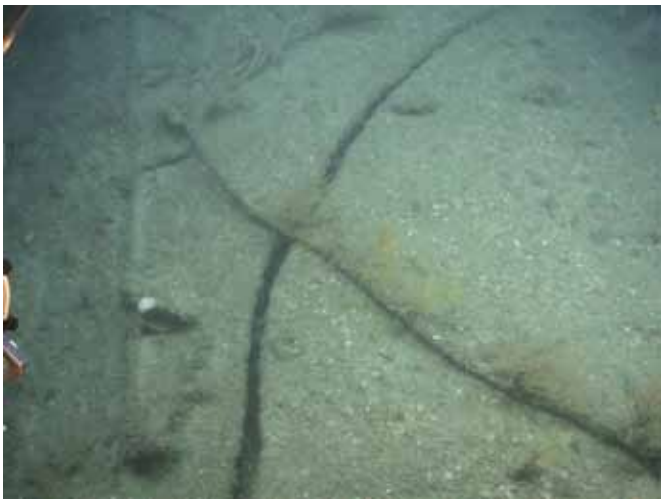

Fig. 87. Hull cracks forward of the dive plane on U-327.

Fig. 88. Trawl nets, lines and float remains close to the stern of U-327.

Fig. 89. Dense trawl nets, lines and floats snagged on U-327.

Fig. 90. Cross-section through the hull of the salvaged U-534, Liverpool, England, clearly showing the basic construction of a U-boat pressure hull and outer casing, which is structurally related to U-327's pressure hull damage (Fig 83).

Escape from a submarine was a difficult procedure. Due to the force of the water pressure outside the hull, hatches could not be opened until the U-boat interior was flooded to a particular level, pressurized air from storage tanks bled in, and the pressure equalized with the ambient sea pressure. This could take minutes or even longer depending on the situation.

An example of an escape from a U-boat is given below. U-701, commanded by Kapitänleutnant Horst Degen, was sunk by a depth charge aerial attack delivered by an American Hudson aircraft of the US Army Bomb. Sqdn. 396 on the afternoon of 7 July 1942 near Cape Hatteras, Atlantic east coast of the USA:[7]

"The aerial attack was immediately fatal to the U-701. The pressure hull was torn open in the after compartments and the sea poured in. The instruments in the conning tower were all smashed. Degen ordered the ballast tanks blown, but to no avail, the U-701 would never surface again. They were on the bottom in moments and the boat took a list of 20 degrees to the starboard with the sea flooding in. Within two minutes the control room was almost filled with seawater and the crew was forced to make an escape attempt quickly or they would drown inside the boat.

Degen later recalled that the hatch opened easily and he floated up out of the boat almost effortlessly.

Sixteen other men made their escape through the conning tower hatch to the rough sea surface to join him.

> Between them they only had one life jacket and three escape lungs for floatation.
>
> The men in the forward torpedo room had been able to dog the hatch to the control room and survive the initial flooding. They had to remove the bracing across the forward torpedo loading hatch opening, then another eighteen men escaped the submarine one after the other through the loading hatch tube which is about twenty inches in diameter and four feet long. These sailors all made the surface about thirty minutes after Degen and the control room men did and they were as poorly equipped as their comrades, since very few had floatation gear for their survival."

Other than the World War I submarine U-103, which was scuttled, reports do not exist for the other sites of survivors or bodies recorded or collected from the water wearing escape sets. Many of the men may not have had sufficient time to put a set on.

A great fear for the crew was the danger of saltwater coming into contact with their batteries (stored in compartments below the radio room, aft of the conning tower and below the officer's accommodation just forward of the conning tower), which could cause poisonous chlorine gas to be produced. Crews carried out drills and procedures to attempt to surface a submarine to enable them all to escape to life rafts. This option was far preferable to relying on rebreather sets or having to deal with chlorine gas.

Chemical and biological processes working in conjunction with mechanical ones shaped site-formation processes. Odyssey's surveys created an opportunity to study four similar U-boats of two types and an individual example from World War I. The surveys were non-invasive and did not include *in situ* corrosion measurements. However, similar corrosion processes were visible on all the sites. An example of a mechanical process was the observation on all sites of sections of concretion having been knocked off the outer hull casings by trawl gear. U-1208 is the most damaged and internally exposed U-boat, while U-326 (the deepest U-boat wreck) is probably the least damaged. U-103 sustained only one fatal blow and was scuttled. Internally, U-103 is likely to be the best preserved due to minimal apparent hull damage. All the others would probably had serious damage internally from explosive shockwaves.

All the submarines except U-326 in the Bay of Biscay are located in the Western Approaches to the English Channel in a depth range of 53-103m. Thus, environmentally all are generally similar regarding type of seabed, current, tidal action and marine life. The most important differences would relate to site-specific divergent oxygen and pH levels. All displayed comparable corrosion conditions when examined visually. The wood decking sections of the external casings are missing or degraded with holes. Superstructure fittings and equipment that have fallen off the top of the pressure hull and along sections of external casing are now lying on the seabed alongside the keel on the side towards which the U-boat lists. One important question affecting issues of preservation is whether the U-boats are corroding at the same rate or whether those with sections of large exposed pressure hull are corroding faster than the relatively intact submarines. A definitive answer would require formal corrosion potential measurements to be taken followed by ongoing site monitoring. This would potentially explain whether there is a correlation between better preservation and depth.

Amongst the U-boats surveyed by Odyssey, the World War I U-103 exhibited the least damage. It was rammed and then scuttled, whereas all the other submarines suffered explosion trauma. The preserved condition of U-103 is superior to some of the badly damaged World War II U-boats. It would be a highly interesting future development to compare the corrosion conditions of U-103 with U-988 because both are isolated in the middle of the western entrance to the English Channel. Further revealing data may be obtained by comparing U-326 in 164m of water with U-327 at a depth of 88m since both are the same type of U-boat and were launched within a month of each other. Marine growth is conspicuous on all the submarines and U-103 is the most densely covered. This may be due to having spent 17 years longer underwater than the others and is perhaps also related to her location and depth.

A corrosion study has been carried out on the Australian submarine HMAS AE2, which sank in 1915 in the Sea of Marmara, Turkey. It was scuttled and rests in a silt mound at a depth of 73m. Conducted by Dr. Ian D. MacLeod of the Western Australian Museum Collections and Research Centre, part of the results of this investigation concluded that "The data gathered from in-situ corrosion measurements on the hull of the submarine AE2 and the core profiles close to and 20 metres from the vessel show that the dense marine concretion and the great depth of the wreck site is providing a relatively benign storage environment for the vessel" (MacLeod, 2010: 35).

Taking into consideration the compactness of a U-boat, all the different types of metal structures and the battery banks, it is highly likely that long-range or proximity corrosion (long distance galvanic coupling between engines and motors and batteries) has taken place amongst the Atlas U-boat group. All the compartments within the U-boats would have been flooded and everything may be anticipated to be covered internally with a concretion layer. Dissimilar concreted metals lose their electrical isolation, resulting in the more reactive metals corroding, while the more noble alloys are protected (North, 1988: 8-11).

Species Type	Genus
Pollack	*Pollachius pollachius*
Cod	*Gadus morhua*
Ling	*Molva molva*
Conger eel	*Conger conger*
Bib	*Trisopterus luscus*
Dogfish	*Scyliorhinus canicula*
Angler fish	*Lophius piscatorius*
Lobster	*Homarus gammarus*
Crab	*Cancer pagurus*
Squat lobster	*Munida rugosa*
Edible sea urchin	*Echinus esculentus*
Common starfish	*Asterias rubens*
Sea anemone	*Sagartia elegans*
Plumose anemone	*Metridium senile*
Dead man's fingers	*Alcyonium digitatum*
Moss animals	*Bryozoan turfs*
Polyps (Hydroids)	*Nemertisia Sp.*
Coral	*Caryophyillia Sp.*

Table 8. Marine species recorded on the Atlas zone U-boat wrecks.

5. Marine Life

All the Atlas U-boat sites display common marine life colonization. Although this paper concentrates on history, site-formation and impacts, images of the marine life from a selection of the sites surveyed were submitted to Dr. Clare Peddie of the School of Biology at the University of St. Andrews for species identification and insights into the basic colonization sequence.

All unprotected, apparent solid surfaces in the sea sooner or later become fouled. There is a frequently observable colonizing sequence from the initial formation of a macromolecular film followed by bacteria and then diatoms to form a biofilm that is later inhabited by marine animal larvae and algal spores. The brown/gray marine growth observed on all the surfaces of the U-boat sites is referred to as a circalittoral faunal turf. The composition of these turfs varies depending on current, depth, substrate and other factors.

Most of the constituents can only be identified to species level following sampling and microscopy. The U-boat wreck formations display a type of turf normally found on exposed sites (hydroids and bryozoans prevalent) and typified by some or substantial tidal influence. Based on underwater photographs, the brown matting-like material all appears to be circalittoral faunal turf – the short turf is probably more exposed to tide than the longer turf, which is associated with larger animals and grows in the more sheltered areas of the wrecks (Figs. 92-94). The species observed on the sites are listed in Table 8.

The marine life present on the Atlas U-boat wrecks would appear to be as anticipated for any shipwreck site in these geographical catchment zones (Figs. 95-104). The establishment of a stable colony of marine life is of particular interest to the fishing industry. In general terms, in all cases wrecks attract marine life and in turn the attention of commercial fishing activities. Of the species identified, the following are commercially fished: pollack, cod, ling, bib, conger eel, dogfish, angler fish, lobster, crab, squat lobster and edible sea urchin.

6. Human Remains

While Odyssey's surveys of the Atlas U-boats were non-invasive and no human remains were observed, the subject is an important consideration within shipwreck studies. Shipwrecks are events that were not designed or planned, after which the deceased do not receive a proper burial. In the unique case of submarines, whole crews of 40-55 men are likely to remain trapped within compartments in the pressure hulls. Crews often referred to submarines as iron coffins.

The question of what happens to human remains within submarines is crucial to issues of scientific study and preservation philosophy, and can be examined through marine forensic taphonomy – the study of the decomposition of human remains. The percentage of shipwrecks containing human remains is an unknown quantity. Certainly it would be wholly false to argue that all shipwrecks contain human remains. Their deposition on shipwrecks is dependent on numerous interacting environmental, chemical and biological factors.

While human skulls and bones are frequently discovered in undisturbed underwater caves and submerged sites characterized by anaerobic heavy silts and mud, such as the warm mineral spring sites at Little Salt Springs in Sarasota County, Florida, where skull and bone fragments from the Upper Paleolithic Period (12,000 to 9,000 years ago) were discovered on ledges in a sinkhole (Clausen *et al.*, 1979), comparable human remains are rare on the wrecks of wooden ships.

Out of 1,259 Mediterranean shipwrecks catalogued in Parker's study of *Ancient Shipwrecks of the Mediterranean and the Roman Provinces* (1992), only two sites were recorded as containing human remains. The 10th century AD, 54-55m deep Early Islamic Bataiguier wreck off France was associated with the bones of three adults, while the Marsala Punic wreck, Sicily, an oared galley in 2m lost *c.* 250-175 BC, held the remains of at least one human and a small dog (Parker, 1992: 70, 262-3). Within Odyssey's Atlas

Shipwreck Survey project search area, limited human bones have only been discovered on one wreck, HMS *Victory* of 1744 (Cunningham Dobson and Tolson, 2010: 281-8).

Human remains evolve various ecological functions in marine contexts. Depending on their disposition, they may provide a rich marine resource, including a source of energy for a varied selection of scavenging fishes and invertebrates; provide micro-habitat shelter for small non-scavenging species; attract a variety of secondary predacious species attracted to the original scavengers; and during advanced stages of decomposition provide a substrate for invertebrate grazers attracted to bacterial films on bones, or to the bones themselves as a source of calcium and other minerals (Haglund and Sorg, 2006: 568).

Decomposition in seawater may be slow or rapid, and the preservation and distribution of human remains dependent on temperature, salinity, depth, currents, nature of the substrate interactions between physical and chemical processes and the number and type of scavenging organisms present. In the case of human remains entombed within submarine compartments, they may remain unaffected by all the above processes (Haglund and Sorg, 2006: 568).

The scavengers that feed on human remains are generally fish, gastropod mollusks (snails, slugs, cowries, or limpets), crustaceans (crabs, lobsters, crayfish, shrimp, krill and barnacles) and echinoderms (feather stars, starfish, brittle stars, holothurians (sea cucumbers) and sea urchins

The scavenging action of biting, tearing and chewing may affect a corpse in various ways. Clothing over the body may be altered, disarticulation and dissemination of body parts may be quickened. An increase in tissue surface area, which encourages faster bacterial and micro-scavenger activity, all assist to decrease the time to skeletonisation (Haglund and Sorg, 2006: 569). The majority of the above scavengers were observed on the Atlas U-boat sites surveyed.

Some of these scavengers may not be able to feed on the human remains trapped within sealed compartments. Of importance to the rate at which the corpses are reduced to skeletal form is the cause of death. In the case of the surveyed U-boats, death could be attributed to the following causes:

- Drowning: trapped in a water filled space or during escape to the surface.
- Asphyxiation: lack of oxygen, (human consumption over time), increased levels of carbon dioxide (human expulsion over time, trapped machinery exhaust), chlorine gas (seawater in contact with batteries), phosgene gas, various other toxic gases/fumes from various sources such as torpedo fuel, lubricants, and other elements.
- Trauma: explosions (flying debris including machinery breaking loose, concussion waves), fire (severe burns), embolisms (rapid pressure changes), pulmonary barotrauma.

The rate of human remains decomposition would be affected by the nature of the injury, with those suffering dismemberment of some degree decomposing more rapidly than those expiring from drowning, asphyxiation, or internal injuries (Lerner and Lerner, 2006: 433-756). In archaeological terms, this would not make much difference in the initial discovery of human remains.

The human remains trapped within U-boats would most likely go through a process of adipocere formation caused by fat decomposition of the lipids (fatty cells) that make up the subcutaneous fat layers. Corpses immersed in cold water may undergo a uniform adipocere formation resulting in the superficial outer layers of skin slipping off. As bodies decompose in water, the resultant free fatty acids react with hydrogen to form acids and other stearic (fatty acid) compounds in a process known as saponification (turning into soap). These processes may be further affected by the pollutants within the compartments, such as fuel oil, lubricants and other substances (Lerner and Lerner, 2006: 433-756).

The recovery of eight servicemen trapped inside the Civil War submarine *H.L. Hunley*, sunk off Charleston in 1864, determined that the remains had deteriorated to skeletal form, even though contextualized textiles were preserved. Some bones were embedded in the concretion that formed over the corroding iron hull. A detailed program of scientific analyses (osteological study, replication of bones, genealogical research, stable isotope analyses leading to crew identification, photographic super-imposition study

Fig. 91. A German World War II Dräger escape set from U-877 displayed in the Elgin Military Museum in St. Thomas, Ontario.

and concluding with facial reconstructions) was conducted prior to the final burial of the remains in Charleston's Magnolia Cemetery (Jacobsen, 2005).

While the sites within the Atlas survey zone are the final resting places for the officers and crew, it may be likely in the future that as the sites continue to degrade, or are damaged further by fishing activities, human remains from within the submarines will be displaced from their original contexts, scattered on the seabed, get washed off-site or become caught in fishing nets. Where possible and following permission, study may add greatly to a preliminary model of decompositional changes for human remains deposited within the confines of a submarine, and allow for respectful interment pursuant to the wishes of the appropriate authorities.

Fig. 92. Marine growth and marine life on the stern section of U-327.

7. Post-Depositional Impacts

The main potential post-depositional impacts on all of the Atlas zone U-boat sites are continuing fishing activities, ordnance, divers and seabed development. All the wrecks except U-326 are located in active areas of commercial fishing in the Western Approaches to the English Channel. U-326 has trawl net snags, but is less affected than the other eight U-boats, which display damaging evidence of trawling and gill net fishing. This damage is not deliberate: wreck sites are rich environments for fish. Losing nets is expensive. However, in practical terms as fish stocks decline fishing boats are likely to risk returning to an established site of proven productivity. So dense were the shoals of fish around U-988 that it hindered the visual site survey.

Considering the strong steel construction of a U-boat, trawling activities have inflicted a surprising amount of damage. U-1208 was the worst snagged U-boat recorded during the survey. It displayed much battle damage, and the exposed frames of the pressure hull made them easy targets for trawl nets to snag on. U-650 was heavily draped in trawl net, with line and floats in the water column. So dense were the lines that the ROV Zeus's thrusters became ensnared. U-1201, which lies only 10km off the coast, was not only snagged by trawl nets, but had lobster/crab creels caught in the debris along the keel line. U-327 exhibited evidence of a trawl net snagged on the bow; the net continued all the way to the stern, while a few meters off the stern were large bundles of trawl net, which a snagged fishing boat had most likely cut away.

The damage caused by fishing activities is not reversible. The nets become snagged and, as the trawler continues to work, parts of the U-boats may be torn away or damaged. Lines, floats and rollers strike the hull to remove

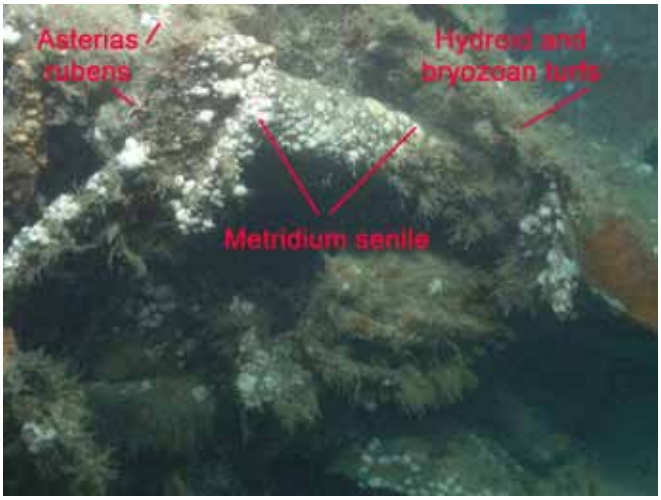

Fig. 93. Marine growth and marine life on a section of U-400.

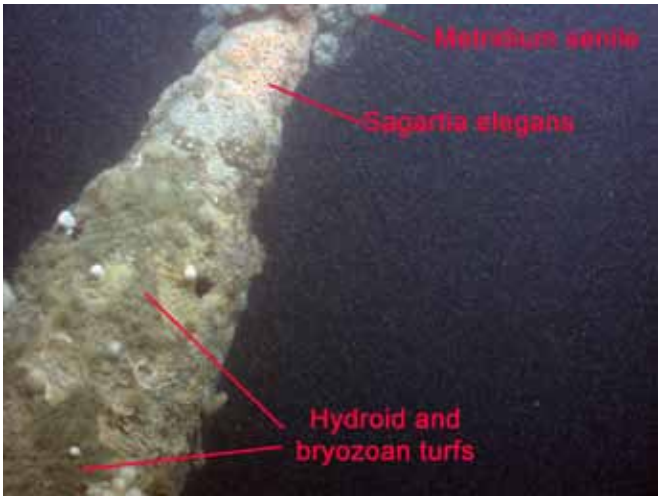

Fig. 94. Marine growth and marine life on the periscope section of U-988.

U-Boat	Type	Museum	Description
Brandtaucher	Early experimental, 1850	Museum for Military History, Dresden, Germany	Completely restored
U-1	Pre-war boat, 1906	Deutsches Museum, Munich, Germany	Restored, open hull section display
U-20	Pre-war boat, 1913	Strandingsmuseum St. George, Thorminde, Denmark	Conning tower only
UB-46	Type UB II, 1916	Turkish Naval Museum, Istanbul, Turkey	Parts of hull displayed
U-61	War mobilisation boat, 1916	Bayerische Armeemuseum, Ingolstadt, Germany	8.8cm gun
U-9	Type IIB, 1935	Marine Museum of the Black Sea Fleet, Sevastopol, Ukraine	Salvaged conning tower in museum grounds
U-505	Type IXC, 1941	Museum of Science & Industry, Chicago, USA	Complete; displayed in museum grounds
U-995	Type VII/C41, 1943	Naval Memorial, Laboe, Kiel, Germany	Completely restored
U-534	Type IXC/40, 1943	Birkenhead, Liverpool, UK	Complete; on display
U-2540	Type XXI, 1945	German Shipping Museum, Bremerhaven, Germany	Complete; displayed in museum grounds

Table 9. Complete or sections of U-boats on display worldwide.

sections of the hull concretion. U-103 has bundled trawl net around the periscope and aft deck gun. The majority of the U-boats have nets caught on their bow and stern sections as well as on the conning towers. Fishing damage to wrecks is not exclusive to U-boats in the Western Approaches to the English Channel. In a period from 2005 to 2008, Odyssey surveyed 267 wreck sites within this area of which 112 displayed evidence of damage by fishing activities (Kingsley, 2010: 224). Fishing activities are likely to continue and, as a result, further damage will continue. However, the survey of the Atlas zone U-boats has now created baseline reports about the condition of the submarines and status of fishing damage.

Fishing impacts are well recorded from other submarine wrecks. The *Resurgam*, the world's second built mechanically propelled submarine and lost in 1880 in Liverpool Bay, Rhyl, Wales, was found when a diver was clearing fishing nets at a depth of 18m after the site was snagged by a Colwyn Bay trawlerman.[8] *HMS/m A1* sank in Bracklesham Bay, West Sussex, England, while unmanned in 1911, and was discovered in 1989 after a fisherman again snagged his net on the wreckage and reported the hang (Wessex Archaeology, 2006: 3).

The *Holland 5* submarine lost in 1915 off the Royal Sovereign Lighthouse, Sussex, was found heavily netted in 2005 and 2006. A steel cable wrapped over the wreck almost certainly destroyed some of the submarine's upper works and external features. Major net damage has been inflicted on the cast iron exhaust pipes leading from the top of the pressure hull over the petrol engine to the exhaust box further aft along the upper deck. Two of the four pipes have been totally trawled off and a further pipe was only partially present (Wessex Archaeology, 2009).[9]

The Australian submarine *AE2* (a British E-Class submarine) sunk in 1915 and found at a depth of 73m in the Sea of Marmara, Turkey, had been damaged by uncontrolled fishing activity, which fouled the hull, stripped the protective marine formations and resulting active corrosion (particularly visible at the bow and conning tower), caused hull plates and rivets to be sprung, and produced noticeable denting along the hull sides (Smith, 2000: 12).

The M24 Japanese midget submarine sunk in Sydney Harbour in 1942 was found at a depth of 54m off Bungan Head covered in post-1960s commercial nylon fishing nets. Trawling is possibly responsible for the disappearance of most of the conning tower, the bow net cutting equipment, the bow and propeller protective cages, the rudders, and the crew access chute. Another theory under investigation is whether the submarine had been rolled by past fishing net hookups, an idea supported by the presence of a rope twice wrapped around the vessel at the aft hull.[10]

As naval weapons, U-boats carried torpedoes, ammunition for deck guns and, in some cases, mines. It was evident from the surveys that torpedoes and other ordnance remain onboard many of the submarines. U-boats were fitted with bow and stern torpedo tubes. The U-boat types surveyed had four tubes forward and one or two tubes aft. Of the surveyed sample, U-988, U-325 and U-650 showed evidence of torpedo tubes, some of the loading doors are open, the propellers of the torpedoes visible and some with exposed torpedoes partly exposed out of their tubes. Evidence of shells for the deck gun was observed spilled out of

Fig. 95. A shoal of pollack (Pollachius pollachius) *around the torpedo-loading hatch of U-988.*

Fig. 96. A ling fish (Molva molva) *on a wreck in the vicinity of U-988.*

Fig. 97. A Conger eel (Conger conger) on the bow of U-326.

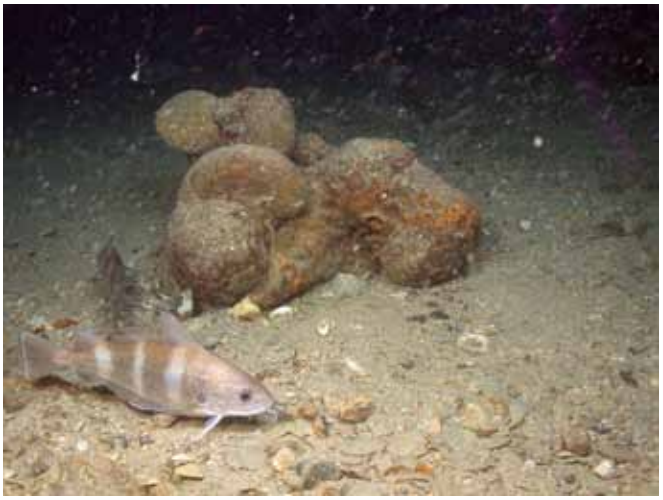

Fig. 98. A bib (Trisopterus luscus) *in the vicinity of U-326.*

Fig. 99. A spotted dogfish (Scyliorhinus canicula) *on U-326.*

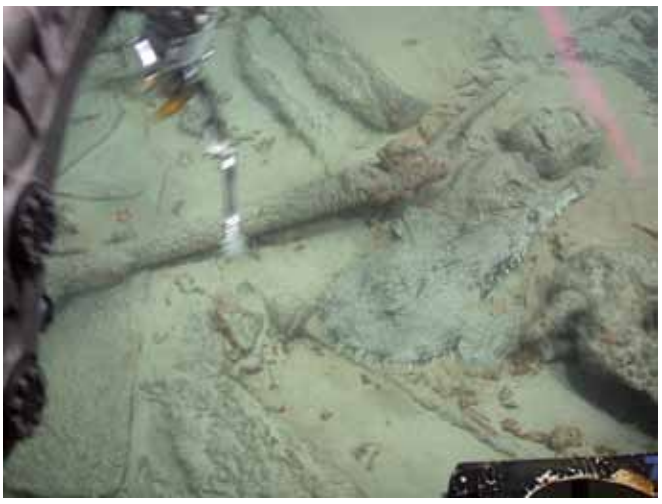

Fig 100. A monk fish/angler fish (Lophius piscatorius) *on U-326.*

Fig 101. A lobster (Homarus gammarus) *on U-326.*

Fig 102. Crabs (Cancer pagurus) *on U-327.*

Fig 103. Squat lobsters (Munida rugosa) *on U-327.*

Fig. 104. An urchin (Echinus esculentus) *on U-325.*

their ammunition box on U-103. U-650 may also contain some unexploded hedgehog depth charges.

What impact could these unexploded torpedoes and ordnance have on the future integrity of these submarine wrecks? In order to address this issue, the author contacted a local navy Bomb Disposal team and spoke to one of its members. CPO Eddie Yates (Northern Diving Group, HMB Clyde, Faslane, Scotland) explained that the explosives Torpex and Hexanite are used in depth charges and torpedoes. Through time exudation occurs. The explosive mixture weeps out of the joints of the torpedo to form crystals, which are contact sensitive. If hit hard enough, they will set off a chain reaction that may detonate the weapon.

Therefore, it is highly recommended that ordnance not be disturbed or removed from U-boats unless rendered safe by Explosive Ordnance Disposal (EOD) teams. With regard to fishing activities, it is possible that a torpedo could be dragged up from a U-boat in trawl nets. This is a common occurrence with mines that fishermen snag around the coastline of the UK. Organizations such as the Maritime and Coastguard Agency have records of these incidents, although such events are not always reported. If ordnance does explode on U-boat wreck sites, considerable damage to the site and potentially the fishing boat would obviously occur.

U-boats are also popular dive sites and the removal of parts of submarines by trophy hunters is common. For instance, recreational divers removed pieces of *HMS/m A1* in Bracklesham Bay, including a porthole and five deadlights. Both torpedo loading hatches secured by Chichester BSAC club were subsequently opened and interior fittings removed (Wessex Archaeology, 2006: 3-4). Fortunately, the wrecks Odyssey surveyed are deep enough to deter air divers, but are within the range of technical divers using rebreathers and Trimix gases. Even though divers should be aware that U-boats are war graves protected by legislation, a minority still removes 'trophies' from them. Relatively

intact U-boats with closed hatches restrict the opportunity for divers to enter them, but there have been instances where divers have risked entry. The narrow hatches and possible chances of snagging diving equipment normally deter interference. The author has spoken to a few divers who have dived U-103, which lies at a depth of 103m.

It is possible that some of the U-boat wrecks may still contain tanks holding fuel and oil. Through time and the degradation of the steel tanks, these substances could leak out to create environmental hazards. None of the Atlas U-boats surveyed showed signs that any fuel or oil has remained in tanks. Although not a submarine, the sunken wreck of HMS *Royal Oak* highlights the issue of steel wrecks with fuel and oil still remaining in their tanks. This Royal Navy Revenge-class battleship was launched in 1914 and completed in 1916. While at anchor at Scapa Flow in Orkney, Scotland, on 14 October 1939, she was torpedoed by the German U-boat U-47 commanded by Günther Prien. Of the ship's crew of 1,234 men and boys, 833 lost their lives.[11]

Lying upside down at a depth of 33m, the *Royal Oak* is a designated war grave on which diving is prohibited. The Ministry of Defence has conducted several surveys of the ship, and in the 1990s an increased rate of oil leaking from her corroding hull was observed. Plans were made to remove the oil because the possible future splitting of the tanks would cause environmental issues and pollution. The *Royal Oak* was carrying up to 3,000 tons of fuel oil. All the double bottom tanks were emptied by the end of 2006 and work on emptying the inner wing tanks commenced in 2007. By 2010 some 1,600 tonnes of fuel oil had been removed, thus eradicating the threat of pollution. Occasional visits are made to pump out the remaining small pockets of oil.[12]

It is conceivable that similar methods of oil removal used on HMS *Royal Oak* could be applied to any sunken U-boat that poses a pollution threat.

8. The Future

What strategies should be considered for the future of the Atlas survey zone U-boat wrecks? There certainly is no case to warrant recovery. Many examples exist on dry land of recovered and restored U-boats, which are now part of museum collections or tourist attractions (Table 9). Ten examples of complete U-boats or sections are on display covering their early development until the end of World War II (Mõller and Brack, 2004: 210-14).

U-995 is a Type VIIC/41 submarine, four of which were surveyed by Odyssey. This U-boat class has been fully restored and today an example sits on public display in front of the Marineehrenmal Laboe (Naval Memorial) near Kiel in Schleswig-Holstein, Germany. An extensive body of research and documentation exists about U-boats. Submarines are a very popular subject. The internet is full of sites dedicated to them, the men who served on them and a large market exists for U-boat memorabilia.

Non-invasive surveys of submarines have been conducted around the world. More comparable projects would benefit our understanding of submarine wrecks. These have included corrosion measurement studies, such as initiated on the Australian submarine *HMAS AE2*, discovered in the Sea of Marmara by Selçuk Kolay, Director of the Rami M. Koç Museum in Istanbul, whose identity was confirmed in 1998 by a combined Turkish-Australian team (MacLeod, 2010: 31). Of cultural significance to both Turkey and Australia, this site is the subject of ongoing debate about its future and management.

On the East Coast of the USA, the National Park Service, Minerals Management Service, East Carolina University, the University of North Carolina Coastal Studies Institute, and the State of North Carolina collaborated in 2008 with the National Oceanic and Atmospheric Administration Office of National Marine Sanctuaries on an archaeological expedition to survey three World War II U-boats sunk by America during the Battle of the Atlantic. Within sport diving range, these sites were surveyed, measured and documented due to concerns over looting.

Another important U-boat survey conducted by the US Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, was the New Orleans multidisciplinary study of World War II shipwrecks in the Gulf of Mexico. This project consisted of comprehensive biological and archaeological investigations of six World War II vessels, including the German submarine U-166 lying in two sections in 1,480m of water. From the report the site preservation is documented as follows (Church *et al.*, 2007: 134):

> "U 166 is in a good state of preservation. The splashguard, often among the first components to be lost, is showing the signs of deterioration, but is otherwise mostly intact. The wood decking along the vessel's exposed areas is gone. The damaged area of the stern is buried and could not be examined. The bow area that ripped away from the main hull is partially visible and shows considerable damage. The bow section forward of the damaged area is well preserved. Rusticle growth is most profuse on the conning tower and near the bow's exposed damaged sections."

Notably, no fishing net was snagged or draped over the hull remains. The U-166 site may be relatively unique in terms of preservation. Other than the typical modern

rubbish dumped at sea that has landed on and around the site, it is a relatively pristine and an excellent example for the study of wreck formation process undisturbed by human influences. A 24m-long World War II Japanese midget submarine found sitting intact and upright at a depth of over 400m in Pearl Harbor is another example of excellent deep-sea preservation beyond trawler impact depths (van Tilburg, 2006).

The work carried out by World War II U-boat expert Dr. Axel Niestlé with dive groups from all over the world is of great significance. His goal is to positively identify the final resting places of lost World War II U-boats based on his experience that many official war records contain errors or no longer exist. By correcting them and documenting the U-boats' positions and names, a database is being created that is very useful for the German government, German navy archaeologists, historians and, most importantly, for the relatives of those who lost their lives in service to their country.

It is now 65 years since the end of World War II. The oral testimony of those who built, served aboard and survived attacks on U-boats remains highly important. Their stories are invaluable and should the opportunity to interview them arise, should not be missed. The sea warrior veterans of World War II are rapidly dying, and soon there will be no more to tell the tales.

9. Conclusion

This survey has proved that the ROV is a very effective tool for the survey of U-boat wrecks. The ROV is able to maneuver around sites, usually avoiding the danger of net snags and with lighting and cameras is able to document diagnostic features. Through their ability to remain underwater for long periods and not disturb the site, ROV's are by far the best tool suited to the study of deep-sea submarines as archaeological sites (cf. Wessex Archaeology, 2007).

The best management option for the future of the Atlas survey zone U-boats surveyed by Odyssey is to leave them undisturbed, even though they will undoubtedly continue to suffer damage from both human and natural causes. If future visits occur, then the opportunity to conduct non-invasive surveys and, if possible, corrosion and environmental studies would be the best management strategy.

The history of the German submarine is a fascinating story of technological development and engineering. For two world wars the U-boat was a serious naval weapon that at times almost turned the outcome of the war. The Battle of the Atlantic was the longest campaign of World War II. These underwater memorials are a testimony to the men who designed, built, served and lost their lives in the submarine service. Let their memory and those who were lost be never forgotten.

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Notes

1. See, www.uboataces.com/uboat-type-xxi.shtml.
2. See, www.uboat.net/boats/u326.htm.
3. See, http://www.designation-systems.net/dusrm/app4/retrorocket.html.
4. See, www.uboataces.com/torpedo-tiii.shtm.

5. See, www.uboat.net/wwi/boats/index.html?boat=103.
6. See, www.uboat.net/boats/u327.htm.
7. See, www.divehatteras.com/U-701.html.
8. See, www.3hconsulting.com/SitesResurgam.htm.
9. See, www.nauticalarchaeologysociety.org/projects/holland5.php.
10. See, www.environment.nsw.gov.au/M24/discovery/archinvestig.htm.
11. See, www.hmsroyaloak.co.uk.
12. See, www.briggsmarine.com/our-capabilities/case-studies/royal-oak-oil-removal-programme.

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Appendix 1

The following is a list of all the U-boat crews lost from the nine submarines discussed in this paper. This information was extracted from the ubootwaffe, Kriegsmarine and U-Boat History archives at www.ubootwaffe.net:

U-326 (Sunk 25 April 1945)

Walter Blume (MaschMt), Otto Brandhorst (MechGfr), Herbet Dipp (FkGfr), Walter Dorn (MtrGfr), Hans-Heini Drücker (MtrGfr), Hans Dunkelmann (Mtr), Karl-Heinz Edmunds (MaschMt), Karl Evers (MtrOGfr), Richard Faulstroh (MaschMt), Berend Feeken (OStrm), Fritz Fichte (MaschMt), Wilhelm Frey (MaschMt), Heinz Golle (MaschOGfr), Heinz Hartmann (MtrGfr), Erich Huber (MechOGfr), Gerhard Hübsch (MechMt), Johann Jacobi (FkMt), Kurt Jankowitsch (MechGfr), Werner Johannböke (BtsMt), Gerhard Knabe (FkMt), Karl Krahn (MaschHGfr), Werner Kubisch (MaschGfr), Heinz Laske (MaschGfr), Franz Lenzen (MaschGfr), Peter Matthes (KpLt), Leonhard Meisburger (MaschGfr), Fritz Möhren (OMasch), Karl Morawietz (MtrOGfr), Helmut Morban (FkOGfr), Alois Müller (MaschOGfr), Wolfgang Oberlohbeck (MaschMt), Helmut Pfeifer (OLt.z.S), Florian Puschautz (MaschOGfr), Karl Schäfer (OBtsMt), Gerhard Schäfrig (MaschMt), Richard Schaufler (MtrGfr), Michael Schenk (MtrGfr), Klaus Scherf (FkOGfr), Eckart von Schmeling Diringshofen (Lt.z.S), Rudolf Schmidt (OBtsMt), Philipp Schmitz (OMasch), Paul Seeling (StOStrm), Heinz

Trippmacher (OLt.ing), Alfred Urhahn (MtrOGfr), Hans Wagner (SanMt).

U-988 (Sunk 29 June 1944)

Cornelius Alberts (MtrOGfr), Wolfgang Barella (Lt.z.S), Heinz Bergner (MaschMt), Heinrich Billotet (MtrGfr), Werner Bruch (OLt.ing), Wilhelm Demharter (MaschOGfr), Erich Dobberstein (OLt.z.S), Siegfried-Walter Fischer (MechOGfr(T)), Alfred Geinitz (MaschOGfr), Horst Göbel (MechMt), Kurt Gutmeyer (MaschOGfr), Kurt Hanisch (MaschOGfr), Franz Hauser (MaschOGfr), Otto Heeger (OMasch), Helmut Herrmann (FkMt), Friedrich Hoffmann (FkMt), Ernst Hohmann (MtrGfr), Helmut Hopert (MaschOGfr), Harald Jaap (MaschGfr), Heinrich Jablonowski (MtrOGfr), Horst Kaupke (Lt.z.S), Heinrich Keil (OSanMt), Walter Klemm (MaschOGfr), Otto Kohls (OBtsMt), Werner Krause (MtrOGfr), Walter Kürbitz (MaschOGfr), Eduard Mader (MaschOGfr), Heinrich Malhöfer (OMaschMt), Paul Marcinkowski (MtrGfr), Franz Mariani (MaschMt), Karl Mikel (MtrGfr), Wilhelm Mohr (MtrOGfr), Hermann Ortgies (FkOGfr), Wilhelm Papert (Cadet MN), Siegfried Reichelt (MechOGfr), Werner Richert (MtrOGfr), Karl Riehmann (MaschMt), Günter Schimmack (StrmMt), Bernhard Schmidt (FkOGfr), Walter Schneider (OStrm), Friedrich Schnelle (MaschOGfr), Franz Schürle (MtrOGfr), Helmut Schulz (MtrOGfr), Fredo Splettstößer (MechGfr), Willi Stöckler (MaschOGfr), Heinz Strauß (MaschMt), Walter Todte (MaschOGfr), Werner Weißwange (Lt.z.S), Kurt Wölke (BtsMt), Heini Zeidler (OMasch).

U-325 (Sunk 30 April 1945)

Alfred Becker (Btsmt), Karl Benner (MaschMt), Harry Berndt (MaschMt), Alfons Biernath (MtrGfr), Hans-Erich Bischoff (OLt.z.S), Arnold Boßbach (FkOGfr), Gerd-Heinz Briel (FkOGfr), Walter Büttner (OBtsMt), Horst Buschmann (MaschOGfr), Arthur Buse (FkOGfr), Emil Chilinski (MaschOGfr), Erwin Dohrn (OLt.z.S), Karl Eickmann (MaschOGfr), Harry Fabian (OFkMt), Werner Geserick (Lt.z.S), August Grosse (MaschMt), Karl Hägele (MtrGfr), Kurt Hausdorf (MechGfr), Richard Heise (MtrGfr), Heinrich Hilpert (OMasch), Hans Hortian (OMasch), Richard Jeske (MechOGfr), Johann Kästl (MaschGfr), Arthur Kimmling (OStrm), Werner Kratzke (StrmHGfr), Gerhard Kreft (MtrOGfr), Dietrich Kreutzer (Mtr), Ernst Krüger (MtrHGfr), Wilhelm Lange (MtrGfr), Wolf-Karl Liere (MaschOGfr), Walter Lieske (MaschMt), Hans Michel (MaschOGfr), Arnold Müller (MaschGfr), Joachim Niklas (Lt.ing), Walter Olschewski (FkMt), Rudolf Podszus (SanMt), Siegfried Puls (BtsMt), Heinz Ribbeck (MechMt), Hermann Schlemmer (MtrGfr), Heinz Schlüter (MaschGfr), Robert Schmidt (MtrGfr), Hans Schneede (MaschMt), Bernhard Schröder (MaschGfr), Oktawian Schuster (MaschOGfr), Kurt Schwarz (MaschGfr), Fritz Sicken (MtrGfr), Theodor Spanier (MtrOGfr), Martin Strauß (Lt.z.S), Rudolf Stubner (MtrGfr), Erich-Richard Sufka (MechOGfr), Horst Utrecht (OGfr), Otto Vavru (MaschMt).

U-650 (Sunk January 1945)

Heinz Bartels (MechMt), Georg Barth (OMaschMt), Hugo Becker (OSanMt), Friedrich Behn (MtrGfr), Fritz Borchers (OFkMt), Karl-Heinz Bötte (MtrOGfr.d.R), Rudolf Busch (MtrOGfr), Karl Danne (Mtr), Erich Dvorak (MaschOGfr), Otto Ehlers (FkOGfr), Johann Füller (OMasch), Rudi Gans (BtsMt.d.R), Alfred Gehring (MechGfr), Alfred Gessner (Mtr), Otto Grabenhofer (MtrOGfr), Albert Harant (MaschOGfr), Karl-Heinz Hitz (OLt.ing.d.R), Hubert Holstein (MaschOGfr), Franz Hornik (MtrGfr.d.R), Wilhelm Holz (MaschOGfr), Leonhard Idems (MaschOGfr), Walter Jakubowski (MtrOGfr), Walter Jünger (OStrm), Karl Kinnet (MtrOGfr), Erwin Klawin (MaschMt), Ernst Kreutz (MaschOGfr), Arthur Mahn (OBtsMt), Wolfgang Mosbach (MechOGfr), Walter Müller (FkOGfr), Kurt Neuendorff (MtrOGfr), Gottfried Pfeiffer (MaschOGfr), Franz Rommelfanger (MaschMt), Lothar Sasse (OFkMt), Alexander Scheytt (OMaschMt), Rolf Schmidt (MaschMt), Herbert Schnuchel (MtrOGfr), Gerhard Spanier (MaschOGfr), Johann Tomann (MaschOGfr), Willi Vach (MtrGfr), Siegfried Walberg (MaschOGfr), Werner Walz (MaschOGfr), Alfons Wardecki (OLt.z.S.d.R), Heinz Weber (OLt.z.S), Johann Wienkötter (BtsMt), Karl-Heinz Witt (MaschOGfr), Walter Wolff (OMasch), Rudolf Zorn (OLt.z.S).

U-1208 (Sunk 24 February 1945)

Roland Bauroth (MechOGfr), Berger (OLt.ing), Markus Beyer (FkOGfr), Hans-Georg Claußen (OStrm), Heinz Cybulla (MaschOGfr), Sebastian Deger (MaschOGfr), Willi Engel (MaschMt), Joachim Faßhauer (MtrGfr), Gerhard Fehler (MaschGfr), Walter Fehr (OMasch), Joachim Fichtner (MtrOGfr), Erwin Fickbohm (MaschOGfr), Werner Gärtner (MaschOGfr), Otto Glorius (MaschGfr), Herbert Gromotka (OMasch), Walter Haase (OMaschMt), Georg Hagene (KKapt.), Heinrich Huhk (FkOGfr), Gerhard Jörchel (MaschOGfr), Johann Kiwitt (MaschMt), Karl-Heinz Krüger (OFkMt), Heinz Künne (MaschGfr), Ewald Lange (OSanMt.d.R), Klaus Lange (Lt.z.S), Franz Langguth (MtrOGfr), Gerhard Leunert (MaschOGfr), Friedrich Lindemann (Lt.z.S), Hans Macherey (BtsMt), Max Michaelis (MtrOGfr), Josef Niegel (BtsMt), Hans Nowak (MechOGfr), Werner Piethe (MechMt), Karl Ra-

dlsböck (MaschOGfr), Karl Scheuing (MaschOGfr), Johann Schmitz (MaschMt), Gerhard Schorm (MtrOGfr), Erich Schreiber (MtrOGfr), Kurt Schubert (OBtsMt), Johannes Schulten (MtrOGfr), Friedrich Schwertz (StOStrm), Kurt Simon (MechGfr), Harald Sölter (FkOGfr), Alfred Sweeren (FkMt), Lorenz Weigmann (MaschOGfr), Siegfried Wendlandt (MtrOGfr), Wolf Werner (OLt.ing), Wilhelm Wetzel (MtrOGfr), Franz Wiezorek (MtrOGfr), Rolf Zierenberg (MtrOGfr).

U-400 (Sunk December 1944)

Willi Bauer (MtrOGfr), Wilhelm Bonneß (OMasch), Wolfgang Brune (MechGfr.(A)), Hans Bublitz (MaschOGfr), Otto Cappel (OBtsMt), Horst Creutz (KpLt.), Wilhelm Dipp (FkMt), Gotthard Dlugosch (OStrm), Helmut Dorr (MtrOGfr), Herbert Ebert (MtrOGfr), Gerhard Eichelmann (MaschOGfr), Kurt Eichler (FkOGfr), Bruno Engel (MaschGfr), Alexander Engelhardt (MtrOGfr), Erich Enskat (MtrGfr), Günther Frahm (MaschOGfr), Gerhard Gärtner (MechGfr), Helmut Gier (MaschOGfr), Werner Graßhoff (MaschMt), Josef Gründinger (MtrOGfr), Hilmar Hager (MaschOGfr), Wilhelm Hanke (MtrOGfr), Kurt Helwich (OSanMt), Franz Herold (MtrOGfr), Johann Hertlein (MtrGfr), Ingomar Himpel (MtrGfr), Friedrich Huhn (MtrOGfr), George Ingerling (MaschOGfr), Otto Jakesch (FkOGfr), Herbert Kamphausen (MaschMt), Ulrich Klein (FkOGfr), Ernst Kleinmann (OMasch), Horst Küpper (MaschGfr), Werner Kunze (MaschGfr), Kurt Labuhn (MaschOGfr), Werner Laue (MaschMt), Heinz Leistner (MechMt), Alfons Lipinski (MaschMt), Wilhelm-Theodor Maas (BtsMt), Hermann-Berhard Naumann (Lt.z.S), Horst-Erich Növe (Lt.ing), Wilhelm Rosen (MaschMt), Paul Rudolph (MaschOGfr), Adolf Schmid (MaschMt), Walter Schön (Lt.z.S), Ernst Schröder (FkMt), Alfred Schulze (OBtsMt), Helmut Seibert (MaschOGfr), Richard Strobl (MaschOGfr), Ubbo Willms (MtrOGfr).

U-1021 (Sunk 14 March 1945)

Herbert Apel (Btsm), Gerhard Bacht (MaschGfr), Werner Biermann (SanMt), Karl-Heinz Bösling (MtrGfr), Reinhold Böttcher (MaschGfr), Werner Braune (MaschGfr), Peter Clemens (MechOGfr), Hans-Joachim Dreyer (OLt.z.S), Hans-Jürgen Fieler, Horst Fuhrmann (FkOGfr), Heinz Gartenschläger (BtsMt), Willi Gericke (MechGfr), Walter Glaser (MaschMt), Georg Götz (MaschOGfr), Leo von Grabczewski (OStrm), Oswald Heymons (Lt.z.S), Walter Hilbeck (MtrGfr), William Holpert (OLt.z.S.), Helmut Ihlenfeld (OLt.ing), Kurt Käsler (FkOGfr), Johann Keilhofer (MtrGfr), Mathias Klein (MtrGfr), Helmut Kruchinski (MtrOGfr), Rudolf Ludwig (Mtr), Kurt Maiwald (MaschOGfr), Harry Mehlfeld (MaschGfr), Sebastian Müller (MechGfr), Heinz Piezonna (MaschMt), Willi Radde (FkOGfr), Fritz Reininger (OFkMt), Kurt-Georg Rieth (MaschMt), Justus Rodinger (OGfr), Heinz Röscheisen (Mtr), Gerhard Rothe (MaschGfr), Edmund Ruthowski (OGfr), Fritz Sädler (MaschGfr), Heinz Schilde (MaschMt), Jakob Schreiber (MtrOGfr), Paul Simianowski (MaschGfr), Kurt Sonntag (OMasch), Wolfgang Sonntag (MaschGfr), Gerhard Thormann (MechMt), Hans-Joachim Wehling (OMasch), Wilhelm Weiß (MaschMt).

U-103 (Sunk 12 May 1918)

Wilhelm Dorka (U-Maschinistenmaat d.Res), Johann Geb (U-Maschinist Anw), Karl Kiesow (U-Obermatrose), Walter Kolbe (Oberleutnant z.S), Hermann Kunze (U-Maschinistenmaat), E. Lauxmann (U-Bootsmannsmaat), Albert Mügge (U-Obermaschinistenmaat), Philipp Reppert (U-Maschinistenmaat), Kurt Reumann (Leutnant z.S.d.R), Heinrich Schröder (U-Oberbootsmannsmaat).

U-327 (Sunk 27 February 1945)

Fritz Akuszewski (MaschGfr), Wolfgang Andräe (MaschMt), Artur Apel (MechMt), Walter Blaschek (MaschMt), Werner Bornmann (Mtr.VII), Franz Brabender (OMasch), Werner Cordes (MaschGfr), Günther Engeler (OMasch), Kurt Fecker (MaschGfr), Josef Geisler (MtrOGfr), Herbert Gohlke (MtrOGfr), Wolfgang Hanske (MaschMt), Paul Hohn (Mtr.I), Willy Kähler (OStrm), Kurt Karow (MaschGfr), Franz Keller (MaschOGfr), Martin Kollmann (MtrOGfr), Fritz Krenz (OFkMt), Gustav Krüger (MaschMt), Heinz Kümmel (MtrOGfr), Heinrich-Floria Lefrere (OStrm), Hans Lemcke (KpLt.), Georg Wilhelm-Helmut von Lenthe (Lt.z.S), Kurt Lieder (MaschGfr), Theodor Lis (MtrGfr), Franz Lohmann (MtrGfr), Siegfried Lohr (MaschGfr), Herbert Mauczik (MtrOGfr), Günther Mehner (MaschGfr), Hermann Meyer (MaschGfr), Josef Mölders (BtsMt), Herbert Neitzel (FkOGfr), Raimund Ochner (OBtsMt), Karl-Heinz Pieritz (FkOGfr), Hans Prussas (OLt.z.S), Heinz Riediger (MaschOGfr), Ernst Römmling (ObSanMt), Johannes Sandkämpfer (MtrGfr), Hans Sandmeyer (FkOGfr), Franz Schätz (MaschMt), Paul Schwarz (MtrGfr), Siegfried Stein (MaschMt), Willi Wiech (FkMt), Walter Witte (Lt.ing), Fritz Wörle (MechGfr), Erich Wößner (MechGfr).