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Supplementary information files for In-situ comparison of high-order detonations and low-order deflagration methodologies for underwater unexploded ordnance (UXO) disposal

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EOD Report Annex A

Mine Foxtrot – High Order

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1. INITIAL SURVEY REPORT

Mine ID	WWII British A Mk 1-4 (Possible A Mk 6)		
Original NEQ	Max 340Kg		
Remaining NEQ	Approx 200Kg		
Explosive Type	Amatol Main Charge with Tetryl Primers		
Mine Dimensions	Measured - Length: 1900mm Dia. 450mm		
Position	5556.90N – 01106.070E	**Depth**	18m
Bottom Type	Sand, Shell, Shingle	**Mine Burial**	<100mm

Figure 1: Mine Foxtrot Heavily Encrusted with Marine Growth. Mine Charge Case Corroded, Exposing a Brown Amatol Explosive Fill.

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2. MINE CONDITION

2.1 Mine Foxtrot was heavily encrusted with marine growth and the explosive section badly corroded with the exposed explosive filling being identified as Amatol. The diver estimated that approximately 60% of the explosive charge remained (Figure1)

3. EOD ACTION

3.1 Mine Foxtrot was deliberately detonated to obtain a high order noise reading.

4. COUNTERMINING CHARGE

4.1 A 10 Kg Composition B charge was positioned in direct contact with the remaining explosive charge.

5. POST BLAST ASSESSMENT

5.1 The mine detonated and large water plume was visible at the surface, and the shockwave felt on board the diving vessel.

5.2 A diver survey with a Shark Marine held sonar recorded a significant crater (Figure 2), estimated to be over 4m in diameter and approx 1m deep.

5.3 Although the mine was in a very poor condition the crater size is conducive to a detonation of the estimated remaining charge weight of approximately 200Kg plus the 10Kg countermining charge. This indicated that whilst the Amatol explosive had been subjected to long term erosion and water absorption, it proved viable when subjected to the shock of the countermining charge.

6. SUMMARY

6.1 Mine Foxtrot was badly corroded, and the explosive exposed. The long-term exposure of Amatol to salt water has resulted in the explosive being in an unknown condition. From the High Order achieved it appears to have been viable and therefore it is reasonable to assume that the mine represented a significant explosive hazard if subjected to impact.

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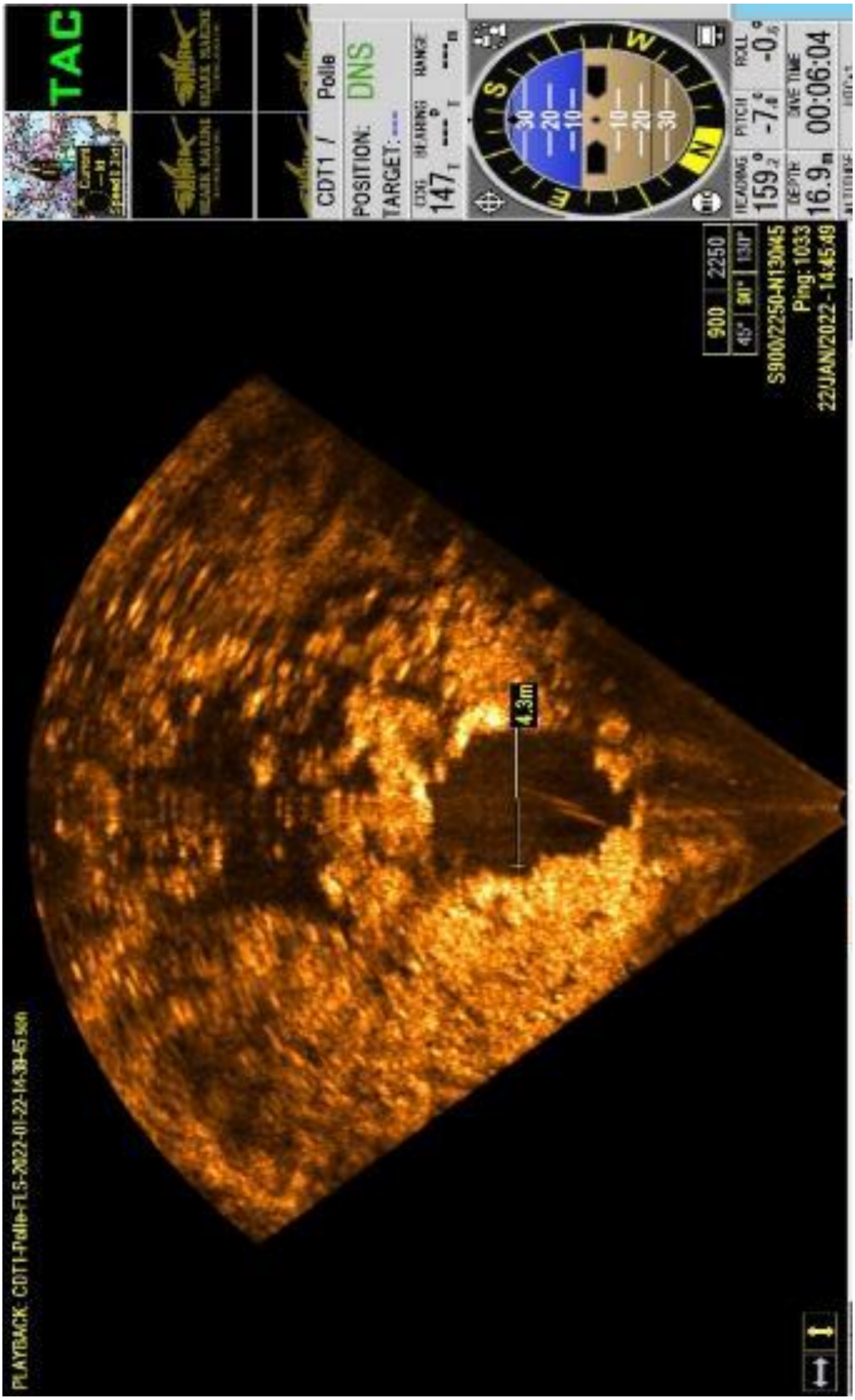

Figure 2: - Shark Marine Sonar Image showing Foxtrot Blast Crater

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EOD Report Annex B

Mine Golf – Low Order

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1. INITIAL SURVEY REPORT

Mine ID	Possible WWII British A Mk 6		
Original NEQ	430 Kg		
Remaining NEQ	344Kg (estimated at 80% of original)		
Explosive Type	AMATOL Main Charge with Tetryl Primers		
Position	5556.964N-01104.961E	**Depth**	19.5m
Bottom Type	Sand, Shell, Shingle	**Mine Burial**	100mm

2. MINE CONDITION

2.1 Mine Golf was originally identified as an A Mk1-4, but heavy marine growth and corrosion made a positive identification very difficult. During the post blast assessment, it is believed that this mine was a later model, possibly an A Mk 6.

2.2 The explosive charge section was open to the environment which enabled the explosive content to be identified by its colour as Amatol. (Figure 1). The exposed explosive was estimated by the diver to have been reduced to approximately 80% of its original charge weight due to water ingress and erosion.

2.3 The mine's open condition presented a potentially difficult target for low order, because the gasses generated by deflagration could vent immediately instead of increasing the internal pressure in the mine body. This in turn was likely to quench the deflagration process and its subsequent disruptive effect.

Figure 1: Mine Golf Survey Recce showing exposed Amatol

3. EOD ACTION

3.1 Mine Golf was attacked using a Low Order charge to record the deflagration noise levels.

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4. DEFLAGRATION CHARGE

4.1 A Pluton 65mm modular shaped charge loaded with 250g Plastic Explosive and a low density, incendiary projectile was used with a fixed air stand-off capsule. The Pluton was positioned by a diver, perpendicular to the centre of mine charge section. It was secured initially with magnets, but subsequently had to be supported due to the amount of marine growth. The charge was initiated using an electric detonator & firing cable to the surface.

Figure 2: Mine Golf with Pluton Shaped Charge in Position Perpendicular, in the Centre of the Charge Case.

5. POST BLAST ASSESSMENT

5.1 The post blast assessment was conducted by an EOD diver and recorded on video and still photographs. The deflagration technique proved to have been very successful. The mine had not detonated and there was no visible cratering or significant local environmental damage. There was also no visible evidence of an explosion on the surface, and only the audible ‘crack’ of the 250g load in the Pluton charge, heard through the hull of the dive vessel some 1200m distant.

5.2 The original explosive hazard (sensitivity to impact) had now been greatly reduced. The remaining explosive (344Kg NEQ) had been subjected to severe shock and heat resulting in a considerable amount of disruption to the firing train.

5.3 The remaining explosive section had been disrupted to the point where it was almost empty. A percentage of shattered explosives estimated at less than 10% of original NEQ, remained in the forward part of the mine (Figure 5). The original solid Amatol explosive main charge had been reduced in mass and volume by the process of deflagration and any that

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remained, shattered into a loose, low-density mix of powder, granules, and lumps. This explosive residue was scattered in and around the remaining mine-carcass further reducing the original hazard.

Figure 3: Deflagrated main Charge Case showing that most of the Amatol main Charge has either burned or shattered and ejected.

5.4 The mine mechanism section was almost severed from the nose section, with only the Search Coil Unit and the remains of the steel outer case possibly holding the mine together. This indicated that the deflagration of unconfined explosive had still been very disruptive. It is also possible that the additional gasses generated using a low density, incendiary, projectile enhanced disruption.

5.5 The Primer Tube had been severed, mid-point in-line with the projectile impact (Figure 4). This also meant that the detonator located in the rear of the primer tube was no longer explosively connected to the forward end of the mine. The severance of the primer tube is also significant because the Tetryl primers, contained in the bakerite tube were likely to have been in good condition and more sensitive to shock than Amatol.

5.6 In Summary, the disruption by deflagration of the original main charge (344Kg) had been reduced by an estimated 90%. This includes severing the primer tube and its separation from the explosive fill. The remaining explosive residue was so dispersed, that the risk of accidental initiation was not considered credible. The remaining mine components were now easily accessible for recovery or disposal operations using a specialist commercial ROV. However, it was Danish Navy EOD policy to countermine the remaining components with their standard 10Kg demolition charge. (Figures 4 & 5).

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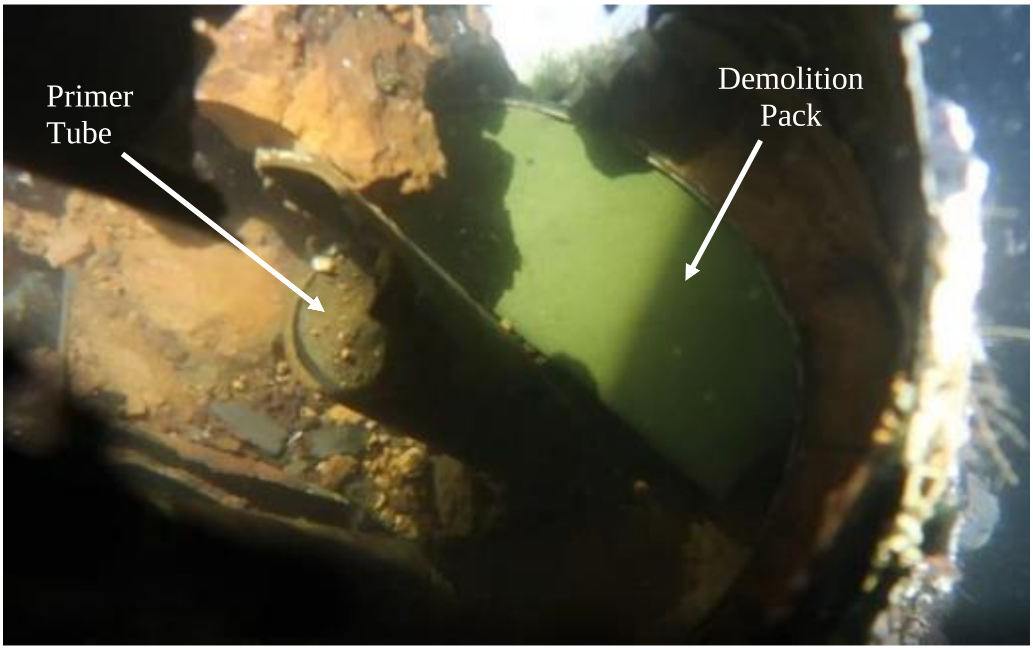

Figure 4: The Bakelite Primer Tube visible Centre has been severed by the deflagration process. The Green Area is the end of the 10Kg Clear-up Demolition Charge.

Figure 5: A small percentage of the original 430Kg charge remained in the nose of the mine.

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EOD Report Annex C

Mine Mike – High Order

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1. Initial Survey Report

Mine ID	WWII British A Mk 1 - 4		
Original NEQ	340Kg		
Remaining NEQ	Approx 170 Kg (Estimated at: 50% - 60% of original NEQ by Diver & Video.		
Explosive Type	AMATOL Main Charge with Tetryl Primers		
Position	5557.7182N - 01103.2198E	**Depth**	18.5m
Bottom Type	Sand, Shell, Shingle	**Mine Burial**	50mm

2. Mine Condition

2.1 Assessment of the diver video survey shows that the mine case was covered in marine growth and very badly corroded. The mine charge section was open along most of its length (Figure 2) and estimated that the remaining explosive charge was approx 50% - 60% of the original 340Kg charge weight. The mechanism section and buoyancy section were also very badly corroded. The hydrostatic switch located in a square pocket (Figure 1) tends to confirm the original mine identification as that of an A Mk 1- 4.

Figure 1: Mine Mike - Hydrostatic Switch.

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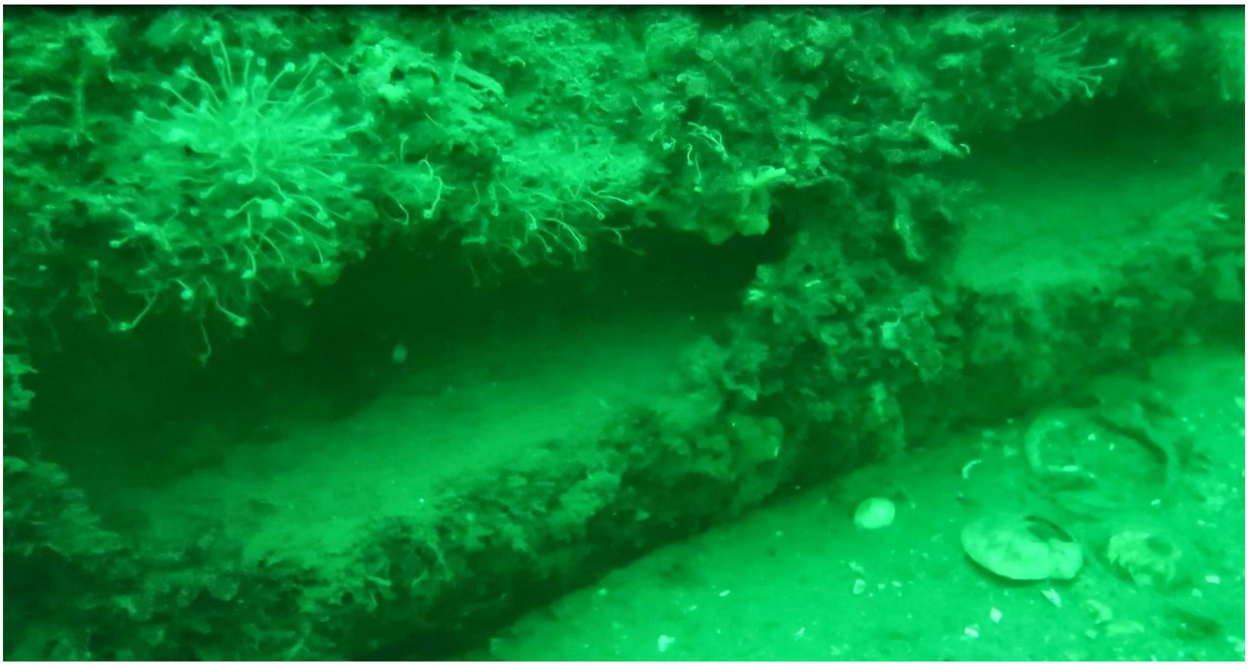

Figure 2: Mine Mike Initial Survey showing extent of mine corrosion.

3. EOD Action

3.1 Mine was detonated using the same method as for Mine Foxtrot, a 10KG Comp. B Demolition Pack. Total NEQ estimated at 170Kg Amatol + the 10Kg demolition charge. The demolition charge was placed in direct contact with the exposed explosives.

4. Post Blast Assessment

4.1 The mine detonated with a large water plume visible at the surface and the blast shockwave felt and heard on board the Diving Vessel. A diver survey with and a held sonar recorded a significant crater as detailed in the video capture (Figure 3).

4.2 Although the mine was in a very poor condition the crater size is conducive to a detonation of the estimated remaining charge weight of approximately 170Kg plus the 10Kg countermining charge. This indicated that whilst the Amatol explosive had been subjected to long term water absorption and considerable erosion, it remained a viable explosive when subjected to sufficient shock.

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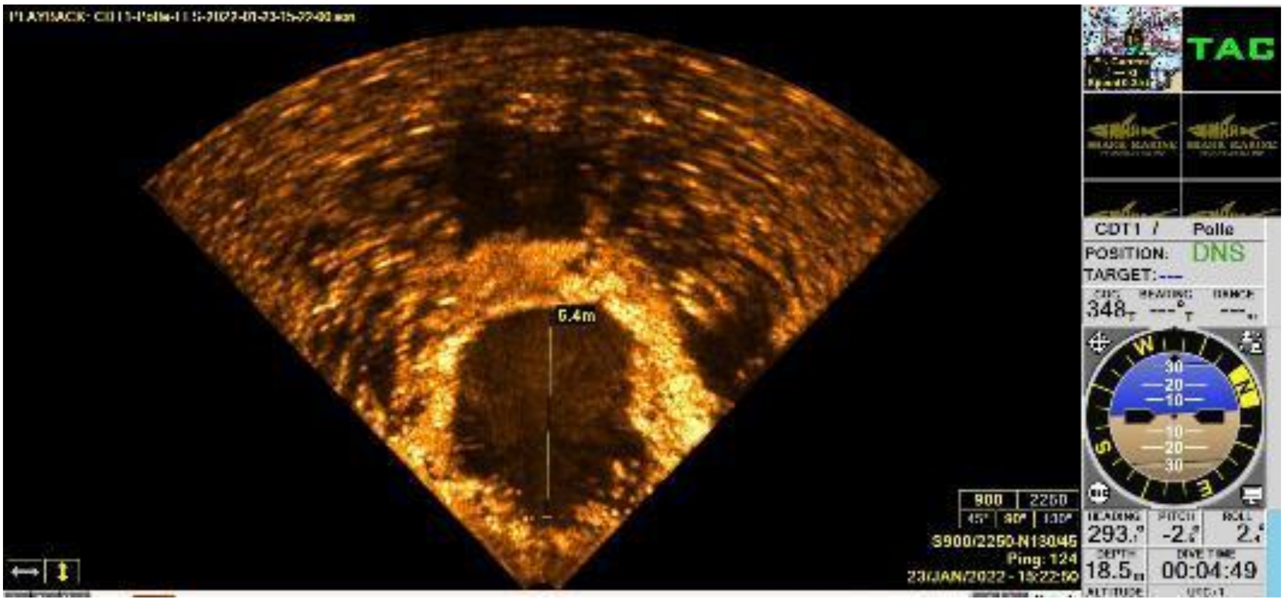

Figure 3: Mine Mike Post Blast Sonar Survey showing Crater Size Diameter of approx 6m.

5. Summary

5.1 Mine Mike was badly corroded, and the explosive extensively exposed. The long-term exposure of Amatol to salt water has resulted in the explosive being in an unknown condition. From the High Order achieved it appears to have been viable and therefore it is reasonable to assume that the mine represented a significant explosive hazard if subjected to impact.

5.2 The resultant crater size of mine Mike (6m) (NEQ 170Kg) was larger than that of mine Foxtrot (4.3m) despite the higher NEQ of 260Kg. As the degree of mine burial and depth of water are similar, this anomaly is thought to be a result of either a different seabed type, explosive power or countermining charge positioning and direction of shock wave.

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EOD Report Annex D

Mine November – Low Order

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1. Initial Survey

Mine ID	WWII British A Mk 1 - 4		
Position	5557.4459N-01103.5817E	**Depth**	17.5m
Bottom Type	Sand, Shell, Shingle	**Mine Burial**	Approx 150mm
Remaining Net Explosive Quantity	340Kg		
Explosive Type	AMATOL Main Charge with Tetryl Primers (Assessed from Post Blast Survey)		

2. Mine Condition

2.1 Mine November was heavily covered in marine growth which obscured the overall mine case condition. Removal of some marine growth at the mid-position exposed the steel charge section, which looked to be in good condition. This suggested that the explosive main charge had mostly been protected from the environment and therefore the charge weight was assumed to be close to the original 340Kg.

2.2 The absence of any visible case fittings post blast meant a positive ID could not be made; therefore it is possible that the mine was in fact an A Mk 6.

3. EOD Action

3.1 The Mine was in a reasonable condition and a good target for low order by deflagration and subsequent noise recording.

Figure 1: Mine November with Pluton Charge positioned for Low Order.

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4. Deflagration Charge

4.1 A Pluton 65mm modular shaped charge loaded with 250g Plastic Explosive and a low density, incendiary projectile with an air stand- off capsule was positioned by diver on a weighted weapon stand (Figure 1) and fired using an electric detonator & firing cable to the surface.

5. Post Blast Assessment

5.1 The post blast assessment was conducted by diver and recorded on video and still photographs. The deflagration technique was very successful. The mine did not detonate, and there was no visible cratering or significant local environmental damage. There was no visible evidence of an explosion on the surface, with only an audible 'crack' conducive with the 250g load in the Pluton charge being heard on the dive vessel.

5.2 On examination, the mine case proved to have been in reasonably good condition with minimal exposure to seawater. Most of the marine growth had been removed by the shockwave with the explosive injection point clearly visible (Figure 2).

Figure 2: Mine November - Pluton Injection Point and Minor Overpressure Damage

5.3 On the opposite side of the injection point, there was clear evidence of explosive deflagration and internal pressure build up. The mine charge section had split along the entire length of the welded seam, further indicating that the mine case had been in good condition.

5.4 The explosive section was almost empty with the original solid mass of the Amatol main charge being burned or shattered into a loose mix of powder, granules, and lumps. This explosive residue was loosely scattered in and around the remaining mine-carcass, reducing the original explosive charge by an estimated 90%. The remaining explosive residue was so dispersed, that the risk of accidental initiation was not considered credible. The remaining mine components were now easily accessible for recovery or disposal operations using a specialist commercial ROV.

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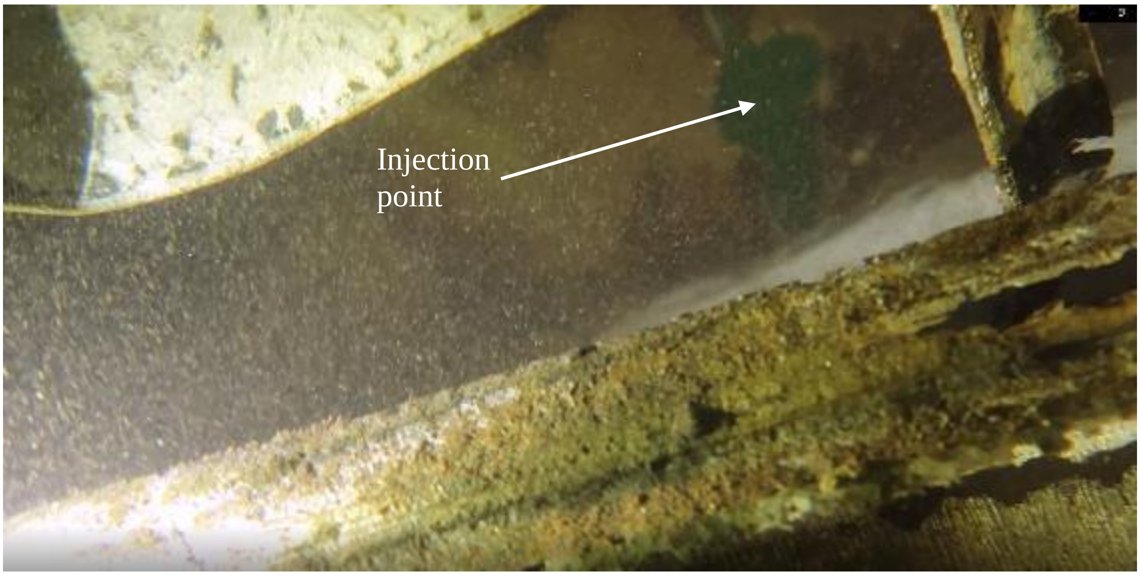

Figure 3: Inside of the Explosive Section Showing the Reverse Side of the Injection Point

Figure 4: Mine November – Deflagration Internal Overpressure split the mine charge section open along its entire length

5.5 The mine mechanism section end plate was ejected by internal over pressure, forcing explosive fill and mechanism components out of the mine case (Figure 5).

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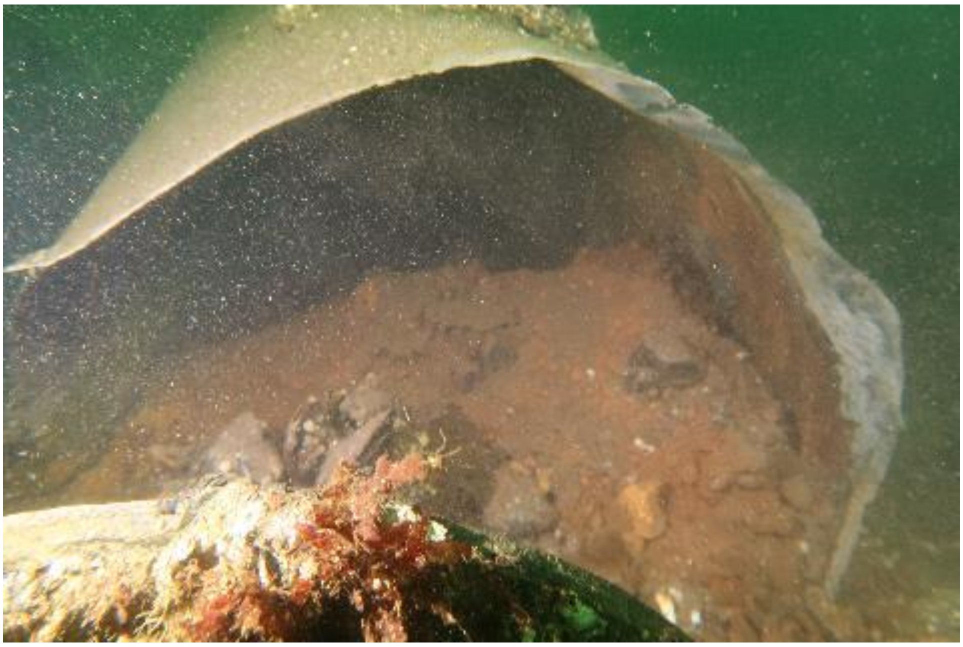

Figure 5: Mine November – end plate ejected by internal overpressure

Figure 6: Mine November – Deflagration Internal Overpressure split the mine charge

5.6 The nose fairing plate was partially ejected by internal overpressure exposing explosive fill. The ejection of both end plates of the mine indicates that the coiled rod units and primer tube have both separated. Separation of the primer tube will have disrupted the firing chain, which is significant because the Tetryl Primers, contained in a bakerite tube were likely to have been in good condition and more sensitive to shock than Amatol.

5.7 With the original mass explosive hazard greatly reduced, the remaining mine components and explosive residue were easily accessible for any final disposal operations using a specialist commercial ROV. However, it was Danish Navy EOD policy to countermine the remaining components with their standard 10Kg demolition charge.

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EOD Report Annex E

Mine Lima – Low Order

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1. Initial Survey

Initial Mine ID	Possible WWII British A Mk 1 – 4		
Mine ID	**WWII British A Mk 6**		
Position	5557.3510N-01102.7805E	**Depth**	17.5m
Bottom Type	Sand, Shell, Shingle	**Mine Burial**	100mm
Remaining Net Explosive Quantity	430 Kg		
Explosive Type	AMATOL Main Charge with Tetryl Primers		

2. Mine Condition

2.1 Mine Lima was heavily covered in marine growth which obscured the overall mine case condition and any significant recognition features. Its condition initially suggested that the explosive main charge had been protected from the environment and therefore the charge weight was assumed to be close to the original 340Kg of an A Mk 1-4.

3. EOD Action

3.1 Mine Lima was attacked using a Low Order charge to record the deflagration noise levels.

4. Deflagration Charge

4.1 A Pluton 65mm modular shaped charge loaded with 250g Plastic Explosive and a low density, incendiary projectile with an air stand-off was positioned by diver on a weighted weapon stand (Figure 1) and fired using an electric detonator & firing cable to the surface.

Figure 1: Pluton Charge Positioned against Mine Lima

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5. Post Blast Assessment

5.1 The post blast assessment conducted by diver was recorded on video and still photographs. The deflagration technique was very successful. The mine did not detonate, and there was no visible cratering or significant local environmental damage. There was no visible evidence of an explosion on the surface, with only an audible 'crack' conducive with the 250g load in the Pluton charge being heard on the dive vessel.

5.2 On close examination of the post blast video, much of the marine growth and corroded metal had been shocked loose and certain features were now visible. Notably a detonator hydrostat and an inspection bung. These features are clear indication that the mine is an A Mk 6 rather than an A Mk 1-4 which meant that the explosive charge weight was actually 430Kg.

Figure 2: A Mk 6 Detonator hydrostat and inspection bung

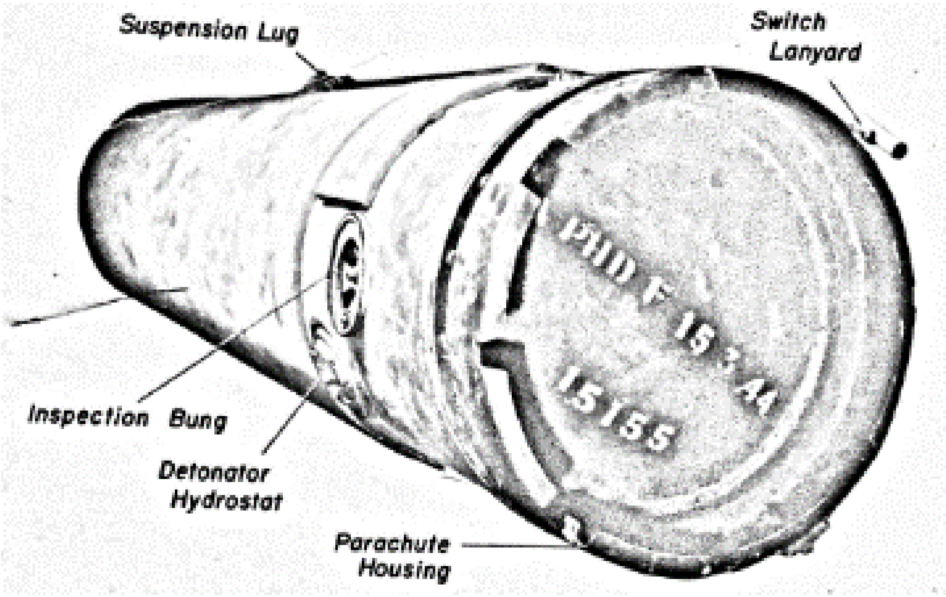

Figure 3: A Mk 6 – Main features

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5.3 The mine charge case had almost been cut in half (Figure 3) with much of the Amatol burned or ejected during the process of deflagration. The remaining steel mine case showed evidence of severe corrosion which had weakened the mine case and reduced the disruptive effect.

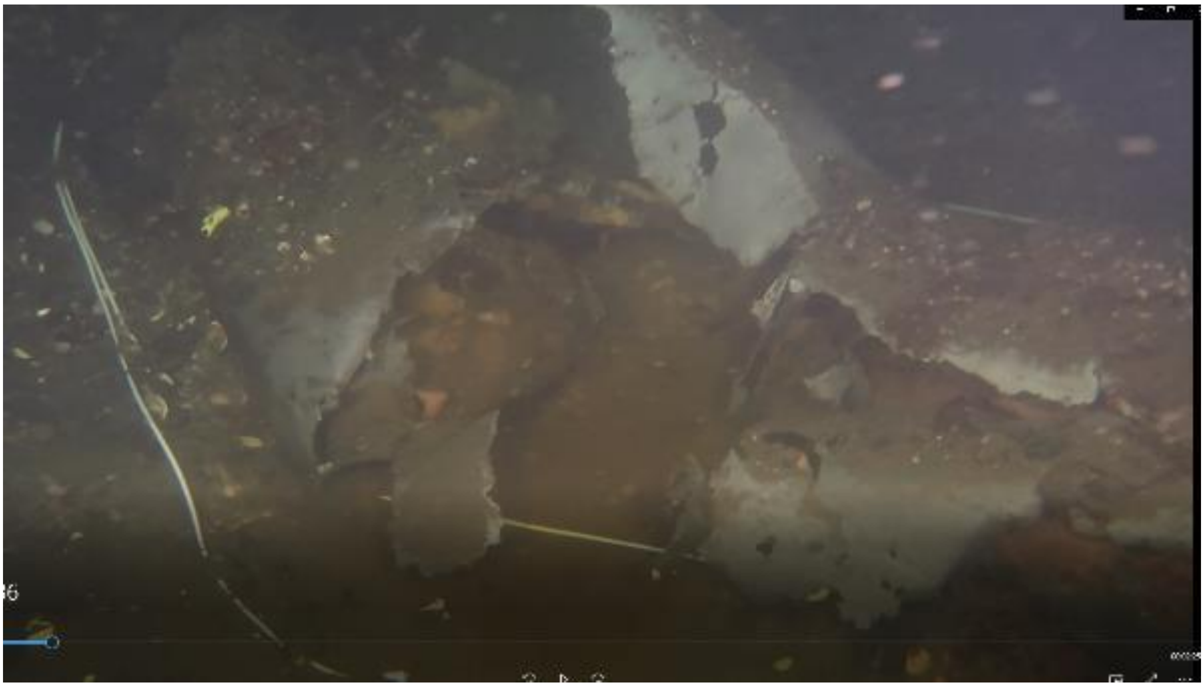

Figure 3: A Mk 6 – Main charge Section completely burst open and almost cut in half.

5.4 The primer tube had been severed (Figure 4) and there was evidence of shattered explosive residue in the nose and close to the mechanism housing.

Figure 4:

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5.5 The original explosive hazard (sensitivity to impact) had now been greatly reduced. The remaining explosive had been subjected to both severe shock and heat and resulted in a considerable amount of disruption to the firing train.

5.6 The remaining mine components were now easily accessible for further disposal operations by EOD divers or a specialist commercial ROV. For example, remote movement, would have emptied the mine carcase of any loose residual explosives.

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EOD Report Annex F

Mine Juliet – Low Order

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1. INITIAL SURVEY

Mine ID	WWII British A Mk 1-4		
Position	557.8838N 01102.6441E	**Depth**	19.5m
Bottom Type	Sand, Shell, Shingle	**Mine Burial**	50mm
Remaining Net Explosive Quantity	Estimated at 340Kg		
Explosive Type	Minol Main Charge with Tetryl Primers		

2. MINE CONDITION

2.1 Mine Juliet was originally identified as an A Mk1-4, but heavy marine growth made an initial positive identification very difficult.

2.2 The end of the mechanism section was open to the environment (Figure 1), and there were small areas of corrosion on the charge section (Figure 2), indicating that the explosive fill had been exposed to salt water, but there was no indication that the total NEQ had been reduced by tidal erosion and it was not possible to identify the type of explosive in the main charge.

Figure 1: Mine Juliet showing damage to the end of the mechanism section

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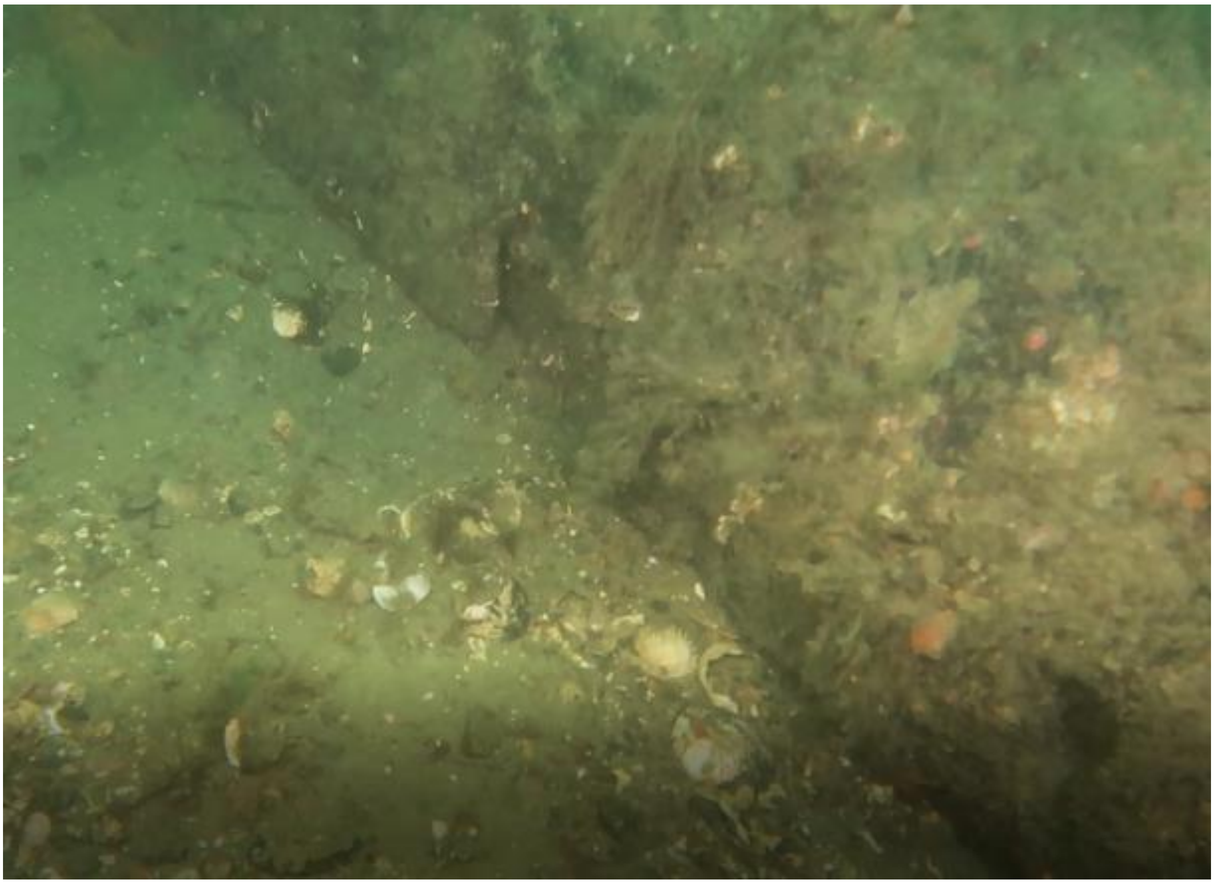

Figure 2: Small areas of corrosion visible in the mine charge section.

3. EOD ACTION

3.1 Mine Juliet was attacked using a Low Order charge to record the deflagration noise levels.

4. DEFLAGRATION CHARGE

4.1 A Pluton 65mm modular shaped charge loaded with 250g Plastic Explosive and a low density, incendiary projectile was used with a fixed air stand-off capsule.

4.2 The single Pluton charge positioning (Figure 3) can be seen to be approximately 500mm back from the nose of the mine which is not the optimum position for an A Mk 1-4 type mine, due to the nose section having an air-filled buoyancy chamber. A better position is further to the rear in the centre of the explosive section. The charge was initiated using an electric detonator & firing cable to the surface.

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Figure 3: Mine Juliet with Pluton Shaped Charge was Position approx 500mm back from the Nose (highlighted).

5. POST BLAST ASSESSMENT

5.1 The post blast assessment was conducted by an EOD diver and recorded on video and still photographs which enabled the confirmation that the mine was an A Mk 1 - 4. The overall deflagration technique proved to have been successful. The mine had not detonated and there was no visible cratering or significant local environmental damage. There was also no visible evidence of an explosion on the surface, with only the 250g load in the Pluton charge, heard through the hull of the dive vessel.

5.2 On examination of the residual explosive scattered in and around the mine carcase, it was observed to be differed in colour to the other mines which were a light brown (Amatol). This explosive residue was a distinct, light gey colour and indicated that the explosive main charge was Minol (See Table 3 of the main report). Minol whilst originally more sensitive than TNT is very hydroscopic and deteriorates even when dry and corrodes steel when wet. This was evident in that the remaining, exposed mine case which showed evidence of severe corrosion.

5.3 Despite the wet condition of the explosives and sub-optimal charge placement, the effects of deflagration had still burst opened the main explosive section, which was almost empty. Explosive residue was scattered in a similar manner to that witnessed in the other mines.

5.4 The percentage of explosives that burned during deflagration is difficult to assess but is likely to be less than that of Amatol. The Minol explosive residue looks to have been reduced to a soft powder similar in texture to silt or mud and was already being dispersed by tidal action, evident by its visible spread around the mine carcase.

Alford House, Epsom Square, White Horse Business Park, Trowbridge, Wiltshire BA14 0XG Tel: 01249 6511111, Fax: 01249 656444

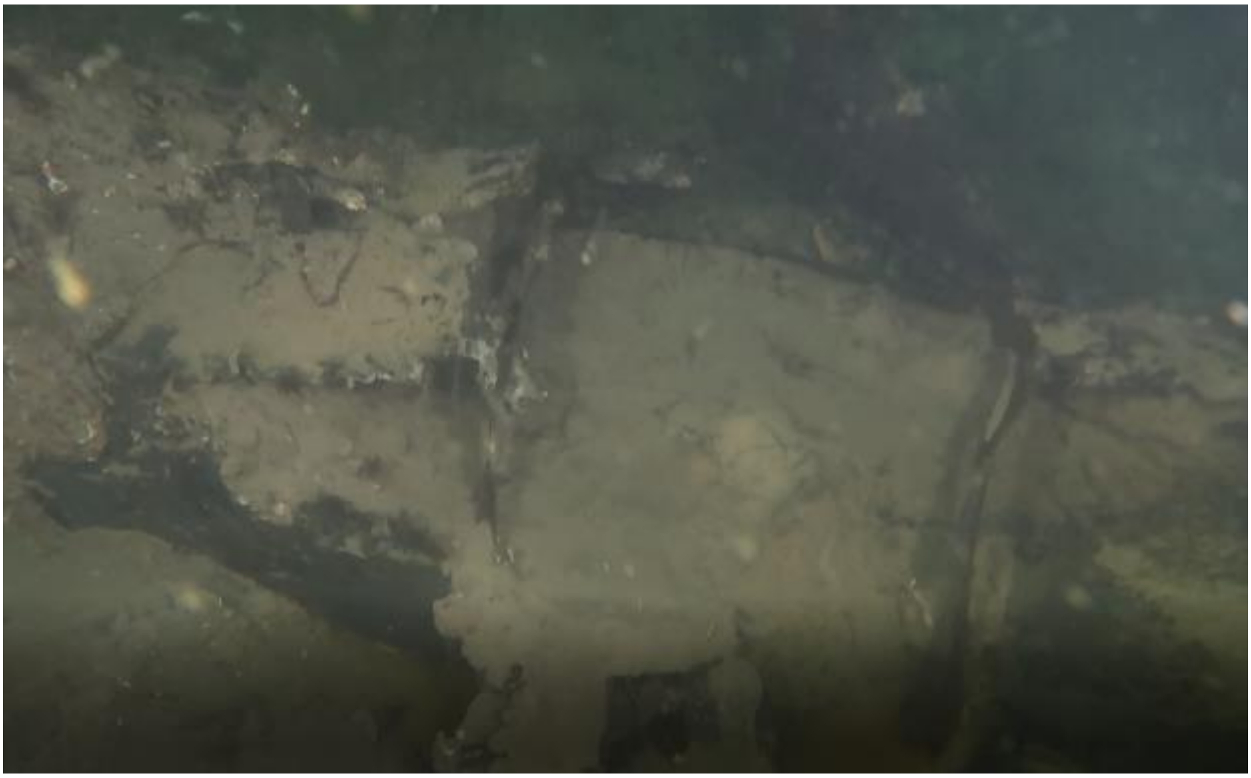

Figure 3: Deflagrated main Charge Case showing the grey Minol main Charge has either burned or been reduced to soft powder.

5.5 The mine having been severely shocked and in an open condition was easily accessible for further EOD action by diver or ROV. Remote movement for example would effectively wash out any explosive residue and make access to other components a simple evolution.

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