



# **Metal Context of Ocean Sediment in Support of UXO Clearance – HMS Raleigh: Third Round**

*Gary Fisher  
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**Defence R&D Canada – Atlantic**

Technical Memorandum  
DRDC Atlantic TM 2005-230  
November 2005

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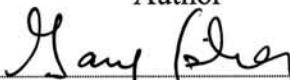
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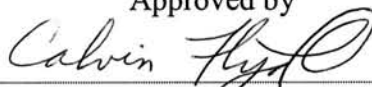
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Gary Fisher

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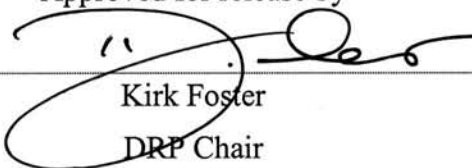


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## Abstract

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This report details the results of a third round of unexploded ordnance (UXO) clearance, completed in June 2005, from the wreck site of the British munitions ship, HMS RALEIGH, which was scuttled in Forteau Bay, NL in 1922. The operation included onsite detonation of UXO. Ocean sediment samples were collected from the site before and after detonation and analyzed for elemental content by inductively coupled plasma – mass spectroscopy (ICP-MS).

As in previous rounds, the elemental composition of ocean sediments at the wreck site was found to be altered by the UXO detonation. Specifically, in this round, the concentration of elements found in common industrial materials (Fe, Ni, Mn, for example) were reduced in wreck site sediments. The concentration of some elements was found to increase in wreck site sediments. These included Cs, Li, Sr and Ti. It was concluded that the cause of this increase was disturbance to geological features by the detonation.

This round of testing included pre- and post-detonation sampling of sediments removed from areas away from the wreck site. The elemental composition of these sediments enabled assessment of the impact of the wreck itself on sediment composition. It was observed that sediments from the wreck site were higher in content of some elements than sediments from other locations. The affected elements included many, such as Al, Co, Mn, Ni and Zn, that are used in common naval materials. Evaluation of sediments from outside the wreck also indicated that the detonation operation spread some site contaminants (As, Co, Mo, Ni and V) over a wider area.

## Résumé

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Dans ce rapport, on présente les résultats d'une troisième série d'élimination de munitions explosives non explosées (UXO), qui a été réalisée en juin 2005, au site du naufrage du navire britannique HMS RALEIGH qui transportait des munitions et qui sombra dans la baie Forteau, à Terre-Neuve, en 1922. L'opération comportait la détonation sur place d'UXO. Des échantillons de sédiments océaniques ont été prélevés, avant et après la détonation des munitions, et analysés par spectroscopie de masse couplée à un plasma induit (SM-CPI) pour déterminer leur composition élémentaire.

Comme dans les séries précédentes, on a constaté que la composition élémentaire des sédiments océaniques avait changé à la suite de la détonation des UXO. En particulier, on a constaté que la concentration de certains éléments, présents dans des matériaux industriels courants (par exemple le Fe, le Ni et le Mn), avait diminué, tandis que la concentration d'autres éléments, tels que le Cs, le Li, le Sr et le Ti, avait augmenté dans les sédiments au site du naufrage. On est arrivé à la conclusion que l'augmentation de

la concentration du Cs, du Li, du Sr et du Ti était le résultat de la perturbation des entités géologiques provoquée par la détonation.

Cette série d'essais comprenait le prélèvement, avant et après la détonation, d'échantillons de sédiments dans des zones éloignées du site du naufrage. La composition élémentaire de ces sédiments permettait d'évaluer l'impact du naufrage sur la composition des sédiments. Les sédiments prélevés au site du naufrage présentaient une concentration plus élevée de certains éléments que les sédiments prélevés ailleurs. Les éléments concernés comprenaient beaucoup de métaux, tels que l'Al, le Co, le Mn, le Ni et le Zn, entrant couramment dans la composition de matériaux de construction navale. L'analyse de sédiments prélevés hors du site du naufrage a aussi indiqué que l'opération de détonation avait répandu certains contaminants du site (As, Co, Mo, Ni et V) sur une zone plus étendue.

## Executive summary

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**Background:** In 1922 the British munitions ship, HMS RALEIGH, sank about 15 metres off Pointe Amour, Newfoundland. The wreck spread unexploded ordnance (UXO) over an area of about 200 x 50 m at water depths ranging from 5 to 9 m in Forteau Bay. Over time some of this UXO began to wash ashore, an obvious safety concern that needed to be addressed.

Removal of the UXO to an on-shore site for detonation and disposal was deemed too dangerous for Explosive Ordnance Disposal (EOD) personnel, as it was feared that pressure changes would cause detonation during removal operations. Therefore an alternate plan was developed whereby the UXO would be detonated underwater at the wreck site.

It was recognized that onsite detonation posed some level of environmental risk due to the release of energetic and metallic constituents into ocean sediments. Thus, a monitoring program was undertaken during UXO clearance operations in which the elemental content of sediment at the site was compared before and after detonation rounds. This report details the results of a third UXO clearance operation completed in Forteau Bay in June 2005.

**Principal Results:** The wreck site was divided into a 3x3 grid for sampling purposes. Sediment samples were collected from each point in the grid prior to and after detonation. Sediment samples were also collected (before and after detonation) from locations 500 metres due north, south and west of the wreck site, permitting evaluation of the impact of the wreck itself and, potentially, a better understanding of the spread of contaminants in the vicinity.

The wreck of HMS RALEIGH introduced elevated concentrations of various elements into local sediments. The majority of these contaminants were from industrial/naval materials that were integral to the ship. The elevated concentrations were not evenly distributed in the sediment and appear to have been predominantly located at the sediment surface;

The detonation of UXO at the wreck site caused changes in elemental composition of sediments in the immediate vicinity. The concentration of many of the more common industrial materials (Fe, Mn, Ni, etc) were lower after UXO detonation while the concentration of mineralogical elements (Li, Sr, etc) were increased.

The detonation of UXO spread wreck contaminants (particularly those containing As, Co, Mo, Ni and V) over a relatively wide area. Increases in concentration of these elements were detected in sediment samples taken 500 metres from the wreck site.

**Significance of Results:** The on-site detonation of UXO from HMS RALEIGH did alter the concentration of some metals in localized sediments and did result in the spread of wreck-site contaminants over a wider area. While this will undoubtedly have some environmental implication, it must be noted that the affected contaminants have been present in a localized area of Forteau Bay for the past 80 years. Their spread over a somewhat larger area seems a small price to pay for the increased safety of residents.

Fisher, Gary & Nault, SLt. Philippe. 2005. Metal Content of Ocean Sediment in Support of UXO Clearance – HMS RALEIGH: Third Round. DRDC Atlantic TM 2005-230. Defence R&D Canada - Atlantic.



## Sommaire

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**Introduction :** En 1922, le navire britannique HMS RALEIGH, qui transportait des munitions, sombra à environ 15 mètres au large de Pointe Amour, à Terre-Neuve, en parsemant des munitions explosives non explosées (UXO) sur une zone d'environ 200 x 50 m à une profondeur allant de 5 à 9 m dans la baie Forteau. Avec le temps, certaines de ces UXO se sont échouées sur la côte où elles constituaient un risque évident qu'il fallait éliminer.

Le déplacement des UXO jusqu'à un site à l'intérieur des terres pour les détoner et les éliminer a été jugé trop dangereux pour le personnel de neutralisation des explosifs et des munitions (NEM), puisqu'on craignait que des changements de pression provoquent la détonation pendant leur déplacement. C'est pourquoi on a élaboré un autre plan où la détonation des UXO aurait lieu sous l'eau sur le site du naufrage.

On a reconnu que la détonation sur place pourrait comporter certains risques pour l'environnement, en raison du rejet de constituants énergétiques et métalliques dans les sédiments océaniques. On a donc entrepris un programme de contrôle pendant les opérations d'élimination des UXO, au cours duquel la composition élémentaire des sédiments sur le site a été comparée avant et après les séries de détonation. Dans ce rapport, on présente les résultats d'une troisième série d'opération d'élimination des UXO menée dans la baie Forteau en juin 2005.

**Résultats :** En prévision des prélèvements, le site du naufrage a été quadrillé en une grille de 3x3. Des échantillons de sédiments ont été prélevés à chaque point de la grille, avant et après la détonation des munitions. Des échantillons de sédiments ont aussi été prélevés (avant et après la détonation) à des endroits situés à 500 mètres au nord, au sud et à l'ouest du site du naufrage, permettant ainsi d'évaluer l'impact du naufrage et peut-être de mieux comprendre la propagation des contaminants dans le voisinage.

Le naufrage du HMS RALEIGH est à l'origine des concentrations élevées de divers éléments dans les sédiments de l'endroit. La plus grande partie de ces contaminants provenait de matériaux de construction industrielle et navale qui faisaient partie intégrante du navire. Les concentrations élevées ne sont pas réparties de façon uniforme dans les sédiments et semblent localisées principalement à leur surface.

La détonation des UXO sur le site du naufrage a modifié la composition élémentaire des sédiments dans les environs immédiats du site. Les concentrations de nombreux éléments entrant dans la composition de matériaux industriels courants (Fe, Mn, Ni, etc.) ont diminué, tandis que les concentrations des éléments minéralogiques (Li, Sr, etc.) ont augmenté.

La détonation des UXO a propagé les contaminants provenant du naufrage (en particulier ceux contenant du As, Co, Mo, Ni et V) sur une zone relativement étendue.

On a constaté une concentration accrue de ces éléments dans des échantillons de sédiments prélevés à 500 m du site du naufrage.

**Portée :** La détonation, directement sur place, des UXO provenant du HMS RALEIGH a modifié la concentration de certains métaux dans les sédiments de cette zone et a eu comme conséquence la propagation des contaminants du site sur une zone plus étendue. La détonation a eu sans doute des conséquences environnementales, mais il y a lieu de souligner que les contaminants en question se trouvent depuis 80 ans dans la baie Forteau. Leur propagation sur une zone un peu plus étendue n'est qu'un faible tribut à payer pour assurer la sécurité des résidents.

Fisher, Gary & Nault, SLt. Philippe. 2005. Metal Content of Ocean Sediment in Support of UXO Clearance – HMS RALEIGH: Third Round. DRDC Atlantic TM 2005-230. Defence R&D Canada - Atlantic.

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# 1. Introduction

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In 1922 the British munitions ship, HMS RALEIGH, sank about 15 metres off Pointe Amour, Newfoundland. The wreck spread unexploded ordnance (UXO) over an area of about 200 x 50 m at water depths ranging from 5 to 9 m in Forteau Bay. Over time some of this UXO began to wash ashore, an obvious safety concern that needed to be addressed.

Removal of the UXO to an on-shore site for detonation and disposal was deemed too dangerous for Explosive Ordnance Disposal (EOD) personnel, as it was feared that pressure changes would cause detonation during removal operations. Therefore an alternate plan was developed whereby the UXO would be detonated underwater at the wreck site.

It was recognized that onsite detonation posed some level of environmental risk due to the release of energetic and metallic constituents into ocean sediments. Thus, a monitoring program was undertaken during UXO clearance operations in which the elemental content of sediment at the site was compared before and after detonation rounds.

Metal content of ocean sediment were reported at References 1 and 2 for UXO clearance operations completed in spring 2003 and spring 2004. Statistically significant increases in the concentration of some elements were indicated. These increases were attributed to degradation of metallic materials deposited in the area as a result of the sinking of HMS RALEIGH and disturbance of the mineralogical content of surficial sediments.

This report details the results of a third UXO clearance operation completed in Forteau Bay in June 2005.

## 2. Procedures and Equipment

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The HMS RALEIGH UXO detonation zone (wreck site) was divided into a 3x3 grid, as indicated below:

A	B	C
D	E	F
G	H	I

Sediment was sampled from each point in the grid before and after UXO detonation. It should be noted that the size of the grid was not known in advance, but would not have exceeded 200 x 50 metres, as this was the size of the entire wreck area. The actual size was determined onsite and was dependent on UXO distribution. In effect, the purpose of the grid was to have a statistically significant number of samples (in this case 9) collected from the site before and after detonation.

All samples were collected by FDU(A) divers into new, unused wide-mouth borosilicate jars (250 mL). The samples were collected by scooping sediment into the jar from the vicinity of the appropriate grid location. As soon as possible after collection, each sample was prepared and stored for analysis in accordance with ASTM D3976. [3]

Previous UXO detonation rounds [1,2] had suggested that sediments from the site contained elevated concentrations of common industrial elements (iron, copper, lead and others), likely as a result of deposition and degradation of materials from the wreck of HMS RALEIGH. Therefore, to better estimate natural elemental concentrations in area sediments, control samples were collected before and after detonation rounds at locations 500 metres due north, south and west of the wreck site. (A control sample was not collected due east of the site due to the closeness of the shore.) These control samples were treated in the same manner as the detonation zone samples.

Due to the presence of a rocky bottom at the wreck and control sites, all samples consisted primarily of water with relatively little sediment. Therefore each sample was filtered through weighed Whatman 41 filter paper and dried for at least 24 hours at 110°C. The filter paper and sediment were then digested in a hot nitric-hydrochloric acid mixture for several hours, in accordance with ASTM D3974 Digestion Practice A. [4] A test blank, consisting of a Whatman 41 filter paper through which 100 mL of distilled water had been filtered, was also treated in the same manner and carried through all subsequent analyses.

After digestion, each sample was diluted in 2% nitric acid and analyzed for metal content using an Agilent 7500ce inductively coupled plasma – mass spectrometer (ICP-MS). Instrument parameters are detailed in Table 1. A 1 part per billion (ppb)

solution of yttrium was used as an internal standard to correct for instrument response fluctuations.

**Table 1.** ICP-MS instrument parameters

PARAMETER	VALUE
Plasma gas flow	15 L/min
Carrier gas flow	0.8 (0.9*) L/min
Make-up gas flow	0.24 (0.17*) L/min
Reaction gas flow	2.4 mL/min
RF power	1500 W
Sampling depth	8.5 mm
Cones	platinum
* - condition when reaction cell utilized	

ICP-MS is, compared to other spectroscopic techniques, relatively free of spectral or background interferences. However, metastable polyatomic species can form in the plasma, particularly in samples that have high dissolved solids content. Some of these species have the same mass as analyte elements. For example,  $^{40}\text{Ar}^{16}\text{O}$  has an atomic mass of 56 atomic mass units (amu) which is the same mass as the major isotope of iron ( $^{56}\text{Fe}$ ). Such interferences can be handled by either selecting a different isotope of the analyte ( $^{57}\text{Fe}$ , for example) or by elimination of the polyatomic species before it enters the mass spectrometer. In this work, elimination of polyatomic species was accomplished by introduction of either  $\text{H}_2$  or He gas into a small reaction chamber situated between the cones and mass spectrometer.  $\text{H}_2$  destroys some polyatomics via chemical reaction while He provides a kinetic barrier that suppresses the introduction of large radii polyatomics into the mass spectrometer relative to the amount of small radii monoatomic species. Table 2 identifies the isotopes that were analyzed in this work and, where appropriate, details which reaction gas was used for suppression of polyatomic interference.

**Table 2. Isotopes analyzed**

ELEMENT	ISOTOPE	REACTION GAS	POLYATOMIC INTERFERENCE
Aluminum	<sup>27</sup> Al	None	
Antimony	<sup>121</sup> Sb	None	
Arsenic	<sup>75</sup> As	Helium	<sup>40</sup> Ar <sup>35</sup> Cl
Barium	<sup>137</sup> Ba	None	
Beryllium	<sup>9</sup> Be	None	
Bismuth	<sup>209</sup> Bi	None	
Boron	<sup>11</sup> B	None	
Cadmium	<sup>111</sup> Cd	None	
Caesium	<sup>133</sup> Cs	None	
Chromium	<sup>53</sup> Cr	None	
Cobalt	<sup>59</sup> Co	None	
Copper	<sup>63</sup> Cu	None	
Gallium	<sup>69</sup> Ga	None	
Indium	<sup>115</sup> In	None	
Iron	<sup>56</sup> Fe	Hydrogen	<sup>40</sup> Ar <sup>16</sup> O
Lead	<sup>208</sup> Pb	None	
Lithium	<sup>7</sup> Li	None	
Manganese	<sup>55</sup> Mn	None	
Mercury	<sup>202</sup> Hg	None	
Molybdenum	<sup>95</sup> Mo	None	
Nickel	<sup>60</sup> Ni	None	
Phosphorus	<sup>31</sup> P	None	
Selenium	<sup>82</sup> Se	Hydrogen	<sup>41</sup> Ar <sub>2</sub>
Silicon	<sup>28</sup> Si	Hydrogen	<sup>12</sup> C <sup>16</sup> O and <sup>14</sup> N <sub>2</sub>
Silver	<sup>107</sup> Ag	None	
Strontium	<sup>88</sup> Sr	None	
Thallium	<sup>205</sup> Tl	None	
Tin	<sup>118</sup> Sn	None	
Titanium	<sup>47</sup> Ti	None	
Uranium	<sup>238</sup> U	None	
Vanadium	<sup>51</sup> V	Helium	<sup>35</sup> Cl <sup>16</sup> O
Zinc	<sup>66</sup> Zn	None	



### 3. Results and Discussion

The results of all sediment analyses, corrected for concentrations detected within test blanks, are detailed in the attached Annexes. Some elements (Ag, Be, Bi, Ga, In and Tl) were not detected in any of the samples. Detection limits for these elements would be less than 10 ppb in the sediments. No further discussion of these elements follows.

#### 3.1 Comparison of detonation zone samples

Comparison of metal concentrations on a point-by-point basis within the detonation zone grid is difficult to interpret due to the high variability of the results. To simplify matters, mean values of element concentration in the entire detonation zone grid were utilized. (To calculate these means, responses of “not detected” were interpreted as zero.) The mean concentrations, in parts per million (ppm), are shown in Table 3.

*Table 3. Mean elemental concentration, before and after detonation.*

ELEMENT	CONCENTRATION (PPM)		ELEMENT	CONCENTRATION (PPM)	
	BEFORE	AFTER		BEFORE	AFTER
Aluminum	1470	1470	Manganese	593	252
Antimony	11.1	1.87	Mercury	0.237	0.314
Arsenic	20.4	14.8	Molybdenum	11.2	5.33
Barium	13.0	4.30	Nickel	17.0	11.7
Boron	35.3	31.4	Phosphorus	914	635
Cadmium	0.067	0.068	Selenium	0.098	0.206
Caesium	0.063	0.144	Silicon	523	707
Chromium	7.53	7.02	Strontium	227	521
Cobalt	4.10	2.40	Tin	1.12	1.79
Copper	64.1	55.3	Titanium	53.8	67.6
Iron	95,600	47,500	Uranium	0.712	0.684
Lead	309	175	Vanadium	18.6	14.9
Lithium	0.553	0.885	Zinc	185	51.8

Direct comparison of the mean concentrations before and after detonation appears to indicate that some elements increased in concentration while others decreased or

remained constant. However, the previously noted high variability of the concentration results suggests that these apparent changes may not be statistically valid. Thus, to clarify matters, a two-sided t-test was used to determine whether there was a statistically significant difference between the “before” and “after” means for each element.

The elements for which a statistically significant difference in mean concentrations at a 95% confidence level was found are shown in Table 4.

**Table 4.** Elements that experienced a statistically significant change in average concentration

CONCENTRATION INCREASED	CONCENTRATION DECREASED
Cs, Li, Sr and Ti	As, Ba, Co, Fe, Mn, Mo, Ni, P and V

The elemental content of ocean sediment in the vicinity of a wreck site can be attributed to two main factors: the composition of the surficial sediment in the area and contributions from degradation/corrosion of materials (primarily metallic) strewn about the vicinity during the wreck. UXO clearance operations involving on-site detonation could reasonably be expected to alter sediment composition in three ways. Firstly, the force released during the detonation could be expected to cause further degradation of nearby metallic materials. This would have the effect of increasing the concentration of these metals in the sediment. Secondly, the energy released during detonation would re-distribute elemental concentrations throughout the affected area. If sediment composition was stratified or localized, average concentrations could be raised for some elements and lowered for others. For example, if the surficial sediment contained an elevated concentration of a particular metallic element (perhaps, due to degradation of materials from the wreck), the re-distribution of the sediment during detonation may cause that elemental concentration to lower due to mixing of the surficial sediments with underlying materials. Conversely, other elemental concentrations may increase as a result of the same mixing effect. Lastly, the detonation process itself may introduce new or elevated concentrations of some materials into the environment. This last factor is not expected to play a significant role for inorganic elements here due to the use of plastic explosives in this operation.

With the possible exception of titanium, the elements whose concentration in the detonation zone sediments increased were not commonly used industrial materials in the early part of the 20<sup>th</sup> century. It is therefore reasonable to conclude that the detected increase in concentration was due to re-distribution and/or disturbance of natural mineralogical features within the zone.

Conversely, most of the elements whose concentration decreased after detonation would be expected to be found in industrial/naval materials from about 100 years ago.

The fact that their concentrations were lowered after the detonation round suggests that a “levelling” effect occurred. This is supported by the results shown in Annexes A and B that indicate that the standard deviations of the grid sediment elemental concentrations were lowered by a factor of 2 or more in the “after” samples for most of these elements.

### 3.2 Comparison of detonation zone sediments with control sediments

Unlike previous HMS RALEIGH UXO clearance operations, this operation included sampling of sediments at points removed from the wreck site. Detailed elemental concentrations of these control locations, before and after the detonation round, are shown in Annex C.

Comparison of elemental concentrations of the detonation zone with the control locations should permit comment on the environmental impact of the HMS RALEIGH wreck. Table 5 compares the mean elemental concentration of the wreck site samples with the control locations, prior to the detonation round.

**Table 5.** Mean elemental concentrations of the grid and control locations, prior to detonation.

ELEMENT	CONCENTRATION (PPM)		ELEMENT	CONCENTRATION (PPM)	
	DET. ZONE	CONTROL		DET. ZONE	CONTROL
Aluminum	1470	785	Manganese	593	120
Antimony	11.1	0.856	Mercury	0.237	0.270
Arsenic	20.4	3.31	Molybdenum	11.2	1.32
Barium	13.0	1.41	Nickel	17.0	2.77
Boron	35.3	21.9	Phosphorus	914	379
Cadmium	0.067	0.266	Selenium	0.098	0.348
Caesium	0.063	0.056	Silicon	523	274
Chromium	7.53	4.55	Strontium	227	595
Cobalt	4.10	0.597	Tin	1.12	0.599
Copper	64.1	45.6	Titanium	53.8	33.7
Iron	95,600	115,900	Uranium	0.712	0.384
Lead	309	90.9	Vanadium	18.6	5.16
Lithium	0.553	0.824	Zinc	185	17.2

The discussion of a “mean” concentration for the control locations implies uniform composition over this relatively large area (approximately 1 kilometre between the two most distant points). This assumption may be suspect. However, it should be noted that the variation in elemental concentrations between control locations is less for most elements than that found within the detonation zone grid, as evidenced by the standard deviations listed in the Annexes. Therefore, treatment of elemental concentration at the control locations as a single population is at least as valid as the similar treatment within the detonation zone.

Using the t-test described earlier, it can be shown that sediment within the detonation zone (wreck site) is significantly higher than the control locations in concentrations of Al, As, B, Ba, Co, Mn, Mo, Ni, P, V and Zn. Due to the industrial/naval importance of many of these elements, most of these increased elemental concentrations can be attributed to the wreck of HMS RALEIGH.

It is somewhat surprising that a statistically significant difference in concentration between the detonation zone and control samples was not found for the two most common metallic elements used in naval materials (iron and copper). Two factors likely contributed to this observation. Firstly, it must be remembered that these results are for the third round of onsite UXO detonation. It seems likely that the expected elevated concentrations of iron and copper may have re-distributed during these rounds. Secondly, iron, more so than most metals, can form oxides have appreciable, albeit limited, water-solubility and oxides that are light and, therefore, easily distributed by water currents.

The sediment samples collected at the control locations also permit estimation of the impact the detonation round may have had on areas outside the detonation zone. Table 6 compares the mean elemental concentrations detected at the control locations before and after detonation.

Using the t-test method, it can be shown that a statistically significant increase in concentration for the elements As, Co, Mo, Ni and V occurred in sediments taken from the control locations after the detonation round, as opposed to before the detonation round. A statistically significant decrease in Fe concentration was also observed.

These results suggest that the detonation of UXO at the HMS RALEIGH site spread contaminants over a relatively wide area. It is interesting to note that all of the elements whose concentration increased within the control samples experienced a decrease in mean concentration within the detonation zone. It seems likely therefore that these elements were present in elevated surficial concentrations within the detonation zone and that these “contaminated” sediments were spread over the vicinity by the force of the detonation.

**Table 6.** Mean elemental concentrations at control locations, before and after detonation.

ELEMENT	CONCENTRATION (PPM)		ELEMENT	CONCENTRATION (PPM)	
	BEFORE	AFTER		BEFORE	AFTER
Aluminum	785	1230	Manganese	120	204
Antimony	0.856	1.56	Mercury	0.270	0.347
Arsenic	3.31	12.1	Molybdenum	1.32	4.72
Barium	1.41	7.77	Nickel	2.77	8.64
Boron	21.9	35.1	Phosphorus	379	569
Cadmium	0.266	0.110	Selenium	0.348	0.237
Caesium	0.056	0.149	Silicon	274	540
Chromium	4.55	5.73	Strontium	595	530
Cobalt	0.597	1.93	Tin	0.599	2.62
Copper	45.6	62.6	Titanium	33.7	58.4
Iron	115,900	41,100	Uranium	0.384	0.762
Lead	90.9	220	Vanadium	5.16	12.6
Lithium	0.824	0.798	Zinc	17.2	32.3

## 4. Conclusions

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Based on the results, three main conclusions are indicated:

- Along with UXO, the wreck of HMS RALEIGH introduced elevated concentrations of various elements into local sediments. The majority of these contaminants were from industrial/naval materials that were integral to the ship. The elevated concentrations were not evenly distributed in the sediment and appear to have been predominantly located at the sediment surface;
- The detonation of UXO at the wreck site caused changes in elemental composition of sediments in the immediate vicinity. The concentration of many of the more common industrial materials (Fe, Mn, Ni, etc) were lower after UXO detonation while the concentration of mineralogical elements (Li, Sr, etc) were increased.; and
- The detonation of UXO spread wreck contaminants (particularly those containing As, Co, Mo, Ni and V) over a relatively wide area. Increases in concentration of these elements were detected in sediment samples taken 500 metres from the wreck site.

It is beyond the scope of this report to comment on the environmental implications, if any, of these findings. However, given that these contaminants have been present in a localized area of Forteau Bay for the past 80 years, their spread over a somewhat larger area seems a small price to pay for the increased safety of residents.

## 5. References

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1. Fisher, G., “Metal Content of Ocean Sediment in Support of UXO Clearance – HMS Raleigh”, DRDC Atlantic Technical Memorandum 2003-154, December 2003.
2. Fisher, G. and ASlt. Nault, “Metal Content of Ocean Sediment in Support of UXO Clearance – HMS Raleigh: Second Round”, DRDC Atlantic Technical Memorandum 2005-062, September 2005.
3. ASTM D3976-92, Standard Practice for Preparation of Sediment Samples for Chemical Analysis, ASTM, West Conshocken, Pa., 2000.
4. ASTM D3974-81, Standard Practices for Extraction of Trace Elements from Sediments, ASTM, West Conshocken, Pa., 2000.

## Annex A: Elemental Composition before Detonation

SAMPLE	CONCENTRATION (PPM)																															
	BEFORE DETONATION																															
	Ag	Al	As	B	Ba	Be	Bi	Cd	Co	Cr	Cs	Cu	Fe	Ga	Hg	In	Li	Mn	Mo	Ni	P	Pb	Sb	Se	Si	Sn	Sr	Ti	Tl	U	V	Zn
A	ND	1090	13.0	22.8	5.69	ND	ND	0.007	2.76	7.72	0.041	13.4	69.2k	ND	0.157	ND	0.234	539	5.60	11.9	849	273	0.365	0.043	146	0.252	95.6	28.0	ND	0.521	18.4	46.3
B	ND	2190	22.1	37.0	7.50	ND	ND	0.029	4.07	7.55	0.037	19.5	106k	ND	0.166	ND	0.569	721	10.3	23.3	1170	409	0.687	0.034	478	1.29	124	55.9	ND	0.232	19.2	205
C	ND	1790	26.4	39.1	1.30	ND	ND	0.023	5.40	7.45	0.068	19.3	103k	ND	0.233	ND	0.910	551	11.9	20.6	1050	337	1.08	0.075	88.8	0.126	272	65.1	ND	0.651	21.3	90.4
D	ND	949	14.6	27.5	9.43	ND	ND	0.020	2.73	5.62	0.055	78.3	69.6k	ND	0.142	ND	0.244	444	7.44	9.95	629	78.7	2.04	0.055	488	0.493	252	48.2	ND	0.614	15.0	40.8
E	ND	1660	21.2	38.8	23.0	ND	ND	0.033	4.19	7.86	0.081	39.7	104k	ND	0.303	ND	0.621	629	20.2	14.2	1130	299	4.40	0.059	874	0.500	129	66.6	ND	0.891	18.7	119
F	ND	1330	22.6	33.6	9.27	ND	ND	0.012	4.47	6.51	0.030	106	110k	ND	0.131	ND	0.435	722	11.2	21.3	973	177	0.663	0.029	478	0.333	105	49.1	ND	0.230	19.2	111
G	ND	1130	21.4	40.7	27.4	ND	ND	0.289	4.14	9.55	0.096	102	83.5k	ND	0.457	ND	0.775	512	11.1	14.8	687	817	11.3	0.387	415	6.05	558	55.3	ND	1.40	14.9	581
H	ND	1690	19.5	37.0	5.62	ND	ND	0.018	4.71	9.11	0.079	84.9	106k	ND	0.144	ND	0.364	754	10.8	20.2	843	110	0.841	0.103	695	0.404	229	55.7	ND	0.778	21.8	85.4
I	ND	1380	22.4	41.5	27.4	ND	ND	0.175	4.40	6.42	0.082	114	109k	ND	0.398	ND	0.826	463	12.4	16.6	897	280	78.1	0.094	1040	0.620	276	60.2	ND	1.09	19.1	389
Mean	-	1470	20.4	35.3	13.0	-	-	0.067	4.10	7.53	0.063	64.1	95.6k	-	0.237	-	0.553	593	11.2	17.0	914	309	11.1	0.098	523	1.12	227	53.8	-	0.712	18.6	185
St. Dev.	-	400	4.2	6.3	10.1	-	-	0.097	0.86	1.26	0.023	41.0	16.8k	-	0.122	-	0.251	118	4.0	4.6	186	218	25.4	0.111	310	1.88	144	11.5	-	0.382	2.4	183

ND = not detected. Detection limit less than 0.01 ppm (10 ppb);

k = thousand



## Annex A: Elemental Composition after Detonation

SAMPLE	CONCENTRATION (PPM)																															
	AFTER DETONATION																															
	Ag	Al	As	B	Ba	Be	Bi	Cd	Co	Cr	Cs	Cu	Fe	Ga	Hg	In	Li	Mn	Mo	Ni	P	Pb	Sb	Se	Si	Sn	Sr	Ti	Tl	U	V	Zn
A	ND	2080	20.1	34.4	5.17	ND	ND	0.039	3.00	11.2	0.168	74.6	56.6k	ND	0.221	ND	0.657	262	6.58	14.6	728	237	2.98	0.134	1110	1.94	425	85.9	ND	0.639	20.3	72.9
B	ND	1500	17.7	31.7	3.32	ND	ND	0.031	2.80	10.3	0.124	58.9	57.0k	ND	0.306	ND	0.542	286	5.61	20.4	711	157	1.71	0.129	546	1.81	353	66.6	ND	0.719	15.9	53.8
C	ND	1610	15.7	29.4	2.32	ND	ND	0.043	2.38	7.40	0.158	54.5	47.8k	ND	0.263	ND	0.633	243	5.28	12.1	644	177	2.70	0.158	682	3.50	402	74.5	ND	0.732	17.3	36.0
D	ND	1460	16.1	30.3	1.57	ND	ND	0.062	2.42	6.73	0.133	75.8	41.3k	ND	0.303	ND	1.31	206	5.15	10.8	616	148	1.14	0.187	654	1.01	710	68.1	ND	0.512	16.2	57.0
E	ND	1460	14.2	34.5	4.10	ND	ND	0.160	2.34	5.40	0.181	122	49.4k	ND	0.453	ND	1.08	227	5.77	9.99	655	241	1.88	0.372	1010	0.932	545	73.1	ND	0.913	14.4	91.0
F	ND	1220	12.4	26.7	5.40	ND	ND	0.043	2.15	4.87	0.114	18.2	43.3k	ND	0.279	ND	0.689	246	4.73	9.31	568	108	1.95	0.122	531	1.60	494	59.4	ND	0.584	12.7	31.2
G	ND	1310	13.2	32.9	5.48	ND	ND	0.064	2.08	6.28	0.112	36.3	47.7k	ND	0.416	ND	1.34	236	5.30	9.33	666	202	1.99	0.177	769	1.16	530	62.2	ND	0.581	12.2	55.1
H	ND	1210	10.7	28.9	ND	ND	ND	0.087	2.21	4.31	0.156	20.8	37.6k	ND	0.370	ND	0.921	343	4.79	9.52	495	131	1.39	0.355	527	1.13	634	58.1	ND	0.756	10.9	29.9
I	ND	1340	13.5	33.5	11.3	ND	ND	0.085	2.21	6.72	0.152	36.9	46.4k	ND	0.211	ND	0.796	220	4.79	8.92	632	175	1.13	0.223	537	2.99	595	60.9	ND	0.716	14.4	39.3
Mean	-	1470	14.8	31.4	4.30	-	-	0.068	2.40	7.02	0.144	55.3	47.5k	-	0.314	-	0.885	252	5.33	11.7	635	175	1.87	0.206	707	1.79	521	67.6	-	0.684	14.9	51.8
St. Dev.	-	270	2.9	2.7	3.23	-	-	0.040	0.31	2.34	0.024	32.6	6.4k	-	0.083	-	0.297	41	0.59	3.7	71	45	0.64	0.095	218	0.91	116	9.0	-	0.120	2.9	20.4

ND = not detected. Detection limit less than 0.01 ppm (10 ppb);

k = thousand

## Annex C: Elemental Composition in Control Samples

SAMPLE	CONCENTRATION (PPM)																															
	BEFORE DETONATION																															
	Ag	Al	As	B	Ba	Be	Bi	Cd	Co	Cr	Cs	Cu	Fe	Ga	Hg	In	Li	Mn	Mo	Ni	P	Pb	Sb	Se	Si	Sn	Sr	Ti	Tl	U	V	Zn
North	ND	562	3.07	20.9	ND	ND	ND	0.260	0.731	7.97	0.061	68.4	84.7k	ND	0.270	ND	0.936	69.5	0.960	1.84	343	20.7	0.323	0.455	298	0.075	95.2	21.1	ND	0.394	4.08	19.6
West	ND	1020	3.42	18.3	4.23	ND	ND	0.043	1.06	3.30	0.056	49.2	138k	ND	0.169	ND	0.387	192	1.18	2.69	403	63.1	1.30	0.157	436	0.562	580	46.2	ND	0.270	4.98	25.7
South	ND	773	3.44	26.6	ND	ND	ND	0.494	ND	2.37	0.052	19.2	125k	ND	0.371	ND	1.15	98.4	1.81	3.79	392	189	0.945	0.433	86.6	1.16	1110	33.8	ND	0.487	6.43	6.30
Mean	-	785	3.31	21.9	1.41	-	-	0.266	0.597	4.55	0.056	45.6	116k	-	0.270	-	0.824	120	1.32	2.77	379	90.9	0.856	0.348	273	0.599	595	33.7	-	0.384	5.16	17.2
St. Dev.	-	229	0.21	4.2	2.44	-	-	0.226	0.543	3.00	0.005	24.8	28k	-	0.101	-	0.394	64	0.44	0.98	32	87.5	0.495	0.166	176	0.543	508	12.6	-	0.109	1.19	9.9
	AFTER DETONATION																															
North	ND	1080	10.9	27.5	23.3	ND	ND	0.033	1.92	3.92	0.122	93.9	39.8k	ND	0.169	ND	0.531	203	4.53	7.74	535	145	1.18	0.224	599	4.63	567	53.0	ND	0.570	11.1	37.6
West	ND	1040	9.87	40.6	ND	ND	ND	0.128	1.58	3.66	0.114	42.2	31.8k	ND	0.330	ND	0.744	188	3.97	6.57	479	352	1.19	0.144	523	0.331	441	57.4	ND	0.575	11.0	19.8
South	ND	1580	15.4	37.1	ND	ND	ND	0.169	2.28	9.62	0.210	51.7	51.6k	ND	0.543	ND	1.12	221	5.66	11.6	693	164	2.30	0.344	497	2.89	583	64.9	ND	1.14	15.6	39.4
Mean	-	1230	12.1	35.1	7.77	-	-	0.110	1.93	5.73	0.149	62.6	41.1k	-	0.347	-	0.798	204	4.72	8.64	569	220	1.56	0.237	540	2.62	530	58.4	-	0.762	12.6	32.3
St. Dev.	-	300	2.9	6.8	13.5	-	-	0.070	0.35	3.37	0.053	27.5	10.0k	-	0.188	-	0.298	16.5	0.86	2.63	111	114	0.64	0.101	53	2.16	78	6.0	-	0.328	2.6	10.8

ND = not detected. Detection limit less than 0.01 ppm (10 ppb);

k = thousand

## List of symbols/abbreviations/acronyms/initialisms

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amu	atomic mass units
ASTM	American Society for the Testing of Materials
EOD	Explosive Ordnance Disposal
FDU(A)	Fleet Diving Unit (Atlantic)
gm	gram
ICP-MS	inductively coupled plasma – mass spectroscopy
L/min	litres per minute
m	metres
mL	millilitres
mm	millimetre
ppb	parts per billion
ppm	parts per million
UXO	Unexploded Ordnance
W	watts

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(U) This report details the results of a third round of unexploded ordnance (UXO) clearance, completed in June 2005, from the wreck site of the British munitions ship, HMS RALEIGH, which was scuttled in Forteau Bay, NL in 1922. The operation included onsite detonation of UXO. Ocean sediment samples were collected from the site before and after detonation and analyzed for elemental content by inductively coupled plasma – atomic emission spectroscopy (ICP-MS).

As in previous rounds, the elemental composition of ocean sediments at the wreck site was found to be altered by the UXO detonation. Specifically, in this round, the concentration of elements found in common industrial materials (Fe, Ni, Mn, for example) were reduced in wreck site sediments. The concentration of some elements was found to increase in wreck site sediments. These included Cs, Li, Sr and Ti. It was concluded that the cause of this increase was disturbance to geological features by the detonation.

This round of testing included pre- and post-detonation sampling of sediments removed from areas away from the wreck site. The elemental composition of these sediments enabled assessment of the impact of the wreck itself on sediment composition. It was observed that sediments from the wreck site were higher in content of some elements than sediments from other locations. The affected elements included many, such as Al, Co, Mn, Ni and Zn, that are used in common naval materials. Evaluation of sediments from outside the wreck also indicated that the detonation operation spread some site contaminants (As, Co, Mo, Ni and V) over a wider area.

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UXO, UXO clearance, HMS RALEIGH, sediment, inductively coupled plasma – mass spectroscopy, ICP-MS

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