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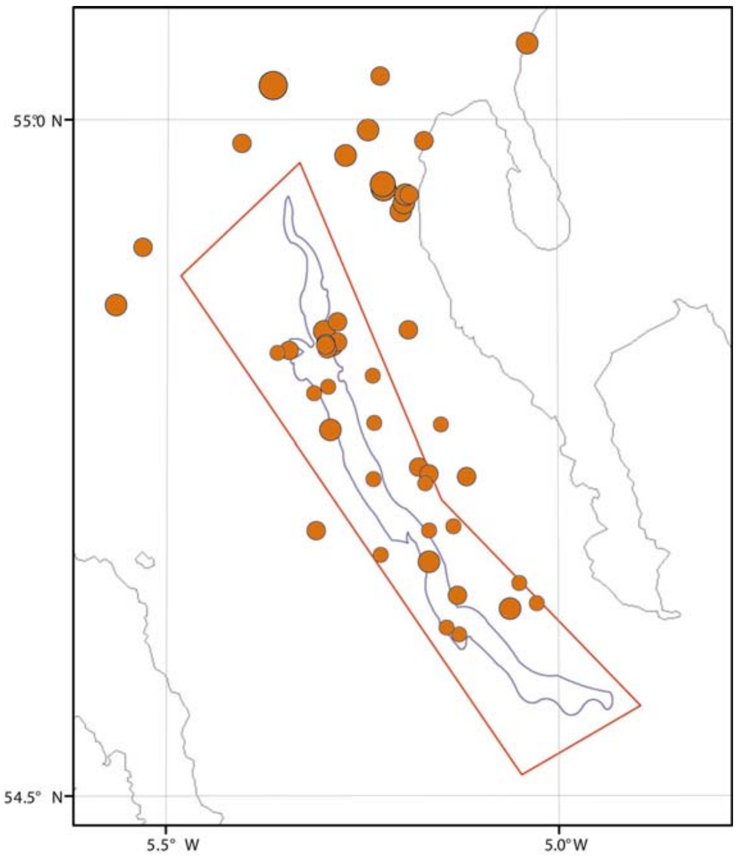
Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004

Seismology & Geomagnetism Programme

Commissioned Report CR/05/064



BRITISH GEOLOGICAL SURVEY

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COMMISSIONED REPORT CR/05/064

Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004

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Summary

Beaufort's Dyke in the North Channel, and surrounding waters were used as a munitions disposal site during the 20th Century, with significant quantities after the two world wars and the last dumping in 1976. The British Geological Survey (BGS) over the years has detected explosions in this area on their seismograph network. Significant explosions were located and kept in the database. The BGS seismicity database also contained smaller explosions that possibly originated from this area, but had not undergone analysis and were thus not given a location. This report describes work carried out to complete the catalogue of underwater explosions in the Beaufort's Dyke area. Using detection on the nearby seismograph networks as search criterion, a total of 186 explosions were considered in this study. Three of these were identified and located in the Beaufort's Dyke area, increasing the total of explosions in this area recorded in the BGS database to 47. However, it is almost certain that the list of explosions is not complete, since due to routine practice, records of smaller explosions were discarded or not detected. In future, it will be possible to improve completeness by analysis of all events in this area based on the existing stations. Installation of additional seismograph stations would help to detect smaller explosions.

1 Introduction

The Beaufort's Dyke is a more than 200m deep trench that is located between Scotland and Northern Ireland. The Beaufort's Dyke area was used after the two world wars for munitions disposal (Marine Laboratory, 1996). The trench is about 50 km long and 3.5 km wide. The Fisheries Research Service conducted a survey to determine precise locations of the disposal sites and found that munitions were distributed in and around the trench (Marine Laboratory, 1996). The largest concentration of munitions was found in and around the northeast sector of the disposal site.

Since the late 1960's, the British Geological Survey (BGS) has been monitoring the seismicity of the UK with a network of seismograph stations that has grown with time. This network now comprises 146 stations, with an average station spacing of 70 km, giving UK-wide coverage and a detection threshold of 2.5 ML for all onshore earthquakes. While the main objective of the monitoring project is to record earthquakes, the network records other types of seismic events such as underwater explosions, quarry blasts, sonic booms and mining collapses. These event types have differing seismic characteristics and can, therefore, be distinguished by the experienced seismic analyst. Correct identification of event types is important to government, industry and the public.

A total of seven BGS seismograph stations are located within about 100km from the Beaufort's Dyke area (Figure 1). Two of them are located in Northern Ireland, two on the Isle of Man, one near the Mull of Kintyre and two in Galloway. The nearest station (GAL-Galloway) is at a distance of about 35km. These stations give reasonably good coverage in all azimuthal directions, which allows for relatively precise event location. For explosions in the Beaufort's Dyke area, the formal horizontal error in epicentre determination (90% confidence) is on the order of 5km. Event locations in this area are based on the LOWNET velocity model (e.g., Simpson, 2004), which was developed for the Midland Valley region of Scotland. However, this model is also considered appropriate for the Irish Sea.

The objective of this study was to identify all possible underwater explosions in the Beaufort's Dyke area between 54.6 to 55.1°N latitude and 5.0 to 5.6°W longitude that are contained in the BGS seismicity database. Most of the explosions in the area were already available with locations and magnitudes. However, it was previously routine practice not to analyse smaller explosions. The identification and location of these small explosions was the main task performed during this work. Furthermore, it was investigated whether the near-shore explosions showed the typical characteristics of underwater explosions.

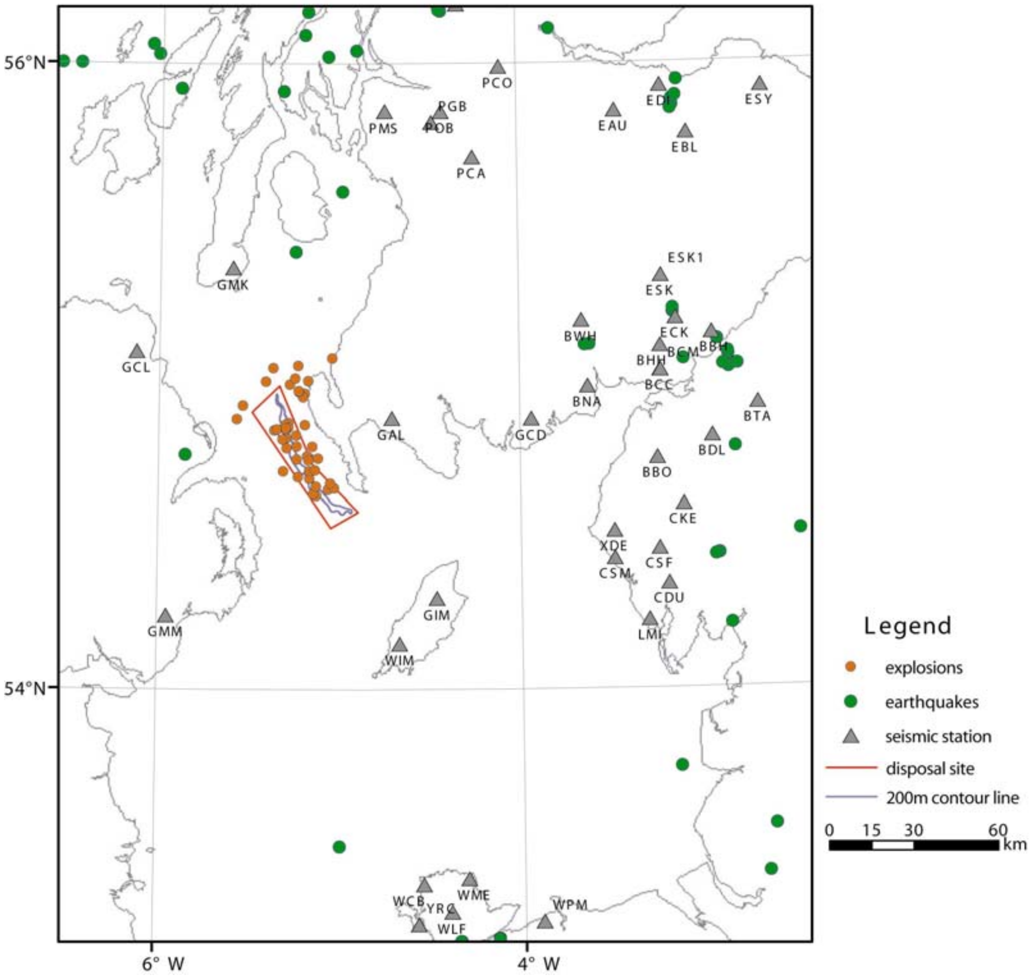

Figure 1 Distribution of BGS seismograph stations (triangles) around the Beaufort's Dyke area, earthquake locations for events above ML 2.5 during 1970-2004 (green circles) and underwater explosions during 1992-2004 (red circles). The charted outline of the Beaufort's Dyke disposal site is given by the red line; the 200m bathymetry contour line within the disposal site area is given by the blue line.

1.1 PROGRAMME OF WORK

The following tasks were defined between the MOD and BGS to be carried out in this study:

- Collate data for those events of an explosive nature that have occurred since 1992 (as detailed records only exist from this date) and that may have originated within the study area.
- Determine precise phase arrivals for seismic waves at all possible stations for each event.
- Use these phase arrival data to determine, where possible, event locations in terms of an origin time, latitude and longitude. For the purposes of this work, the computed depth will be fixed at the earth's surface, since the events are known to be explosions.
- Compare source parameters for all located events with the location of known quarries in nearby onshore areas to discriminate events that may have resulted from quarry blasts onshore.

- Prepare a report of the findings that includes a full analysis of the errors in any locations and also includes any known underwater explosions that are already in the BGS catalogue from this region.

2 Standard practice

It is possible to discriminate between natural earthquakes and other sources of seismic waves based on recordings at a number of seismograph stations. Underwater explosions are commonly detected and classified as such. Their typical seismic characteristics are a distinct absence of S-wave energy, and a low frequency maximum amplitude peak typically in the seconds following the initial P-onset. The signals also show less frequency variation in comparison to tectonic earthquakes (Jacob and Nielson, 1977; Burton et al., 1989). Figure 2 shows seismograms from the largest explosion recorded in the area. The spectrogram for this event (Figure 3) shows that the first arriving signal is seen as a peak at a frequency of about 2 to 5Hz. An example of a smaller explosion is given in Figure 4. The detection threshold in the Beaufort's Dyke area under normal noise conditions is about ML 1.5. However, explosions with magnitude below this threshold have been detected.

Explosions in water are generally more efficient than hard rock shots by a factor of around ten. This is confirmed by some recent studies of underwater explosions in the Dead Sea (Gitterman and Shapira, 2001). They measured magnitudes of 1.7, 3.1, 3.6 and 3.9 for charge sizes of 25, 500, 2060 and 5000 kg respectively and produced the following empirical relationship to predict magnitude values

$M = 0.285 + \log10 W$

where the charge weight W is given in kg. The only empirical study for the UK is by Jacobs and Neilson (1977), who investigated local magnitude (ML) of underwater explosions as a function of charge weight. Their results exhibit wide scatter, taking the mean values, they find 5000 kg = 3.5 ML, 1000 kg = 3.0 ML, 500 kg = 2.5 ML, 100 kg = 2.0 ML. These are somewhat lower than the values for the Dead Sea experiment. The seismic efficiency of underwater explosions depends on the explosion depth. The Dead Sea shots were fired at 70 m. Explosions on the sea floor would result in a reduction in coupling and therefore smaller magnitudes than explosions of a similar size fired at an optimum depth. The study by Jacobs and Neilson (1977) could be updated based on explosions recorded since then to get a more accurate relation for the UK.

Many of the underwater explosions are located, assigned magnitudes and entered into the BGS database of seismic events. Explosions are identified as such in the database. In many cases it is possible to obtain confirmation of an underwater explosion from various groups within the Royal Navy, the Coastguard and DERA. The current practice is that only those events that were felt by the local population, large enough to be detected on several networks, or deemed "interesting" in some other way, are analysed in detail. It is thus almost certain that smaller explosions in the area were not detected, and that relevant data were discarded or not analysed in detail. Prior to 1992, events were discriminated by listening to audio playbacks and events of explosive origin were generally eliminated from further analysis. Therefore there is no record of these events.

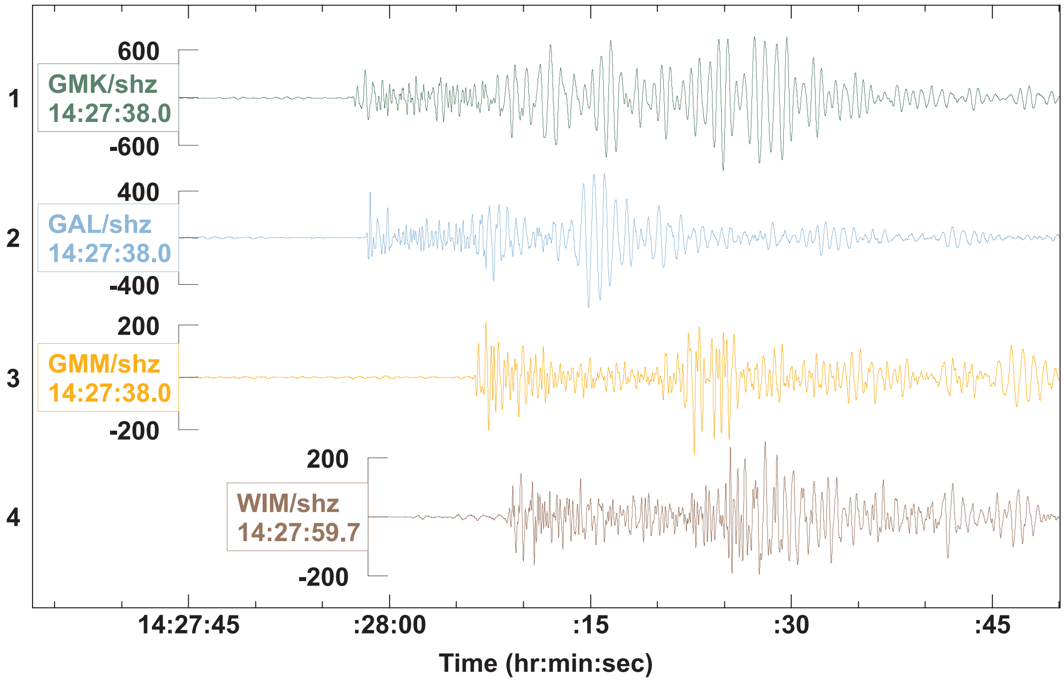

Figure 2 Example of seismogram of the largest underwater explosion recorded in the Beaufort's Dyke area. The event occurred at 14:27 UTC on 3 November 2004 and had a magnitude ML 2.9. The seismograms show ground displacement with the data bandpass filtered between 1 and 10 Hz.

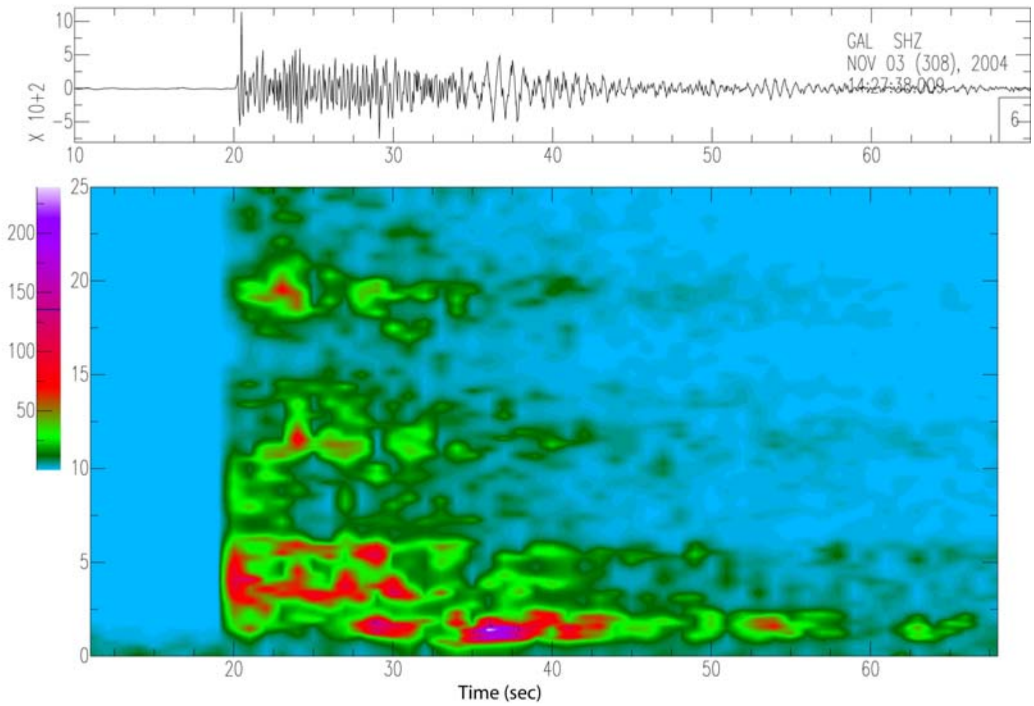

Figure 3 Spectrogram (amplitudes of fourier spectra for time slices are displayed as function of time) for station GAL of the explosion shown in Figure 2.

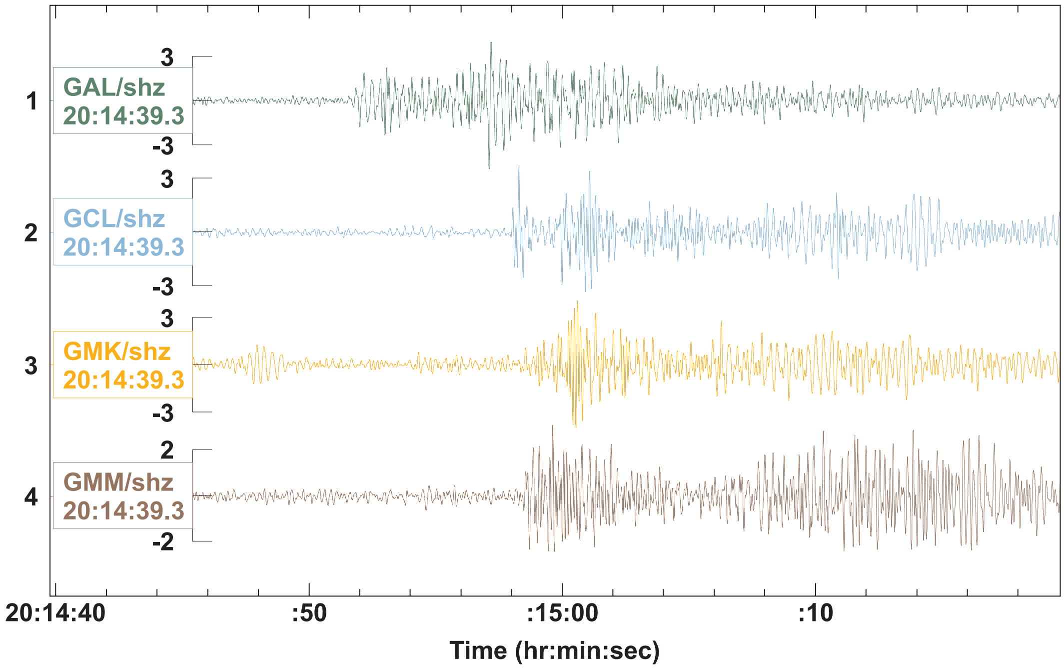

Figure 4 Example of seismogram of an underwater explosion. The event occurred at 20:14 UTC on 28 April 2000 in the Beaufort's Dyke area and had a magnitude ML 0.3. The seismograms show ground displacement with the data bandpass filtered between 3 and 10 Hz.

3 Identification of additional explosions in the Beaufort's Dyke area

As mentioned in the previous section, small explosions, which had not been felt, were not routinely analysed and their location and magnitude were not determined. As part of this work, an effort was made to visually inspect all potential events that fall into this category. Out of all marked and unlocated explosions in the BGS database for the period 1992-2004, events that were potentially in the Beaufort's Dyke area were selected by searching for events that were recorded by the seismograph networks nearest to the area of interest (Galloway, Borders and Paisley). A total of 186 selected events were visually inspected to identify potential events in the dyke area. This is possible, because depending on its location, an event has a specific pattern of signal arrivals at the seismograph stations, with which the analysts are familiar. The identified events were then analysed in detail to determine location and magnitude. The resulting epicentre location is the criterion, which decides whether an event was in the Beaufort's Dyke area. This analysis revealed three underwater explosions in the area, which had not previously been attributed to the Beaufort's Dyke. All other events that were analysed were considered to be onshore quarry blasts.

4 Confirmation of near-shore underwater explosions

Some of the offshore explosions in the Beaufort's Dyke area occurred close to the coast. In order to rule out the possibility that any of these events were actually onshore quarry blasts, they were visually analysed to confirm that their seismograms show the characteristics typical of underwater explosions. Many of the near-shore events had been previously confirmed to be explosions. The visual inspection carried out here confirmed that indeed all these events were compatible with the characteristics of underwater explosions.

5 Explosions in the Beaufort's Dyke area

Including the three events identified during this work, the BGS seismic database contains 47 underwater explosions in the Beaufort's Dyke area for the period 1992 to 2004 (Figure 5,

Table 1). The majority of explosions are located within the charted disposal site area. However, a number of explosions are located to the northeast of this area. Some events are located outside the main dyke area, which matches the observations made by the Fisheries Research Services (Marine Laboratory, 1996).

Table 1 Underwater explosions in the Beaufort's Dyke area between 1992 and 2004. The three explosions identified during this work are highlighted. The comment "confirmed explosion" means that a deliberate explosion was confirmed as such by the responsible agency. However, it is not standard practice to seek an explanation for every event identified as unnatural source and, therefore, events without this comment could have been deliberate explosions as well.

YearMoDy	HrMnSecs	Lat	Lon	kmE	kmN	Dep	Mag	Locality	Comments
19920702	034342.6	54.67	-5.16	196.0	535.6	0.0	1.6	U/W-NORTH CHANNEL	
19920728	061736.6	54.85	-5.28	189.4	555.6	0.0	1.5	U/W-NORTH CHANNEL	
19920731	224234.7	54.86	-5.57	171.2	557.9	0.0	1.7	U/W-NORTH CHANNEL	
19930707	185516.2	54.77	-5.29	188.3	546.7	0.0	1.9	U/W-NORTH CHANNEL	
19930131	**081955.3**	**54.91**	**-5.53**	**173.6**	**562.5**	**0.0**	**1.3**	**U/W-NORTH CHANNEL**	
19930923	140411.4	55.06	-5.04	206.0	577.8	0.0	1.8	EXPL-STRANRAER	EXPL-ORDNANCE DETONATION DETONATED APPROX 0.8KM FROM LOCH RYAN,D & G
19940608	205113.8	54.70	-5.31	186.8	538.6	0.0	1.4	U/W-NORTH CHANNEL	
19941025	075716.5	54.97	-5.27	190.6	569.2	0.0	1.9	U/W-NORTH CHANNEL	
19941214	163937.2	54.73	-5.24	191.7	542.6	0.0	0.2	U/W-NORTH CHANNEL	
19941216	193257.9	54.78	-5.23	192.0	547.2	0.0	0.0	U/W-NORTH CHANNEL	
19950207	152004.0	54.83	-5.36	184.3	553.4	0.0	0.4	U/W-NORTH CHANNEL	
19950622	010026.1	54.94	-5.20	195.2	565.1	0.0	1.6	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION.

YearMoDy	HrMnSecs	Lat	Lon	kmE	kmN	Dep	Mag	Locality	Comments
19950715	154934.8	54.83	-5.34	185.3	553.5	0.0	1.5	U/W-NORTH CHANNEL	
19950811	090052.8	54.98	-5.17	197.1	570.2	0.0	1.4	U/W-NORTH CHANNEL	
19950811	195956.0	55.03	-5.23	193.8	575.7	0.0	1.5	U/W-NORTH CHANNEL	
19950812	054046.1	54.99	-5.24	192.6	571.3	0.0	1.6	U/W-NORTH CHANNEL	
19950904	235806.8	54.95	-5.20	195.4	565.9	0.0	1.6	U/W-NORTH CHANNEL	CONFIRMED MINE DISPOSAL
9960423	212900.3	54.64	-5.06	202.4	531.4	0.0	1.7	U/W NORTH CHANNEL	
19960828	172309.1	54.62	-5.13	198.2	529.5	0.0	0.6	U/W-NORTH CHANNEL	
19960903	035049.3	54.95	-5.19	195.7	565.8	0.0	1.5	U/W-NORTH CHANNEL	EXPL-ORDNANCE DETONATION EXPLOSION BY WARSHIP M103 CONFIRMED BY COASTGUARD
19960916	043834.0	54.74	-5.17	196.3	542.9	0.0	1.1	U/W-NORTH CHANNEL	
19960920	010228.0	54.74	-5.18	195.5	543.5	0.0	1.4	U/W-NORTH CHANNEL	
19961108	165418.8	54.62	-5.14	197.2	530.1	0.0	0.6	U/W-NORTH CHANNEL	
19970502	125301.5	54.93	-5.20	195.0	564.5	0.0	1.8	U/W-NORTH CHANNEL	
19970821	143917.3	54.65	-5.13	198.2	532.8	0.0	1.5	U/W-NORTH CHANNEL	
19980823	212829.3	54.70	-5.17	196.1	538.2	0.0	0.6	U/W-NORTH CHANNEL	
19981031	**173956.1**	**54.80**	**-5.29**	**188.3**	**550.3**	**0.0**	**0.7**	**U/W-NORTH CHANNEL**	
19990211	013248.7	54.98	-5.40	182.2	570.7	0.0	1.2	U/W-NORTH CHANNEL	PART OF NAVAL EXCERCISE IN AREA
19990505	021546.5	54.64	-5.03	204.7	531.8	0.0	1.0	U/W-NORTH CHANNEL	
20000428	201445.4	54.73	-5.17	195.9	542.1	0.0	0.3	U/W-NORTH CHANNEL	VARIOUS POSSIBLE SOURCES CHECKED, NOBODY CONFIRMED
20000429	023606.8	54.70	-5.13	198.1	538.4	0.0	0.4	U/W-NORTH CHANNEL	VARIOUS POSSIBLE SOURCES CHECKED, NOBODY CONFIRMED
20000504	110323.4	54.78	-5.15	197.4	546.8	0.0	0.5	U/W-NORTH CHANNEL	
20000705	215945.2	54.66	-5.05	203.3	533.4	0.0	0.2	U/W-NORTH CHANNEL	
20010816	054843.1	54.81	-5.24	192.0	551.0	0.0	0.7	U/W-NORTH CHANNEL	
20010928	204227.4	54.74	-5.12	199.4	542.5	0.0	1.5	U/W-NORTH CHANNEL	
20011119	202242.1	54.68	-5.23	192.0	536.3	0.0	0.6	U/W-NORTH CHANNEL	
20021028	163937.0	54.84	-5.19	195.1	554.7	0.0	1.5	U/W-NORTH CHANNEL	
20030615	194207.4	54.83	-5.29	188.8	553.8	0.0	1.8	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION
20030615	200516.2	54.84	-5.30	188.2	554.9	0.0	1.8	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION
20030626	**075907.0**	**54.80**	**-5.31**	**187.1**	**549.8**	**0.0**	**0.7**	**U/W-NORTH CHANNEL**	
20030924	232132.3	54.95	-5.22	193.6	566.4	0.0	2.4	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION
20030925	142650.9	54.95	-5.22	193.6	566.8	0.0	2.3	U/W-NORTH CHANNEL	
20040223	170851.9	54.84	-5.28	189.2	553.9	0.0	1.5	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION
20040223	171908.2	54.83	-5.29	188.4	553.5	0.0	1.5	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION
20040223	173000.4	54.83	-5.30	188.3	553.8	0.0	1.3	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION
20040223	173140.9	54.84	-5.30	188.3	553.9	0.0	1.4	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION
20041103	142749.6	55.03	-5.37	184.9	575.3	0.0	2.9	U/W-NORTH CHANNEL	CONFIRMED EXPLOSION

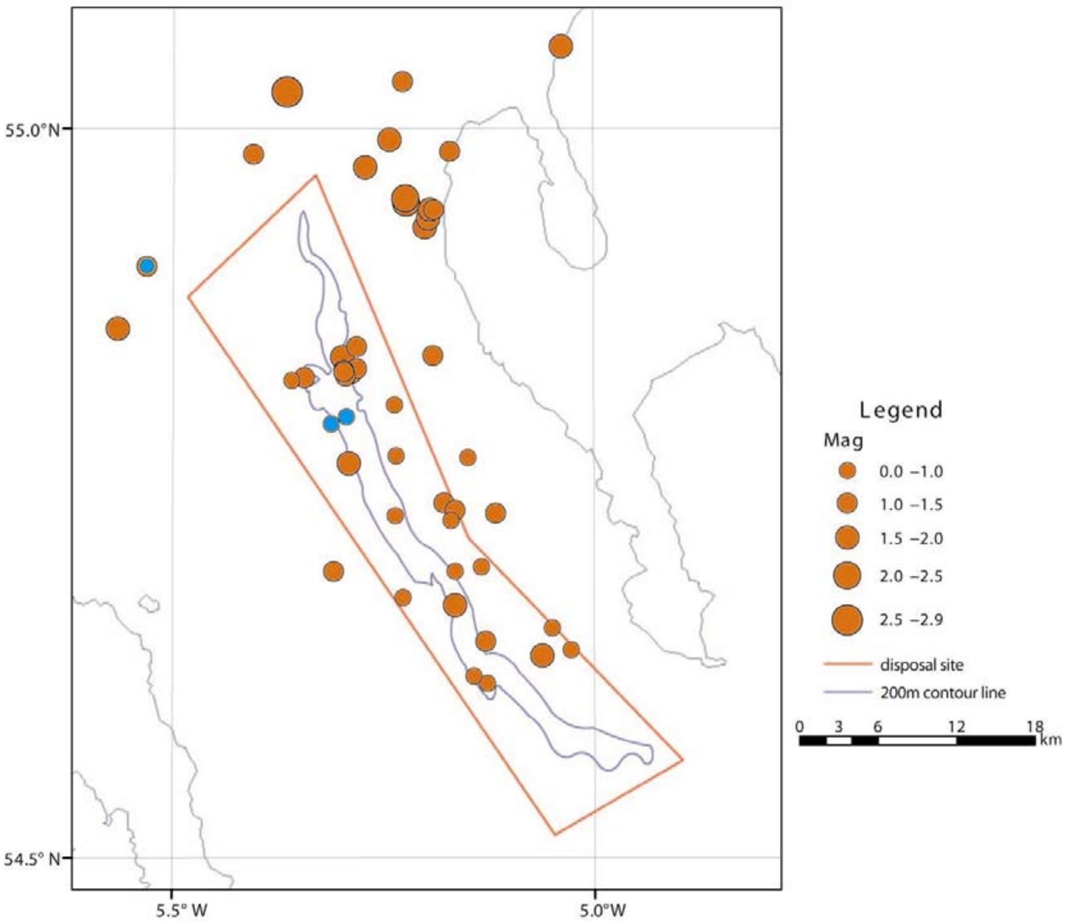

Figure 5 Locations of underwater explosions in the Beaufort's Dyke area between 1992 and 2004 that were detected by the BGS seismograph network and are available in the BGS seismicity database. The blue circles give the location of events identified in this study.

6 Discussion

The main objective of this study was to identify explosions in the Beaufort's Dyke area that had previously not been located in the BGS seismicity database. A total of 186 events were inspected in detail. However, only three additional events were identified, giving a total of 47 underwater explosions in this area recorded between 1992 and 2004 in the BGS database. The work undertaken here has made every possible effort to complete the list of explosions in this area. However, it should be stressed that the inclusion of these data still does not make a definitive catalogue of the seismic activity in this area, and the catalogue almost certainly remains incomplete. The reason for this is that due to past routine practice, smaller explosions may have been discarded, which means that no data for these are available. While it is expected that events above magnitude ML 1.5 were detected, it is possible that smaller explosions were not detected by the seismic networks.

While there is no more to be gained from the past data kept in the BGS database, it is possible to change the routine practice to store and analyse data from explosions in the Beaufort's Dyke area, or more generally around the UK. The BGS could in future also extract data for given times of explosions in case the events are not automatically detected by the seismograph networks. In addition, it would be possible to install extra seismograph stations at a short distance from the disposal site area. This would improve the detection threshold and allow for detection of even smaller events.

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