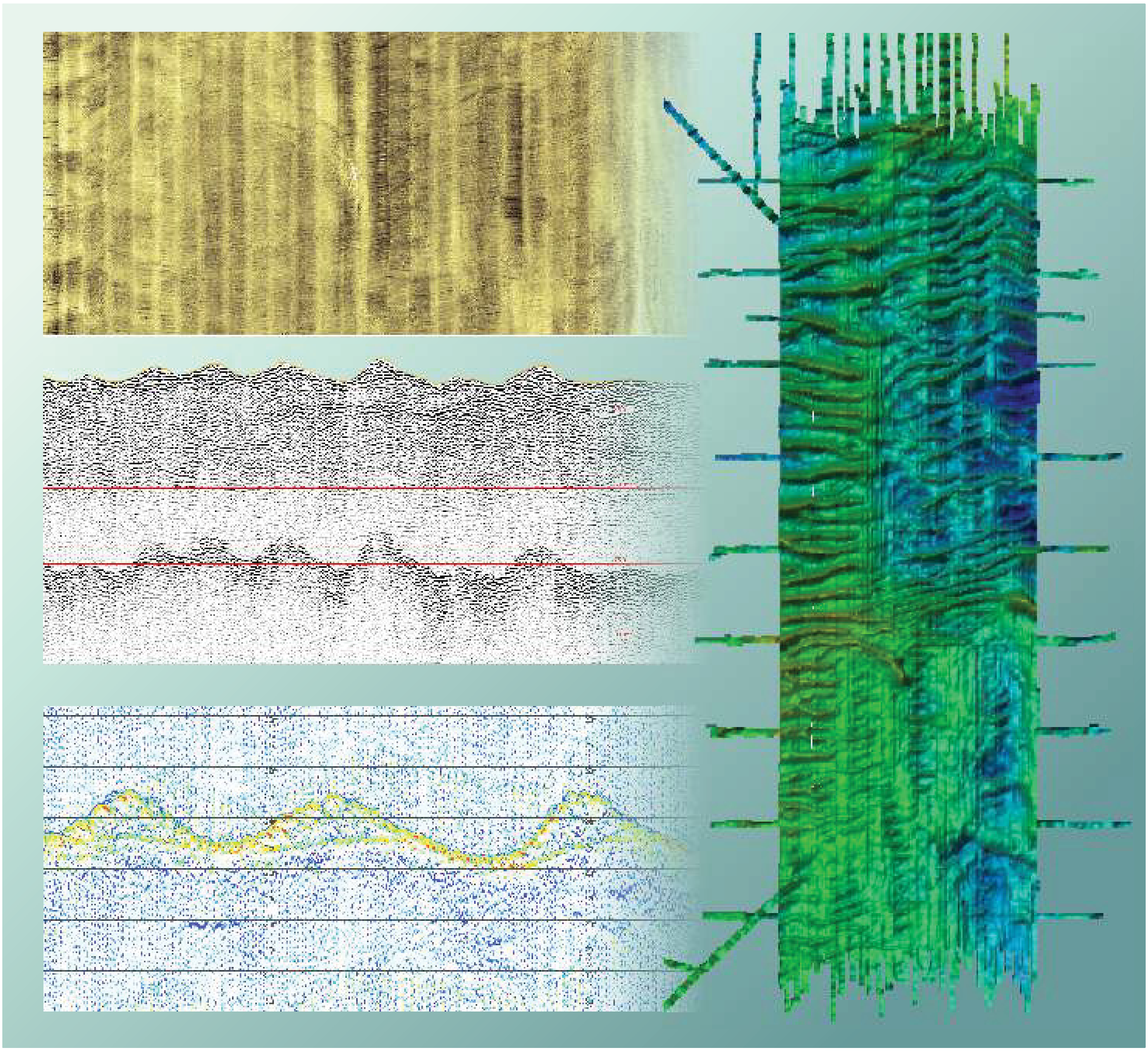
Wessex Archaeology

Seabed Prehistory: Site Evaluation Techniques (Area 240)

Geophysical Survey

Final Report



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October 2009

SEABED PREHISTORY:
SITE EVALUATION TECHNIQUES (AREA 240)

GEOPHYSICAL SURVEY

FINAL REPORT

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Summary

Wessex Archaeology (WA) were funded by English Heritage (EH), through the Aggregate Levy Sustainability Fund, to conduct a project studying the application of geophysical and geotechnical/seabed sampling methodologies to marine aggregate deposits that have been demonstrated to contain potential pre-Devensian or Devensian artefactual material.

Artefactual material, including hand axes, flakes, cores and faunal remains, were recovered from dredging licence Area 240 (licensed to Hanson Aggregates Marine Ltd.) in 2008, situated approximately 11km off the coast of Great Yarmouth. The findings show that significant archaeological material can be present in deposits that are being targeted for marine aggregate extraction. The place where the finds were dredged is relatively discrete, and the provenance of the artefacts is secure. The area where the hand axes were recovered is currently subject to a rectangular exclusion zone based on dredger trackplots, implemented voluntarily by Hanson Aggregates Marine Ltd.

The principal aim of the project is to improve the future management of the potential effects of aggregate dredging on the marine historic environment by developing techniques to evaluating the source of prehistoric artefactual material discovered in the East Coast region.

This report presents the findings of *Stage 2: geophysical survey* and is concerned with the acquisition, processing and interpretation of geophysical data from the approximately 3.5 km x 1.1 km site within Area 240 where the hand axes were discovered. Data were also acquired along additional tie-in lines and a small area in the northwestern corner of Area 240.

In *Stage 1: review of existing data*, existing geophysical data (acquired in 2005) and geotechnical data (acquired between 1999 and 2007) from Area 240 were interpreted. It was found that Area 240 shows a complex history of erosion and deposition since the Late Pliocene / Early Pleistocene. In the smaller 2009 survey area, three sediment units (Units 2, 4 and 6) were found to sub-crop the surficial sediments. Units 4 and 6 have been identified as the most likely origin of the hand axes and (non-fossilised) faunal remains.

The *Stage 2: geophysical survey* was undertaken in April and May 2009 and comprised the acquisition of sidescan sonar, magnetic, single-beam echosounder and four different sub-bottom profiler datasets (boomer, pinger, parametric sonar and chirp).

The datasets were used to monitor changes at the hand axes site since the 2005 dataset was acquired and to provide information on the current distribution of sub-surface sediments to a high vertical and lateral resolution. Within the 3 x 1 km survey area eight seismic units were identified and were divided into five sediment units comparable with the units identified in the 2005 dataset. Along the length of the northern tie-in line and the northwestern survey area, two further units were identified and correlated well with the 2005 dataset.

The mapping of sub-cropping sediments as well at the thickness of overlying Holocene sediments from the 2009 dataset made it then possible to propose several transects for

project *Stage 3: seabed sampling*. The transects were selected in order to sample the sediment units interpreted as likely to contain flint artefacts and faunal remains.

Furthermore, the use of several sub-bottom profilers allowed for direct comparison between the datasets with regards to data quality and suitability of the geophysical instruments to sediment properties.

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The Seabed Prehistory: Site Evaluation Techniques (Area 240) Project was commissioned and funded by English Heritage through the Aggregate Levy Sustainability Fund.

Wessex Archaeology would like to thank Helen Keeley and Gareth Watkins of English heritage for their assistance throughout the project and Dr Ian Selby of the Crown Estate for his contributions, particularly concerning the dredging history and overall interpretation of the area.

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The data were processed by Tina Michel, Ben Urmston and Paul Baggaley; Tina Michel prepared the report with contributions from Louise Tizzard, and incorporating sections of the 70751.02 report. Kitty Brandon prepared the illustrations. The project was managed for Wessex Archaeology by Paul Baggaley and Antony Firth developed the project design.

Data Licences

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1. INTRODUCTION

1.1. PROJECT BACKGROUND

1.1.1. Wessex Archaeology (WA) were funded by English Heritage (EH), through the Aggregate Levy Sustainability Fund, to conduct a project studying the application of geophysical and geotechnical/seabed sampling methodologies to marine aggregate deposits that have been demonstrated to contain pre-Devensian artefactual material.

1.1.2. Artefactual material, including hand axes, flakes, cores and faunal remains, were recovered from dredging licence Area 240 licensed to Hanson Aggregates Marine Ltd. (HAML) in 2008. Area 240 is situated approximately 11km off the coast of Great Yarmouth, situated towards the west of a large area of aggregate licence areas covering an area of around 250km^2 (**Figure 1**).

1.1.3. In total, 75 different Palaeolithic artefacts were discovered within material dredged from Area 240. The condition of the hand axes implies that they were recovered in three different environments: mint (from a primary context), fresh (from an eroding surface) and weathered (from secondary contexts, mainly from the seafloor); dating has proven difficult – the hand axes are thought to date to a wide time period of between 500,000 to 22,000 BP, although a possible smaller time period of 250,000 to 40,000 BP has also been suggested (Wessex Archaeology 2009).

1.1.4. The faunal remains were also dated; five out of six bones were dated to between 43,000 to 31,000 BP, the sixth between 65,000 to 46,000 BP. 70% of the more than 100 bones found are thought to date to the above mentioned dates, but the remaining 30% are heavily fossilised and thought to be older than 500,000 BP (Mr Jan Glimmerveen, pers. com. 30/03/09).

1.1.5. These artefacts were reported by aggregate dredging employees through the *BMAPA/EH Protocol for Reporting Finds of Archaeological Importance* (implemented in 2005); in total, almost 50 finds have been reported between 2005 and 2009 in the dredging licence areas offshore East Anglia. In Area 240, several animal bones, including mammoth bones (380,000 to 10,000 BP), possible worked flint of unknown age and peat concentrations (undated) were reported as well as finds in adjacent dredging areas. These are listed in detail in the *Stage 1: review of existing data* report (Wessex Archaeology 2009).

1.1.6. As part of the East Coast Regional Environmental Characterisation (EC REC), a clamshell grab sample was taken at sampling station GC6 within the 2009 survey site in May 2009, west of the HAML exclusion zone, see **Figure 1.** This sample yielded among other things a flint artefact which was confirmed as a worked broken secondary flake. The condition of the flint artefact suggests that it was recovered *in situ* (Wessex Archaeology 2009).

1.2. AIMS AND OBJECTIVES

1.2.1. The aim of the project is to improve the future management of the potential effects of aggregate dredging on the marine historic environment by developing techniques to evaluating the source of prehistoric artefactual material discovered in the East Coast region.

1.2.2. In order to achieve this aim the following objectives were devised (Wessex Archaeology 2009a):

O1 Refine practical techniques for establishing the presence or absence of prehistoric archaeological material (artefacts, deposits, faunal and other palaeoenvironmental material) on the seabed and for establishing the character, date, extent, quality, preservation and special interest of such material, if present;

O2 Improve the understanding of the character of the historic environment in the East Coast region, specifically its potential for prehistoric material;

O3 To pass on the knowledge gained to the archaeological and scientific community, to industry, and to the general public.

1.2.3. The project undertaken by WA consists of nine project stages, of which *Stage 1: review of existing data* has already been completed. These are listed in **Table 1**.

Stage	Task description
1	Review of existing data
2	Geophysical survey
3	Seabed sampling
4	Visual inspection/palaeo-environmental sampling
5	Palaeo-environment assessment and dating
6	Palaeo-environmental analysis
7	Synthesis
8	Dissemination, knowledge transfer and outreach
9	Archive deposition

Table 1: Project stages

1.2.4. This report presents the findings of *Stage 2: geophysical survey*. This stage contributes to the project aim of improving management by developing techniques to evaluate artefactual material in the East coast region and meets the three objectives outlined above.

1.2.5. This stage contributes to the project objective of refining practical techniques for establishing the presence or absence of prehistoric archaeological material on the seabed (O1) and to the project objective of improving the understanding of the character of the historic environment in the East Coast region.

1.2.6. Firstly, several different sub-bottom profilers have been used at the same site using identical or slightly shifted line plans to allow for direct comparison between the different datasets. This highlights which of the sub-bottom profilers used achieved best results regarding data quality, resolution, penetration and applicability for the sediment type found at the site (sands and gravels) and which can be further recommended, especially with regards to archaeological applications in similar environments.

1.2.7. Secondly, the acquisition of a new dataset makes it possible to establish the current condition of the suspected hand axes site within Area 240 and to monitor changes in surface and sub-surface sediments (e.g. due to movement of bed forms and dredging) since the 2005 dataset was acquired. The new dataset has been acquired at much narrower line spacing than the 2005 dataset and focuses on the smaller site within Area 240 where the hand axes are thought to originate from. This and the use of several kinds of sub-bottom profiler will allow, after integration with the findings of the more regional 2005 report, to identify the presence of possible prehistoric archaeological material with more confidence regarding its properties and composition, and to greater lateral and vertical detail.

1.2.8. The methodological and interpretive results of the survey will be a key component of the overall project results that is to be passed onto the archaeological and scientific community, to industry and to the general pubic to help meet Objective 3.

1.2.9. A further report addendum will be produced alongside this report and will focus on the wrecks identified in the geophysics data reviewed so far (Stage 1 and Stage 2 data).

1.2.10. As part of a planned series of meetings, English Heritage and Crown Estate attended a progress meeting on 20th May 2009 to discuss the preliminary results of the existing data review (Stage 1), initial results presented in this report (Stage 2) and the proposed sampling survey (Stage 3).

1.3. STUDY AREA

1.3.1. A review of the dredging trackplots made it possible to delimit the area from which the artefacts originate with a reasonable degree of certainty. This area has been subject to a rectangular exclusion zone which has been voluntarily implemented by HAML since 2008 (**Figure 1**).

1.3.2. The study area has been designed to cover a wider area around the exclusion zone and measures approximately 3 km x 1 km, see **Figure 1**. Corner coordinates are give in Table 1:

Easting (m)	Northing (m)
425880	5821570
427020	5821570
427020	5825020
425880	5825020

Table 2: Coordinates of the geophysical study area (WGS84, UTM zone 31)

2. METHODOLOGY

2.1. INTRODUCTION

2.1.1. This report is concerned with the acquisition, processing and interpretation of geophysical data from the approximately 3.5 km x 1.1 km site within Area 240 where the hand axes were discovered. This site covers an area slightly larger than the HAML exclusion zone, see **Figure 1**.

2.1.2. The following section describes the properties of the geophysical instruments used for the survey and details the settings and methodologies used to acquire, process and interpret the geophysical data.

2.1.3. Throughout the report, the Universal Transverse Mercator (UTM) Zone 31 co-ordinate system based on the WGS 84 datum is used. Where necessary, co-ordinates were transformed and projected using the Quest Geodetic calculator by Quest Geo Solutions Limited. The vertical datum used was the Lowest Astronomical Tide (LAT) Lowestoft which is 1.5 m below Ordnance Datum Newlyn (OD). All depth references in this report have been reduced to OD.

2.2. GEOPHYSICAL SURVEY

2.2.1. The geophysical survey was undertaken by Wessex Archaeology on the *M/V Wessex Explorer* between 14 April and 4 May 2009. The port for the duration of the survey was the Royal Norfolk and Suffolk Yacht Club in Lowestoft.

2.2.2. During the geophysical survey, sidescan sonar, magnetic, single-beam echosounder (SBE) and four different sub-bottom profiler datasets (boomer, pinger, parametric sonar and chirp) were acquired. A Trimble GPS in combination with HYPACK survey software was used to provide positioning. A TSS motion reference unit was used to correct the SBE and parametric sonar data for heave.

2.2.3. The main survey area covered an area of approximately 3 km x 1 km with 28 main lines of approximately 3 km length oriented north-south with a line spacing of 40 m and up to ten cross lines of approximately 1 km length with a line spacing of either 200 m or 400 m and east-west orientation.

2.2.4. The main survey area was covered by all instruments, although no cross lines were acquired with the chirp due to unsuitable weather conditions. There were two survey plans for the main area: one for the sidescan sonar, magnetometer, boomer and chirp, and another survey plan 20 m offset for the pinger and parametric sonar datasets. Bathymetric data were acquired for all survey lines using the SBE and the parametric sonar, respectively. Track plots for the different sub-bottom profilers are provided in **Figures 2** to **5**.

2.2.5. Line plans were designed to take into account the strong tidal currents in the area with main lines running north-south (in the direction of the tidal currents); the chosen line spacing was set in accordance with the results of *Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging* (Wessex Archaeology 2008), which demonstrated the need for narrow line spacing in order to map small features.

2.2.6. A summary of the different stages of the geophysical survey is presented in **Table 3**, see below:

Survey dates	Geophysical equipment used
20/04/2009 to 22/04/2009	Boomer, sidescan sonar, magnetometer and SBE
23/04/2009 to 28/04/2009	Pinger and SBE
28/04/2009 to 01/05/2009	Parametric sonar
29/04/2009	Pinger
02/04/2009 to 04/05/2009	Chirp and SBE

Table 3: Survey stages

2.2.7. Based on the initial interpretation of the 2005 geophysical dataset, additional lines were designed that would tie specific features to the main survey area. This included two tie-in lines and a series of small lines over a specific bank and channel feature in the north-west corner of Area 240.

2.2.8. Two tie lines were run to the north-west and south-west of the main survey area (one of 3.8 km length oriented south-west to north-east and the second of 1.5 km length oriented south-east to north-west) as well as a small grid of five lines of 1.5 km length to the north-west of the survey area, see **Figures 2** to **5**. These additional lines were run using sidescan sonar, magnetometer, SBE, pinger, boomer and parametric sonar; they were not acquired for the chirp. Furthermore, several additional north-south lines were run north and north-west of the main area with the parametric sonar.

2.2.9. Further additional lines were acquired over a small area to the east of Area 240 over an area were a wreck of a bomber is thought to be as reported through the *BMAPA/EH Protocol for Reporting Finds of Archaeological Importance*. The survey comprised five north-south lines and four east-west lines.

2.2.10. The results of this survey do not fall under the remit of this report, but will be produced as a separate addendum report.

Positioning

2.2.11. Vessel positioning was supplied by a Trimble differential GPS (DGPS) system which provided time, latitude and longitude. The DGPS was used to provide positioning with an accuracy of less than one metre with an update every second.

2.2.12. Offsets from the DGPS receiver antenna on the vessel to the echosounder / parametric sonar and the towing points for the different tow fish (sidescan sonar, magnetometer and the towed sub-bottom profilers) were measured and applied during the processing stage, as discussed in the following sections.

2.2.13. HYPACK 2008 was used to create line plans and record position and depth values from the Trimble DGPS and the single-beam echosounder / parametric sonar respectively. Navigation was then fed back to the devices that recorded the geophysical data.

2.2.14. A DMS3-05 motion reference unit was used to correct the data for heave. It was vertically mounted on the starboard side of the vessel next to the bracket that held both single-beam echosounder and parametric sonar. The heave value was then fed into the single-beam echosounder / parametric sonar; depth values were output and recorded in HYPACK 2008 as well as plotted to paper rolls.

Single-beam Echosounder Dataset

2.2.15. Bathymetry data were collected to provide information on water depth and seabed morphology and to generate a vertical reference datum for the identified horizons from the sub-bottom profiler data. It was also used to compare the position of bed forms and depths to the 2005 dataset to establish how bed forms have moved and in what areas sediment had been affected by dredging since 2005.

2.2.16. The SBE data were acquired using a Knudsen 320M dual frequency echosounder working at 3.5 and 250 kHz simultaneously. The Knudsen echosounder transducer was deployed on a pole on the starboard side of the vessel at a depth of 1.28 m below the sea surface. Bar checks to determine the speed of sound were undertaken and yielded a consistent value of 1478 m/s. The heave-corrected depth values were recorded on-line in HYPACK and additionally printed to paper rolls using a thermal printer.

2.2.17. The single-beam echosounder data were of good quality throughout the survey.

Sidescan Sonar Dataset

2.2.18. Sidescan sonar data were acquired to provide information on the seafloor sediments and bed forms as well as recent dredging and trawling activity in the area.

2.2.19. The sidescan sonar data were acquired using a Klein System 3000 dual frequency sidescan sonar operating at 500 and 100 kHz. The sidescan sonar was towed behind the vessel using a winch at varying laybacks; range was 50m for the main lines and 50 / 150 m for the cross lines. The data were recorded in SonarPro version 11.3 as *xtf* files.

2.2.20. The sidescan sonar data were of generally good quality, but were slightly affected by interference from the boomer. The interference caused very small recurring horizontal stripes on the data, but these are too small to obscure any features and only have a marginal effect on data quality.

Magnetometer Dataset

2.2.21. The magnetometer was used to identify magnetised sediments within the area and to identify magnetic response caused by anthropogeic features on, or buried beneath, the seabed such as wrecks, debris etc.

2.2.22. The magnetometer data were acquired using a Marine Magnetics Explorer magnetometer which was cycled at 4 Hz; accuracy is 0.2nT. The magnetometer was towed 10 m behind the sidescan sonar which was deployed from the stern of the boat and operated by a winch; the data were recorded in Sealink version 8.00013 as text files.

2.2.23. Similarly to the sidescan sonar dataset, the magnetometer data were affected by interference with the boomer. These data issues were relatively insignificant as they were remedied during data processing; thus, data quality was in general moderate to good, but data coverage was not achieved for the entire site with the magnetometer.

Sub-bottom Profilers

2.2.24. Sub-bottom profilers are used to image the sub-seabed geology. A seismic source is deployed and triggered at a fixed firing rate in pings per second (Hz). It emits seismic energy which travels through the water column and penetrates the seabed; the energy is reflected back to the surface as it encounters layers with different density and velocity. The reflected energy is then detected by transducers and recorded.

2.2.25. Seismic sources can be surface towed (e.g. boomer and surface-towed pinger), sub-surface towed (chirp) or hull-mounted (e.g. hull-mounted pinger and parametric sonar); seismic transceivers can be either deployed separately (e.g. hydrophone for boomer) or are combined with the seismic source (e.g. pinger, chirp and parametric sonar).

2.2.26. The effectiveness of a sub-bottom profiler system depends on several factors: penetration, positional accuracy (see 2.2.11), and lateral and vertical resolution.

2.2.27. Penetration is determined by power and frequency of the source. Penetration is comparatively low for high frequency sub-bottom profilers and highest for high power / low frequency profilers such as the boomer.

2.2.28. Lateral resolution is the measure of accuracy of separating sub-surface features laterally and depends on the amount of data readings in lateral direction and the directivity and foot print of the seismic source. The amount of data readings in lateral direction depend on ping rate and speed of the vessel - e.g. a ping rate of 3 Hz at 4 knots (or approximately 2 m/s) survey speed would yield a value every 0.66 m; a ping rate of 10 Hz at 4 knots a value every 0.2 m. The footprint of the seismic source is the area ensonified by the seismic signal and depends on the directivity of the seismic source. The directivity is frequency dependent; generally, the higher the frequency, the larger the emission angle of the seismic source, the larger the beam width and foot print and the lower the lateral resolution.

2.2.29. Vertical resolution is the measure of accuracy to which vertical reflectors can be separated and is mainly determined by the dominant frequency. Experience shows that the maximum resolution possible is approximately one quarter of the wavelength of the pulse. The size of the wavelength is determined by dividing the seismic velocity by the frequency of the system (Lavergne, 1989).

2.2.30. In general, data quality mainly depends on suitability of the sub-bottom profiler to sediment composition, water depth and to a great extent weather conditions. Hull-mounted and sub-surface towed equipment will generally be less susceptible to weather conditions than surface towed equipment.

2.2.31. A summary of the sub-bottom profilers used for the survey and their properties including dominant frequencies, vertical resolution, ping rate, footprint and towing depth are displayed in **Table 4**, see below:

Sub-bottom profiler	Dominant frequency	Maximum vertical resolution	Ping rate in Hz	Beam width	Radius in m (in x m of water)	Towing depth
Boomer	1 kHz	40 cm	3	30 – 40°	17.5 m (in 25m; for 35°)	sea surface
Pinger	3.5 kHz	10 cm	5	55°	35.7 m (in 25 m)	sea surface
Parametric sonar	8 kHz	5 cm	~ 15	1.8°	0.8 m (in 24 m)	1 m below sea surface; on pole
Chirp	2 - 15 kHz	6 cm	6	17°	5.2 m (in 17 m)	8 m below sea surface

Table 4: Details of sub-bottom profiler systems used in the geophysical survey

2.2.32. Data examples of the different sub-bottom profilers are displayed in **Figures 9** to **11**.

Sub-bottom Profiler Dataset - Boomer

2.2.33. The boomer seismic source operates at high power and comparatively low frequencies of approximately 1 kHz. Thus, it achieves high penetration, but relatively low resolution (up to approximately 40 cm). Boomers are very well suited to sand and gravel sediments and have beam width of typically 30° to 40° (Parkinson, 2001)

2.2.34. The boomer dataset was acquired using an Applied Acoustics Model AA200 Seismic Source capable of generating 100 Joule at 4 Hz with a CSP300 Portable Capacitor Charging Unit; the unit was run at a slightly lower pinger rate of 3 Hz to avoid deformation of the rubber sheet within the boomer. The boomer was surface towed over the starboard side of the stern of the vessel at a distance of approximately 15 m. To receive the data, an eight element hydrophone was towed over the port side of the vessel. The data were recorded in *SEG-Y* format using the CODA DA 1000 Series.

2.2.35. The boomer data were generally of good quality with some lines of moderate quality, due to variable weather conditions. Some effects of steep sand waves could be seen on the data: the steep slopes lead to the scattering of the seismic energy and resulted in weaker signal return. Penetration to the seabed multiple (up to more than 30 m) was achieved on all lines with a vertical resolution of better than one metre in the near surface. Lateral resolution with a ping rate of 3 Hz equates to a data reading every 0.66 m at 4 knots survey speed. Also, beam width is relatively high: assuming a beam width of 35°, the radius of the footprint in 25 m of water is approximately 17.5 m.

Sub-bottom Profiler Dataset – Pinger

2.2.36. The pinger seismic source operates at higher frequency, typically 3.5 kHz, and with lower power than the boomer. It shows higher resolution, but much lower penetration than the boomer seismic source. Its footprint is the largest of all sub-bottom profilers used as it is surface-towed and operates at a comparatively high frequency. Generally, the quality of pinger data is adversely affected by certain sediment types, especially gravels and gravelly sands.

2.2.37. The pinger dataset was acquired using a GeoAcoustics 136A sub-tow pinger. It was operated at a frequency of 3.5 kHz at 70% power. The surface towed pinger was towed at a distance of approximately 15m over the starboard side of the stern of the vessel. The data were recorded in *SEG-Y* format using the CODA DA 1000 Series. The hull-mounted pinger on the Wessex Explorer was also used (using the same settings as above) as the surface-towed pinger proved to be very susceptible to weather conditions; approximately half of the survey lines were acquired with the hull-mounted pinger and the remainder with the surface-towed pinger.

2.2.38. The pinger dataset was of generally moderate to low quality; this was partly due to unfavourable weather conditions and strong tidal currents, but data quality was also affected by the physical properties of the sands and gravels at seabed which caused pronounced ringing and prevented penetration into the sediments. Additionally, the signal was obscured by hyperbolae created by sand ripples overlaying the larger sand waves. Maximum penetration of up to 6m was achieved in parts, but penetration was considerably less on most lines. The expected vertical resolution of 10 cm at 3.5 kHz was not accomplished due to ringing caused by physical properties of the sediments – vertical resolution of approximately 40 to 50 cm was achieved for the dataset. Horizontal resolution was 0.4m at 5 Hz and 4 knots; the radius of the footprint in 25m water depth is approximately 35.7m (at 55° beam width). The large footprint especially affected the cross lines which were run parallel to sand wave crests – these were imaged on the data and obscured further any sub-bottom reflectors.

Sub-bottom Profiler Dataset – Parametric Sonar

2.2.39. The parametric sonar seismic source works on different principles than standard sub-bottom profilers. Parametric arrays generate their acoustic signal using non-linear principles: if two close frequencies are transmitted at very high levels, non-linear propagation of the sound signal induces a secondary wave with a frequency equal to the difference between the two primary frequencies (Lurton, 2002). By using the high frequency to generate the low frequency, very small beam width (here of less than 2° and no side lobes) are achieved; also, the ping rate is considerably higher. Due to relatively high secondary frequencies, very good resolution is achieved, but penetration is comparatively low in sediments such as sand and gravel. Furthermore, the parametric sonar is pole-mounted and thus less susceptible to weather.

2.2.40. The parametric sonar dataset was acquired using a SES2000 compact system. It was mounted on a pole over the starboard side at 1m below the sea surface. The parametric sonar uses a low and a high frequency channel with a primary frequency of 100 kHz with a secondary frequency which is adjustable between 5 to 15 kHz; it acts as a single-beam echosounder as well as a sub-bottom profiler. The system was run with a low frequency of 6/8 kHz at a rate of approximately 16 Hz. The data were corrected on-line for heave and recorded in *ses* format using the SES 2000 software; additionally, heave-corrected depth values were output and recorded on-line in HYPACK.

2.2.41. The parametric sonar dataset was generally of good to very good quality using a low frequency of 6 / 8 kHz. Penetration of up to 6m was achieved in parts and resolution was generally very good (up to approximately 10 cm resolution). The parametric sonar dataset allowed for accurate mapping of the thickness of the Holocene sediments as it was of the highest resolution and was not affected by ringing. Horizontal resolution is excellent due to high ping rates of approximately 15 Hz which equates to a reading at 0.13m at 4 knots survey speed. Beam width is extremely low; for the specified beam angle of 1.8°, the radius of the footprint is only 0.8m. This means that lateral resolution is extremely good, but also that only reflectors directly below the instrument are shown – reflectors just outside the footprint are not imaged.

Sub-bottom Profiler Dataset - Chirp

2.2.42. The chirp seismic source generates a sweep over a user defined frequency range and the reflected signal is passed through a pulse compression filter. It can achieve high resolution, but comparatively low penetration, e.g. the typical penetration in calcareous sand is 6m. Chirps have a relatively small beam width for sub-bottom profilers.

2.2.43. The chirp dataset was acquired using an Edgetech SB216S chirp system which was operated at 2 – 15 kHz. The chirp was deployed over the stern of the vessel and was flown at a depth of approximately 8m below the sea surface. The data were recorded in *SEG-Y* format using the provided Edgetech software.

2.2.44. The chirp dataset was generally of moderate to low quality; penetration was approximately 2m to 3m and resolution was much lower than expected. Because the chirp was towed at approximately 8m below the sea surface, the data is less affected by weather and the radius of the footprint is relatively small at 5.2m. The comparatively low data quality is thought to be mainly due to the sediment types (sands and gravels) present at site.

2.3. GEOPHYSICAL SURVEY COMPARISON WITH 2005 SURVEY

2.3.1. **Table 5** details the differences in the data acquired during this survey and that acquired during the 2005 survey (reviewed as part of the Stage 1 report (Wessex Archaeology 2009)). The 2005 data covers the entire Area 240, whereas the 2009 survey only covers a smaller area of Area 240 (**Figures 2 – 5**).

Survey	2005			2009		
	Source	Line km	Line spacing	Source	Line km	Line spacing
Sub-bottom profiler	Boomer	360	N-S at 100m; E-W at 1,000m	Boomer	141	N-S at 40m; E-W at 200 or 400m. Plus extra lines
				Pinger	157	N-S at 40m;

						E-W at 200 or 400m. Plus extra lines
				Chirp	108	N-S at 40m
				Parametric sonar	165	N-S at 40m; E-W at 200 or 400m. Plus extra lines
Bathymetry	Multibeam echosounder	360	N-S at 100m; E-W at 1,000m	Single-beam echosounder	141	N-S at 40m; E-W at 200 or 400m. Plus extra lines
Sidescan sonar		360	N-S at 100m; E-W at 1,000m		141	N-S at 40m; E-W at 200 or 400m. Plus extra lines
Magnetometer	Not acquired				141	N-S at 40m; E-W at 200 or 400m. Plus extra lines

Table 5: Comparison of 2005 and 2009 geophysical survey datasets

2.4. Geophysical Data Processing and Interpretation

2.4.1. The dataset acquired by WA comprised sidescan sonar data, magnetometer data, four sets of sub-bottom profiler data (boomer, pinger, parametric sonar and chirp profilers) and single-beam bathymetry data.

2.4.2. Laybacks were measured during the survey and applied during processing. Tidal corrections were also applied using recent tidal information from a tide gauge at Lowestoft (Proudman Oceanographic Laboratory, 2009) – this information was checked and then applied to the datasets.

Single-beam echosounder

2.4.3. The single-beam echosounder / parametric sonar dataset (depth values) were processed using the HYPACK 2008 software. During processing, tidal corrections were applied and spikes and erroneous values were removed from the dataset. It was then further processed using IVS Fledermaus version 6.5.0 and finally gridded with a bin size of 8m. The data were provided referenced to chart datum, Admiralty Chart number 1543. In order to associate the offshore deposits with terrestrial sediments, the bathymetry data were reduced from chart datum to Ordnance Datum (OD) Newlyn. Chart datum relative to OD (Newlyn) is -1.50m at Lowestoft (Admiralty Chart number 1543). The dataset is displayed in **Figure 6**.

Sidescan sonar

2.4.4. The sidescan sonar data were processed by WA using Coda Geosurvey software. This allowed the data to be replayed with various gain settings in order to optimise the quality of the images. The data were visually scanned to give an understanding of the geological nature of the area and then added to a mosaic in Coda Geosurvey, see **Figure 7.** The sidescan sonar dataset was used to provide information on seabed sediments as well as bed forms, recent dredging activity and anthropogenic features such as wrecks and debris etc..

Magnetometer

2.4.5. The magnetic data were processed to give *XYT* files comprising of grid co-ordinates (X, Y) and total magnetic field strength (T) recorded in nanoTeslas (nT). Each line of data was de-spiked and then smoothed and processed to remove the regional magnetic field and also any long period diurnal variations by effectively applying a low pass filter to each magnetic profile in the data set to create a smoothed profiles which are then subtracted from the original profiles. The data were then gridded to produce a contour map of the survey area and plotted with the magnetic field strength values represented by graded colour bands to show changes in the magnetic field strength, see **Figure 8**.

Sub-bottom profiler – boomer, pinger and chirp

2.4.6. The sub-bottom profiler data in *SEG-Y* format (boomer, pinger and chirp) were processed by WA using Coda Geosurvey software. This software allows the data to be replayed with user selected filters and gain settings in order to optimise the appearance of the data for interpretation.

2.4.7. The data were processed on a line by line basis and filters adjusted accordingly in order to maximise the quality of the data. For the boomer, trace mixing and a band pass filter of 1,000 to 2,000 Hz were applied. A band pass filter of 3,000 to 4,000 Hz was used for the pinger data and the chirp data were processed with a band pass filter of 1,000 to 2,200 Hz.

Sub-bottom profiler – parametric sonar

2.4.8. The parametric sub-bottom profiler data were processed by WA using Innomar's ISE2.92 software. This software also allows the data to be replayed with user selected filters and gain settings in order to optimise the appearance of the data for interpretation. Heave had already been applied to this dataset and tidal information was applied during processing.

2.4.9. The data were also processed on a line by line basis and gains adjusted to maximize the quality of the data. The Innomar ALGO 1P filter was applied to the dataset (this filter analyses the slope and amplitude of the signal).

Sub-bottom profiler – general

2.4.10. The sub-bottom profiler data were interpreted with two-way travel time (TWTT) along the z-axis. In order to convert from TWTT to depth the velocity of the seismic waves was estimated to be 1,600m/s for all datasets. This is a standard estimate for shallow, unconsolidated sediments (Sheriff and Geldart, 1983).

2.4.11. One of the aims of the geophysical survey was to identify geological formations and shallow small-scale features outcropping below the Holocene sediments as these are the sediments the artefacts are expected to have been dredged from. Interpretation was based on the findings of the previous regional report (Wessex Archaeology 2009), with special emphasis on identifying small scale cuts and fills and erosional features close to the surface. Each sedimentary boundary, shallow cut and fill and erosional feature was tagged along each line.

2.4.12. Interpolations between the sediment boundaries and features interpreted from different lines were mapped and georeferenced using ArcView GIS software.

2.4.13. The depth of boundaries sub-seabed were also exported and gridded into layers using IVS Fledermaus software, referenced to the seabed depths acquired during the bathymetry survey (reduced to metres below OD).

2.4.14. The geophysics review was conducted in several phases. First, the quality of all datasets was assessed. It was decided to base the initial interpretation on the boomer and parametric datasets as these were of the highest quality and then incorporate features identified on the pinger and chirp datasets. Thus, the boomer dataset and the parametric sonar dataset were interpreted first and cross-checked.

Then, the updated boomer dataset were compared to the 2005 dataset and again updated. Finally, the pinger and chirp datasets were interpreted. The final interpretation derives from a combination of all datasets.

3. SUMMARY OF THE EXISTING DATA REVIEW

3.1.1. The *Stage 1: Existing Data Review* report (Wessex Archaeology 2009) outlines the geological and geomorphological background within the wider Area 240, presents results of the interpretation of the existing boomer dataset acquired in 2005 and proposes a chronology for the geological units encountered in Area 240. This section summarises the findings of this report.

3.2. THE 2005 BOOMER DATASET

3.2.1. The data reviewed in the *Stage 1: Existing Data Review* report comprised sub-bottom profiler (boomer) and multibeam bathymetry data.

3.2.2. The boomer data were acquired using an EG&G 230 surface tow system and the plate was powered at 200 Joule at a rate 2.6 Hz. The multibeam dataset was acquired using a Geoswath system and gridded at 2m bin size. The dataset covered the whole of Area 240 with main lines running north-south at 100m line spacing and crosslines acquired at 1 km line spacing.

3.3. PREHISTORIC ARCHAEOLOGY

3.3.1. During the last 700,000 years BP, climatic conditions oscillated between glacial and interglacial episodes causing fluctuating sea-levels with high sea-levels during interglacials (up to 5m higher than at present) and low sea-levels during glaciations (up to 120m lower than at present) when large amounts of water where locked up in ice sheets. This means that most of the North Sea continental shelf would have undergone successions of exposure and inundation with the sea repeatedly transgressing and regressing. Sediments were consequently reworked and both deposition and erosion occurred, which means that the chronological sequence in Area 240 is far from complete (Wessex Archaeology 2009).

3.3.2. The Yarmouth Roads Formation dates back to approximately 2.3mya to 480,000 years ago, and represents the earliest deposit with possible human occupation in Area 240; floodplain deposits found in sediments at Pakefield Flat are partially equivalent to the Yarmouth Roads Formation and have yielded, among other things, flint artefacts dated to 700,000 BP, the earliest indication of human occupation in Britain. The Yarmouth Roads Formation was formed during a marine transgression and comprises sediments of fluviatile to estuarine origin. The age of the formation in Area 240 is difficult to estimate, but it is possible that the formation could contain evidence of human occupation although the uppermost sequence is likely to have been affected by erosion (Wessex Archaeology 2009). The Yarmouth Road Formation is found throughout the site and consists of fine to medium grained sands with clay laminae and occasional flint pebble layers, with local beds of clay and shelly sand.

3.3.3. Within Area 240 the Yarmouth Roads Formation overlies the Westkapelle Ground Formation. The Formation comprises clays, muddy sands and sands deposited in an open marine environment (Cameron *et al*. 1992:105), and are partially equivalent to the Crag deposits recorded onshore (Arthurton *et al* 1992:32).

3.3.4. There appear to be no sediments deposited during the Anglian, Hoxnian, Wolstonian or Ipswichian age documented within Area 240.

3.3.5. During the last glaciation, the Devensian (110,000 to 13,500 BP), Area 240 was not covered by an ice sheet, but exposed to periglacial conditions; the Brown Bank Formation (110,000 to 70,000 BP) was deposited during the marine regression at the onset of this glacial stage which reached its maximum approximately 18,000 BP. It comprises more fluviatile current-bedded silt and finely laminated clays filling late Ipswichian/ early Devensian channels, up to 20m deep (BGS, 1991). During the deposition of the Brown Bank Formation, humans are not thought to have been present in Britain with human occupation again reported from 60,000 BP (until 22,000 BP).

3.3.6. No sediments of mid- or late Devensian origin are documented from secondary sources in Area 240, although some scattered periglacial sediments have been reported further east. Furthermore, possible Devensian sediments have been identified from boreholes onshore as the floor of a buried river valley although the age of the sediments is not known and are estimated to be Devensian to early Holocene with suggested maximum age of late Anglian/Wolstonian/late Hoxnian date. Gravel deposits found in Area 254 to the north of Area 240 have also been interpreted as fluvial sediments dating to the Wolstonian Glacial (Wessex Archaeology 2008).

3.3.7. Inundation of Area 240 occurred approximately 7,500 to 8,000 BP after the retreat of the Devensian ice sheet. Present-day onshore, a formation representing a buried river valley is recorded which consists mainly of silt and clay and also comprises several peat layers of which the basal peat layer is possibly associated with Area 240. This is described as having formed between 7580 +/- 90 BP and is found at a depth of approximately 23m OD with a thickness of 2m. This formation is thought to extend offshore, to the north-west of Area 240.

3.3.8. Offshore East Anglia, Holocene marine sediments form a thin veneer of sediment overlaying older Pleistocene sediments. Within Area 240, seabed sediments comprise sandy gravel and most of the survey site is covered by mobile sand waves. The thickness of Holocene marine sediments comprising these sand waves is generally less than 5m, with sediments in most parts thinner than 1m in between the sandwaves (BGS, 1988).

3.4. RESULTS OF THE EXISTING DATA REVIEW

3.4.1. The Existing Data Review (Wessex Archaeology 2009) identified eight geological units in Area 240 based on their seismic characteristics. Only five of these are present in the proposed 2009 3 km x 1 km survey area (**Units 1**, **2**, **4**, **6** and **8**). **Units 5** and **7** are observed on the tie-in lines and the small area surveyed in the north-west corner of Area 240. The character of these sediment units is described below.

3.4.2. **Unit 1** is the deepest unit observed and present throughout Area 240. This unit has been interpreted as the Westkapelle Ground Formation and comprises a series of faint, sub-parallel reflectors although pro-grading or dipping reflectors are also observed.

3.4.3. **Unit 2** overlies **Unit 1** and has been interpreted as the Yarmouth Roads Formation. Its seismic characteristics are described as varying between acoustically transparent with occasional faint reflectors to faintly dipping reflectors. It is present across the 3 km x 1 km survey site where it is thought to comprise silty, gravely, fine to coarse sands (Wessex Archaeology 2009). It is known to comprise a complex delta-top sequence forming part of the Ur-Frisia delta plain, consisting of sands with pebbles (including chalk), abundant plant debris and peat clasts (Cameron *et al*. 1992).

3.4.4. **Unit 3** was interpreted as possible Yarmouth Roads Formation exhibiting a different seismic character to **Unit 2**. **Unit 3** was not observed within the 3 km x 1 km survey area or on the tie-in lines and the area to the north-west of Area 240.

3.4.5. In the 3 km x 1 km survey area, **Unit 4** directly overlies **Unit 2** and generally consists of sands and gravels. This unit is seismically complex and its base is not always well defined indicating a gradual change in sediments between **Units 2** and **4**. Within the 3 km x 1 km survey area, **Unit 4** has been divided into **Unit 4** and **4a**; **Unit 4** is marked by a strong basal reflector whereas the basal reflector of **Unit 4a** is more diffuse. Where the signature is diffuse, it is not possible to establish whether the basal reflector is indistinct due to gradual changes in sediment or whether the unit is not present and the underlying **Unit 2** crops out directly below **Unit 8**. The unit shows chaotic seismic characteristics with subtle changes in seismic characteristics which indicate different depositional environments. **Unit 4** comprises sands and gravels and it is suggested that it could form part of the fluviatile Brown Bank Formation (Wessex Archaeology 2009).

3.4.6. **Unit 6** is found in patches with the 3 km x 1 km survey area, exhibits transparent seismic characteristics indicative of finer sediments and is found to infill small depressions. Based on the vibrocore data, the unit comprises slightly gravelly, slightly silty fine to medium sands with clays (Wessex Archaeology 2009). There is some indication for deposition of this unit in a tidal estuarine or near coastal environment.

3.4.7. **Units 5** and **7** are interpreted as channel infill deposits. **Unit 5** is a fine-grained fill deposit associated with a channel cut into **Unit 2** orientated northwest to southeast. Whereas **Unit 7** is the fill of a younger shallow channel observed in the northwest corner of Area 240 orientated north to south. Vibrocores indicate **Unit 7** comprises clays and peat layers. **Units 5** and **7** are not observed within the 3 km x 1 km survey area. However, **Unit 7** is expected to be present on the southeast to northwest orientated tie-in line and **Unit 5** is expected in the northwest corner of Area 240.

3.4.8. **Unit 8** is the uppermost unit present and is observed across the entire site in the form of a lag deposit or forming sand ripples and sand waves. Vibrocores indicate that the lag deposit comprises shelly, gravelly, medium to coarse sand and the bedforms comprise shelly well-sorted sand.

4. RESULTS OF THE 2009 SURVEY

4.1. INTRODUCTION

4.1.1. This section describes the results of the interpretation of the bathymetry, sidescan sonar, magnetometer and sub-bottom profiler datasets acquired during the 2009 survey and includes a comparison between the 2005 and 2009 bathymetric and seismic datasets.

4.1.2. For reasons of consistency, units have been labelled in accordance with the Existing Data Review (Wessex Archaeology 2009). A gazetteer that lists all sub-bottom features that have been identified (7000 numbers) is found in **Appendix I**.

4.2. SEABED SEDIMENTS AND BED FORMS

4.2.1. According to the BGS (1988), the seabed sediments in Area 240 and the 3 km x 1 km survey site comprise sandy gravel and the seabed sediments recovered by vibrocores within the survey site consist of sand.

4.2.2. Generally, the seabed in the 3 km x 1 km survey site slopes from west to east and water depth varies between 21.5m below OD at the crests of sand waves and approximately 36m below OD to the east of the site. Most of the site is covered by large sand waves trending east-west up to 6m high. Only the south and south-east regions of the area are not covered by these bed forms. Here, lag deposits are found.

4.2.3. Current regimes in the area are very strong and the comparison of the 2005 and the 2009 bathymetry shows that bed forms have moved significantly, generally by more than 10m, and also changed shape, particularly with regards to curvature and bifurcations. A detailed comparison between the datasets is difficult because of the different bin sizes (2m for the 2005 multibeam dataset and 8m for the 2009 single-beam dataset), but the general trend of highly mobile sediments with quickly shifting bed forms is evident. The bathymetric datasets are displayed in **Figure 6**.

4.2.4. The effects of dredging show as areas of greater depth in the east and south-east of the site, which are also coincident with smaller sand waves than those appearing further to the west. However, dredging is likely to have been more extensive (Wessex Archaeology 2009); this could be due to small amounts of dredging, movement of bed forms and the fact that the kind of dredging used in Area 240 generally does not leave pronounced dredge scars.

4.2.5. Thus, it is difficult to estimate the amount of dredging activity that has taken place between 2005 and 2009. Spot checks in areas without sand waves have shown on average 1.0 to 1.5 m difference in depths between 2005 and 2009 indicating removal of large amounts of sands and gravels in parts of the site within that time period.

4.2.6. Large sand waves, dredging scars and the wreck of the *Tregantle* are visible on the sidescan sonar mosaic, see **Figure 7**. The dredging scars are all orientated north - south and are mainly found in the central, northern section of the 3km x 1km survey area, outside of the Exclusion Zone established by HAML in 2008. These dredging scars are likely to be from relatively recent dredging activity.

4.2.7. The dredging scars seen within the Exclusion Zone are less coherent as they have been partially filled by recent sediment movement across the area.

4.2.8. **Figure 8** displays the variation in magnetic field strength in the survey area, clipped at ±20nT. The wreck of the *Tregantle* is found as a pronounced magnetic anomaly on the data – the large amplitude of the anomaly is due to the size of the wreck and the fact that is not covered by sediments. This anomaly masks smaller anomalies / background field strength in the vicinity of the wreck where interpretation is not possible. North of the wreck, several low amplitude north-west south-east trending stripes can be observed on the data. These are thought to be geological in origin but no obvious source has been identified from either sidescan sonar of sub-bottom profiler datasets.

4.2.9. Numerous small magnetic anomalies are seen in the area around the wreck which have been interpreted as ferrous object likely to be of modern origin. No anomalies were identified from the sidescan sonar dataset at these locations, therefore the objects causing these magnetic anomalies are presumed to be buried.

4.2.10. The sidescan sonar and magnetic data sets confirmed the absence of any modern obstructions lying on the seafloor with the exception of the wreck of the *Tregantle* meaning that there were no regions of the 3km x 1km which had to be excluded from consideration for the geotechnical investigations to be conducted as stage 3 of this project.

4.3. GEOLOGY AND SMALL-SCALE FEATURES

4.3.1. The Westkapelle Ground Formation (**Unit 1, 7070**) is the oldest formation imaged on the boomer dataset and forms the geological base of the 2009 dataset. It slopes downwards from west to east with depths ranging from approximately 36 m OD (at 9.5 m below seabed) in the west to 42 m OD (at 15.7 m below seabed) in the east. On the seismic profiles, it exhibits a strong, mostly straight top and comprises parallel or dipping strong reflectors (**Figures 9**, **10** and **11**). The unit has very distinct characteristics and can be easily distinguished from the overlaying Yarmouth Roads Formation (**Unit 2**).

4.3.2. The seismic characteristics for **Unit 1** are similar in both the 2005 and 2009 datasets; comparison with the 2005 dataset in Fledermaus shows excellent correlation for this unit in the survey area with generally less than 0.5 m difference between the datasets.

4.3.3. The Yarmouth Roads Formation (**Unit 2, 7060**) overlies the Westkapelle Ground Formation (**Unit 1, 7070**) and is present across the site. On sub-bottom profiles it is mainly structureless with some internal dipping layers or comprised of a series of faint reflectors (**Figures 9**, **10** and **11**); although its base is well defined, the top of the unit is sometimes difficult to determine as it is overlain by sediments (**Unit 4**) with similar seismic properties and this transition is not always well defined on the boomer data. Where it has been mapped, it is found at an average depth of 5 m below the surface.

4.3.4. Within **Unit 2**, a channel feature **(7044)** has been identified on a single boomer line; however, this channel is observed greater than 5 m sub-seabed.. **Figure 12** shows the distribution of the Yarmouth Roads Formation across the site, and highlights the areas (based on the 2005 and 2009 datasets) where the unit subcrops beneath the surficial sediment (**Unit 8**).

4.3.5. The 3 km x 1 km dataset only resolves the top of **Unit 2** in a small part of the survey area where it shows good correlation with the 2005 dataset (generally less than 1.0 m difference), where it is clearly overlain by the overlying **Unit 4** (**Figure 13**). However, in areas where the top is not defined, it cannot be determined whether **Unit 2** extends to the surface or is overlain by **Unit 4**. Thus, for purposes of interpretation, the results of the 2005 dataset have been combined with the 2009 interpretation to determine where the top of the Yarmouth Roads Formation reaches the surface.

4.3.6. The Yarmouth Road Formation (**Unit 2**) is overlain by **Unit 4** (**Figure 13**). As described above, the difference in seismic characteristic between Units 2 and 4 can be subtle and is not always well defined. Where it is obvious, it has been divided into two sub-units, **Units 4d** and **4e**. **Unit 4d (7050)** comprises sands and gravels of similar acoustic properties to **Unit 2** (mainly structureless and transparent); its basal reflector is formed by the top of **Unit 2** (**Figure 9**). **Unit 4e (7051)** is observed as a unit of stronger reflectors on the sub-bottom profiles with some internal structure or even occasional layering (**Figure 10** and **11**) and a well defined base and has been mapped across almost half of the survey area (**Figure 13**). The top of this unit is always found at the surface, where it outcrops below **Unit 8**, except where the cut and fills of Unit 6 are observed (**Figures 10** and **11)**. The difference in acoustic properties of **Units 4d** and **4e** suggests formation in different depositional environments. **Unit 4** forms a general north-west south-east trend with average depths of 5 m sub-seabed in the centre of the area and maximum depth of more than 12 m sub-seabed in the north of the survey area. This unit is thought to form part of the fluviatile Brown Bank Formation.

4.3.7. As outlined above, the base of **Unit 4d** (top of **Unit 2**) shows good correlation with the 2005 dataset. The base of **Unit 4e** has been less extensively picked in comparison to the 2005 dataset, but comparison of depth values shows good correlation with a deviation of less than 1.5 m for most of the site; where discrepancies do occur it is likely caused by a difference in interpretation and a more resolute interpretation due to the increased line spacing and number of sources used in the 2009 dataset.. Interestingly, seismically **Unit 4e** and **Unit 4** (in the 2005 and 2009 datasets) show different seismic characteristics, although **Unit 4d** and **Unit 4** show similar characteristics.

4.3.8. **Unit 6** is observed within **Units 2** and **4** as pockets across the site and consists of cuts and fills and some more erosional features mostly at or near the surface. Its seismic characteristics are variable and is has been divided in two sub-units, **Unit 6a** and **6b**. **Unit 6a (7000 - 7041)** is dominated by small, very shallow cuts and fills and some erosional surfaces; this unit shows similar properties to the surrounding sediments, with occasional more transparent fills, and reaches depths of up to 3 m sub-seabed (**Figures 9** and **10**). **Unit 6b (7042, 7043** and **7045)** exhibits a more transparent seismic character and reaches depths of up to 5 m sub-seabed; it is thought to comprise finer sediments than **Unit 6a** (**Figure 11**). The differences between **Unit 6a** and **6b** are possibly due to formation in slightly different depositional environments, but could also be due to how the fills are imaged in different survey directions and by different instruments.

4.3.9. **Figure 14** shows the extent of **Units 6a** and **6b** on the 2005 and 2009 dataset, respectively. Some lateral correlation can be observed, although the unit is mapped more extensively in the south and centre of the site for the 2005 dataset;. Discrepancies between these units could be due to the affect of dredging the upper sediments between 2005 and 2009; the higher resolution of the 2005 dataset in imaging this unit or that the 2009 dataset is interpreting the unit on a finer scale interpreting the data over 10m line spacing as oppose to 100m in the 2005 dataset. For the 2009 dataset, several additional smaller pockets of this unit has been identified, especially in the north-east of the 3 x 1 km survey area; this is thought to be due to higher lateral resolution due to tighter line spacing and the use of additional datasets from high-frequency sub-bottom profilers. Comparison of depth values shows some discrepancies which are probably due to differences in resolution and interpretation.

4.3.10. **Unit 8** consists of Holocene sediments which cover the site, either as mobile sediments or lag deposits, and form the uppermost unit at the site (**Figures 9**, **10** and **11**).

4.3.11. Along the length of the tie-in lines and throughout the small area surveyed in the north-west corner of Area 240 **Units 1** and **2** were observed (**7071** to **7076**). To the west, the top of **Unit 1**/base of **Unit 2** is observed within one metre of the seabed deepening to the east to a maximum of 13.7m sub-seabed (**7073**).

4.3.12. **Unit 4** is observed along the southern tie-in line (**7083**), the northern tie-in line (**Figure 15**, **7082**) and in the north-west survey area (**7077 – 7081**). The distribution and base of the unit correlates with the 2005 dataset.

4.3.13. **Unit 5** (**7084** and **7085**) and **Unit 7 (7086** and **7087)** are observed in the north-west corner and the northern tie-in line; these units were not observed in the main 2009 survey area (**Figure 15**). **Unit 7** is observed as a strong reflector within two metres of the seabed and is seen clearly on the boomer and parametric sonar data (**Figure 15**). **Unit 5** is observed as a small cut and fill feature with a seismically transparent fill unit up to 4m thick. Both **Unit 5** and **7** correlate well with the 2005 dataset.

4.3.14. **Table 6** summarises the units interpreted from the *Stage 1: Existing Data Review* dataset and the 2009 survey.

2005 survey	2009 survey (hand axe area)	Interpretation
Unit 8	Unit 8	Holocene seabed sediments
Unit 7	Not recorded	Fine-grained sediments and peat deposits
Unit 6	Unit 6	Estuarine fine-grained sediments
Unit 5	Not recorded	Fine-grained sediments (estuarine/freshwater) (Brown Bank Formation)
Unit 4	Unit 4	Sands and gravels (?Brown Bank Formation)
Unit 3	Not recorded	?Deltaic fine-grained sediments (Yarmouth Roads Formation)
Unit 2	Unit 2	Shallow marine sands and gravels (Yarmouth Roads Formation)
Unit 1	Unit 1	Open marine clays and sands (Westkapelle Ground Formation)

Table 6: Comparison of sediment units identified in the 3 x 1 km hand axe area in the 2005 and 2009 survey datasets

4.4. COMPARISON OF THE 2005 AND 2009 BOOMER DATASETS

4.4.1. Comparison between the dataset used in the Existing Data Review and the 2009 geophysical dataset shows some differences, especially in the shallow sub-surface data.

4.4.2. This variability in interpretation can be attributed to the line spacing used, number of sources used, and dredging activity between 2005 and 2009. Differences in data quality is thought to be mainly due to more favourable weather conditions during the 2005 survey and possibly to a minor extent to the use of different instruments.. These factors are discussed in a bit more detail below.

4.4.3. The 2009 survey was conducted at much narrower line spacing and the data coverage and density are higher in this dataset than in 2005. This is highlighted particularly in the interpretation of **Unit 6** (**Figure 14**), where interpretation over 100m line-spacing (2005 dataset) may over interpret the data, whereas the denser line-spacing of the 2009 dataset results in a more accurate, resolute interpretation.

4.4.4. Between 2005 and 2009, dredging activity in the 2009 survey area has taken place in 2005, 2006 and 2007 and affected most of the area apart from its western part.

Dredging ceased in 2008 with the creation of the exclusion zone, see **Figure 1**. Dredging generally complicates the interpretation of the geophysical data as it affects the sediments close to the surface by removing or modifying existing features, but also affecting the imaging of underlying sediments due to scattering of seismic energy at the disturbed surface. As it is not possible to estimate exactly which parts of the survey site within Area 240 have been affected by dredging since 2005, direct comparison of shallow sub-bottom features is challenging and integration of the datasets is not always possible.

4.4.5. Further differences in interpretation are thought to be due to mobile sediments; sand waves in the area can reach heights of up to 6m and cause a decrease in penetration and scattering of the seismic signal, particularly in the chirp and pinger datasets.

4.4.6. Differences in data quality were primarily due to weather conditions. Conditions during the 2009 boomer survey were variable and ranged from wind force 1-2 to 3-4 with sea states varying between smooth to moderate. In contrast, the 2005 survey was carried out in extremely favourable weather conditions.

4.4.7. The 2005 boomer data were acquired using an EG&G 230 surface tow system and the plate was powered at 200 Joule at a rate of 375ms (2.7 Hz); the 2009 boomer data were acquired using a Applied Acoustics Model AA200 Seismic Source and the plate was powered at 100 Joule at 3 Hz. This means that lateral resolution is almost identical; also, power output of the seismic source does generally only affect penetration (which was very good for both datasets), not resolution. However, minor differences in data quality due to the different systems used are conceivable.

4.5. CHRONOLOGY AND IMPLICATIONS

4.5.1. **Unit 1** (Westkapelle Ground Formation) is of Late Pliocene / Early Pleistocene age; this unit is overlain by **Unit 2** (Yarmouth Roads Formation) in the entire 3 km x 1 km survey area. Dating of **Unit 2** is thought to either belong to the Cromerian Complex around 700,000 BP or to be older. The base of **Unit 4** represents a channel cut into the Yarmouth Roads Formation and is thought to have formed during the Late Anglian (478,000 BP) at the earliest, but at least some of the channel fill deposits are thought to be Late Devensian. It is not possibly to estimate the age of **Unit 6**, only that it is of the same age or younger than **Unit 4**.

4.5.2. Based on the appearance of the hand axe and associated finds, the most likely provenance of the hand axes recovered in Area 240 are **Units 4** and **6** which are interpreted as Mid to Late Devensian age, although **Unit 4** could be older than this. This is discussed in further detail in the *Stage 1 Review of existing data* report (Wessex Archaeeology 2009).

4.5.3. The heavily fossilised bones (older than 500,000 BP) are likely to have been found within **Unit 2**; it subcrops surficial sediments in the east and north of the 2009 survey area.

4.5.4. The younger bones recovered within the survey site are interpreted as having been dredged from **Unit 4**; this unit could also have yielded the mammoth bones found in the area.

4.5.5. The piece of worked flint found at CG6 clamshell grab location during the EC REC seabed sampling survey was found within a lag deposit (the geophysical surveys indicate that no sand waves were present at the grab sample location).

4.5.6. Based on the 2005 data the flint was thought to have been retrieved from the upper lag (seabed sand and gravel layer) **Unit 8** or associated with the underlying **Unit 6** deposits, but it was thought unlikely that the clamshell grab would have penetrated the 1.4m of surficial sediments to reach this unit.

4.5.7. Comparison of the 2005 and 2009 bathymetric datasets show that no dredging has taken place at CG6 in that time period, and no dredging scars are visible on the 2005 bathymetry dataset. As the area had been dredged extensively before 2005, it follows that the worked flint derives from sediments older than **Unit 8**. In the 2005 dataset **Unit 8** is underlain by **Unit 4**; also, a shallow cut and fill (**Unit 6**) is present nearby, but is not observed as extensively as in the 2005 dataset. As such, the 2009 data indicate that the flint could be associated with the sands and gravels of **Unit 4**, if **Unit 4** is observed within the top metre of the seabed. .

4.6. PROPOSED TRANSECTS FOR PROJECT STAGE 3

4.6.1. Based on the results of the geophysics interpretation a series of transects are proposed for Stage 3 of the project: seabed sampling. Two phases are proposed; phase 1 being priority. The transects have been selected in order to sample the units interpreted as likely to contain flint artefacts and faunal remains (**Units 2**, **4** and **6**).

4.6.2. Initially, the sediment types subcropping the surficial sediments (**Unit 8**) were mapped (**Figure 16**). The sidescan sonar, sub-bottom profiler and bathymetric data were then assessed to ensure that the transects are situated in areas where the surficial sediments were at a minimum, thereby increasing the chances of sampling the sediment unit of interest. **Figure 17** illustrates the subcropping sediments, overlain by the position of the sandwaves and the proposed transect locations.

4.6.3. The proposed transects are detailed in **Table 6** and are illustrated in **Figures 16** and **17**. Transect 1 to 4 are phase 1; 5 to 7 are phase 2.

Transect	Sediment unit targeted
1	Brown Bank Formation (**Unit 4e**) at CG6
2	Brown Bank Formation (**Unit 4** (undifferentiated) and **4d**) and shallow cut and fill **(Unit 6a)**
3	Yarmouth Roads Formation (**Unit 2**)
4	Brown Bank Formation (**Unit 4e**) and shallow cut and fill **(Unit 6a)**
5	Shallow cut and fill (**Unit 6b**) / Brown Bank Formation (**Unit 4e**) at CG6
6	Shallow cut and fill (**Unit 6a**) and cut and fill with some semi-transparent infill (**Unit 6b**) within **Unit 4e**
7	Shallow cut and fill (**Unit 6b**) and Brown Bank Formation (**Unit 4e**)

Table 7: Proposed transects for project stage 3

4.6.4. Transect 1 is purposefully targeting the location where the CG6 (ECREC) flint was found. Transect 2 crosses shallow cuts and fills of **Unit 6a** within the Brown Bank Formation (**Unit 4**) and is illustrated in **Figure 18**. Transects 3 targets the older sediments of **Unit 2** where they subcrop the surfical sediment and is located in an area that has been subject to past dredging. Transects 4 to 7 focus on targeting **Units 4** and **6**.

4.6.5. Although, sediment units of interest are situated in the central portion of the survey area, the sandwave and Holocene sand cover are considered too thick to sample. Based on the data, the southern area is considered the most likely area to yield results, particularly in light of the CG6 (EC REC) grab sample. Hence, three of the four phase 1 transects are located in this area.

5. DISCUSSION OF SOURCES

5.1.1. As expected, the boomer achieved the highest penetration of all sub-bottom profilers with penetration to the multiple for the entire dataset and also showed good horizontal resolution; both penetration and resolution were sufficiently high to identify larger geological units, such as tops and bases of formations, as well as small-scale features such as bases of sand waves, shallow cuts and fills and erosional features (**Figures 9 – 11**, and **15**).

5.1.2. The pinger uses a comparatively high frequency and was thus not expected to perform as well as the boomer in gravelly sediments such as those encountered in the 3 x 1 km survey area. These sediments prevented penetration further than to a maximum of 6 m and caused pronounced ringing in the data obscuring any small scale features such as cuts and fills and erosional surfaces. Interpretation is further complicated by the diffraction of the seismic energy by small sand ripples which are present over most of the site (**Figures 9** and **10**). Furthermore, the large footprint caused the imaging of sand wave crests on cross lines (which were run parallel to the sand waves) thus rendering cross lines almost unusable. Although the data were strongly affected by the effects of the surface sediments and the large footprint, the bases of sand waves, and sediment structure was observed in the upper sediments (**Figures 9**, **10** and **11**) were imaged. To the northwest (on the northern tie-in line sediment units were particularly well defined (**Figure 15**). Although, not useful as a sole source for interpretation, the pinger, was used as a supplemental interpretation tool.

5.1.3. The parametric sonar also uses comparatively high frequencies for sub-bottom profiling, but is in comparison to the pinger not affected by ringing, diffraction on ripples or imaging of sand wave crests on cross lines. This is mainly due to the very small footprint and the low pulse width which prevents reverberation. Thus, the parametric sonar shows a similar to better penetration than the pinger at a much higher resolution and images the thickness of Holocene sediments, the bases and internal layering of sand waves as well as resolving shallow cuts and fills and erosional features where penetration permits (**Figures 10** and **15**). The small footprint on the one hand prevents the imaging of features off the side of the survey line, but on the other hand only features directly below the instrument are imaged. Furthermore, the high ping rate leads to extremely high lateral resolution, even in strong tidal regimes; also, it is only to a comparatively small amount affected by bad weather as it is mounted on a pole and data quality was consistently high.

5.1.4. The chirp uses a sweep of comparatively high frequencies and is strongly affected by the nature of the sediments at the site. Penetration was lowest of all sub-bottom profilers used in the survey and resolution was much lower than expected. Similar to the pinger data, the base of sandwaves and faint reflectors were observed within the upper 4 m sub-seabed (**Figures 9**, **10** and **11**).

5.1.5. To summarise, the boomer dataset proved to be the most useful dataset for interpretation at this site. It showed good penetration and resolution which made it possible to identify geological formations at the surface as well as deeper down and their extent and distribution across the site. Thus, it was possible to determine which geological units are present at the surface; also, shallow features close to or at the surface were well resolved by the boomer. The parametric sonar was shown to resolve the thickness of Holocene sediments and shallow features at high vertical and horizontal resolution, but large sand waves were not penetrated and thus not all shallow features present have been imaged. Both pinger and chirp were strongly affected by the nature of the sediments (and bed forms) and were found to yield the least useful datasets for interpretation.

5.1.6. This highlights the strong effect geology has on the choice of sub-bottom profiler. The pinger proved useful in the previous Seabed Prehistory Project (Wessex Archaeology 2008) in Area 254 to the north of Area 240 where it helped confirm the presence of fine grained material (silts and clays) which was not as obvious in the boomer data. However, the same result has not been observed just a few kilometres away in the 2009 survey data in Area 240. This is likely due to sediment type. Fine-grained sediments identified in Area 254 were also identified to the north of the 2009 survey area in the 2005 dataset associated with a channel feature. Had pinger data been acquired over these sediments, it may have proved useful, however, the sediments identified in the 2009 survey area generally comprise sands (fine to coarse grained) and gravels. As such, the pinger is less useful in identifying these sediment types.

5.1.7. Also the chirp system which proved successful in Happisburgh and Pakefield (Wessex Archaeology 2008) has failed to reproduce its effectiveness due to the nature of the surface sediments. The parametric sonar, which has not previously been used by WA, .proved to be the most useful system for providing additional information for the interpretation of the boomer data, e.g. by resolving shallow features and the thickness of Holocene sediments. Therefore, as with Seabed Prehistory in Area 254 this project has proved the effectiveness of using more than one type of sub-bottom profiler on a site.

6. CONCLUSION AND RECOMMENDATIONS

6.1.1. Stage 2 of the project has been successful in acquiring, processing and interpreting a multitude of geophysical datasets; this has made it possible to map the current distribution of geological units outcropping beneath overlying Holocene sediments to a high lateral resolution and to estimate the thickness of Holocene sediments for the design of transects for project stage 3.

6.1.2. Within the 3 x 1 km survey area eight seismic units were identified and were divided into five sediment units (**Units 1**, **2**, **4**, **6** and **8**) comparable with the units identified in the 2005 dataset. Along the length of the northern tie-in line and the northwestern survey area, two further units (**Units 5** and **7**) were identified and correlated with the 2005 dataset.

6.1.3. Initial results of the dating of animal bones found with the hand axe artefacts indicate two distinct groups (Jan Glimmerveen pers. comm.). The majority of the bones are thought to be between 70,000 and 23,000 BP; the remainder are heavily fossilised and are though to be greater than 500,000 BP. The heavily fossilised bones are likely to be associated with **Units 1** and **2**, with the remainder associated with **Units 4** and **6**. Based on both the artefact appearance and the initial dating evidence it is possible that the artefacts may be associated with a range of sediments deposited in a range of environments (**Units 2**, **4** and **6**). Based on the results of the geophysical data interpretation a series of sampling transects were designed for Stage 3 of the project.

6.1.4. Seven transects have been proposed for this stage which will target the units identified as the most likely source of the hand axes and bones, and two have also been placed close to CG6 where a piece of worked flint was found very recently by the ECREC project.

6.1.5. The sediment units identified during the 2005 and 2009 datasets were comparable, but differences in interpretation were apparent. Although, the data quality of the 2005 dataset was better due to more favourable weather conditions during acquisition, the denser line spacing and use of multiple sources resulted in a more resolute interpretation from the 2009 datasets. This was particularly apparent in the interpretation of **Unit 6**, whereby the iunterpretation of the limits of the unit were more resolute indicating a more patchy coverage than the 2005 dataset would suggest. The more resolute interpretation is due to the increased line spacing. Additionally, the parametric sonar provides a more detailed view of the upper few metres than the 2005 boomer dataset, allowing a more detailed interpretation of structure within the uppermost sediment unit.

6.1.6. Sediments, weather conditions and current regimes within the survey area proved to be challenging for geophysical data acquisition; this particularly affected the high-frequency sub-bottom profilers of which only the parametric sonar dataset showed good results suitable for data interpretation on all lines and in all survey directions (where large sand waves were penetrated).

6.1.7. Also, the complexity of sediments within the area especially with regards to mapping faint and shallow reflectors calls for data of the highest possible quality and resolution. Comparison with the 2005 dataset showed that weather conditions during data acquisition play a crucial role. Therefore, although allowance was made for weather downtime in the survey design, it is not financially practical to wait for perfectly calm seas and so most datasets will experience some degradation due to even marginal weather conditions.

6.1.8. For future surveys of similar specifications, a combination of one high and one low-frequency profiler is recommended to provide information about shallow features (a combination of high and low-frequency data) within the wider geological context (low-frequency data). It is essential to consider the suitability of sub-bottom profilers to sediment properties as well as to the aims of the survey – for the identification of very localised, small-scale features a sub-bottom profiler with a small footprint is preferable whereas for more extensive features a larger footprint would be better suited.

6.1.9. If a combination of a high and low-frequency profiler is used, it might also be feasible to first survey at a widely spaced grid using the low-frequency profilers and then target features of interest with the high-frequency instrument at a tighter grid.

7. REFERENCES

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APPENDIX I: GAZETTEER

WA_ID 7000	Unit	Feature	Area / Length	Comment
7000	Unit 6a	Cut and fill	17.7 x10^3 m^2	Shallow cut and fill below sandbank/gravel bank. Found at 3.2 m depth. Fill slightly lighter than surrounding sediment and 2.6 m deep. Observed on three lines.
7001	Unit 6a	Cut and fill	18.6 x10^3 m^2	Shallow cut and fill below base of sand waves. Found at 1.9m depth. Fill slightly lighter than surrounding sediment and 3.2m deep. Observed on five lines.
7002	Unit 6a	Cut and fill	47.5 m	Shallow cut and fill below base of sand waves. Found at 1.2 m depth. Fill slightly lighter than surrounding sediment and 0.75 m deep. Observed on one line.
7003	Unit 6a	Cut and fill	46.6 m	Shallow cut and fill. Found at 0.8 m depth. Fill slightly lighter than surrounding sediment and 1 m deep. Observed on one line.
7004	Unit 6a	Cut and fill	54.5 m	Possible shallow cut and fill below base of sand waves. Found at 2.3 m depth. Fill slightly lighter than surrounding sediment and 1.9 m deep. Observed on one line.
7005	Unit 6a	Cut and fill	4.1 x10^3 m^2	Shallow cut and fill below base of sand waves. Found at 1.0 m depth within Brown Bank Formation. Fill slightly lighter than surrounding sediment and 2.2 m deep. Observed in two lines.
7006	Unit 6a	Cut and fill	45.3 m	Possible shallow cut and fill below base of sand waves. Found at 0.8 m depth. Fill slightly lighter than surrounding sediment and 1.7 m deep. Observed on one line.
7007	Unit 6a	Cut and fill	5.9 x10^3 m^2	Shallow cut and fill below base of sand waves. Found at 2.0 m depth. Fill similar to surrounding sediment and 2.5 m deep. Observed on three lines.
7008	Unit 6a	Cut and fill	41.97 x10^3 m^2	Shallow cut and fill below base of sand waves. Found at 2.0 m depth. Fill lighter than surrounding sediment and 3.1 m deep. Observed on 12 lines.

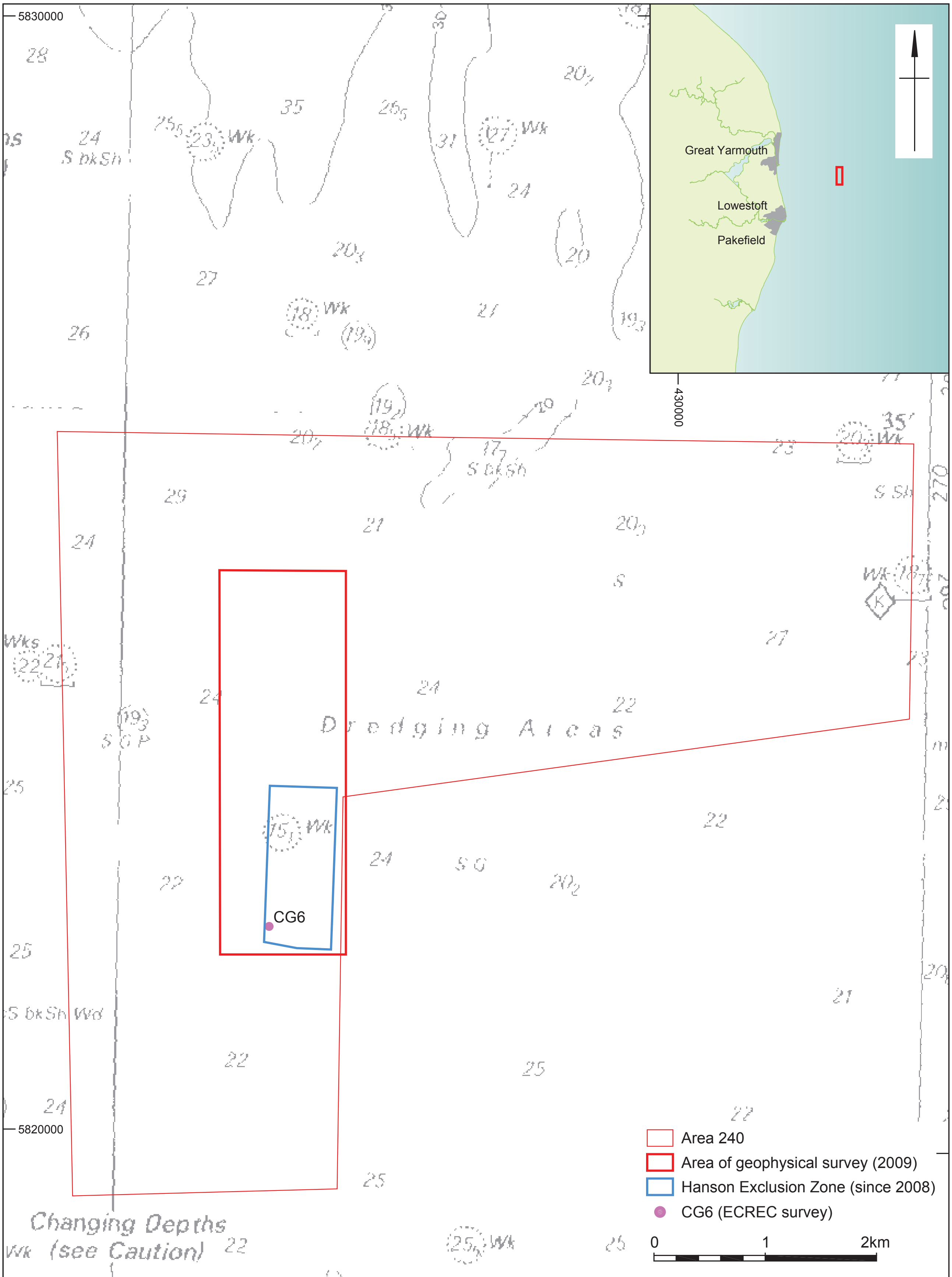
WA_ID 7000	Unit	Feature	Area / Length	Comment
7009	Unit 6a	Cut and fill	6.1×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 1.5 m depth. Fill similar to surrounding sediment and 1.2 m deep. Observed on three lines.
7010	Unit 6a	Cut and fill	41.8 m	Shallow cut and fill below base of sand waves. Found at 0.9 m depth. Fill similar to surrounding sediment and 2.5 m deep. Observed on one line.
7010a	Unit 6a	Cut and fill	5.2×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 0.5 m depth. Fill slightly lighter than surrounding sediment and 3 m deep. Observed on two lines
7011	Unit 6a	Cut and fill	40.9×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 2.0 m depth. Fill lighter than surrounding sediment and 3.0 m deep. Possibly associated with site 7045. Observed on five lines.
7012	Unit 6a	Cut and fill	24.0×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 1.9 m depth. Fill lighter than surrounding sediment and 2.5 m deep. Observed on seven lines.
7013	Unit 6b	Cut and fill	74.3 m	Shallow cut and fill below base of sand waves. Found at 2.0 m depth. Fill lighter than surrounding sediment and 1.6 m deep. Observed on one line.
7014	Unit 6a	Cut and fill	56.1×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 2.8 m depth. Fill lighter than surrounding sediment and 3.4 m deep. Observed on nine lines.
7015	Unit 6a	Cut and fill	20.9×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 2.7 m depth. Fill lighter than surrounding sediment and 3.7 m deep. Observed on four lines.
7016	Unit 6a	Erosional surface	9.2×10^3 m^2	Shallow cut and fill. Found at 1.0 m depth. Fill darker than surrounding sediment and 2.5 m deep. Observed on two lines.
7017	Unit 6a	Cut and fill	7.2×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 1.5 m depth. Fill lighter than surrounding sediment and 1.7 m deep. Observed on three lines.

WA_ID 7000	Unit	Feature	Area / Length	Comment
7018	Unit 6a	Cut and fill	17.96×10^3 m^2	Possible shallow cut and fill below base of sand waves. Found at 1.3 m depth. Fill lighter than surrounding sediment and 1.3 m deep. Observed on four lines.
7019	Unit 6a	Cut and fill	8.9×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 0.8 m depth. Fill similar to surrounding sediment and 2.4 m deep. Observed on two lines.
7020	Unit 6a	Cut and fill	6.3×10^3 m^2	Possible shallow cut and fill below base of sand waves. Found at 0.9 m depth. Fill similar to surrounding sediment and 3.3 m deep. Observed on three lines.
7021	Unit 6a	Cut and fill	89.8 m	Possible shallow cut and fill below base of sand waves. Found at 0.5 m depth. Fill similar to surrounding sediment and 1.7 m deep. Observed on one line.
7022	Unit 6a	Erosional surface	2.7×10^3 m^2	Erosional surface below base of sand waves. Found at 0.4 m depth. 3.2 m deep. Observed on four lines.
7023	Unit 6a	Cut and fill	56.2 m	Shallow cut and fill at surface. Fill similar to surrounding sediment and 2.1 m deep. Observed on one line.
7024	Unit 6a	Cut and fill	185.4×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 1.0 m depth. Fill similar to or slightly lighter than surrounding sediment with some layering and 4.0 m deep. Observed on 21 lines.
7025	Unit 6a	Erosional surface	74.9 m	Erosional surface at surface. 2.1 m deep. Found on one line.
7026	Unit 6a	Cut and fill	51.4 m	Shallow cut and fill below base of sand waves. Found at 1.4 m depth. Fill similar to surrounding sediment and 1.3 m deep. Observed on one line.
7027	Unit 6a	Cut and fill	80.2 m	Shallow cut and fill. Found at 0.8 m depth. Fill slightly darker than surrounding sediment and 1.3 m deep. Observed on one line.

WA_ID 7000	Unit	Feature	Area / Length	Comment
7028	Unit 6a	Cut and fill	92.7 m	Shallow cut and fill. Found at 0.8 m depth. Fill similar to surrounding sediment and 1.3 m deep. Observed on one line.
7029	Unit 6a	Erosional surface	12.1 $\times10^3$ m^2	Erosional surface close to surface. Found at 0.4 m depth. 2.9 m deep. Found on two lines.
7030	Unit 6a	Erosional surface	34.97 $\times10^3$ m^2	Erosional surface below base of sandwaves. Found at 1.0 m depth. 3.0 m deep. Observed on seven lines.
7031	Unit 6a	Erosional surface	46.9 m	Erosional surface at surface. 3.2 m deep. Found on one line.
7032	Unit 6a	Cut and fill	24.6 m	Shallow cut and fill. Found at 0.6 m depth. Fill lighter than surrounding sediment and 1.0 m deep. Observed on one line.
7033	Unit 6a	Cut and fill	44.9 m	Possible shallow cut and fill between sand waves. Found at 1.0 m depth. Fill similar to surrounding sediment and 1.0 m deep. Observed on one line.
7034	Unit 6a	Cut and fill	26.6 m	Shallow cut and fill close to surface. Found at 0.4 m depth. Fill lighter than surrounding sediment and 0.7 m deep. Observed on one line.
7035	Unit 6a	Cut and fill	41.6 m	Possible shallow cut and fill close to surface. Found at 0.4 m depth. Fill lighter than surrounding sediment and 1.0 m deep. Observed on one line.
7036	Unit 6a	Cut and fill	145.6 m	Shallow cut and fill at surface. Fill darker than surrounding sediment and 2.1 m deep. Found on one line.
7037	Unit 6a	Cut and fill	83.1 m	Shallow cut and fill at surface. Fill darker than surrounding sediment and 2.1 m deep. Found on one line.
7038	Unit 6a	Cut and fill	44.84 m	Shallow cut and fill close to surface. Found at 0.8 m depth. Fill layered and darker than surrounding sediment and 1.8 m deep. Observed on one line.
7039	Unit 6a	Cut and fill	18.5 m	Shallow cut and fill close to surface. Found at 1.0 m depth. Fill lighter than surrounding sediment and 1.0 m deep. Observed on one line.

WA_ID 7000	Unit	Feature	Area / Length	Comment
7040	Unit 6a	Cut and fill	40.9×10^3 m^2	Shallow cut and fill below base of sand waves. Found at 1.0 m depth. Fill slightly darker than surrounding sediment and 3.0 m deep. Observed on five lines.
7041	Unit 6a	Cut and fill	86.3 m	Possible shallow cut and fill close to surface. Found at 1.3 m depth. Fill lighter than surrounding sediment and 0.8 m deep. Found on one line. Observed on one line.
7042	Unit 6b	Cut and fill	90.1 m	Shallow cut and fill below surface. Found at 1.5 m depth. Fill lighter than surrounding sediment and 2.3 m deep. Found on one line. Observed on one line.
7043	Unit 6b	Cut and fill	433.1 m	Shallow cut and fill below surface. Found at 2.7 m depth. Fill lighter than surrounding sediment and 3.9 m deep. Observed on one line.
7044	Unit 2	Cut and fill	187.6 m	Cut and fill close to surface within Yarmouth Roads Formation. Found at 5.5 m depth. Fill layered and darker than surrounding sediment and 4.5 m deep. Found on one line.
7045	Unit 6b	Cut and fill	48.3×10^3 m^2	Shallow cut and fill close to surface below sand waves. Found at 0.5 m depth. Fill lighter than surrounding sediment and 4.5 m deep. Observed on five lines.
7050	Unit 4d	Formation	See Figure 13	Brown Bank Formation with well defined base
7051	Unit 4e	Formation	See Figure 13	Brown Bank Formation with diffuse base
7060	Unit 2	Formation	See Figure 12	Yarmouth Roads Formation
7070	Unit 1	Formation	Covers entire site	Westkapelle Ground Formation
7071	Unit 1	Formation	$269 \times 10^3 m^2$	Westkapelle Ground Formation in area to the northwest corner of Area 240. Top of the Unit is observed between 2.2 and 8.5m sub-seabed.
7072	Unit 1	Formation	1890 m	Westkapelle Ground Formation along the northern tie-in line. Top of the Unit is observed between 2.4 and 11.0m sub-seabed.
7073	Unit 1	Formation	3906 m	Westkapelle Ground Formation along the southern tie-in line. Top of the Unit is observed between 0.8 and 13.7m sub-seabed.
7074	Unit 2	Formation	$269 \times 10^3 m^2$	Yarmouth Roads Formation in area to the northwest corner of Area 240. Base of the Unit is observed between 2.2 and 8.5m sub-seabed.
7075	Unit 2	Formation	1890 m	Yarmouth Roads Formation along the northern tie-in line. Base of the Unit is observed

WA_ID 7000	Unit	Feature	Area / Length	Comment
				between 2.4 and 11.0m sub-seabed.
7076	Unit 2	Formation	3906 m	Yarmouth Roads Formation along the southern tie-in line. Base of the Unit is observed between 0.8 and 13.7m sub-seabed.
7077	Unit 4	Formation	$195 \times 10^3 m^2$	Brown Bank Formation with well defined base in north-west corner of Area 240/254. Base of unit between 1.1 and 8.2m sub-seabed
7078	Unit 4	Formation	77 m	Brown Bank Formation with well defined base in north-west corner of Area 240/254. Base of unit between 1.5 and 5.8m sub-seabed
7079	Unit 4	Formation	190 m	Brown Bank Formation with well defined base in north-west corner of Area 240/254. Base of unit between 1.2 and 3.3m sub-seabed
7080	Unit 4	Formation	187 m	Brown Bank Formation with well defined base in north-west corner of Area 240/254. Base of unit between 1.5 and 4.1m sub-seabed
7081	Unit 4	Formation	2183 m	Brown Bank Formation with well defined base in north-west corner of Area 240/254. Base of unit between 1.5 and 4.1m sub-seabed
7082	Unit 4	Formation	215 m	Brown Bank Formation with well defined base along northern tie-in line. Base of unit between 1.9 and 6.3m sub-seabed
7083	Unit 4	Formation	1058 m	Brown Bank Formation with well defined base along southern tie-in line. Base of unit between 1.6 and 13.7m sub-seabed
7084	Unit 5	Cut and fill	$22.7 \times 10^3 m^2$	Cut and fill feature with transparent fill in the northwestern corner of Area 240. Base of cut between 1.1 and 3.6m sub-seabed
7085	Unit 5	Cut and fill	$36.5 \times 10^3 m^2$	Cut and fill feature with transparent fill in the northwestern corner of Area 240. Base of cut between 0.8 and 3.9m sub-seabed
7086	Unit 7	Cut and fill	117 m	Shallow cut and fill feature with strong reflectors on northern tie-in line. Base of cut between 0.8 and 3.4m sub-seabed
7087	Unit 7	Cut and fill	361 m	Shallow cut and fill feature with strong reflectors on northern tie-in line. Base of cut between 0.7 and 2.8m sub-seabed



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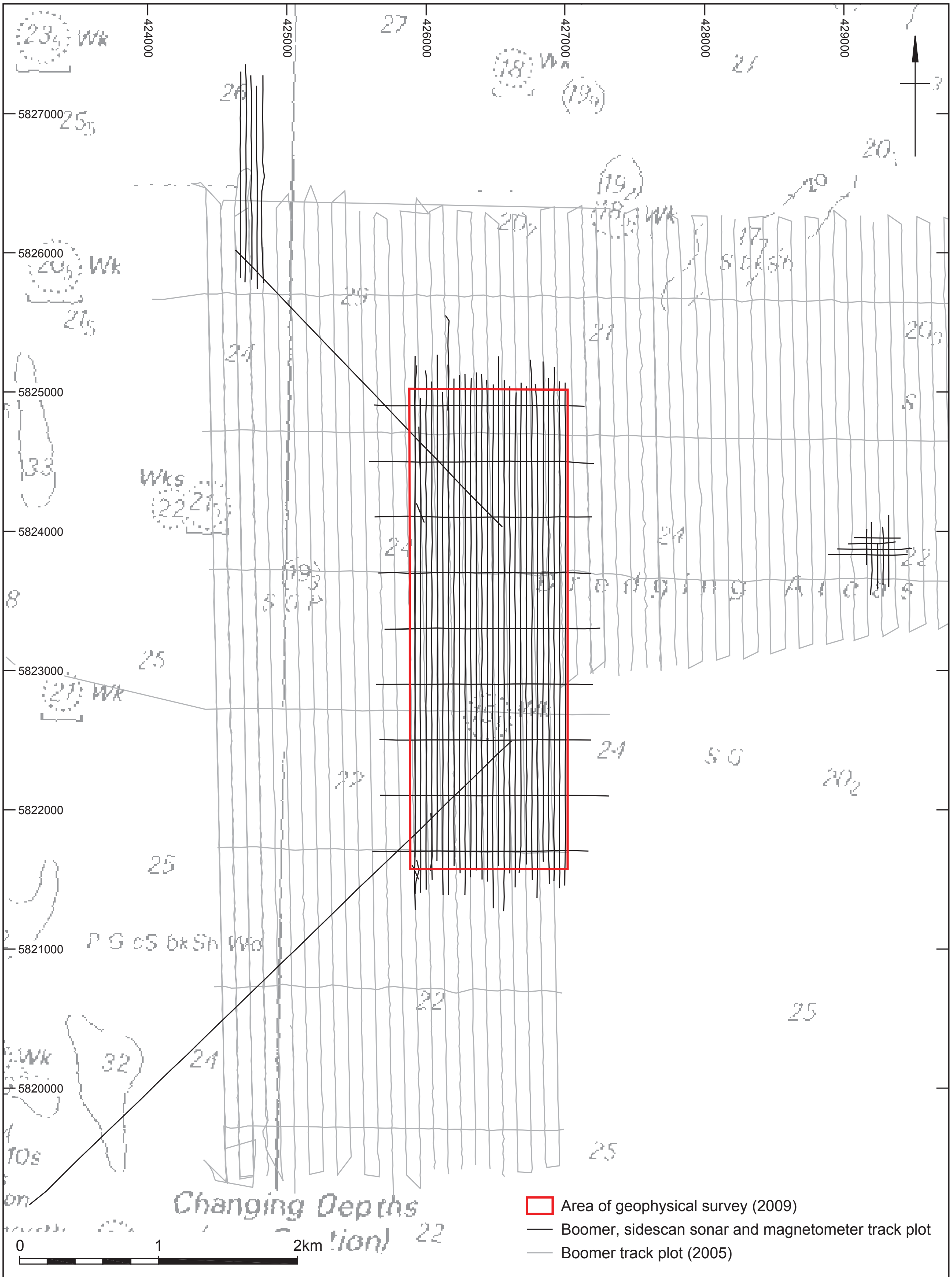
2009 survey area within Area 240

Figure 1



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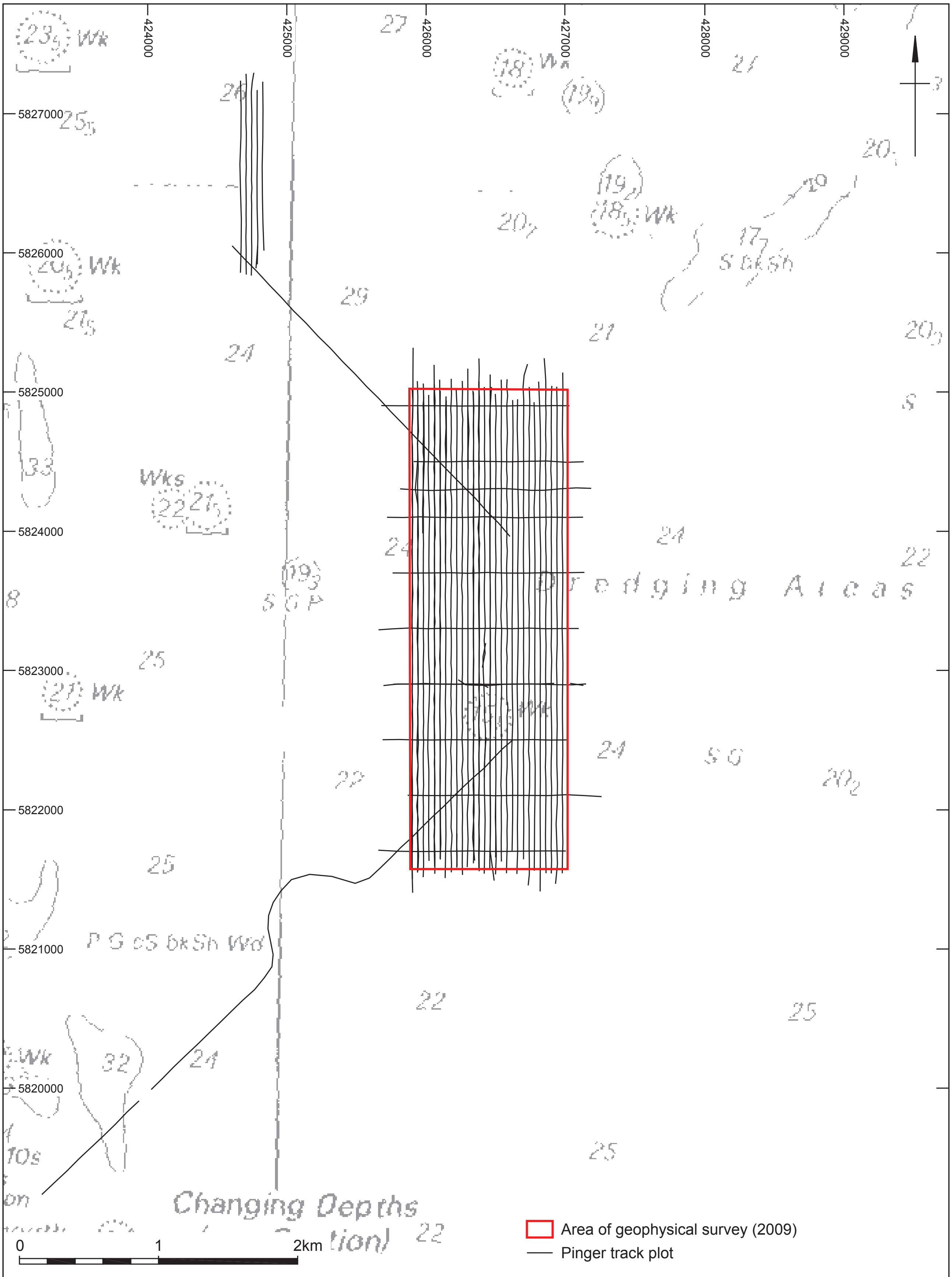
Boomer, sidescan sonar and magnetometer track plot

Figure 2



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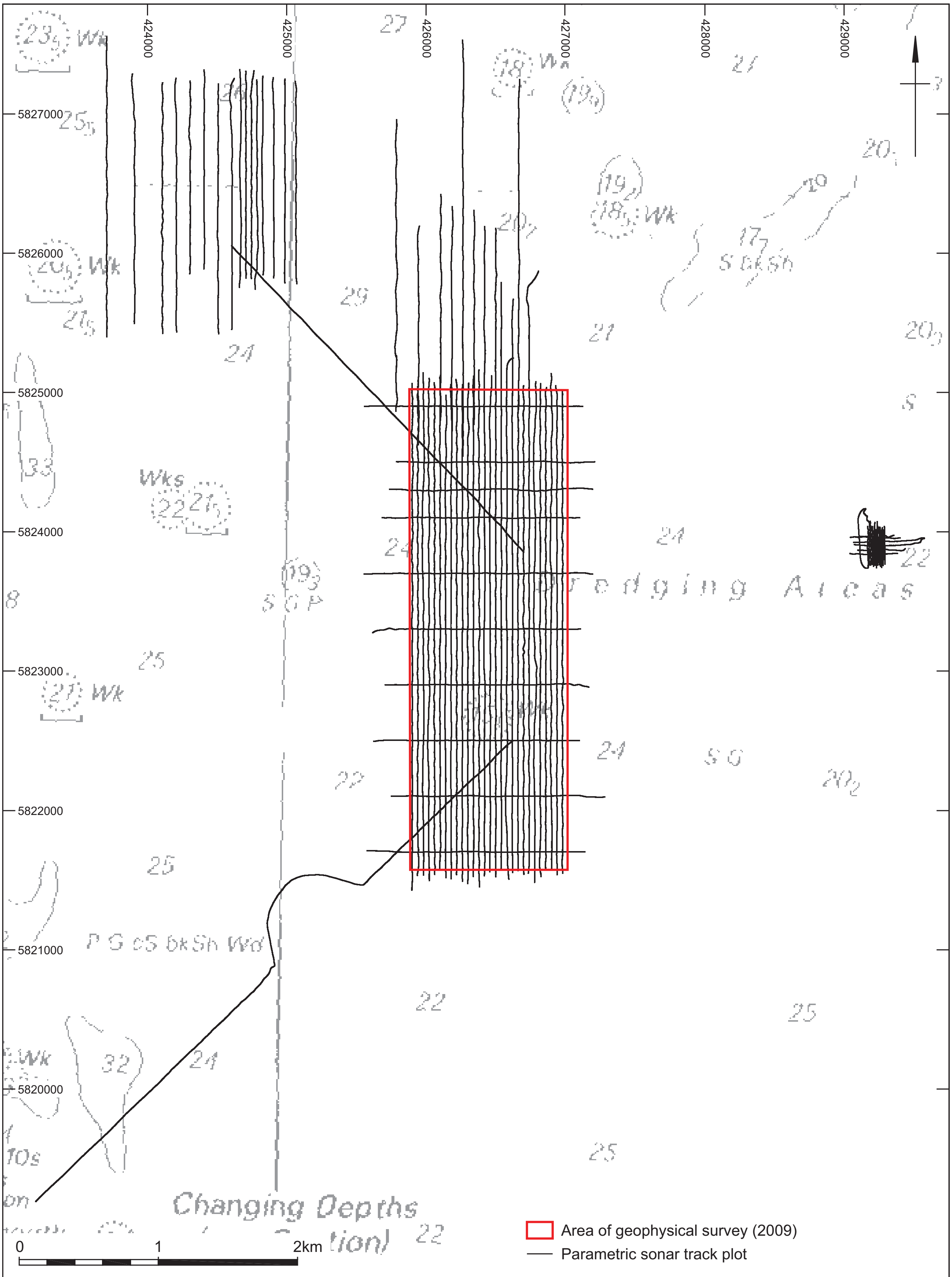
Pinger track plot

Figure 3



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Admiralty Chart 1543 (dated 2000).

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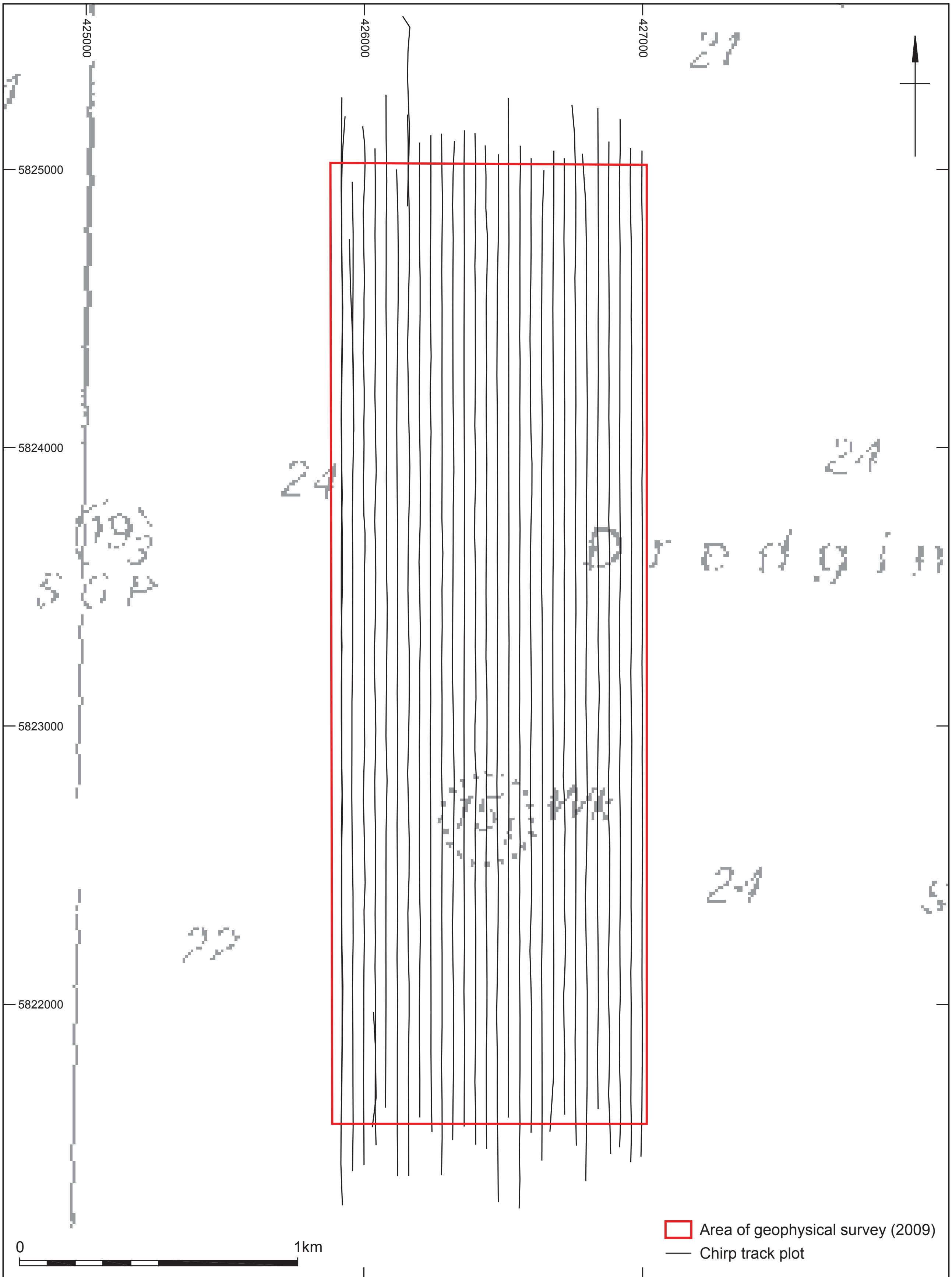
Parametric sonar track plot

Figure 4



Drawing Projection: UTM WGS84 z31N.
Admiralty Chart 1543 (dated 2000).

Date:	14/07/09	Revision Number:	0
Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

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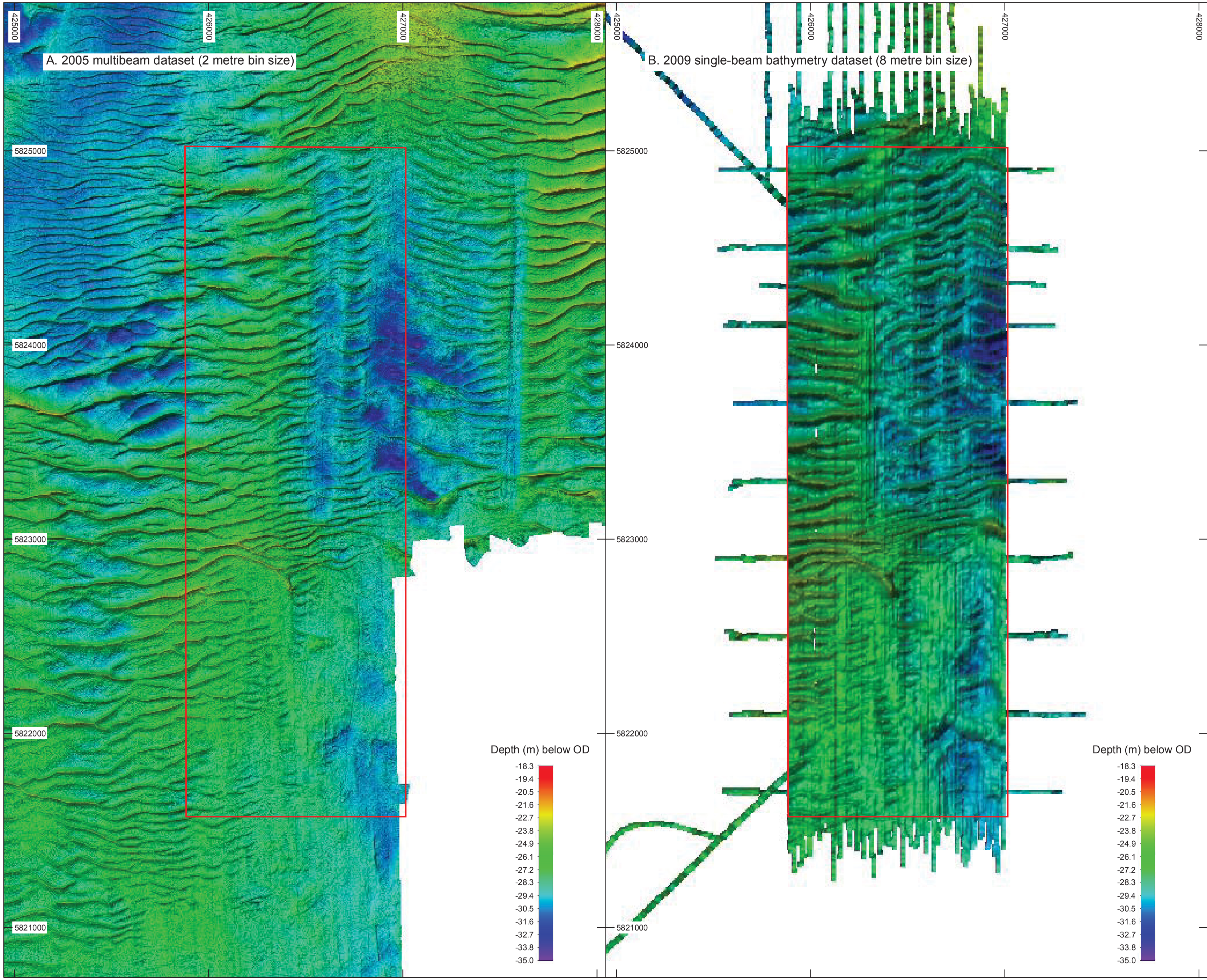
Chirp track plot

Figure 5



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Area of geophysical survey (2009)

0 1km

Both datasets are referenced to OD.

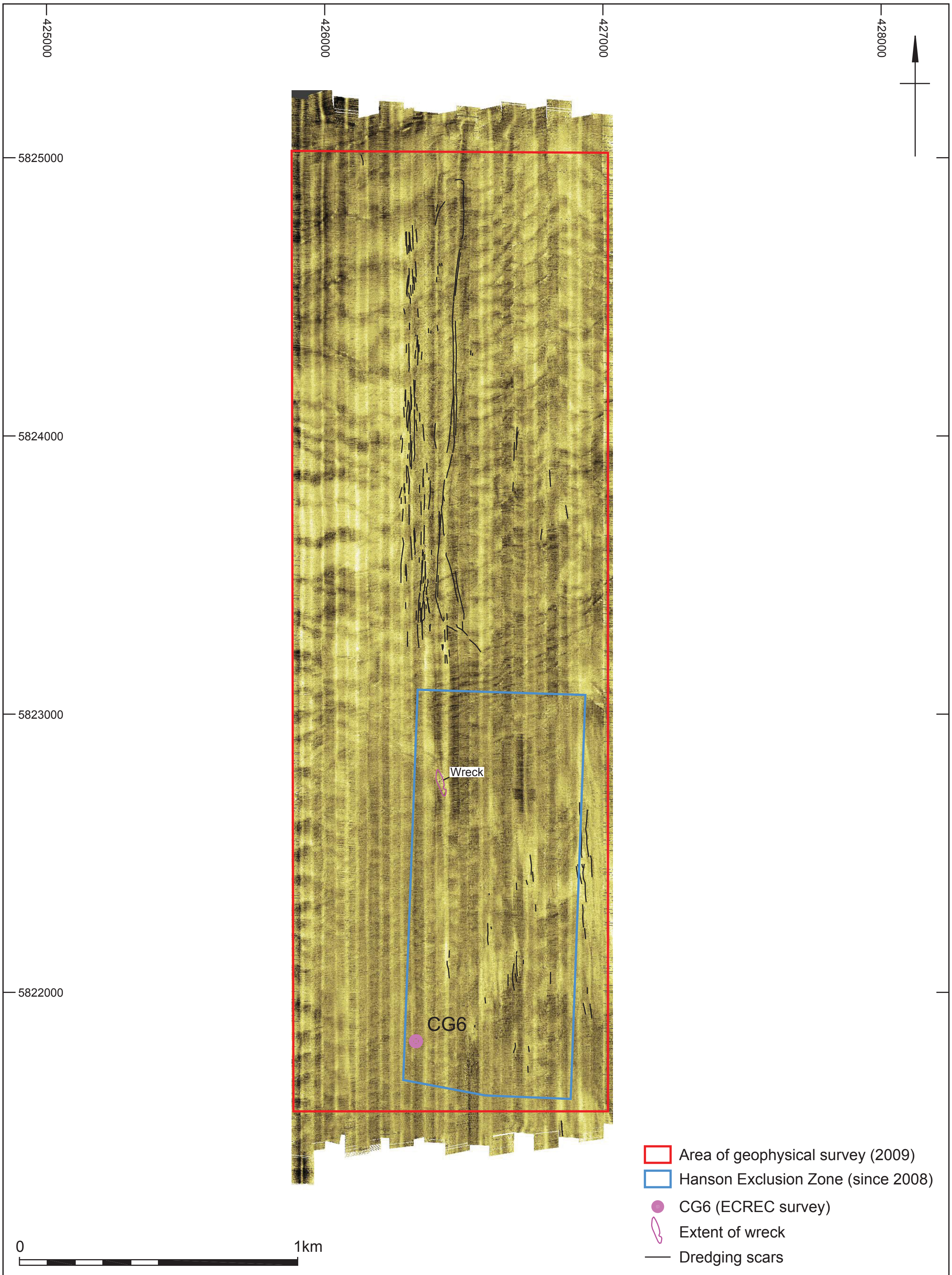
Drawing projection: UTM WGS84 Z31N

Revision Number:	0
Illustrator:	KJB
Date:	10/07/09
Scale:	1:20,000
Path:	W:\Projects\70751\Drawing Office\

Report Figs\Data review\09-07-09\70751_02

Bathymetry - 2005 and 2009 datasets

Figure 6



Drawing Projection: UTM WGS84 z31N.

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Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

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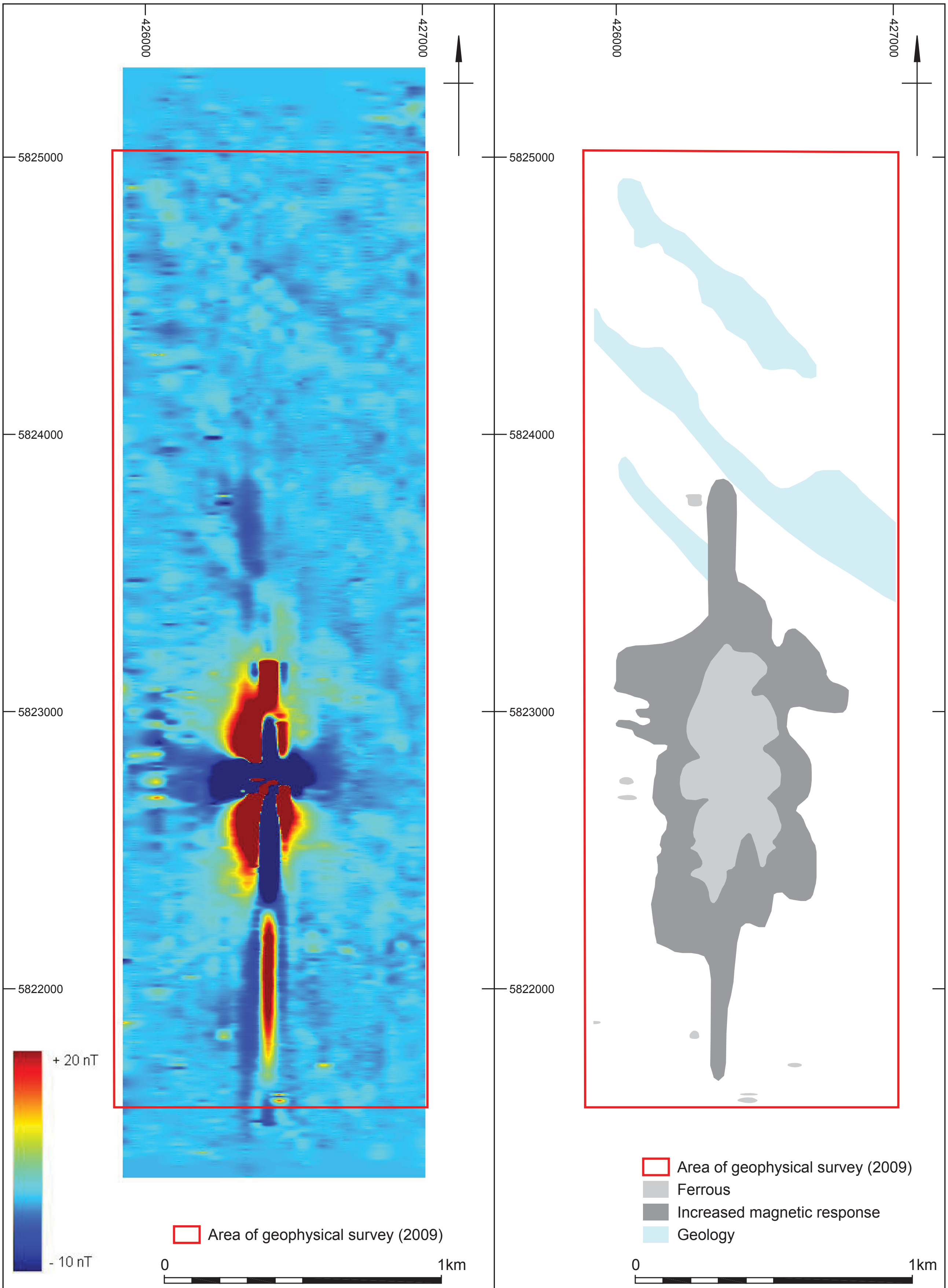
Sidescan sonar mosaic

Figure 7



Variation of magnetic field strength (corrected for regional magnetic field and diurnal variation) gridded at 5 meter by 1 meter bin size

Drawing Projection: UTM WGS84 z31N.

Date:	14/07/09	Revision Number:	0
Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

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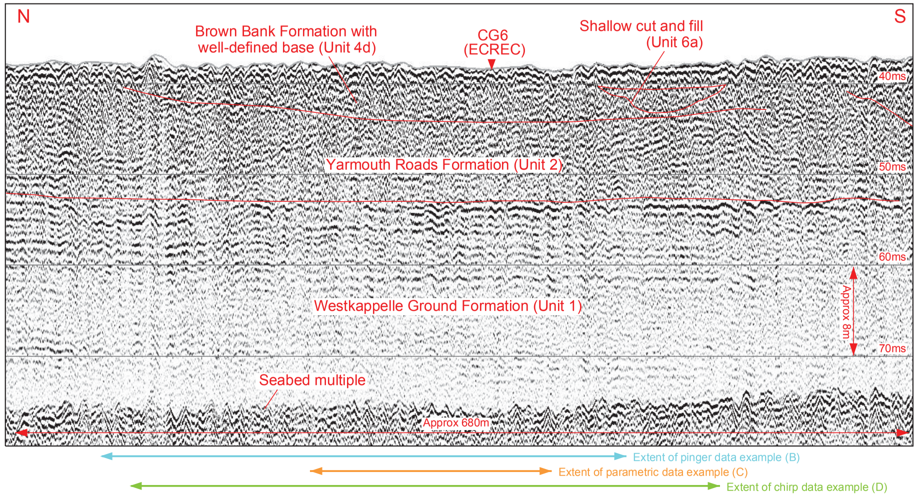
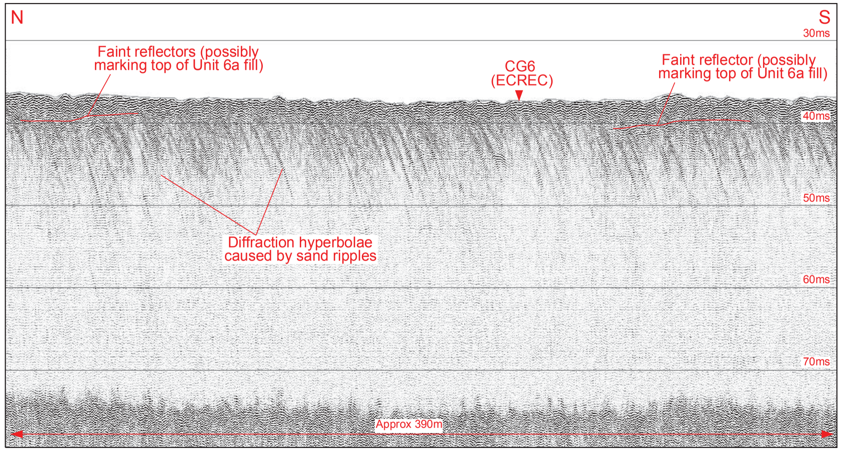
Magnetometer dataset and interpretation – variation in magnetic field strength

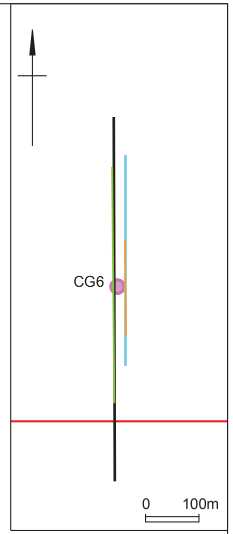
Figure 8

A. Boomer data example

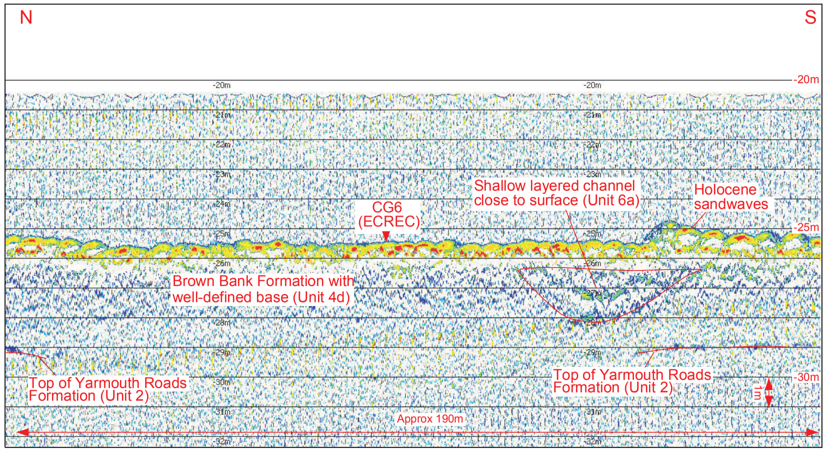


B. Pinger data example

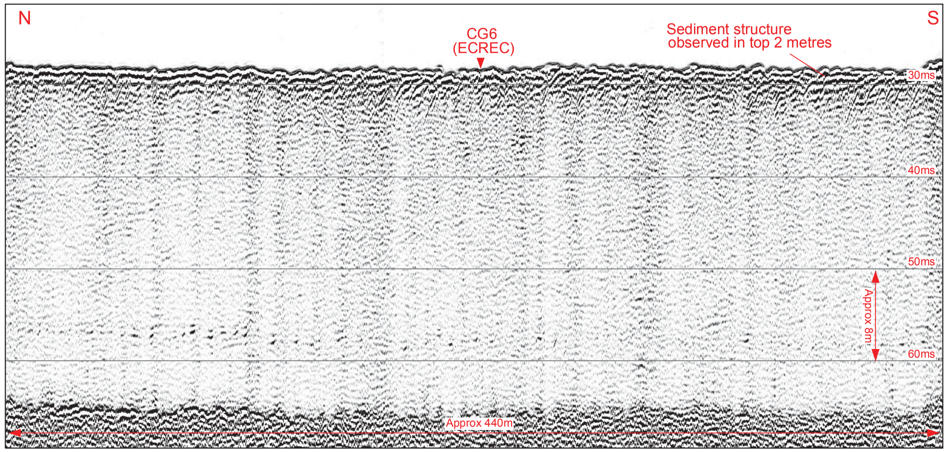




C. Parametric sonar data example



D. Chirp data example



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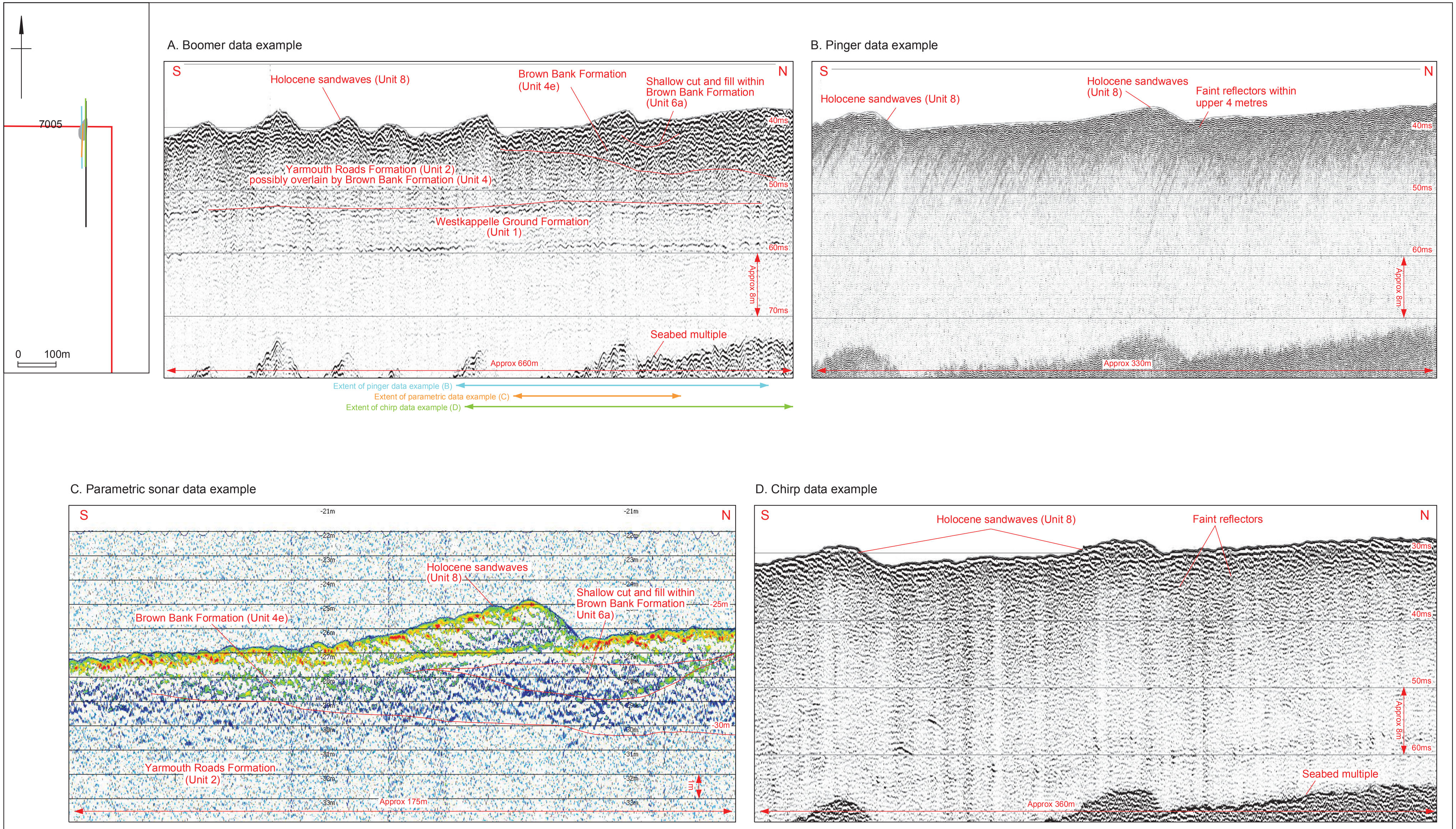
- Area of geophysical survey (2009)
- CG6 Grab Sample location
- Location of boomer data example
- Location of pinger data example
- Location of parametric data example
- Location of chirp data example

Drawing Projection: UTM WGS84 z31N.

Date:	15/07/09	Revision Number:	0
Scale:	A 1:4000 B&D 1:2500 C 1:1250 horizontal (inset 1:10,000)	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

Data example: CG6 Grab Sample location

Figure 9



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Area of geophysical survey (2009)

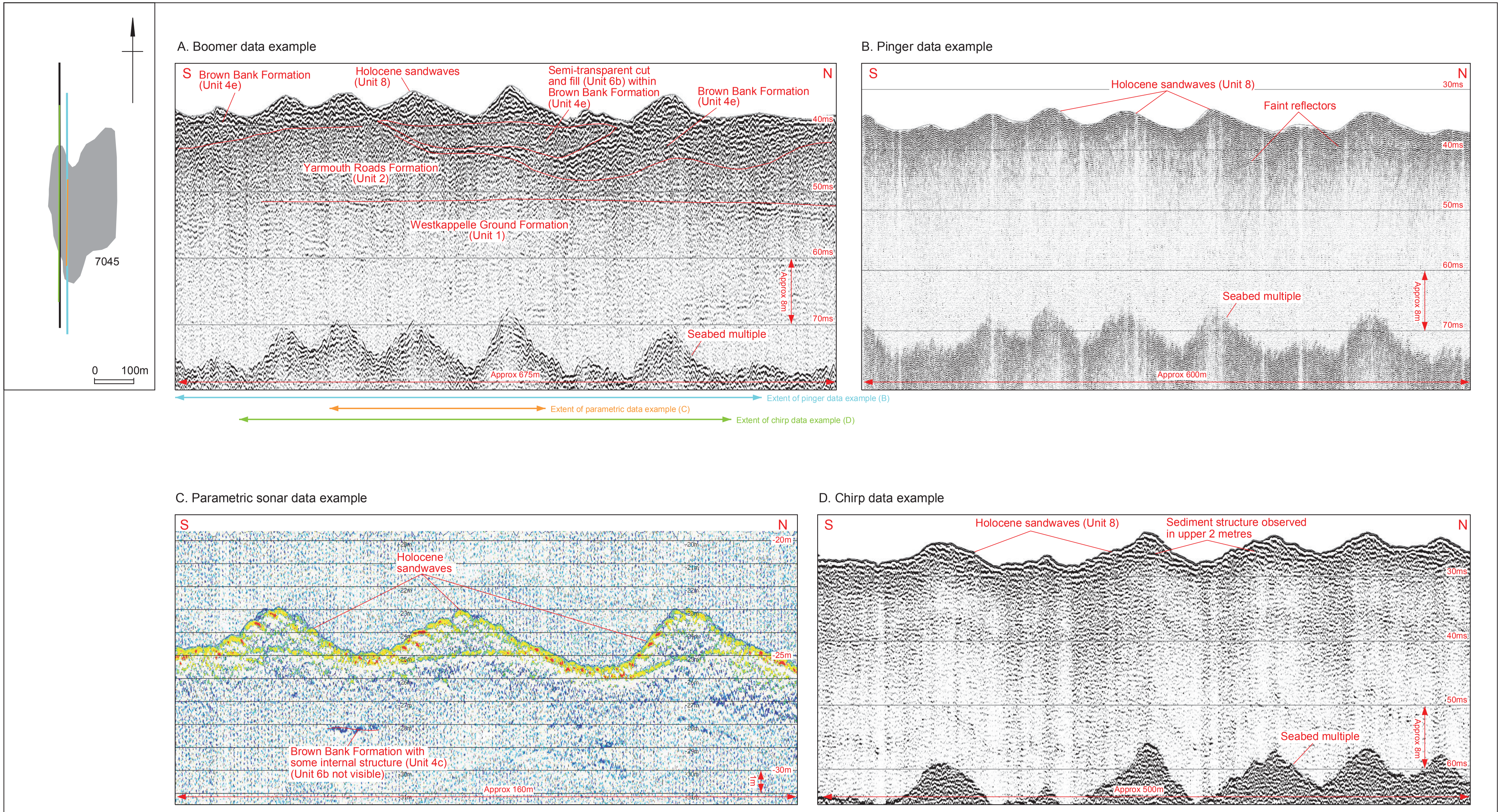
Location of boomer data example
Location of pinger data example
Location of parametric data example
Location of chirp data example

Drawing Projection: UTM WGS84 z31N.

Date:	15/07/09	Revision Number:	0
Scale:	A 1:4000 B 1:2000 C 1:1000 horizontal (inset 1:10,000)	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

Data example: Shallow cut and fill within Brown Bank Formation (site 7005)

Figure 10



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Area of geophysical survey (2009)

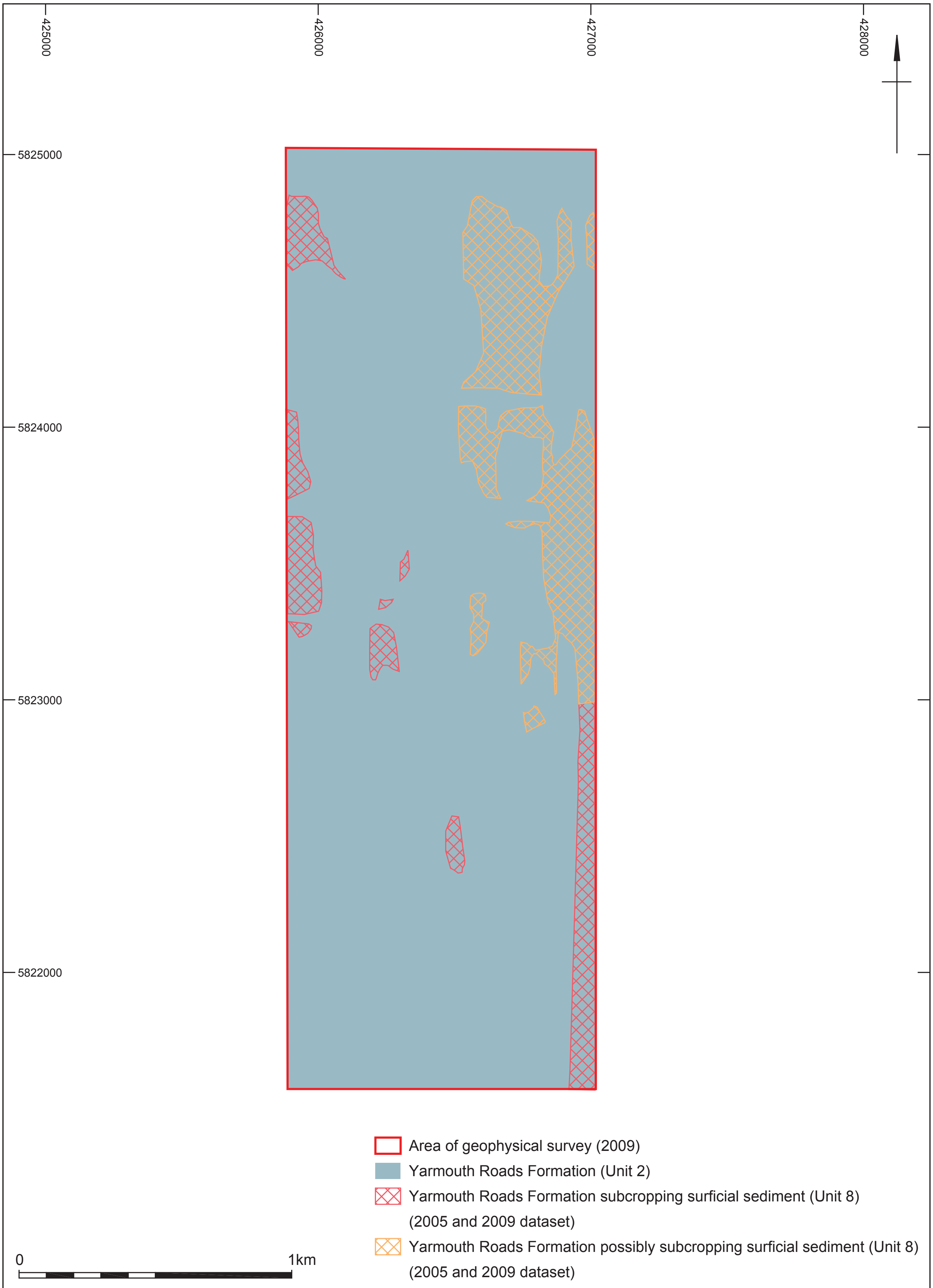
- Location of boomer data example
- Location of pinger data example
- Location of parametric data example
- Location of chirp data example

Drawing Projection: UTM WGS84 z31N.

Date:	15/07/09	Revision Number:	0
Scale:	A&B 1:4000 C 1:1000 D 1:3000 horizontal (inset 1:10,000)	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

Data example: Semi-transparent cut and fill within Brown Bank Formation (site 7045)

Figure 11



Drawing Projection: UTM WGS84 z31N.

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Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

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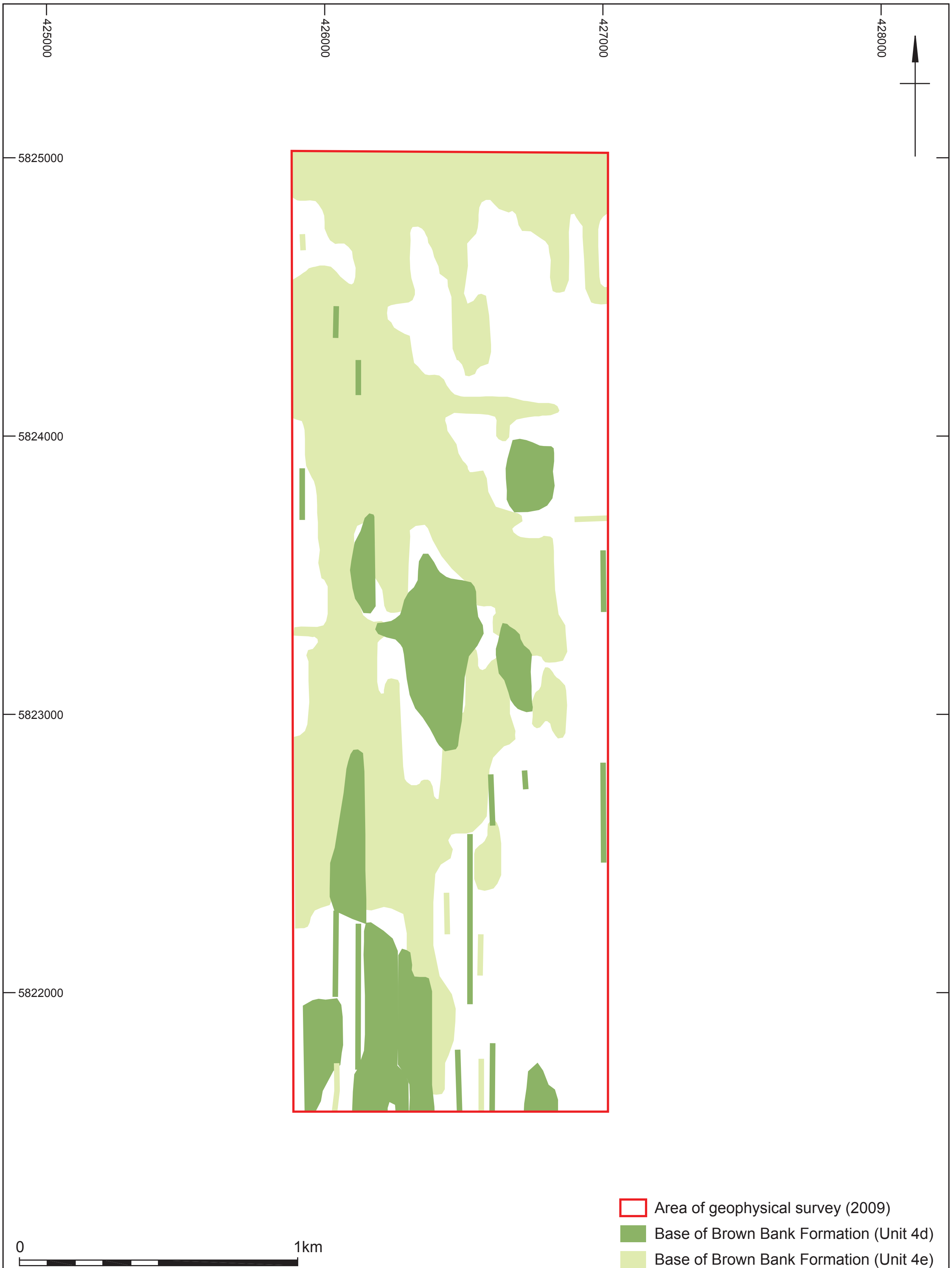
Distribution of Yarmouth Roads Formation (Unit 2) and areas where the formation subcrops the surficial sediment (Unit 8)

Figure 12



Drawing Projection: UTM WGS84 z31N.

Date:	14/07/09	Revision Number:	0
Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Updated PD\09-06-01		

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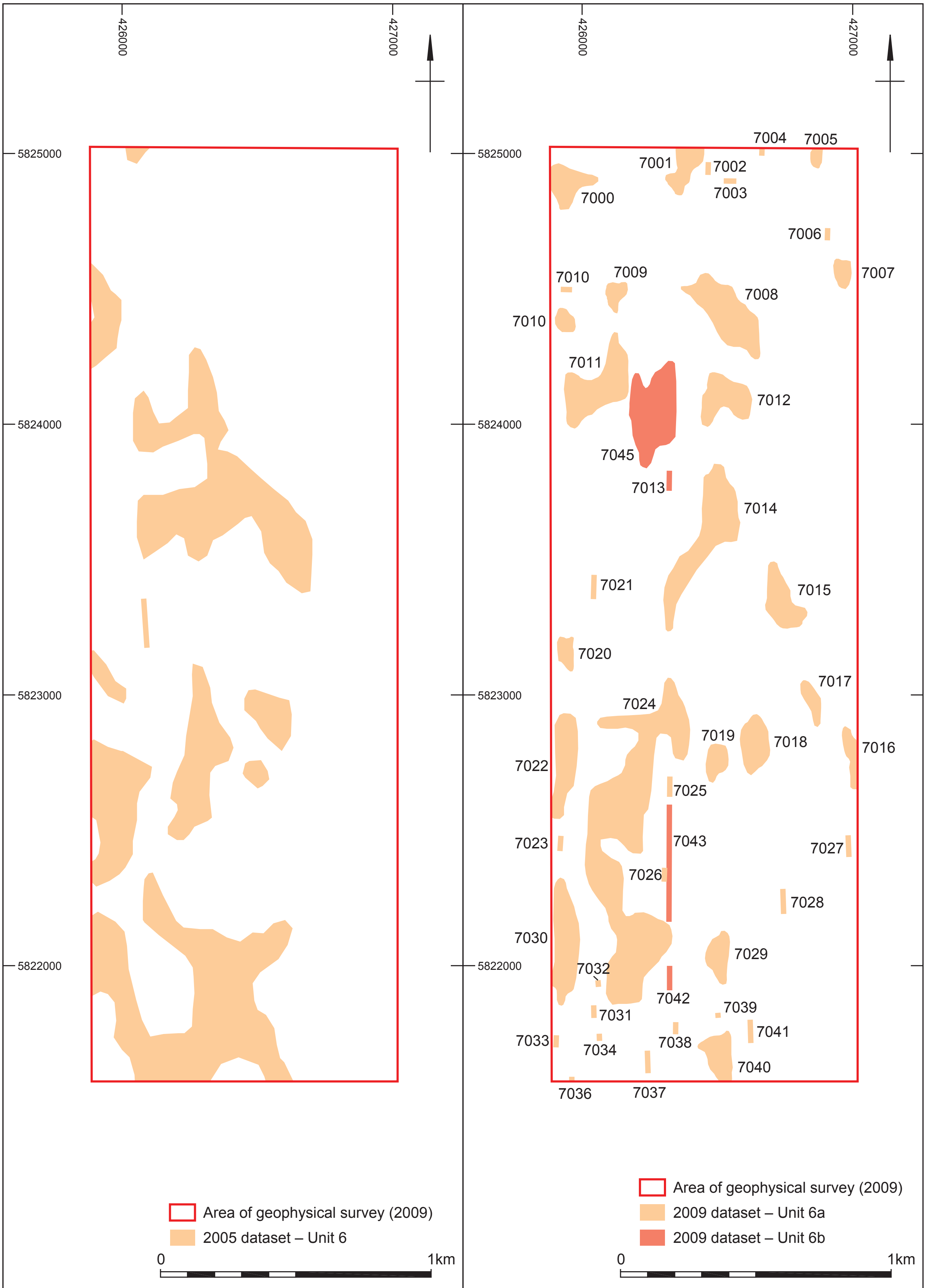
Base of Brown Bank Formation (Unit 4d and 4e)

Figure 13



Drawing Projection: UTM WGS84 z31N.

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Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

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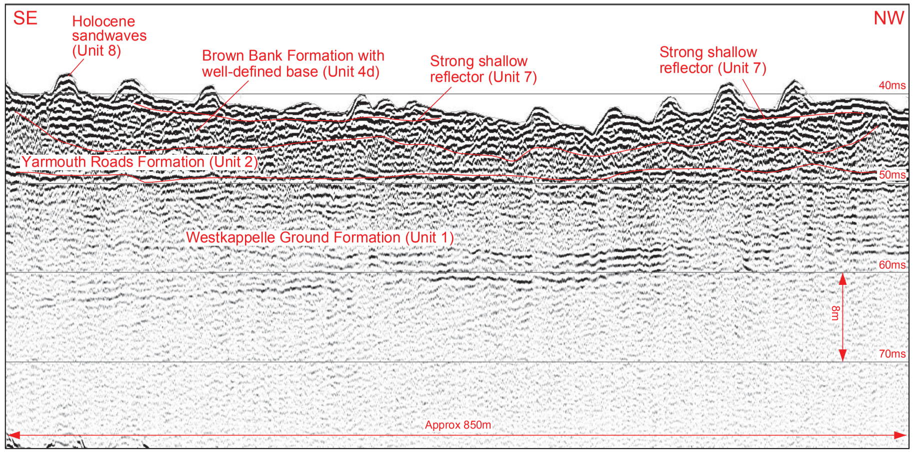
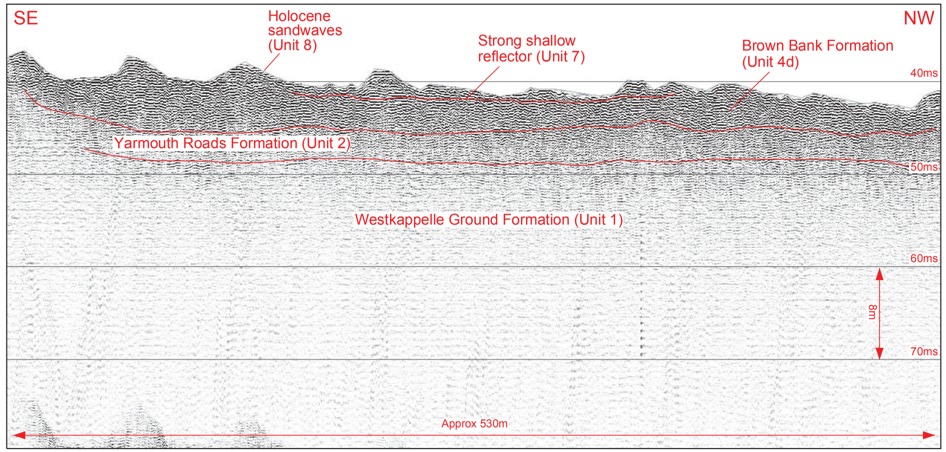
Distribution of Unit 6 in the 2005 and 2009 datasets respectively

Figure 14

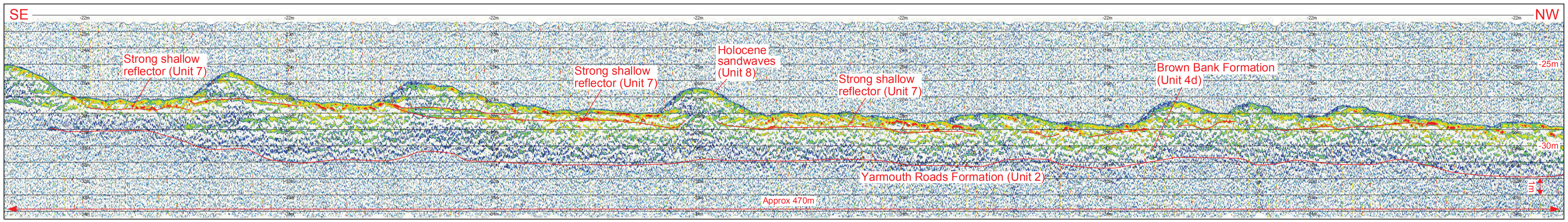
A. Boomer data example

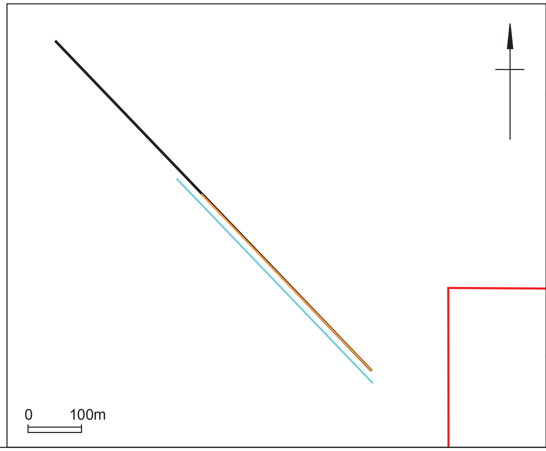


B. Pinger data example



C. Parametric sonar data example





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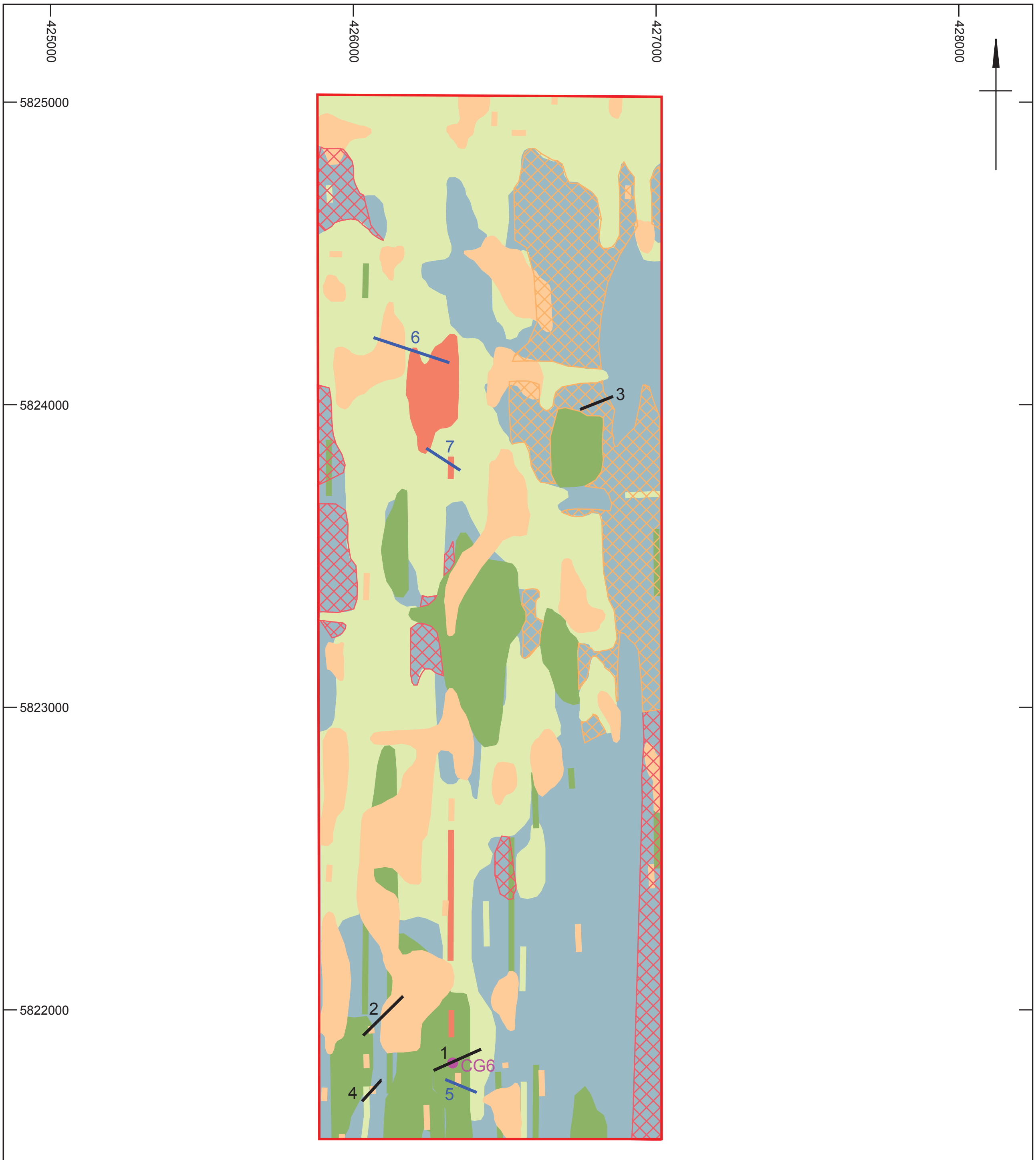
- Area of geophysical survey (2009)
- Location of boomer data example
- Location of pinger data example
- Location of parametric data example

Drawing Projection: UTM WGS84 z31N.

Date:	25/08/09	Revision Number:	0
Scale:	A 1:5000 B 1:3000 C 1:1250 horizontal (inset 1:10,000)	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

Data example of soth-east to north-west oriented tie-in line

Figure 15



Area of geophysical survey (2009)
Proposed transects for project stage 3 (Phase 1)
Proposed transects for project stage 3 (Phase 2)
CG6 (ECREC)

Units subcropping surficial sediment (Unit 8)
Yarmouth Roads Formation (Unit 2) / Brown Bank Formation (Unit 4)
Yarmouth Roads Formation (2005 and 2009 dataset)
Yarmouth Roads Formation possibly subcropping (2005 and 2009 dataset)
Brown Bank Formation (Unit 4d)
Brown Bank Formation (Unit 4e)
Shallow cuts and fills / erosional features (Unit 6a)
Cuts and fills with more transparent fill (Unit 6b)

0 1km

Drawing Projection: UTM WGS84 z31N.

Date:	14/07/09	Revision Number:	0
Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

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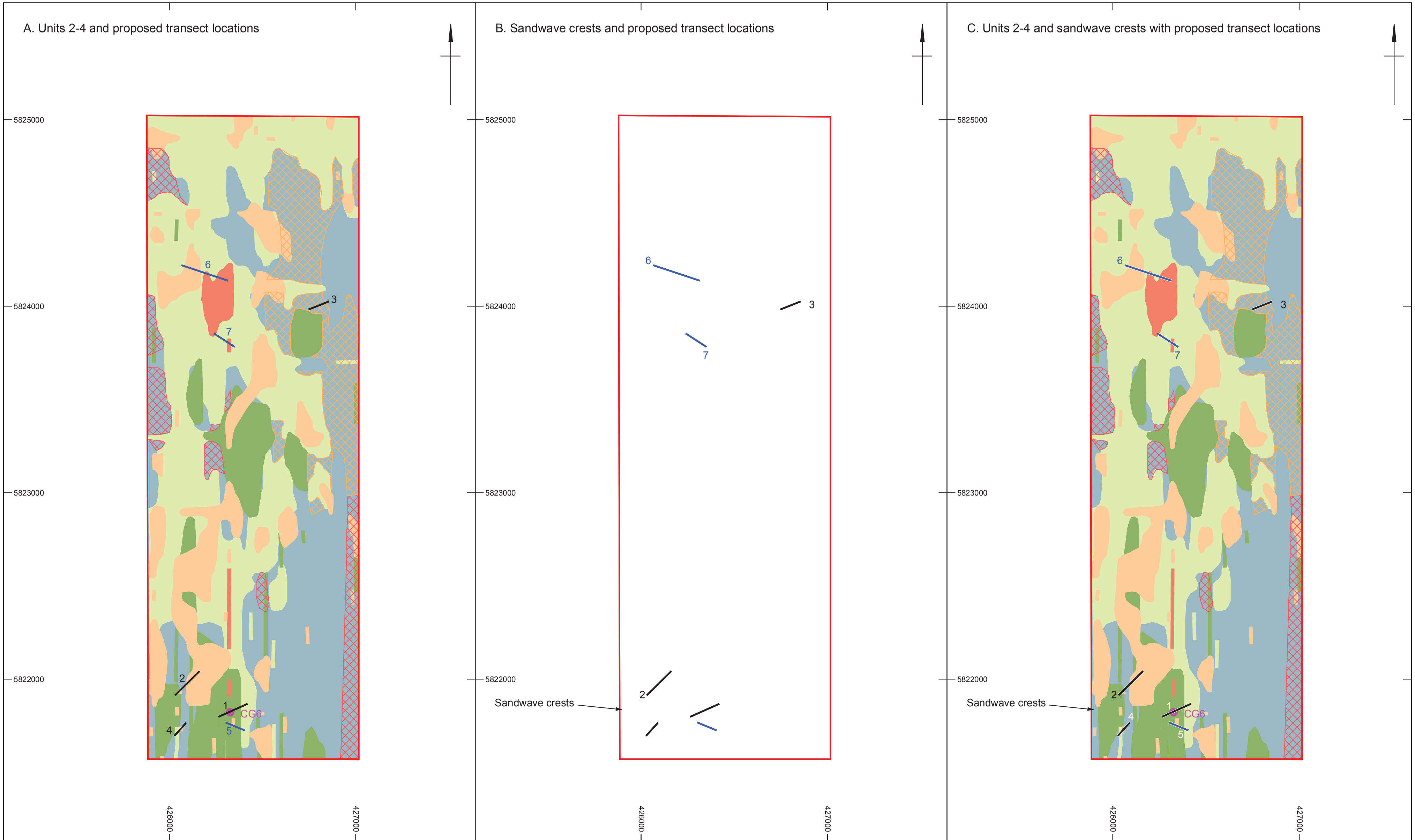
Sediment units for subcropping surficial sediment (Unit 8) and proposed transects for project Stage 3 Figure 16



Area of geophysical survey (2009)
Proposed transects for project stage 3 (Phase 1)
Proposed transects for project stage 3 (Phase 2)
CG6 (ECREC)

Units subcropping surficial sediment (Unit 8)
Yarmouth Roads Formation (Unit 2) / Brown Bank Formation (Unit 4)
Yarmouth Roads Formation (2005 and 2009 dataset)
Yarmouth Roads Formation possibly subcropping (2005 and 2009 dataset)

Brown Bank Formation (Unit 4d)
Brown Bank Formation (Unit 4e)
Shallow cuts and fills / erosional features (Unit 6a)
Cuts and fills with more transparent fill (Unit 6b)

0 1km

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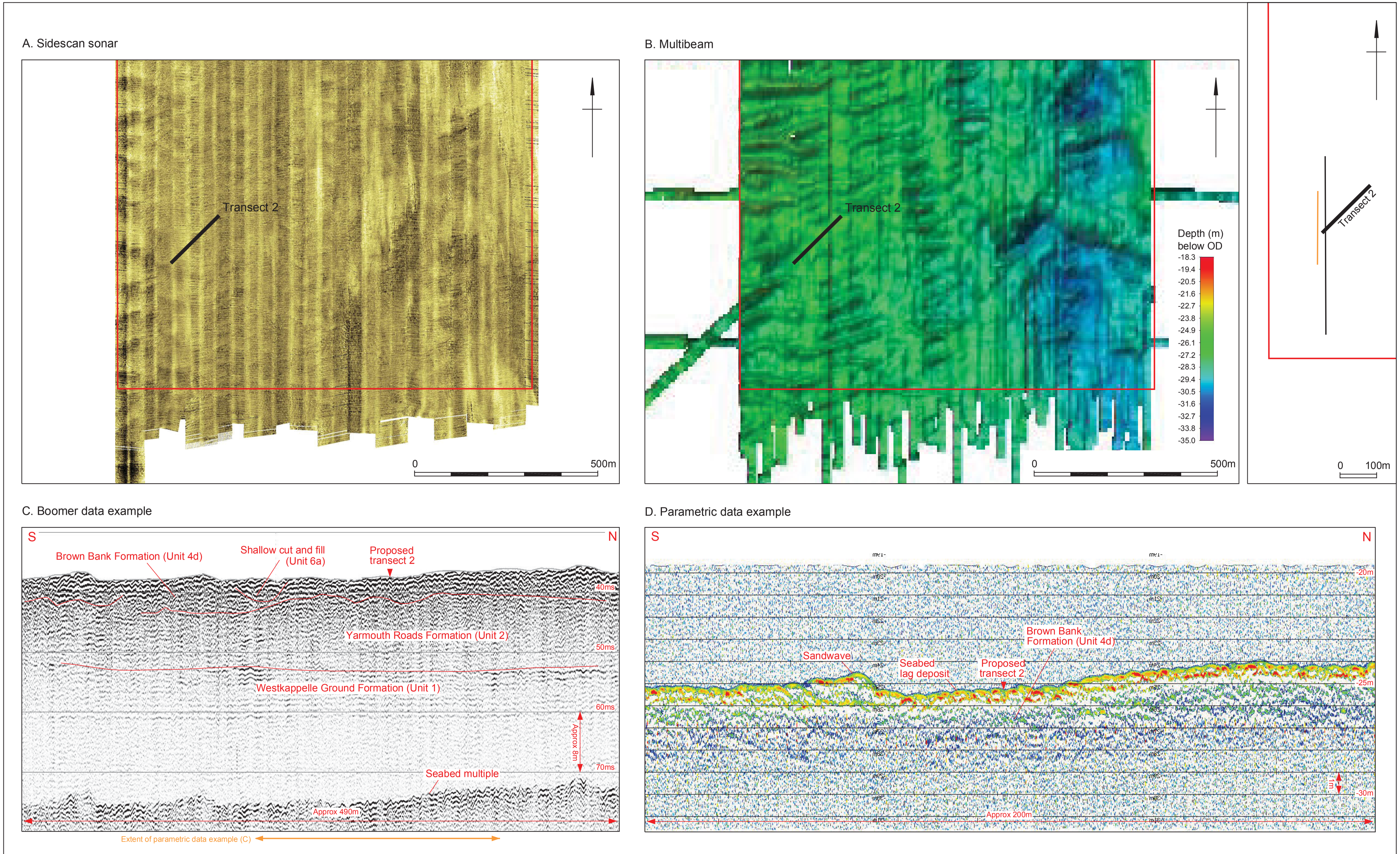
Drawing Projection: UTM WGS84 z31N.

Date:	28/08/09	Revision Number:	0
Scale:	1:20,000 @A4	Illustrator:	KJB
Path:	W:\Projects\70751\Drawing Office\Report Figs\Updated PD\09-06-01		

Proposed transect locations

Figure 17



Area of geophysical survey (2009)
Proposed transect 2 for project stage 3 (Phase 1)
Location of boomer data example
Location of parametric data example

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Drawing Projection: UTM WGS84 z31N.

Date:	26/08/09	Revision Number:	0
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Path:	W:\Projects\70751\Drawing Office\Report Figs\Data review\09-07-09\70751_02		

Data example illustrating surficial sediments along proposed transect 2

Figure 18

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