

OR/15/072 Shallower seismic interpretation

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Seven potential drill sites were selected for the IODP proposal, with a focus on the Quaternary (shallower) section in the Central North Sea to address the specific scientific objectives in the proposal. The potential UK sites are listed in Table 1 along with a summary of scientific objectives. Figure 1 shows the location of the potential drilling sites within the UK North Sea and the data used for selection. Additional sites, investigated by the collaborating Norwegian consortium, are included in the drilling proposal. Not all of the proposed sites are expected to be drilled.

Table 1 List of proposed IODP sites located in the UK sector of the North Sea

Site Name	Proposed Depth	Main Objective (s)
NSEA-03B	810 m	Shallow tunnel valley at 300 ms TWTT to Base Quaternary
NSEA-04A	900 m	Base Quaternary through undisturbed succession
NSEA-09B	50 m	Infill of sea bed tunnel valley
NSEA-10A	45 m	Infill of near-sea bed tunnel valley
NSEA-11B	90 m	Infill of sea bed tunnel valley and internal architecture
NSEA-13A	900 m	Base Quaternary and Early Quaternary prograding sequence
NSEA-14A	490 m	Infill of stacked, buried tunnel valleys

Data availability and quality

For the interpretation of the Quaternary section, both 2D and 3D seismic data were used, alongside a number of hydrocarbon exploration, appraisal and production wells, BGS boreholes, and bathymetric information. Data information is summarised Table 2, and locations in Figure 1. The availability of some of this data, particularly the 3D seismic, is limited due to confidentiality agreements. Most of the other information was available for use within BGS by project participants.

Table 2 Data types used for site selection.
DECC, Department of Energy and Climate Change

Data Type	Owner	Details	Resolution/Information contained	Confidentiality
2D Seismic Reflection Data	BGS	Paper records. Includes: 1985 Sparker 2D survey; 1979 Sparker 2D.	Resolution dependant on individual lines: metre-scale horizontal and vertical separation possible.	Available within BGS.
3D Seismic Reflection Data	PGS	PGS 2009 Central North Sea megamerge. Digital segy data.	50 m horizontal resolution (bin size). 10-12 m vertical resolution dependant on location.	Yes, dependant on agreement with PGS.

OLEX Bathymetric dataset	OLEX* (www.olex.no)	UK OLEX map from 2011. Digital elevation (x, y, z) data.	Up to 5 m horizontal resolution dependant on line spacing. Vertical resolution: 1 m in water depths >100 m; 10 cm water depth <100 m.	Available to BGS.
BGS boreholes	BGS	BGS boreholes: 81/39; 81/37; 81/13; 77/03; 77/02; 81/24.	Lithological descriptions; biostratigraphic reports; paleomagnetic information.	Available to BGS.
Commercial Well data	Various, details available from DECC website.	Commercial well 'Josephine' 30/13-2. Drilled and completed Sept 1972.	Lithological descriptions; biostratigraphic reports; paleomagnetic information.	Variable, dependant on release date.

* The OLEX bathymetric database is compiled, processed and managed by the Norwegian company OLEX AS (www.olex.no). The sea-bed image is based upon voluntary contributions of echosounder data acquired primarily by commercial fishing vessels, but also including data from research vessels. The database is presented as a series of 5 m x 5 m cells with a vertical and horizontal resolution dependent on the volume and accuracy of the voluntary datasets submitted by partners. The horizontal datum is WGS84.

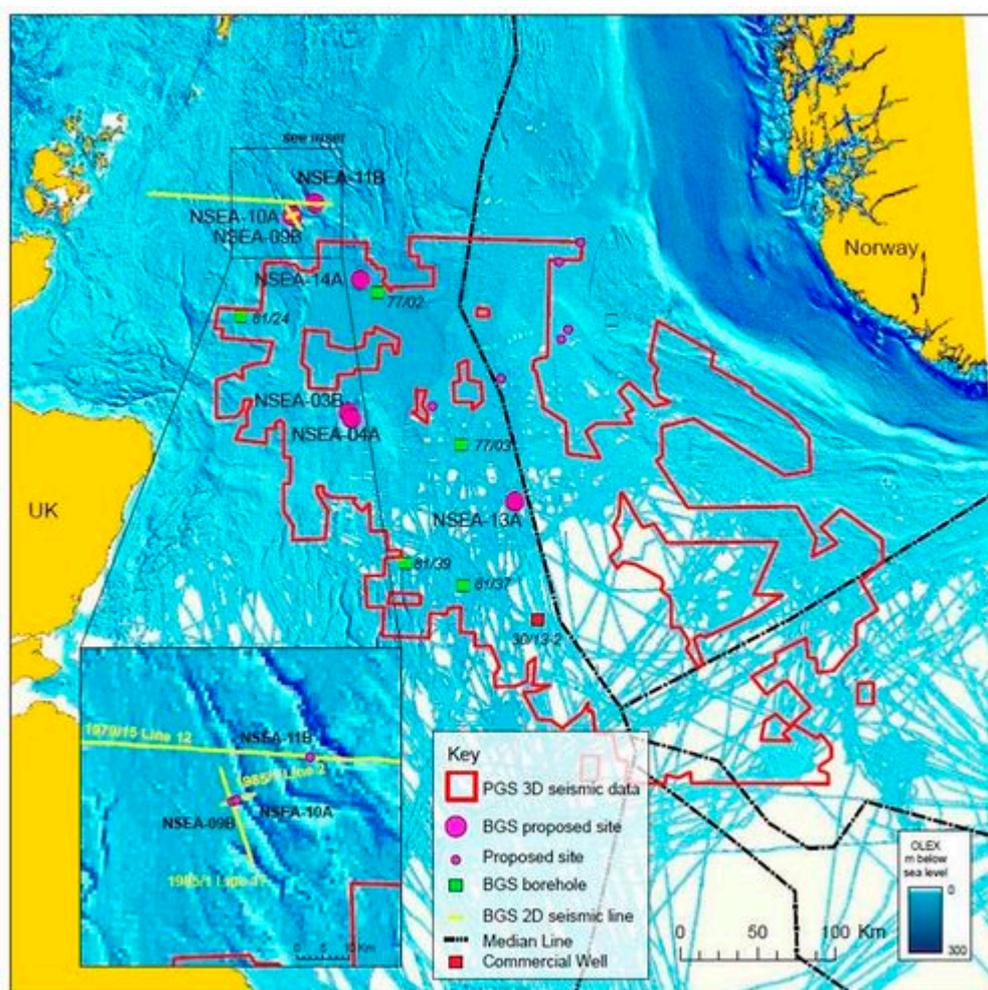


Figure 1 Location map with data used in study and proposed drill sites in the UK sector of the North Sea. Bathymetric data from the OLEX database (www.olex.no), as described for Table 2.

Selected data

Despite a wealth of commercial hydrocarbon wells in the region, many do not capture information on

the top few hundred metres of sediment — the Quaternary strata of interest here. Therefore, well and borehole information used was limited to the BGS boreholes identified in Table 2, and one commercial well, 30/13-2, which was drilled in 1972 and contains some record of the Quaternary/Neogene succession. BGS acquired a number of 2D seismic reflection lines targeted at the shallower section in the 1970's and 1980's, which were utilised here to image in detail shallow glacial features at and near the sea bed. To obtain a good understanding of the regional seismic architecture and large glacial landforms, 3D seismic data is crucial. The PGS Central North Sea 2009 mega-merge 3D seismic reflection volume was obtained for the purpose of this study (for locations see Figure 1).

The rationale for data selection for each proposed drilling site in the UK sector of the North Sea (Table 1) is summarised below:

- The proposed site NSEA-13A aims to obtain 900 m of core and reach a prograding sequence of early to mid-Quaternary strata. The main supporting data for this proposed site is the 3D seismic merged data and information on magnetic reversals obtained from the 30/13-2 well and BGS boreholes. The interpretation is based on the regional seismic stratigraphic framework of the central North Sea that is part of a doctoral research project at the University of Manchester of R Lamb (in preparation)^[1]. The interpretation presented here was undertaken by R Lamb for this project.
- NSEA-03B aims to penetrate a near-sea bed tunnel valley through to the base Quaternary. The proposed NSEA-04A site is 900 m deep and aims to penetrate a complete Quaternary sequence from sea bed to the base Quaternary. The PGS 3D seismic volumes were used to identify sites with good potential and the regional interpretations of key seismic surfaces of Lamb (in preparation)^[1] were used to refine site selection.
- For site NSEA-14A, the main aim is to investigate the age and fill of large, stacked buried tunnel valley systems. The main supporting data for these proposed sites is the 3D merged data provided by PGS. BGS borehole 77/09 penetrates a buried tunnel valley and was used to predict tunnel valley fill and anticipated drilling rates.
- Sites NSEA-09B, NSEA-10A and NSEA-11B aim to investigate tunnel valleys present at and near the sea bed and made use of BGS shallow 2D seismic data shot in 1979 and 1985. The 2D seismic data were collected and interpreted as paper hard copies. BGS borehole 81/39 penetrates part of the fill of a sea bed tunnel valley and was used to prognose expected succession and anticipated drilling rates.

Interpretation method

For all sites that made use of the PGS 3D mega-merge survey, the 3D volumes were interpreted using Petrel software. The BGS 2D lines are available only as paper records, while the commercial well data, including summary logs and associated reports were obtained from the Department of Energy and Climate Change (DECC) website. BGS borehole information was reviewed internally.

Throughout the site analysis, care was taken to avoid any indications of vertical structures or features giving rise to anomalously bright reflections within the 3D seismic data; these are considered to be indicative of shallow gas features which are a serious hazard for drilling. Shallow gas may induce blowouts on platforms, and previous instances of this hazard have been encountered in the central North Sea (i.e. the Mobil blowout at the well 22/04-b). For the proposed IODP sites, the 3D seismic was used to identify any indicators of shallow gas including: vertical disruptions in reflectors; patches of very bright reflectors; mounded bright features previously identified as gas-charged (Brooke et al., 1995^[2]); and pockmarks at sea bed which indicate vertical migration, possibly of shallow gas. Any sites which interact with such features would be considered an engineering

hazard, and were therefore dismissed. For the proposed sites which aim to incorporate information on the older parts of the Quaternary, or the whole Quaternary succession (NSEA-03B; NSEA-04A; NSEA-13A), site choices were investigated on a regional understanding of the seismic architecture and selected to identify relatively undisturbed Quaternary sections. NSEA-13A aimed to capture the northernmost part of Early Quaternary prograding features, which were mapped out in detail using the PGS 3D seismic data and interpretation of key horizons from the BGS boreholes and the commercial well 30/13-2. The proposed site NSEA-03B was selected in order to penetrate a buried tunnel valley, a thick sequence of Quaternary strata, and the newly defined Base Quaternary as part of the PhD project of Lamb (in preparation)^[1] (Figure 2). The PGS 3D seismic mega-merge was used to identify a site with a well-defined valley near the middle of the basin where base Quaternary could be reached at 810 m below sea bed. The estimated Base Quaternary surface was based on a regional seismic stratigraphy of the central North Sea (Lamb et al., in preparation^[1]) which informed selection of Site NSEA-04A and interpretation of the PGS 3D mega-merge survey. The base Jaramillo magnetic reversal event is obtained from selected BGS boreholes listed in Table 2. The objective of site NSEA-04A is to penetrate a thick (900 m), relatively undisturbed Quaternary sequence.

Buried tunnel valleys are kilometre-scale features; best observed in the North Sea in horizontal time-slice within the 3D seismic data and are generally observed at two-way travel times (TWTT) between 180 ms and 500 ms. For the proposed sites which aimed (in full or in part) to capture buried tunnel valley systems, reconnaissance investigations focused on identifying sites where: tunnel valleys were present; where some indication of internal structure was present in the seismic data; where clear examples of cross-cutting, stacked, buried channels were apparent. Once a number of tunnel valleys systems were identified, potential sites were also selected as close as possible to other potential drill sites, in order to minimise drillship transit time during an IODP mission. At the proposed site NSEA-14A, two tunnel valleys are clearly observed in time-slices in the 3D seismic data at a time of 372 ms TWTT (Figure 3). A large, older valley trends NNE-SSW, and is incised by a shallower, younger E-W trending valley with a clear base. The fill characteristics of the two valleys are somewhat different within the 3D seismic data with the lower valley containing disrupted bright reflections, and the younger channel more flat-lying reflections. The proposed site will penetrate both tunnel valleys to an estimated depth of 490 m below sea bed and into the underlying strata.

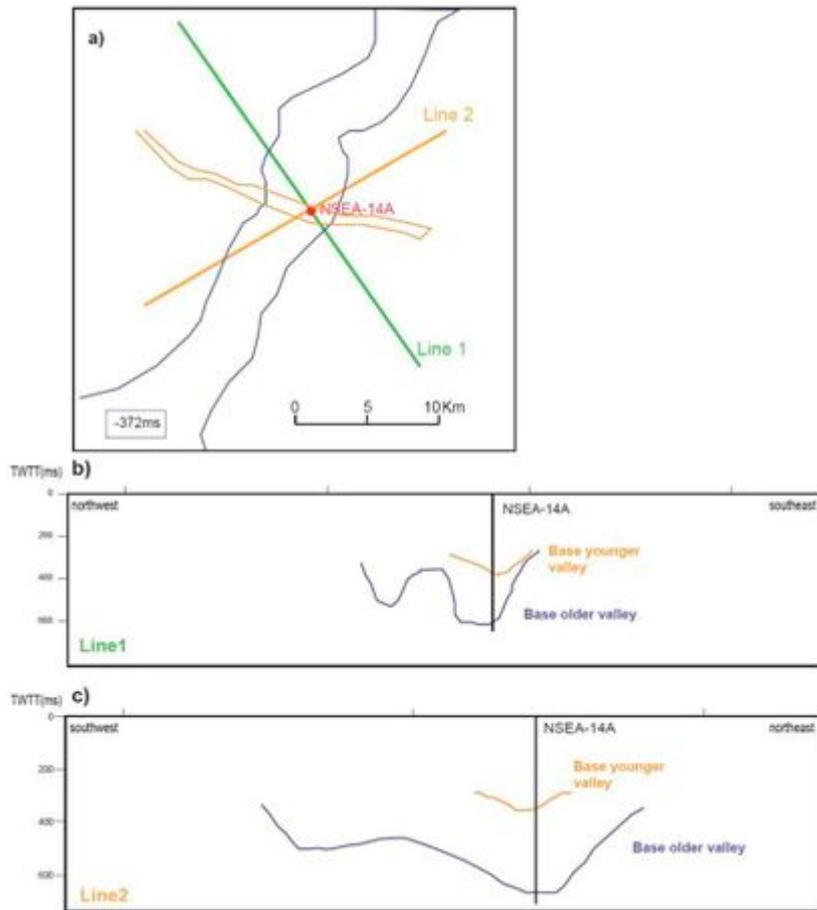


Figure 2 Proposed site NSEA-014A showing:
a) outline of tunnel valleys in time-slice at 372 ms TWTT.
b) and c) proposed site NSEA-14A penetrating two stacked tunnel valleys interpreted within confidential PGS 3D seismic reflection data.

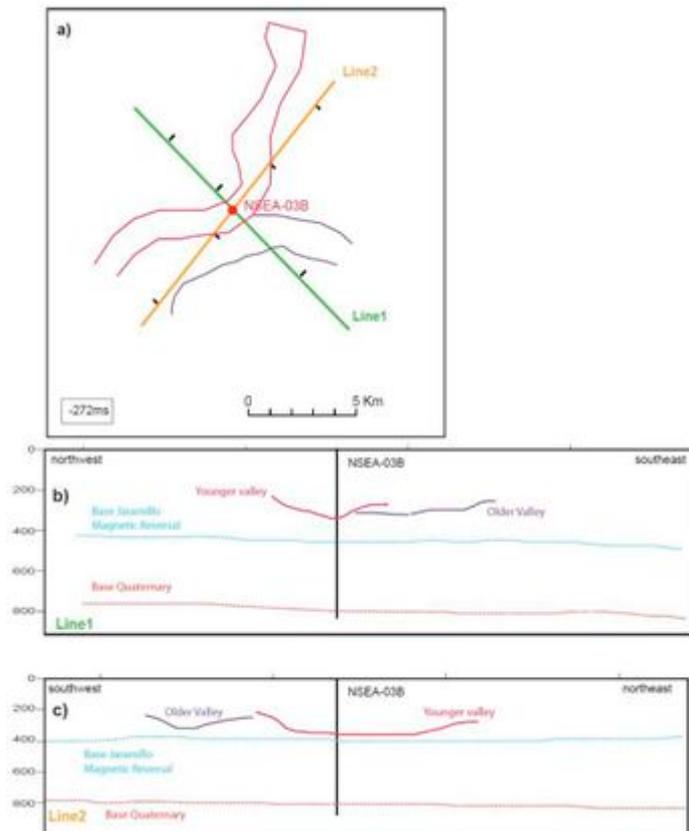


Figure 3 Proposed site NSEA-03B showing:
a) outline of tunnel valleys at 272 ms TWTT.
b) and c) proposed site NSEA-03B penetrating a near sea bed tunnel valley (in red) and the interpreted Base Jaramillo and Base Quaternary. Interpretations based on confidential PGS 3D seismic reflection data.

To investigate the sea bed/open tunnel valleys (sites NSEA-09A; MSEA-10B; NSEA-11B), which are not imaged clearly in the 3D seismic data, BGS 2D seismic reflection data were used, in which the incisions and their fill are clearly imaged. Open and filled tunnel valleys are present in close proximity (less than 5 km) to one another (Figure 4). The extent of the tunnel valleys at sea bed were also imaged and mapped within the OLEX bathymetric database, previously identified and interpreted by Stewart (2009^[3], 2015^[4]).

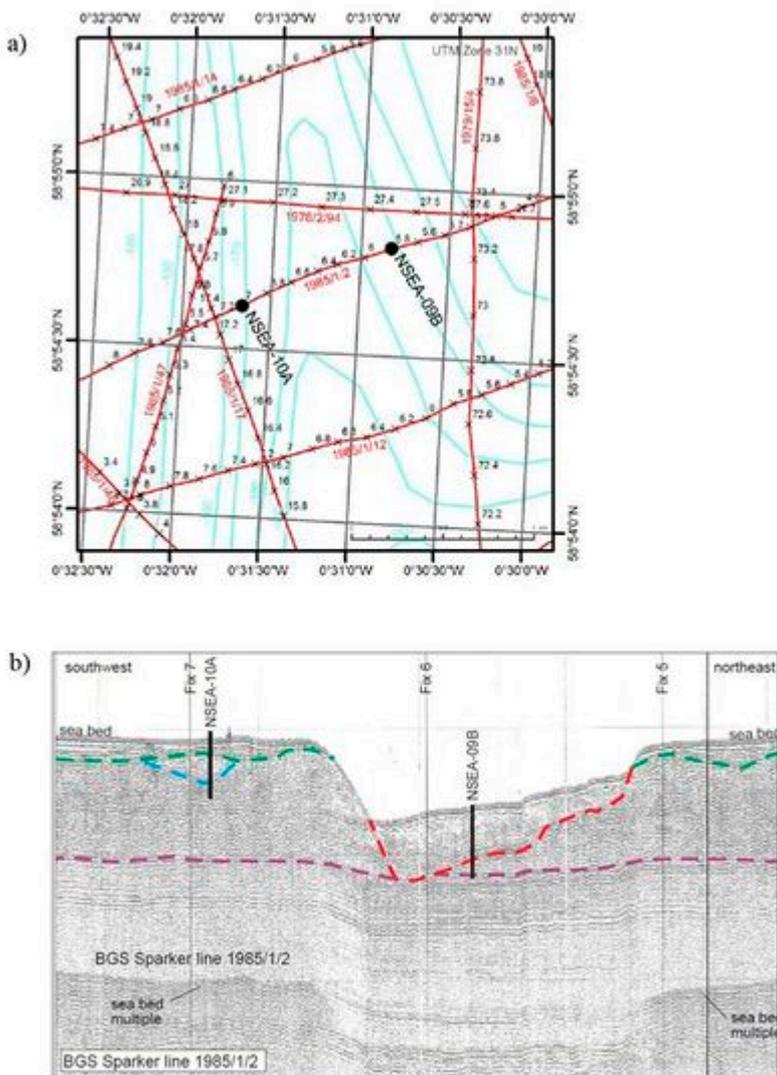


Figure 4 Proposed drill sites investigation near sea bed (NSEA-10A) and open (NSEA-09B) tunnel valleys using BGS 2D Sparker data.

- a) Location of proposed sites superimposed on OLEX bathymetric data.
- b) Two potential sites and the BGS 2D line 1985/1/2.

Results

An interpretation of the Quaternary stratigraphy was made based on the scientific objectives in the IODP proposal for each site. For all sites, an assessment of drilling hazards, in particular the possible presence of shallow gas, was undertaken in order to avoid any potential problems. This was carried out within the extent of the 3D seismic surveys and used to inform decisions on the sites selected below.

Figure 3 shows the interpretation for the site NSEA-03B (with the confidential 3D seismic data redacted). The large tunnel valleys identified at 272 ms TWTT have not previously been mapped in detail but are very similar in form to the features widely mapped in the region by Stewart et al. (2013)^[5]. The Base Jaramillo and Base Quaternary surfaces are newly interpreted (Lamb, in preparation^[1]). The proposed site for NSEA-04A also makes use of the interpretation of Lamb (in press)^[6], placing the Base Quaternary at around 900 m below sea bed. The thick succession of relatively undisturbed strata imaged in the seismic data is considered to comprise the Aberdeen Ground Formation (Stoker et al. 2011^[7]).

Site proposal preparatory work at NSEA-13A included identification of a series of units prograding from the southeast, which Lamb (in press) interpreted regionally using the PGS 3D mega-merge data. The top of the prograding unit was mapped regionally, as well as its major internal units. The lack of well data to provide ages or borehole correlations for these units highlights the need for scientific drilling in this region.

Seismic reflection data around the NSEA-14A site (Figure 2) also imaged tunnel valleys not previously mapped in detail, and provides clear evidence of cross-cutting tunnel valleys previously described by Stewart et al. (2013)^[5].

At sites NSEA-09B, 10A and 11B, the BGS 2D seismic lines revealed tunnel valleys in close proximity at and near sea bed (Figure 4). The age relationships between these features remain uncertain — in the current stratigraphy they are considered to be related to the last glacial maximum (Stoker et al., 2011^[7]). This raises questions from a depositional process point of view regarding why some tunnel valleys were filled and others are open.

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