BRITISH GEOLOGICAL SURVEY

Technical Report WB/89/2

Marine Geology Series

Offshore investigations 1966–87

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PREFACE

In 1835 Britain led the way in developing the new science of geology and became the first country to establish a publicly funded National Geological Survey. Consequently, during the last 154 years Britain has become one of the most intensively surveyed contries in the world. Following the work of the hydrocarbons industry in the early 1960's, the British Geological Survey also began acquiring information on the geology of the offshore area. Thus, again, Britain led the way and is now the only country in the world with a systematic series of maps for a large part of its continental shelf.

This report outlines the work of the Survey on the United Kingdom Continental Shelf from its start in 1966 up to 1987. Much of this work was supported by the Department of Energy. In particular, the type of data collected is described as well as its availability to the public. The Survey has also been contracted by the Department of Energy to curate and interpret material collected by the oil industry, and although much of this information remains confidential, it has provided a wealth of detail, much of which has been released to the geological community.

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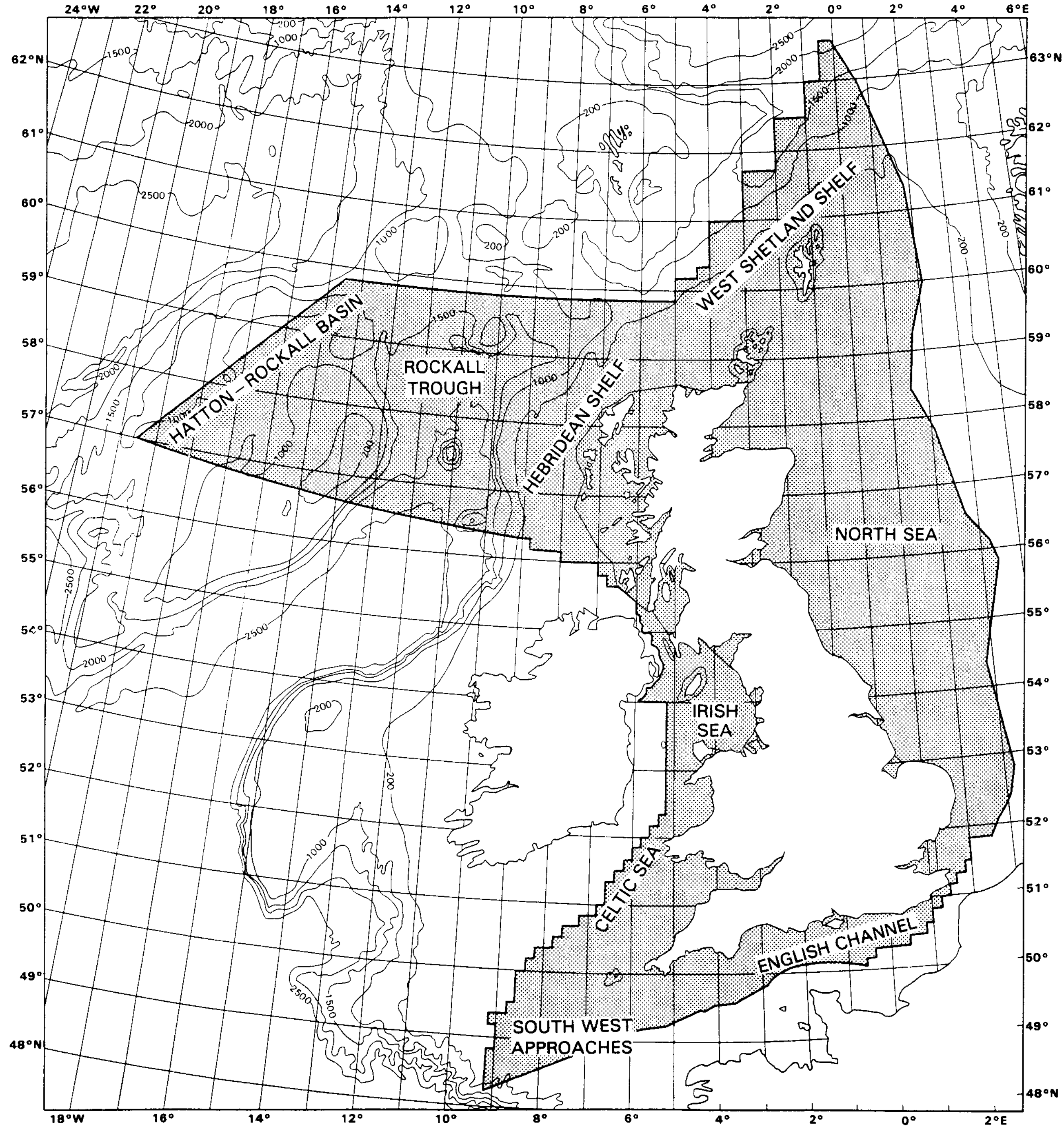

Figure 1. Map showing United Kingdom Designated Waters (Stippled). Bathymetry is shown in metres.

1. INTRODUCTION

Offshore work by the British Geological Survey (then the Institute of Geological Sciences) began in 1966. From the outset, the objective of the programme was to map the geology beneath United Kingdom (UK) Designated Waters, (Figure 1), starting with the inner areas. This imaginative step represented a commitment to investigate national offshore resources on a scale not attempted by any other country.

Initially constrained by available techniques, surveys were undertaken in shallow and protected areas, progressively moving into deeper and more exposed waters. Recent data acquisition has concentrated on the areas to the northwest of the United Kingdom and on the eastern flanks of the Rockall Trough and Faeroe-Shetland Channel.

Initially the offshore work was funded by the Department of Education and Science through the Natural Environment Research Council (NERC). However, following the introduction of the Rothschild principle of customer/contractor funding in 1973, the programme was initially supported by the Department of Trade and Industry and subsequently by the Department of Energy (DEn). DEn is charged with ensuring a continuous, cost-effective and safe energy supply for the nation, and the Petroleum Engineering Division have particular responsibilities concerning the identification and exploitation of hydrocarbons. Consequently in 1979, DEn assumed responsibilities for a large part of the costs of the offshore programmes, and contracted the British Geological Survey (BGS) to investigate and advise upon geological conditions. This resulted in the identification of a carefully defined programme of work and output.

The two principal programmes undertaken on behalf of DEn are:

1. Hydrocarbon studies.
   These involve the collation, curation and interpretation of seismic data, cores and samples supplied by the licencees to DEn under the Petroleum and Pipelines Act (1975) and related legislation. These data are held in confidence by BGS on behalf of DEn, to whom the Survey provides prospectivity reports and comprehensive geological assessments. Released well material is available for further study at the DEn/BGS Core Store in Edinburgh, where non-released material may also be examined provided the permission of the owner is obtained.

2. Regional Mapping Programme (RMP).
   This programme is concerned with the direct acquisition of data, leading to the preparation and publication of a series of geological and geophysical maps and associated reports of the UK offshore area. To this end, BGS complements its own field programme with data and material from other sources.

   Information derived from this programme is held on open file as a National Archive of marine samples, cores and records. This information is available to the scientific and commercial communities, except where restricted by commercial confidentiality. The data are also used to advise Government, industry and other agencies on the resource potential, exploitation and development of the UK offshore area.

In addition to these responsibilities, the Survey uses its extensive databases and infrastructure of equipment and experienced personnel to support research in universities and other institutions, and to collaborate with industry in applied research. In appropriate circumstances, the Survey also accepts commissions from Government and industry for work worldwide.

Interpretation of the geological data supplied by the oil industry is carried out by the staff of the BGS Hydrocarbons Programme. This group, its confidential database, core store and computing facilities are kept entirely separate from those of the rest of the Survey. The RMP and other activities are undertaken by the Marine Geology Programme and the Marine Geophysics and Offshore Services Programme.

The work of all three groups is supported by other specialists within BGS including palaeontologists, geochemists, petrologists, mineralogists, engineering geologists and seismologists. Maps are drafted in BGS Drawing Offices and printed by the Ordnance Survey.

Special studies are also undertaken, either integrated with the main programmes or as independant projects. Examples of the latter include offshore seismicity studies and the investigation of pockmarks, while examples of the former are source rock evaluation of particular formations and provenance studies in basins of sedimentation.

In parallel with the offshore mapping programme, new equipment and operational techniques have

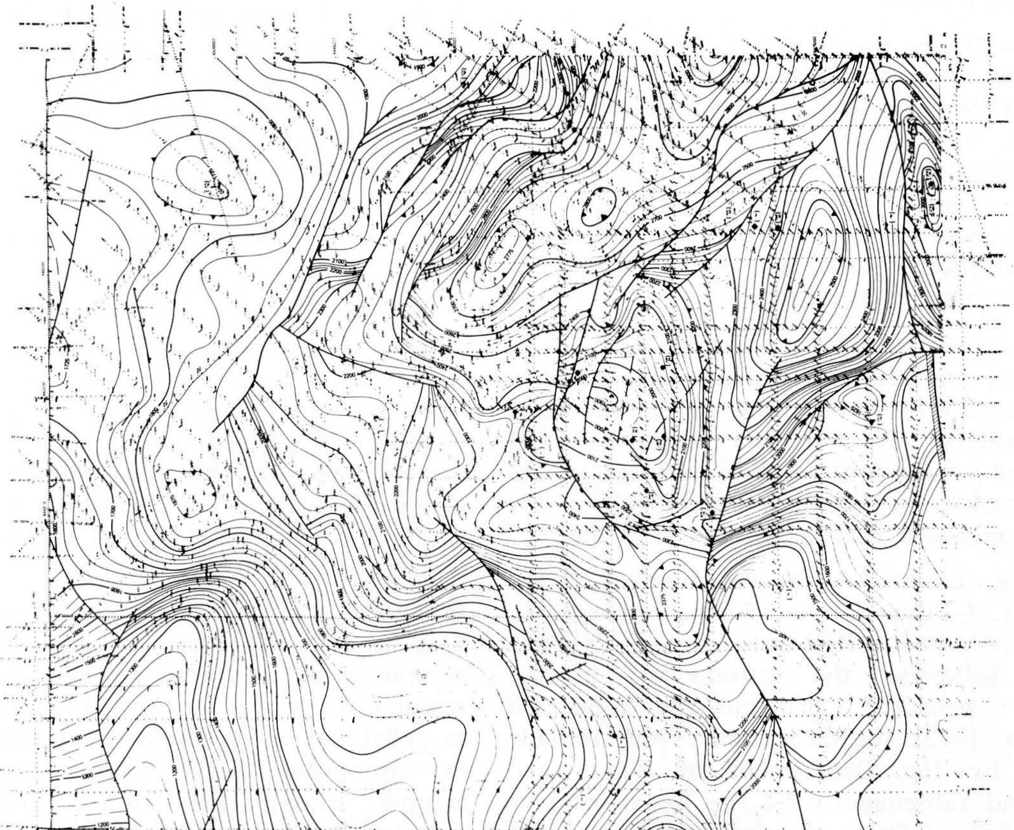

Figure 2. A seismic structure map from the North Sea, in two-way time, of the Cimmerian unconformity level, normally produced at a scale of 1:50 000. This map is typical of the horizon contour maps which may be produced at several horizons for any one area. All seismic profiles shot in the area are available for interpretation in the preparation of the map, but in practice not all are used. For reasons of confidentiality, location details are not shown and the seismic line numbers are

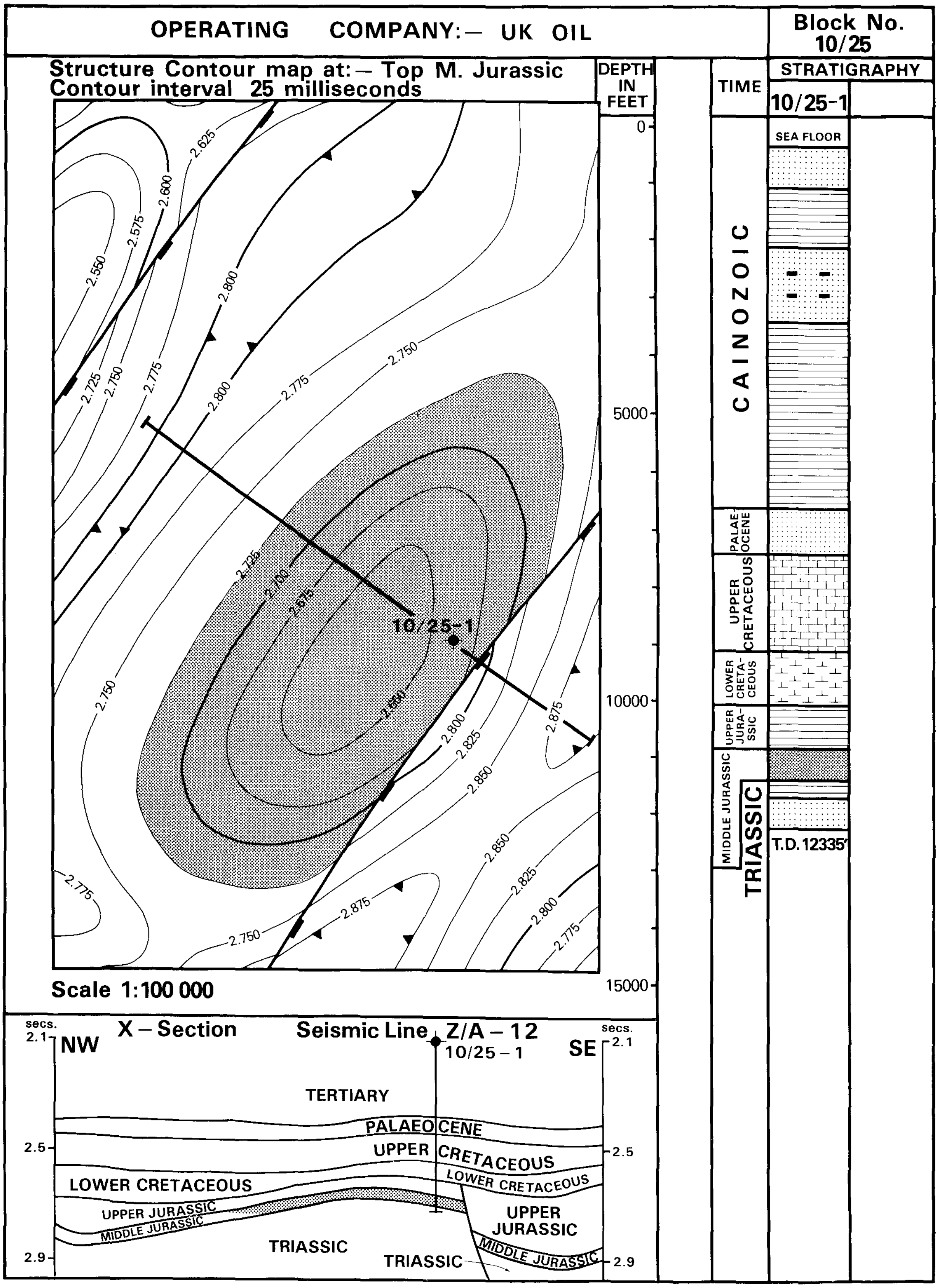

Figure 3. Hypothetical Well Data Sheet defining the main elements of a potential reservoir.

been developed in the fields of geophysics, seabed sampling, coring and drilling. The extensive field programmes have provided wide experience in operations organisation and management, and BGS is now well placed to offer a consultancy service in all aspects of the planning and execution of offshore surveys, as well as the evaluation and interpretation of the data and samples collected.

2. HYDROCARBON STUDIES

The database held by BGS on behalf of DEn includes more than 100 000 m of core, over one million cuttings' samples, the geophysical logs and reports for 4150 wells (both onshore and offshore), and seismic records from over 1.5 million line-kilometres of traverse.

These data are used to provide a quantitive assessment of potential hydrocarbon-bearing structures. Thus BGS provides for DEn, on a routine basis, relevant horizon contour maps at a working scale of 1:50 000 which are revised and updated as new information becomes available (Figure 2). All potential structures identified from the maps are summarised on Well Data Sheets (Figure 3) and Prospect Summary Forms. Prior to a licencing round, BGS provides DEn with the updated 1:50 000 scale maps for all relevant horizons, as well as Prospect Summary Forms and Well Data Sheets for each structure in the areas being offered for licence. Using these and other data, the Department is then able to assess the bids made by companies. The detailed field and reservoir simulation studies are carried out within DEn.

Regional geological studies undertaken include special studies of the structural setting and environments of deposition of, for example, the Brae and Brent areas. Such investigations greatly aid the search for subtle structural and stratigraphic traps. Basin-wide studies are particularly important in providing a context within which DEn can assess geological interpretations made by exploration companies.

Collaborative work by BGS and industry (Rhys, 1974; Deegan and Scull, 1977) has established stratigraphic frameworks for the southern and northern North Sea respectively, and their proposals have been adopted widely.

Other work has included the preparation of interval velocity maps covering most of the North Sea, and depth conversion studies, the latter being particularly important in areas of salt tectonics in the southern North Sea. Modelling of early Tertiary sedimentation patterns in the northern North Sea has been carried out, while special studies of Tertiary volcanism have provided new evidence on the extent of dyke swarms and discovered extrusive centres, including the Erlend centre north of Shetland (Gatliff and others, 1984). Gravity modelling has aided the Tertiary volcanic studies, and been used successfully in the Moray Firth (Dimitropoulos and Donato, 1981) and South-West Approaches (Day and Donato, 1982).

Special studies on penecontemporaneous deformation in the chalk and overpressuring in chalk reservoirs have contributed to an understanding of the Cretaceous sequences in the North Sea, while recent work has identified Carboniferous redbed sediments in the eastern Irish Sea. Seismic interpretation and radio-isotope dating of basement sequences in wells has allowed the extension of the Moine Thrust to be mapped beyond the north of Shetland and has provided a tectonic model for the area. Additionally, studies of the opening of the Rockall Trough and the North Atlantic from the interpretation of data in the deepwater areas to the northwest of Britain have also been published (Smythe and others, 1983).

The data held by BGS on behalf of DEn, and the interpretations made from these data, are mainly confidental. Nevertheless every effort is made, in co-operation with DEn and the industry, to publish data either through conferences or in the scientific literature. BGS staff also arrange core interpretation workshops which have been well supported by both industry and universities.

3. MARINE OPERATIONS

The beginning of offshore work was heralded in 1966 by the examination of aeromagnetic anomalies in Loch Ewe and the Moray Firth using a towed magnetometer and a shallow seismic profiling system. In the same period, scuba-diving geologists from the Land Survey mapped small areas of Carboniferous outcrop off eastern Scotland (Eden and Smith, 1966). The following year, reconnaissance survey work began in the Irish Sea and continued in 1968, together with work in the Sea of the Hebrides and a detailed study of the Humber Estuary (McQuillin and others, 1969). The first Continental Shelf Unit was formally established in 1967, followed by a Marine Geophysics Unit in 1968 and a second geological unit in 1969.

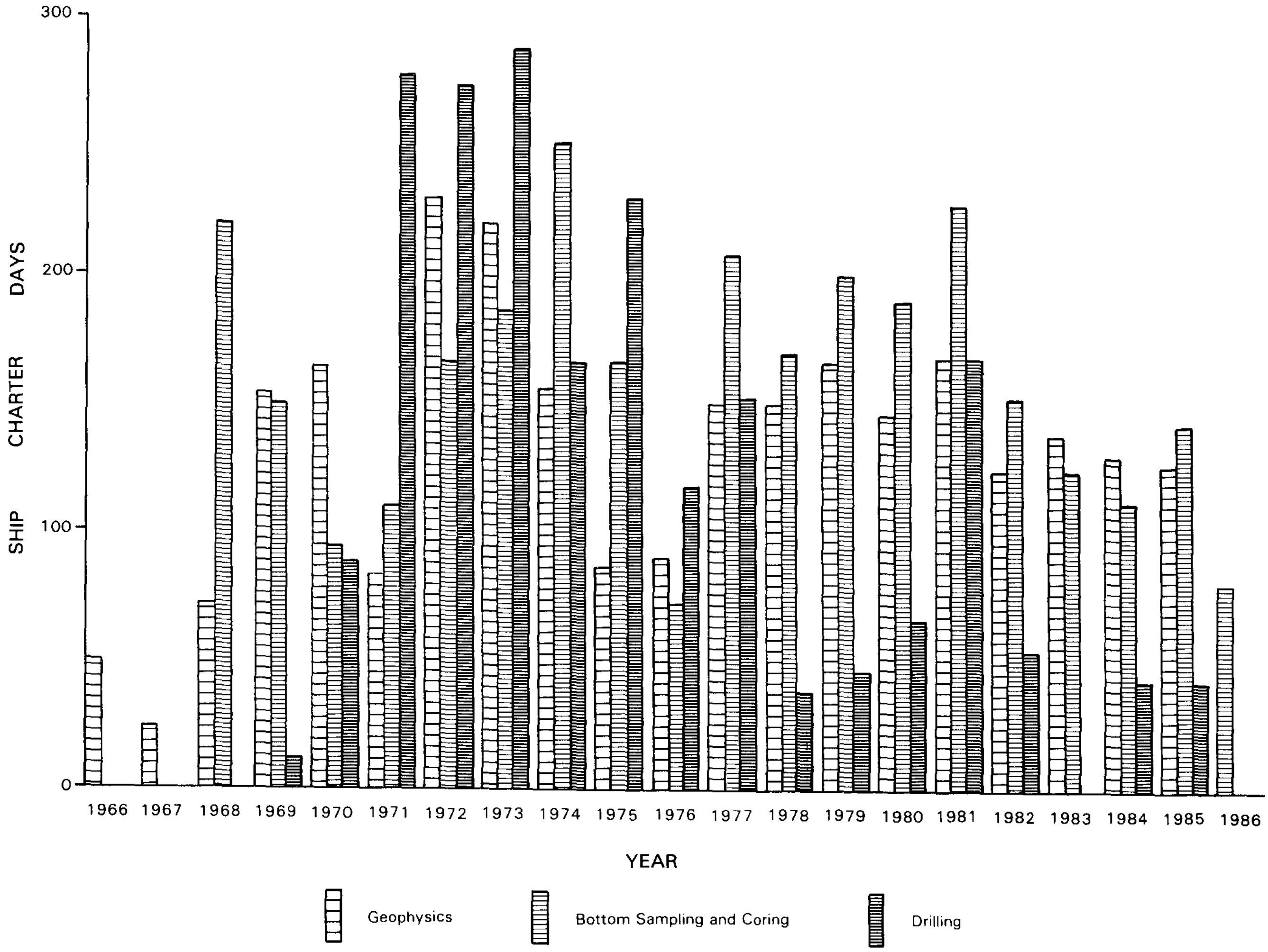

Figure 4. Ship utilisation during the BGS mapping programme. From 1970 to '75, *M.V. Whitethorn* was used as a sampling and drilling vessel.

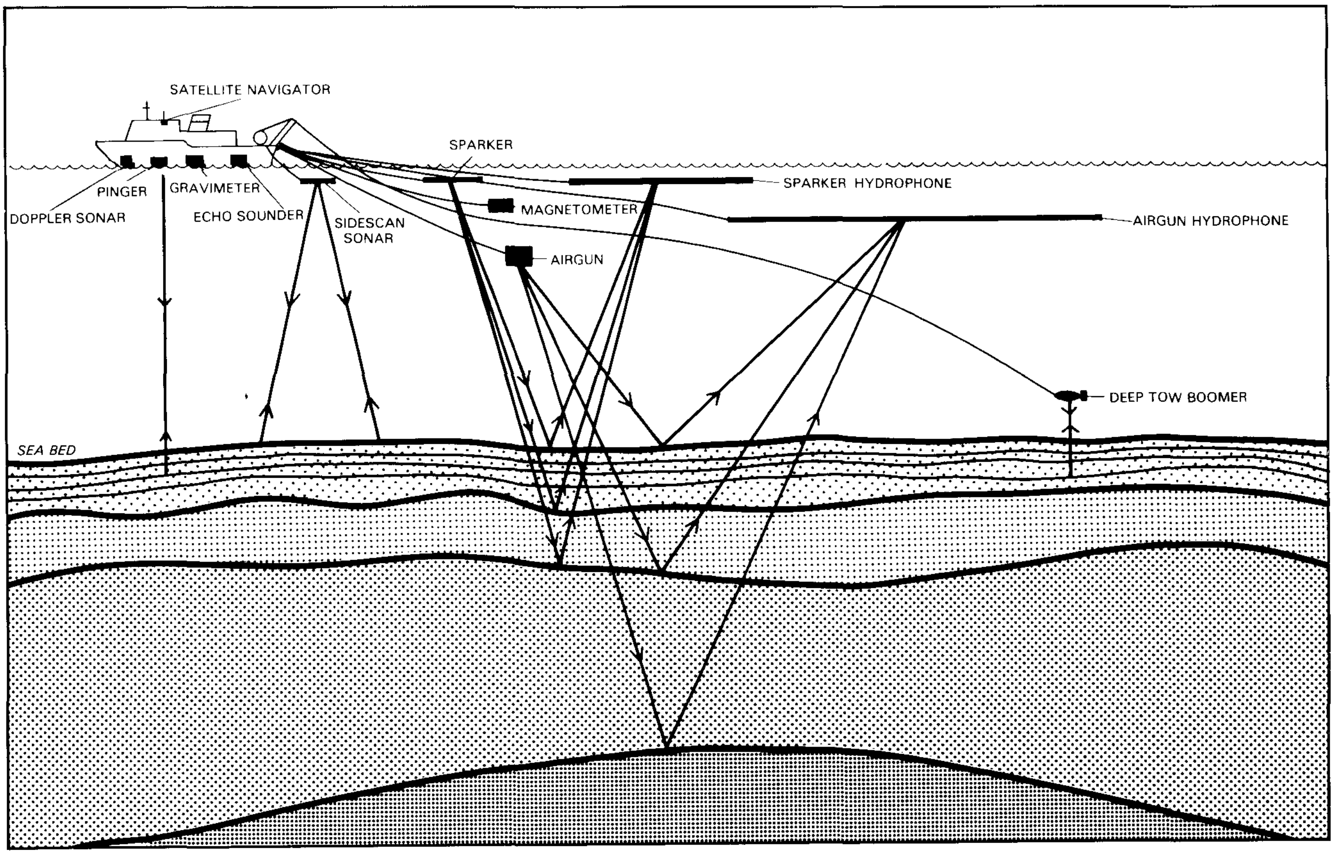

Figure 5. Towing configuration of the simultaneously operated geophysical equipment used in the mapping programme.

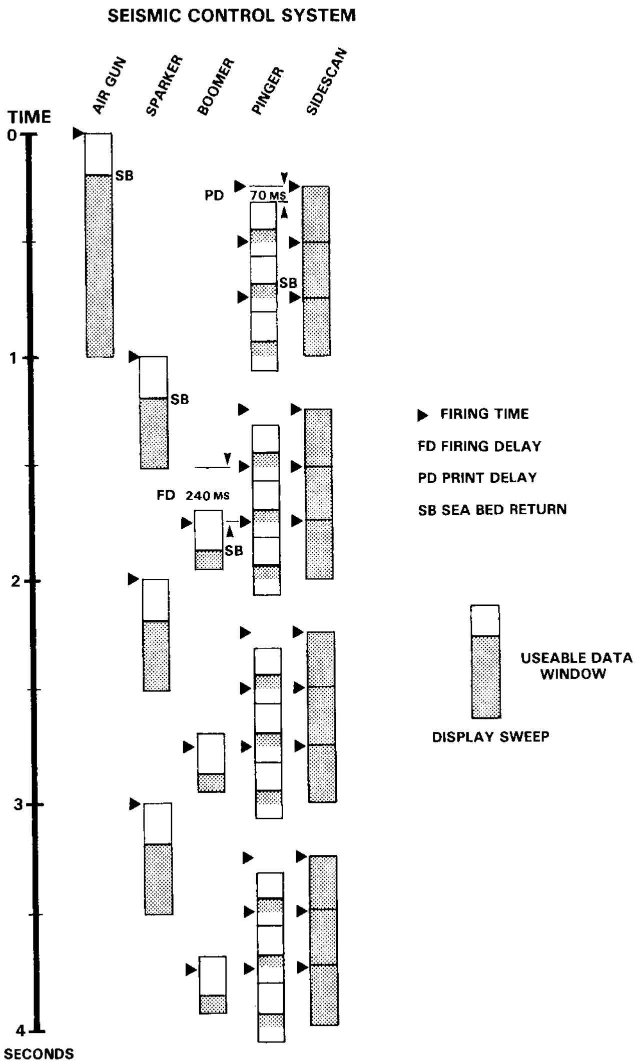

Figure 6. An example of a sequential firing sequence used during routine multi-instrument seismic surveys. The firing delay times for each instrument are designed to minimise interference between sound sources and receivers, and to optimise record quality.

From the outset, the Survey used ships chartered from the commercial market and were thus immediately involved in the selection and modification of vessels for survey work. A wide variety of both anchored and dynamically positioned vessels have been used, including small inshore craft and fishing vessels of all sizes, cargo and passenger ships, rig-supply boats and hovercraft. For more specific tasks, site investigation drilling ships are chartered and, on occasions, seismic vessels and a semi-submersible drilling rig have been used.

Additionally, geologist divers have collected samples or made *in situ* measurements in shallow waters, and some sampling and observation work was carried out in the early seventies using 'Pisces', a manned submersible (Eden and others, 1971). This was followed by the development of the unmanned submersible 'Consub' by the British Aircraft Corporation for BGS (Ardus, 1986). The use of this vehicle was pioneered by BGS and a Mark II version was developed subsequently for use by industry.

The systematic collection of data in any given area has followed a pattern; namely a geophysical survey in the first year, seabed sampling and coring in the second, and shallow drilling in the second or third years. Such field programmes have on occasions involved up to three ships working simultaneously for several months per year (Figure 4).

Accurate navigation is a vital element of any survey, and a revolution in positioning accuracy has occurred during the course of the mapping programme. At first Main Chain Decca was used, often only achieving best accuracies of some hundreds of metres. Special Hifix chains were used for some surveys, but these were limited by both practical and financial constraints. It was not until the introduction of one of the early satellite navigation systems linked to doppler sonar that levels of accuracy of some tens of metres could be achieved. Main Chain Decca has continued to be used for seabed sampling, though borehole sites, which are occupied for longer periods, have been positioned using accurate radar ranging or satellite navigation.

Geophysical surveys

The geophysical surveys (McQuillin and Ardus, 1977; McQuillin and others, 1979) were designed to acquire high-resolution seismic profiles to provide information on both the seabed and shallow subsurface, together with medium-resolution penetration to elucidate the underlying solid geology. The latter permit integration of interpretations with those made from deep seismic records. Gravity and magnetic data also provide information on the deeper structure of basins and the nature of underlying rocks.

The equipment suite in a typical geophysical survey currently includes echosounder, pinger and/or deep-tow boomer, sparker, airgun or watergun, sidescan sonar, magnetometer and gravimeter (Figure 5). All this equipment is operated simultaneously, and the firing of the seismic systems is co-ordinated by a Seismic Control System developed by BGS (Figure 6), which minimises interference between the instruments (Dobinson and others, 1982). Given the broad requirements of the survey, the advantages of simultaneously acquiring records which provide details of the seabed and near surface together with data down to 0.5-1.0 second are significant and maximise the cost-effectiveness of ship charter and operation. To date, some 200 000 km of multi-equipment seismic traverses have been run (Figure 7).

Many modifications have been made to the geophysical equipment over the years . A major development has been the modification of the Huntec deep-tow boomer which has now been operated at tow depths down to 1000 m. A small 400 Joule sparker has been added to the fish body, giving the option to operate as either a deep-tow boomer or sparker.

During a geophysical survey, the geologist on board makes an initial interpretation of the data and, in a more detailed appraisal, sample and drilling sites are identified. The seabed sampling, coring and drilling programmes are designed to calibrate the seismostratigraphy established from interpretation of the geophysical data.

Seabed sampling surveys

At first much of the sampling work concentrated in coastal areas, to some extent influenced by the water depth limitations of the vessels used in the early years. Subsequently, the *M.V. Whitethorn* was chartered in 1970 for five years, and operated eleven months per year as a drilling ship which also carried seabed coring and sampling equipment (Ardus and Rose, 1975). Initially, most requirements were met by equipment which was already available, but soon the Survey found it necessary to initiate the design and development of new instruments to cope with increasing water depth, a harsh working environment and the nature of the geological terrain.

The seabed sampling and coring ships normally carry a Shipek grab for bottom sampling and a gravity corer and 6 m vibrocorer for sediment coring. Vibrocore stations require the survey vessel to maintain position by anchoring or by dynamic positioning relative to a transponder mounted on the corer. In the early 1970's, a small underwater rockdrill was built which has subsequently been developed and integrated with the 6 m vibrocorer (Pheasant, 1984) to provide the capability of drilling, vibrocoring or water-jetting through sediment to drill underlying rock (Figure 11). The rockdrill system presently has a maximum penetration of 5.5 m and a capability to sample sediments and rock in water depths down to 2000 m.

Over 25 000 seabed samples have been collected, and preliminary descriptions and analyses of the samples have been carried out onboard ship. Ashore, the grab samples are described further, and subsamples taken for particle size, micropalaeontological and geochemical analyses. The sediment cores are split longitudinally, photographed, described and subsampled for particle size, micropalaeontological, palaeomagnetic and geochemical analyses. Some geotechnical properties are also measured onboard and subsamples taken for laboratory testing. Cores may be X-rayed and non-destructively scanned for acoustic velocity and bulk magnetic susceptibility. Rock cores are described and subsampled for analysis ashore.

Shallow drilling

The BGS drilling programme has been an essential element of the reconnaissance survey. Although the boreholes penetrate at most a few tens of metres into solid rock, this has proved sufficient to identify and date many of the units recognised in the seismic records. Drilling at the feather-edge of basins has often made possible the identification of rocks which form the earliest sediments infilling a basin. This approach is cost-effective for exploration and BGS borehole data have, as a result, been consulted extensively by the oil industry.

A modified land rig operated over the side of the *M.V. Whitethorn* was used from the late sixties. Subsequently, site investigation drilling vessels were used, including the dynamically positioned ships *M.V. Wimpey Sea Lab* (later re-named *Pholas)* (Figure 12) and the Norwegian ship *Bucentaur*. The drilling techniques on these vessels have been modified to meet BGS requirements and the Survey, in the course of this work, has developed its own suite of drilling equipment specifically designed for shallow geological exploration (Figure 8). The drilling technique is based on a conventional marine wireline system, drilling in uncased holes and using a standard 5" inch API drillstring bored out to 4 inch ID. In some cases a natural gamma log record is also taken, but because the tool is operated through the pipe and not in open-hole, it is not practicable to deploy radioactive sources. This equipment and BGS' associated expertise is now used widely by industry both in UK waters and overseas (Ardus and others, 1982; Skinner, 1987).

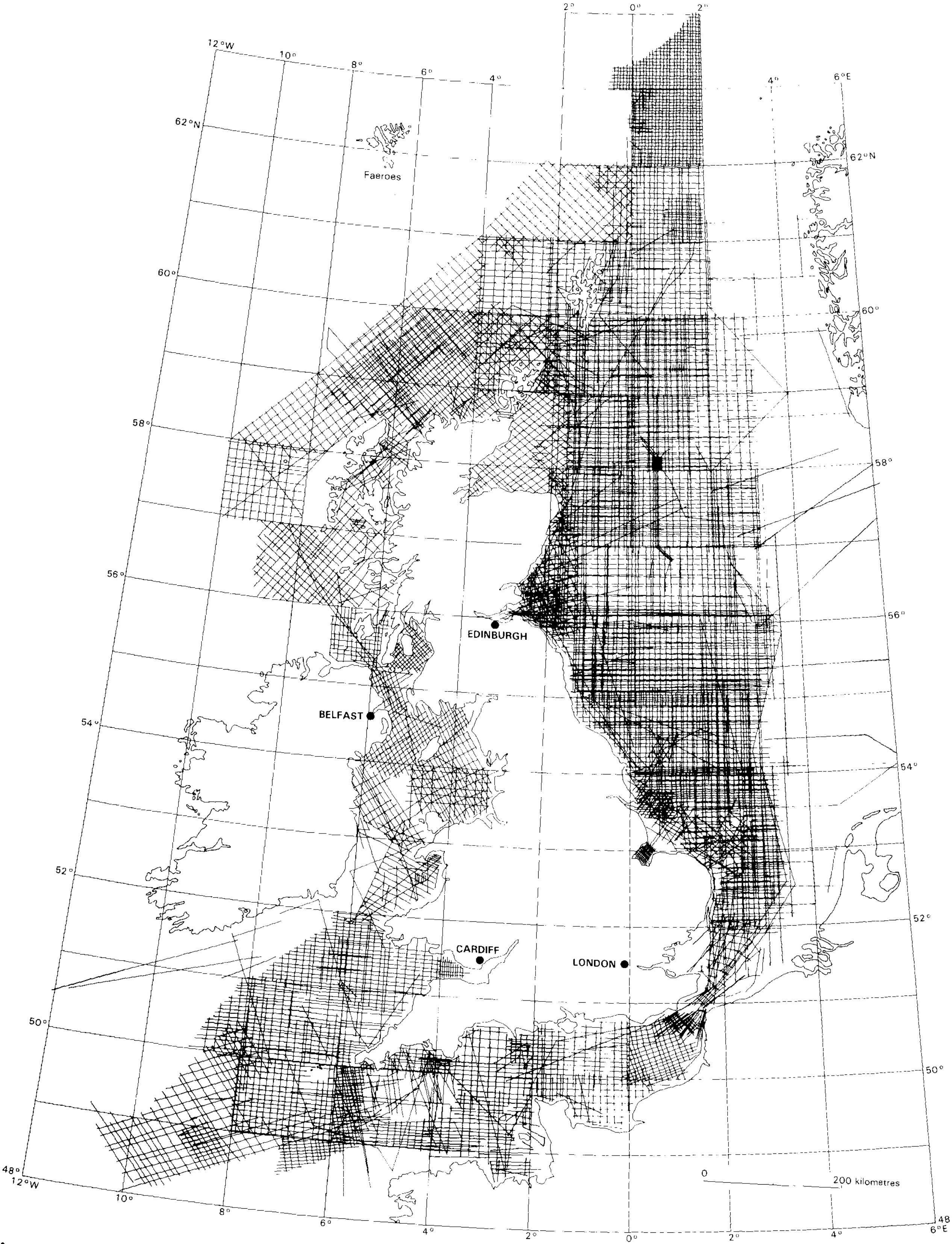

Figure 7. 'Multi-instrument' seismic tracks shot by BGS around the UK. The lines indicate the density and orientation of the coverage.

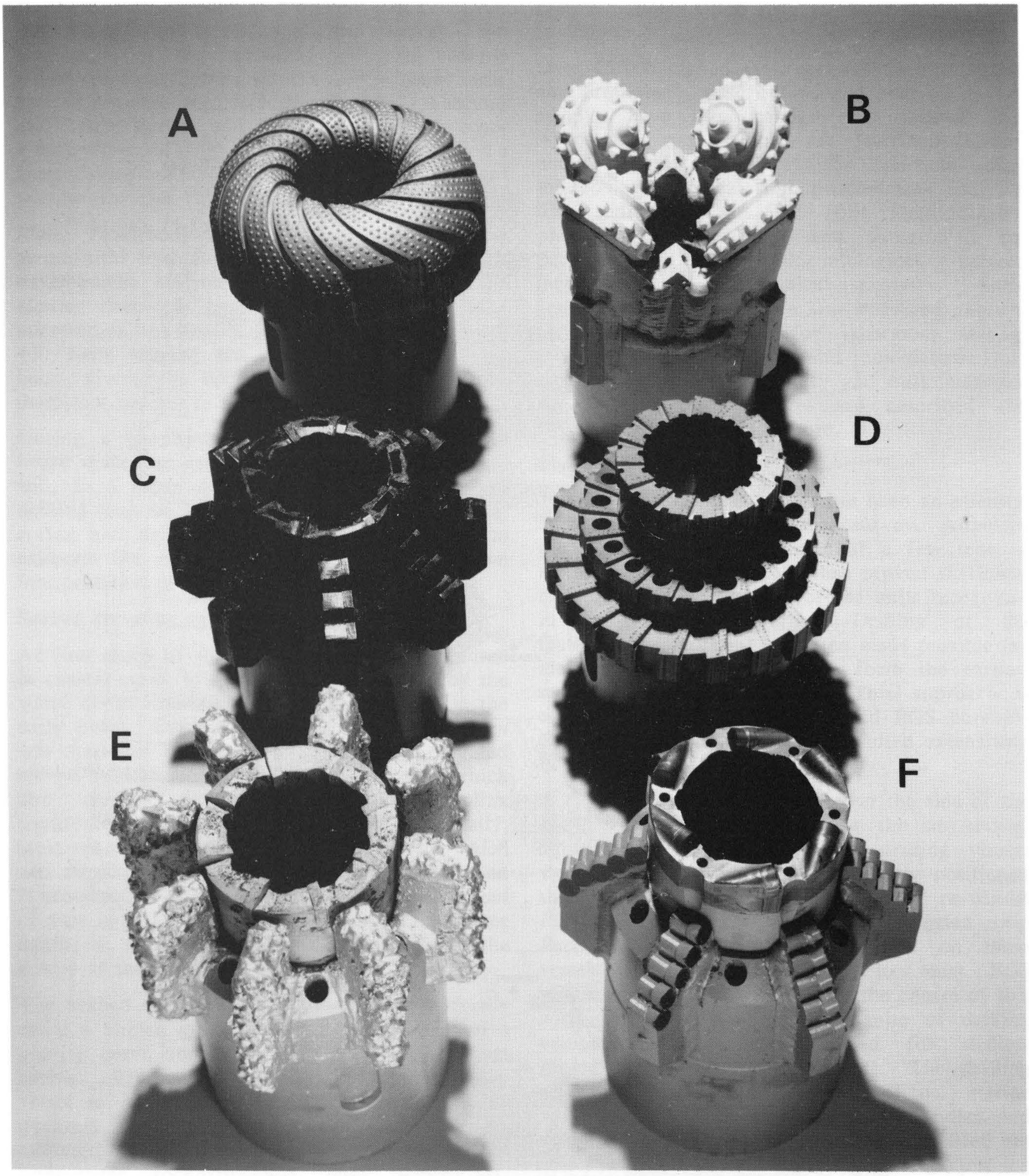

Figure 8. Examples of some of the coring bits used by BGS. Only bit A is available from standard manufacturers catalogues and is a surface set natural diamond bit with spiral face discharge. Bit B is a tungsten carbide tipped roller coring bit while C and E are tungsten carbide faced coring drag bits with interchangeable face and port discharge pilot sections. Bit D is a sawtooth diamond bit with interchangeable pilot, and F is a polycrystalline diamond bit having greater cutting and wearing abilities.

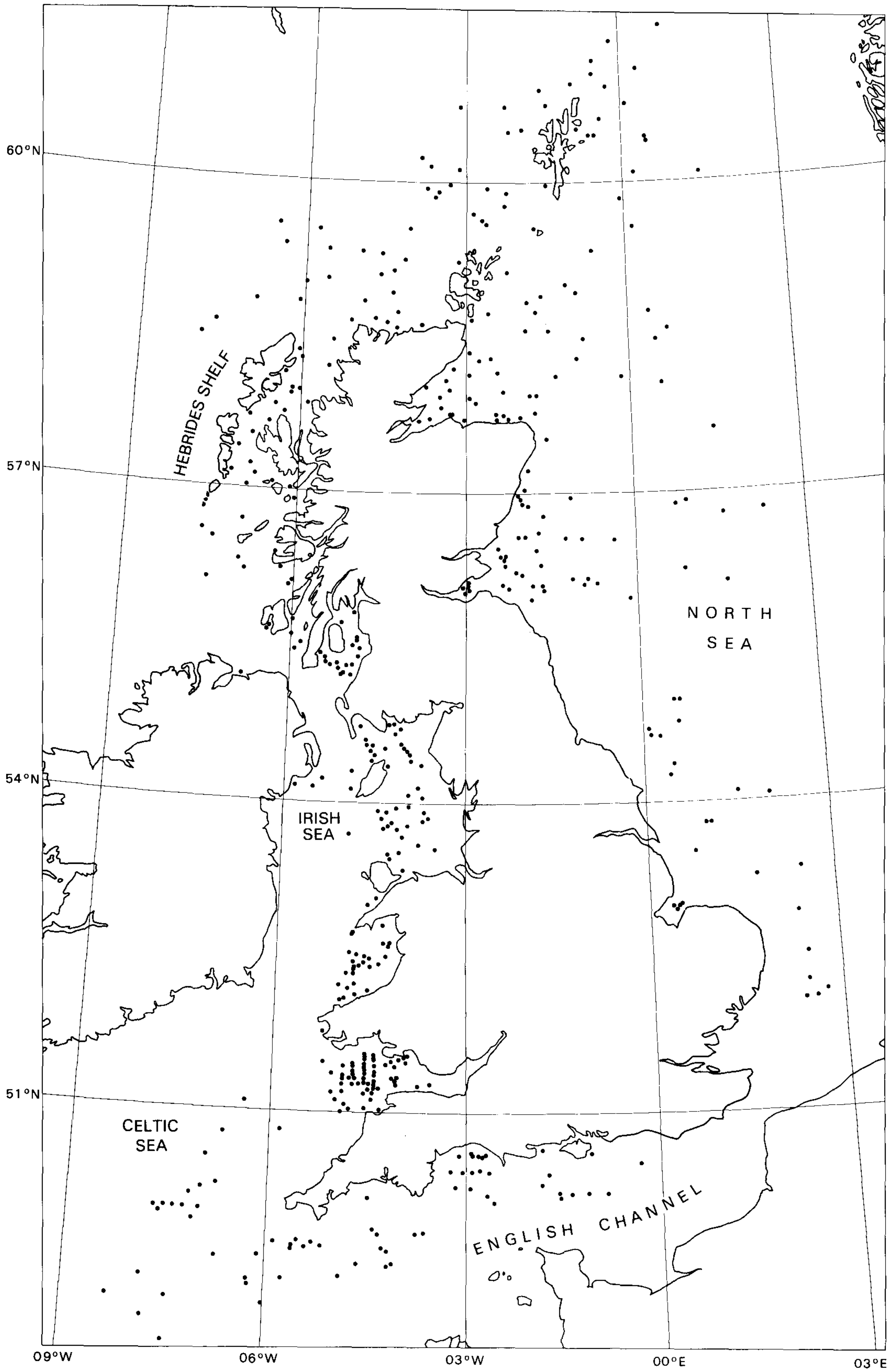

Figure 9. Shallow boreholes drilled by BGS as part of the Regional Mapping Programme.

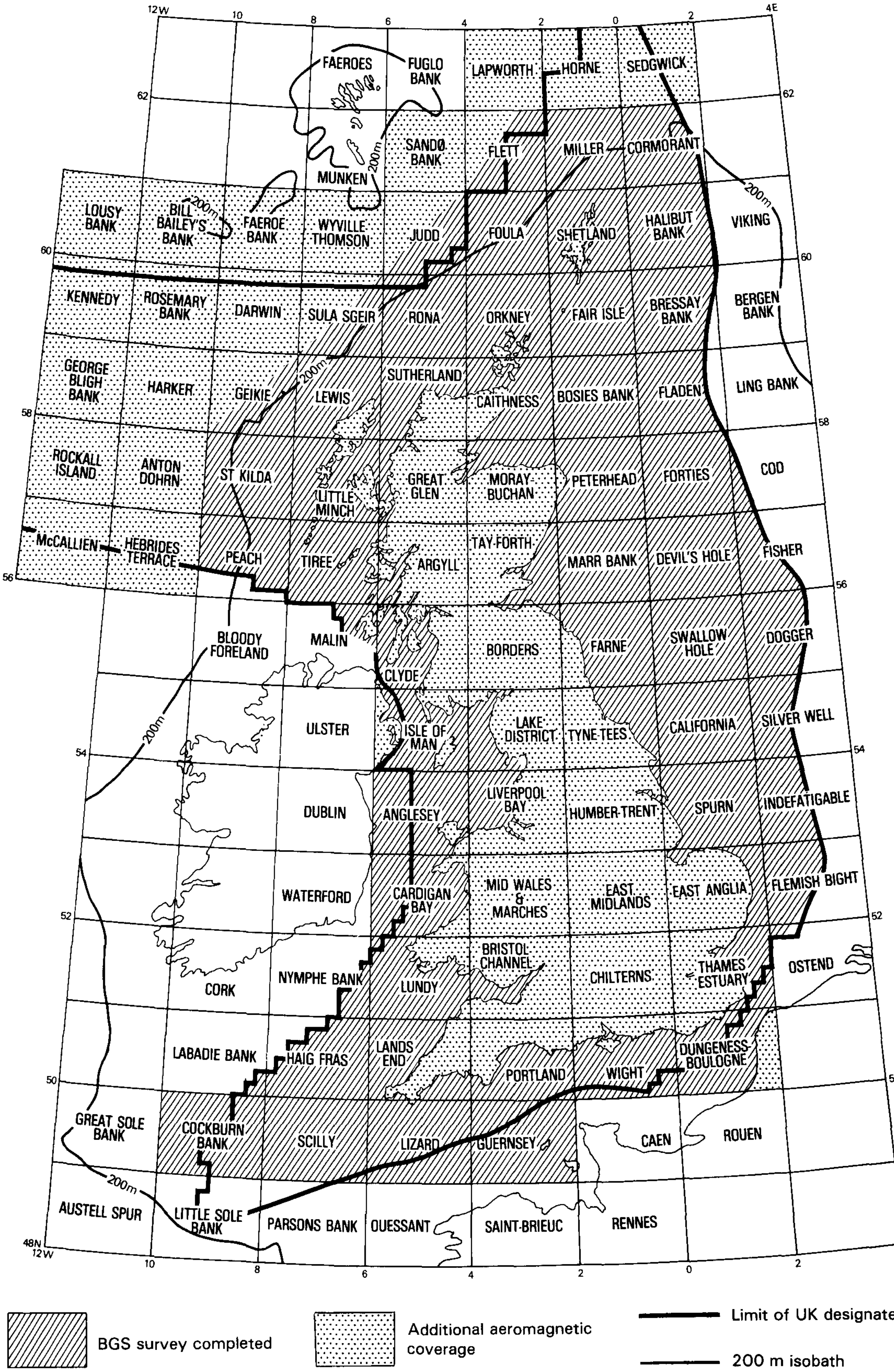

Figure 10. 1:250 000 map names for part of the UK Continental Shelf. Areas covered by aeromagnetic and BGS shipborne geological and geophysical surveys are also shown.

To date, the deepest borehole drilled by BGS penetrated to 235 m below seabed, but boreholes are commonly 100-150 m deep requiring a site occupancy of two to three days. Over 500 shallow boreholes have been drilled on the shelf (Figure 9), and although some sites were chosen to explore the Quaternary sequence, most were selected to identify the underlying solid rock. The cores are logged, tested and subsampled onboard ship, where X-ray and other non-destructive testing may also be carried out.

In 1977, BGS with DEn used a semi-submersible rig, *Zephyr I*, to drill at four sites in the South-West Approaches (Evans and others, 1981). The wells were drilled in water depths ranging from 75 m to 136 m and total depths varied from 873 m to 1230 m. The cores proved Triassic or Devono-Carboniferous rocks beneath a cover of Cretaceous chalk or Liassic mudstone.

4. MAP PRODUCTION

Following the decision to prepare the offshore series of geological maps at a scale of 1:250 000 using the Universal Transverse Mercator projection,the shelf was divided into sheet areas each covering one degree of latitude by two degrees of longitude. The sheets are identified by the position of their southwest corner and have each been given names (Figure 10).

A series of up to six maps are prepared for each sheet area:

1. Sea Bed Sediments
2. Quaternary Geology
3. Solid Geology
4. Bouguer Gravity Anomaly
5. Free Air Gravity Anomaly
6. Aeromagnetic Anomaly

The geological maps (1-3) are printed in colour with descriptive text, diagrams and sections dispayed in the margins (Figures 13, 14 and 15). The black and white gravity and aeromagnetic maps are either printed or reproduced as paper or transparent film dyelines. (Figures 16 and 17). A total of 341 maps is planned for the series.

The maps are prepared largely from data collected during the BGS field programmes, supplemented by information from the Hydrographic Department, universities, other institutes, released exploration data and shallow geological data from site investigation studies.

Sea Bed Sediment maps

The maps show the distribution of sediment types, and isobaths to indicate the topography of the sea-floor (Figure 13). The sediments are defined in terms of a modified Folk classification (Folk, 1954) as percentage of gravel and the ratio of sand:mud (silt and clay). The map may also contain information on bedforms, water surface or subsurface current data, and the position of fixed structures. Explanatory text together with diagrams defining specific parameters of the sediments, such as carbonate content or the nature and distribution of the sand fraction, appear on the map margins. Depending on the area, photographs of the seabed, sidescan sonar records, geotechnical data and computer-graphic perspectives may also be included. The positions of seismic lines and sample stations are shown.

The maps highlight the wide variation in the seabed around Britain (BGS, 1987 a and b; Pantin, *in press*). To the west and northwest of Scotland, the seabed is rugged with rock outcrops and a variable cover of sediments. Recent biogenic material is an important element in the superficial deposits, with broken shell locally forming over 90% of the sediment. Extensive rock platforms exist around Orkney and Shetland and occur intermittently in the coastal zone off eastern Scotland and northern England. In the English Channel and South-West Approaches, sediment cover may also be incomplete leaving extensive areas of exposed rock at the seabed. Much of the southern North Sea is covered by sand which is moving under the influence of tidal currents and storm action, with large sandwaves and banks forming prominent features. In the central North Sea there is much silty clay, and the subtle influence of slight bathymetric variations becomes evident, with the finer sediment in the depressions. Fine sediment predominates in much of the Minch and the Irish Sea where extensive mud belts occur, reflecting either deep water or the effect of tidal gyres.

Quaternary Geology maps

These maps have proved to be the most complex and difficult of the series to prepare (Figure 14). They are constructed primarily from the grid of seismic profiles from which a seismostratigraphy has been established. Once the geometry of these units has been mapped they are, wherever possible, cored in an attempt to establish litho-, bio- and chronostratigraphies. Additional information on the maps commonly includes cross-sections, a description of the units and a stratigraphic diagram relating them in space and time, block or fence diagrams correlating boreholes, and a table of geotechnical properties. In areas where the Quaternary is thin or the cover incomplete, the Quaternary and Sea Bed Sediment maps are combined and published as a single sheet.

The thickness of the Quaternary deposits varies greatly, and up to one kilometre has been discovered in parts of the North Sea (Fannin, 1975), including a thick wedge of early Pleistocene sediments in the southern North Sea. A stratigraphic framework for the Quaternary in the North Sea has been established (Stoker and others, 1985; Cameron and others, 1987) and forms a basis for correlation between the British and European successions and the deep-ocean record from the North Atlantic. Extensive erosion features, which can be correlated over wide areas (Cameron and others, 1987), show the succession to be incomplete but the presence of middle and lower Pleistocene sediments has been proved by palaeomagnetic and palaeontological methods (Stoker and others, 1983).

A striking feature of the Quaternary is the presence of large gully and valley systems, some of which have been cut beneath an ice cover (Cameron and others, 1987). The unravelling of the complex relationships of sedimentary facies and their rapidly changing physical properties has greatly aided soils engineers in foundation design, while the recognition of shallow gas from seismic records has contributed to the safety of offshore activities. The mapping of the Quaternary thus has important practical applications.

Solid Geology maps

The layout of the Solid Geology (pre-Quaternary) maps (Figure 15) follows a similar format to that of other maps in the series. They are constructed by interpretation of seismic profiles calibrated by boreholes and cores, and show the outcropping and subcropping pre-Quaternary geology, often with the aid of data made available by the oil companies. Where thick Tertiary sediments obscure the older rocks, horizon contours have been added to the 1:250 000 map, as well as being included in marginal diagrams. Horizontal sections, logs of released wells and a diagram illustrating the main structural elements of the area may also be shown.

The Solid Geology maps, which include the geology of land areas, highlight the extent of the Mesozoic and younger sequences offshore, contrasting particularly with the older rocks of northern and western Britain. In the North Sea, Mesozoic and older rocks form a relatively narrow nearshore platform which is buried by an easterly thickening wedge of Tertiary sediments. This cover of Tertiary sediment also surrounds the UK to the north and west where it occurs on the outer shelf. To the north and west of Scotland, there are fault controlled basins containing Mesozoic and upper Palaeozoic sequences, while in the Irish and Celtic seas and English Channel, thick Triassic and Mesozoic sequences are predominant. The extent of basement and intrusive rocks has been mapped, and some of the main structural lines on land have now been traced offshore. Investigation of deep crustal structure around the UK (Smythe and others, 1982) and the integration of the BIRPS (British Institutions Reflection Profiling Syndicate) lines with the existing database has added significantly to an understanding of the upper mantle and lower crust and their influence on the development of the overlying sedimentary basins.

Gravity Anomaly maps

Gravity data are presented as Bouguer Gravity Anomaly maps for the whole of the UK, including its sea areas (Figure 16). Anomalies are referred to the Gravity Formula 1967 and tied to the National Gravity Reference Net 1973 (Masson-Smith and others, 1974). The coverage on land averages one station per 2 km^2, and offshore it is typically a square grid of between 5 and 10 km spacing. The contour interval is 1 mGal on land and 2 or 5 mGal offshore depending on the quality of the data. Recent surveys have average crossover errors of 1 or 2 mGal, though older surveys have greater discrepancies. Free Air Anomaly maps are published in addition to the Bouguer Anomaly maps in areas of deeper water.

Magnetic Anomaly maps

Maps of the total magnetic field (Figure 17) are produced using the aeromagnetic surveys over Britain and inshore parts of the surrounding seas commissioned by the Geological Survey between 1955 and 1965. Commercial surveys are incorporated farther offshore. The surveys were flown to different specifications, and the flight-line interval varies from 2 to 9 km, with tie lines at 10 to 48 km spacing. As the data have been used without recontouring, the contour interval and reference fields vary. Northern Ireland is covered by a separate survey, which is published at a scale of ¼ inch to one mile (1:253 440).

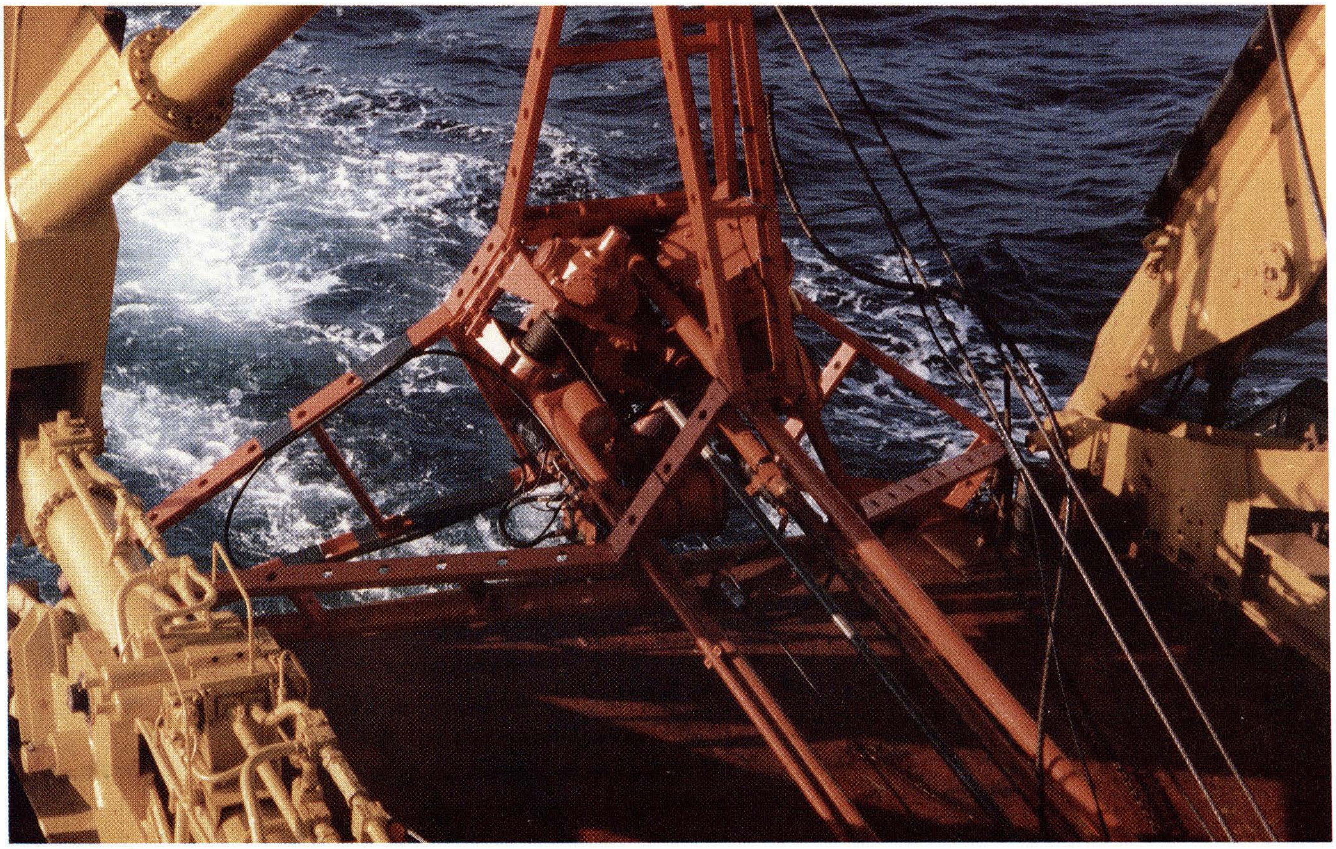

Figure 11. The BGS rockdrill developed in combination with the vibrocorer. A kelly drive mounted on the base plate provides rotation of the hexagonal outer barrel. A microprocessor mounted on the base plate monitors the drilling parameters which are controlled from the ship.

Figure 12. The dynamically positioned drilling vessel *M.V. Pholas*. BGS have used this ship to drill in over 460 m water depth, and to borehole penetrations of over 180 m below seabed.

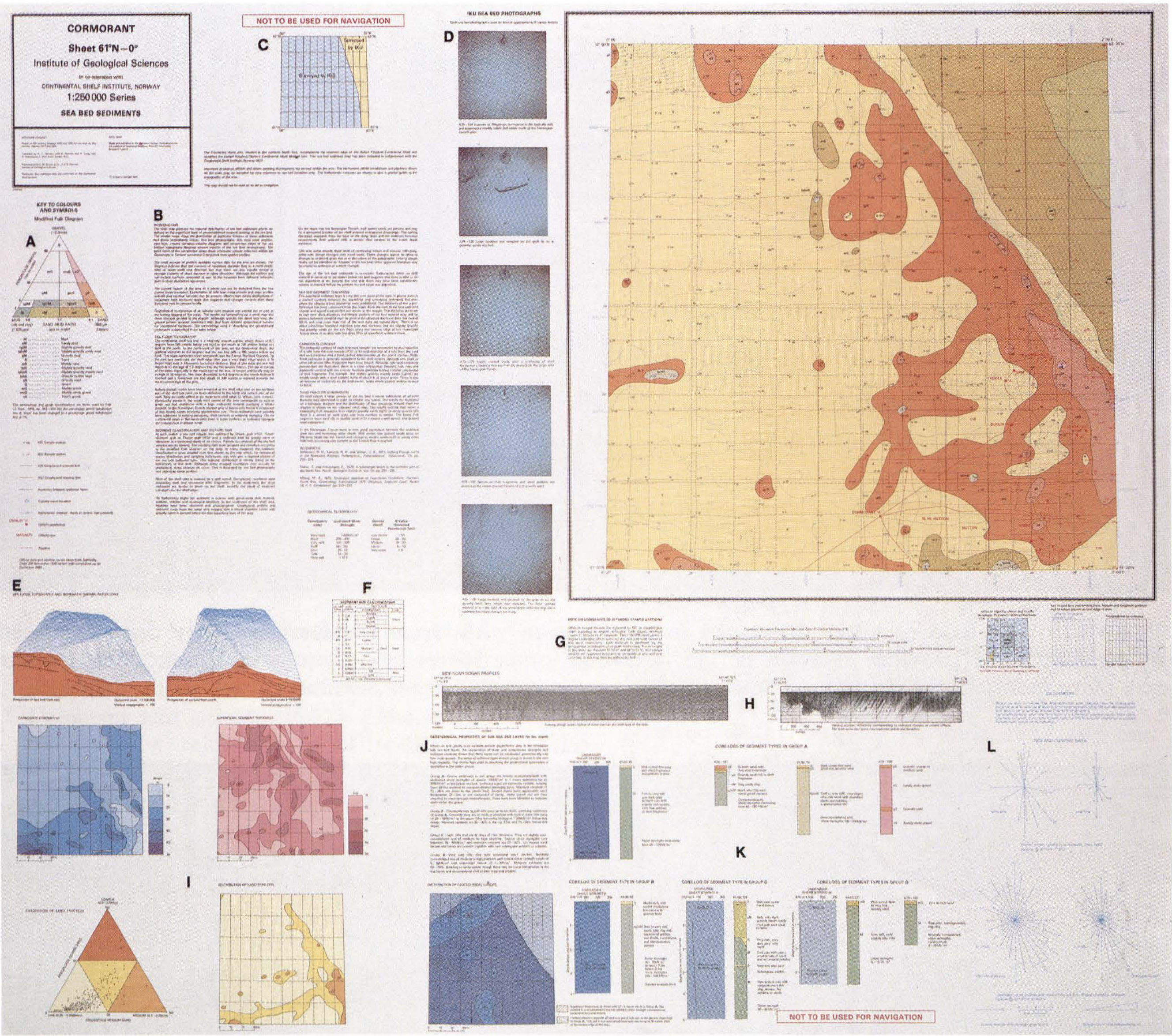

Figure 13. A photo-reduction of the 1:250 000 Series Sea Bed Sediment map of the Cormorant area (61°N-0°). Information shown around the margins of the map is as follows: **A**, key to colours and symbols including the modified Folk triangle defining sediment classes (Folk, 1954). **B**, Text describing the sediments and morphology of the area. **C**, Figure showing areas surveyed by BGS (blue) and by Institutt for Kontinentalsokkelundersøkelser (IKU) in the Norwegian sector (yellow). **D**, Seabed photographs. **E**, Computer drawn perspectives of the seabed. **F**, Table relating Phi, Wentworth and Folk sediment Classifications. **G**, Explanation of the BGS sample station numbering system. **H**, Sidescan sonar records. **I**, Diagrams depicting the carbonate content of the sediments, thickness of the superficial sediment layer and subdivision and distribution of the sand fraction. **J**, Diagram with description of the geotechnical properties of the seabed layer to 5 m depth. **K**, Lithological and shear strength profiles. **L**, Bathymetric and current information.

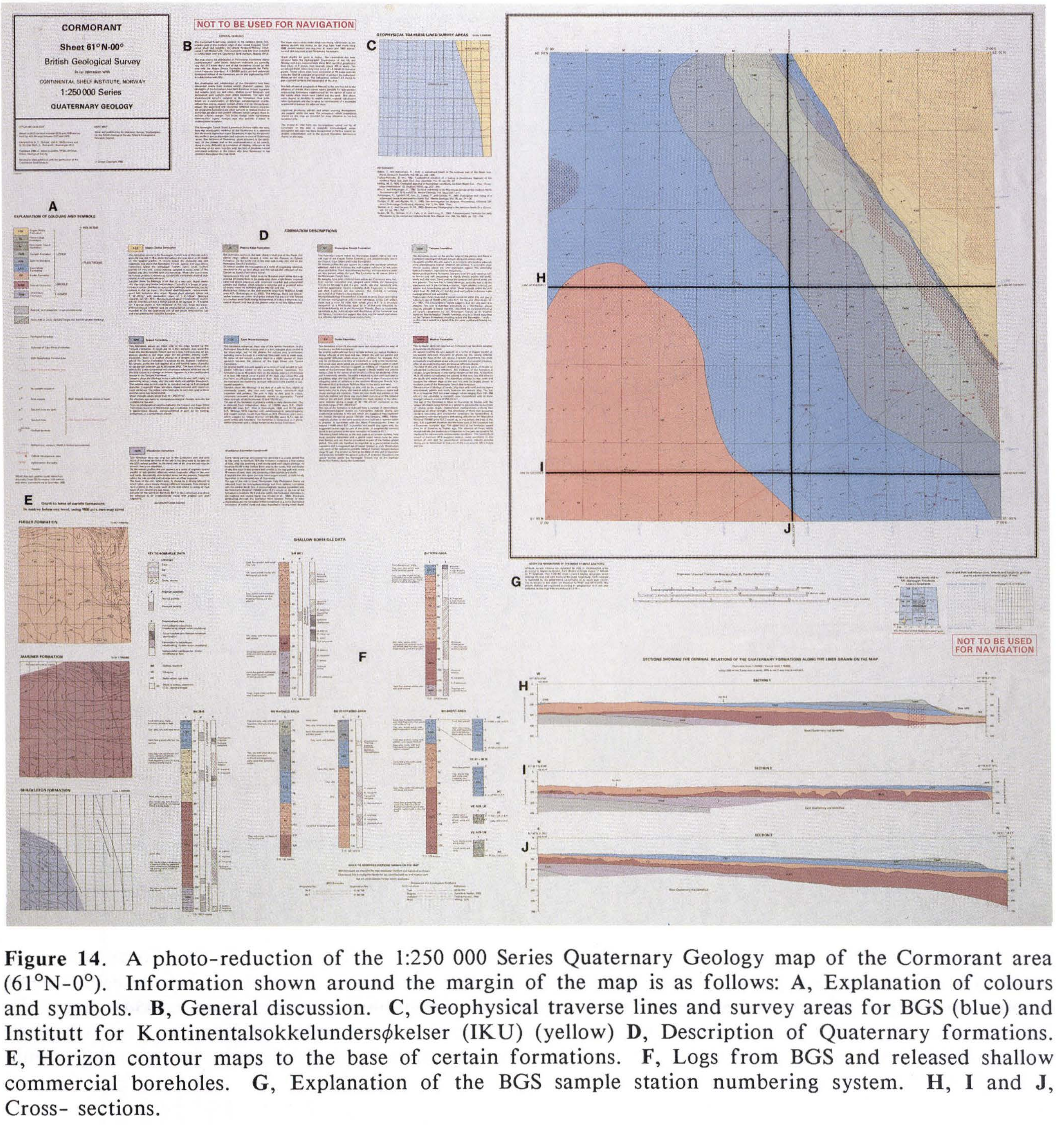

Figure 14. A photo-reduction of the 1:250 000 Series Quaternary Geology map of the Cormorant area (61°N-0°). Information shown around the margin of the map is as follows: **A**, Explanation of colours and symbols. **B**, General discussion. **C**, Geophysical traverse lines and survey areas for BGS (blue) and Institutt for Kontinentalsokkelundersøkelser (IKU) (yellow) **D**, Description of Quaternary formations. **E**, Horizon contour maps to the base of certain formations. **F**, Logs from BGS and released shallow commercial boreholes. **G**, Explanation of the BGS sample station numbering system. **H**, **I** and **J**, Cross- sections.

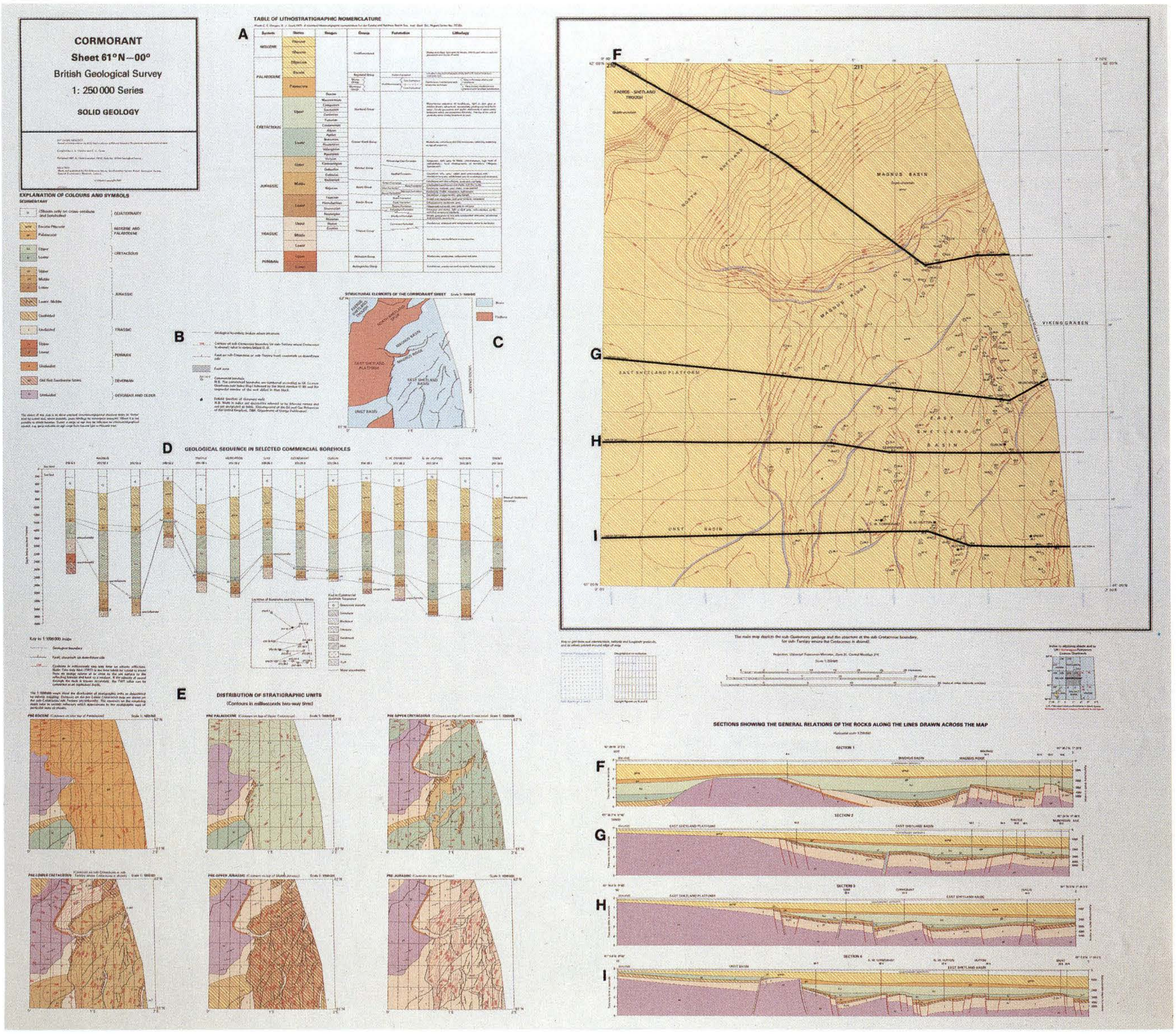

Figure 15. A photo-reduction of the 1:250 000 Series Solid Geology map of the Cormorant area (61°N-0°). The contours on the main map define the sub-Cretaceous boundary. Information shown around the margins of the map is identified as follows: **A**, Table of lithostratigraphic nomenclature. **B**, Explanation of colours and symbols. **C**, Structural elements of the area. **D**, Stratigraphic sequence from released wells with a location diagram. **E**, Subcrop maps showing the distribution of stratigraphic units. **F**, **G**, **H** and **I**, Cross-sections.

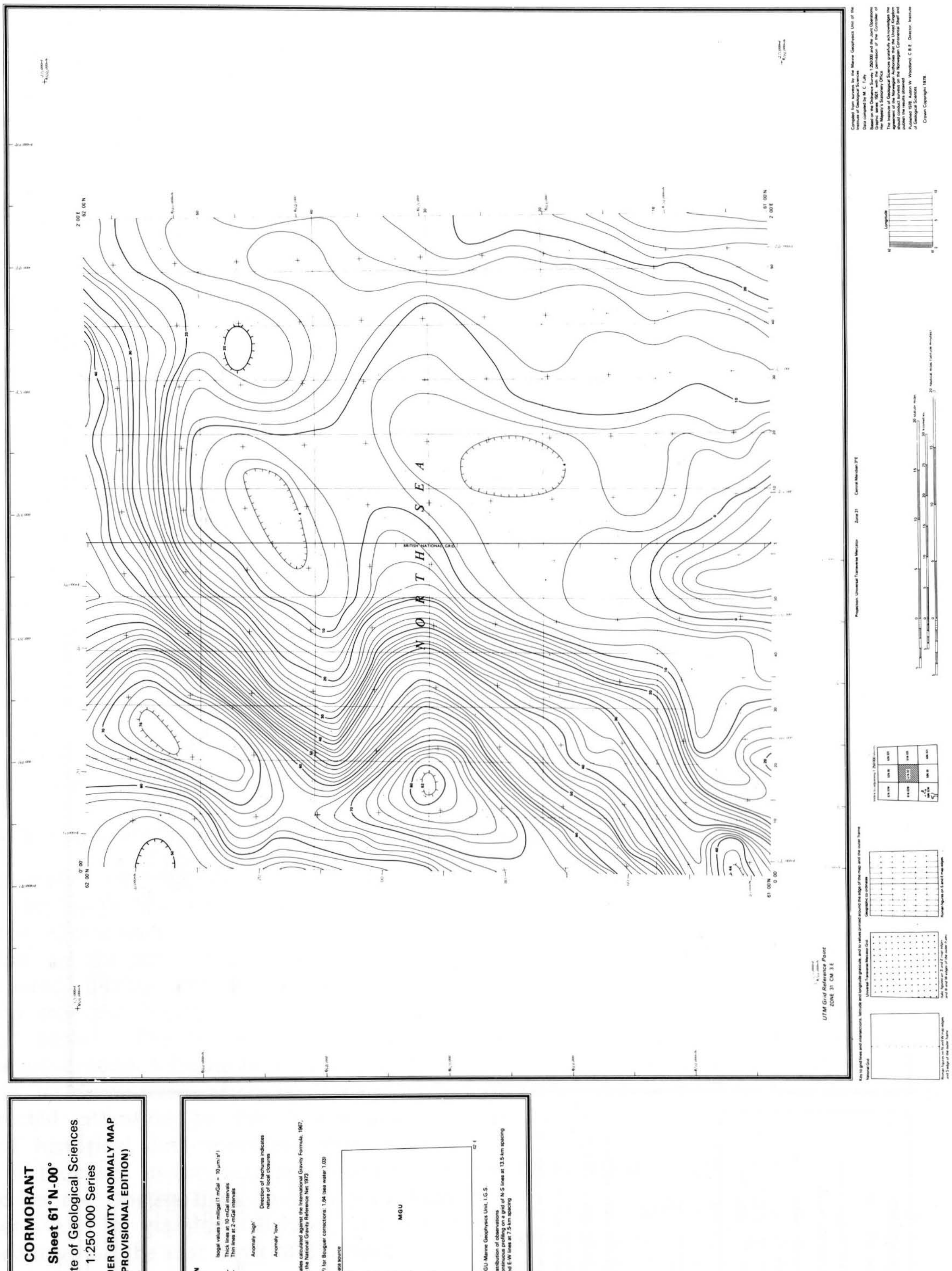

Figure 16. A photo-reduction of the 1:250 000 Series Bouguer Gravity Anomaly map for the Cormorant area (61°N-0°) (Provisional Edition). The map is available on paper or film. Contour values are in milligals (1 mGal = 10 μms^2) with a contour spacing of 2 mGal, and thicker lines at 10 mGal intervals. This map predates the change in name of the BGS from the Institute of Geological Sciences.

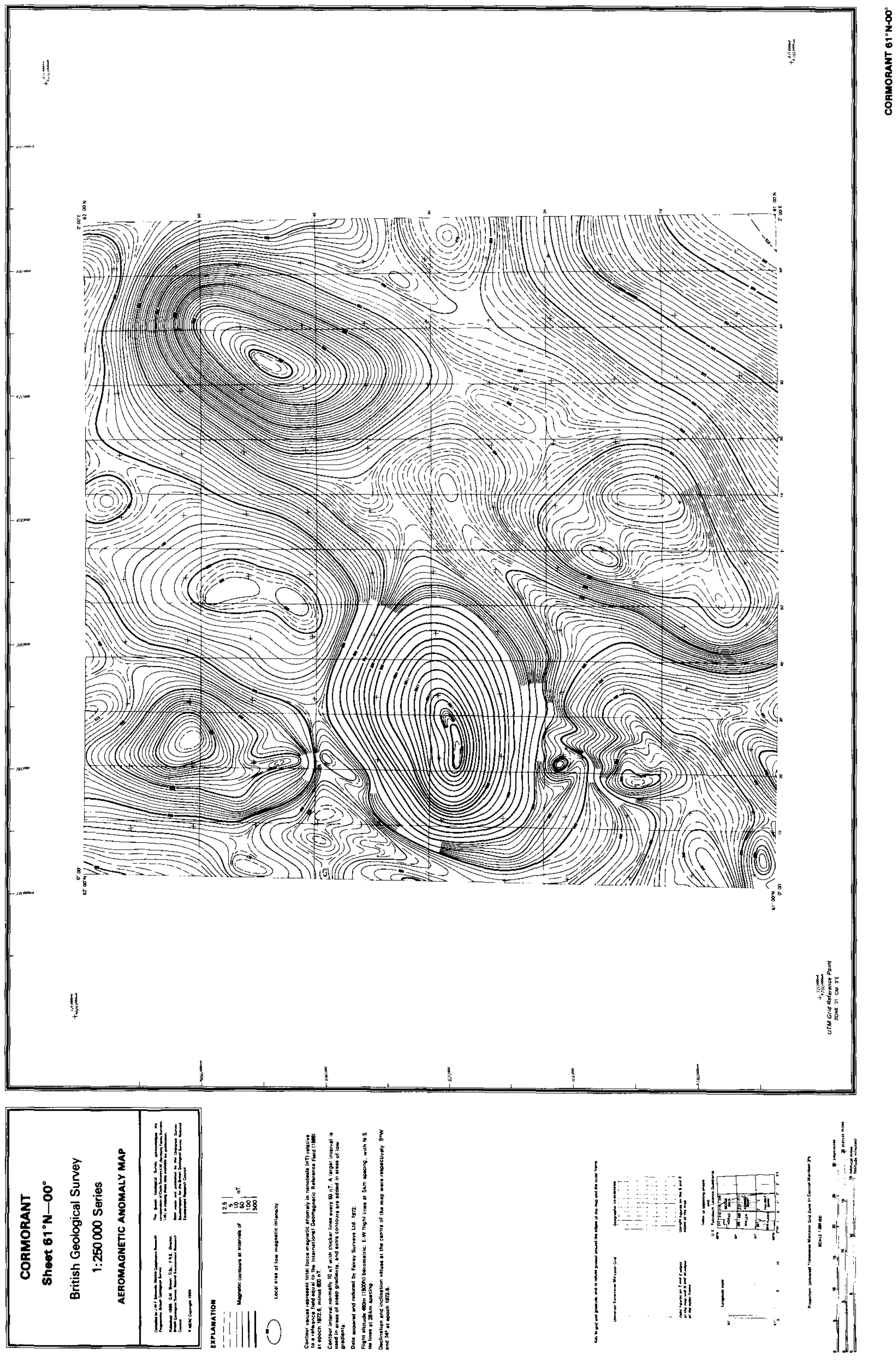

Figure 17. A photo-reduction of the 1:250 000 Series Aeromagnetic Anomaly Map for the Cormorant area. (61°N-0°) The map is available on paper or film. Contour values of total magnetic force are in nanoteslas (nT). The contour interval is normally 10 nT but may vary depending on the local gradient. The thicker lines represent 50 nT intervals.

Magnetic measurements are made during BGS offshore geophysical surveys using a towed proton magnetometer, but the survey line interval is not normally close enough to allow the anomalies to be contoured. Marine magnetic data are included only on maps where the aeromagnetic coverage is inadequate. Two magnetic anomaly maps consisting of both aeromagnetic and marine magnetic data have been published (Farne and Tyne-Tees).

Other maps and reports

Maps published at other scales include: the Sub-Pleistocene Geology of the British Isles and the adjacent Continental Shelf (1:2.5 million); the Pre-Permian Geology of the United Kingdom (1:1 million); Bouguer Gravity Anomaly maps (1:1 million) and two summary Sea Bed Sediment maps (1:1 million). Summary maps of the Quaternary and the solid geology at the 1:1 million scale are in preparation.

During the period of the survey, many reports on the geology of the offshore area have been produced, together with a large number of publications, (Evans, 1986). Additionally, the Survey is currently embarking on the production of a series of ten UK Offshore Regional Reports which will be broadly analagous in scope to the British Regional Guides for the UK landmass.

5. SEISMIC MONITORING

One unexpected outcome of the early mapping work in the North Sea was the recognition of a very thick Quaternary sequence, which led to speculation on the amount of subsidence which had occurred during the Pleistocene and the realization that the North Sea is still a rapidly subsiding basin. The LOWNET network of seismometers around Edinburgh regularly showed detectable, medium-sized offshore earth tremors that directed attention to the North Sea. A review of historical data supported this interest, because earthquakes in the northern North Sea in 1927 and on the Dogger Bank in 1931 were both felt extensively in mainland Britain, the latter causing damage on the east coast of England.

In the early 1970's, monitoring was directed to the landmass, thus while networks such as LOWNET were capable of recognising offshore events, the threshold of detection was inadequate and the ability to identify location and depth of occurrence was relatively crude. In 1979, the BGS Global Seismology Group and DEn embarked on a programme to improve North Sea monitoring with the establishment of three seismic stations in Shetland, followed by networks around Inverness and in East Anglia. These stations were complemented by two UK installations in Norway and, later, six Norwegian stations along their west coast (Figure 18). In addition, offshore stations have been established adjacent to the Beryl and Statfjord oil platforms (Figure 19). Monitoring of the Irish Sea is enhanced by linking UK based stations with Irish land stations.

Both North Sea stations were designed with similar configurations. A seabed seismometer is hard-wired to a tension-leg spar buoy from which data are transmitted to the adjacent platform. The Beryl station was installed in October 1980 and maintained until February 1985. The Statfjord station was installed in August 1985.

The improved network in the North Sea, with its enhanced detection threshold, show that the area is seismically active (Figure 20) and that the pattern of seismicity in the north is related to the main structural lines of the Viking Graben (Marrow and others, 1987). It is notable that no events have been recorded on the Shetland Platform or from the Horda Platform. Event magnitude varies considerably, up to 4.8 ML within the monitoring period, although earthquakes between magnitudes 5 and 6 ML have occurred in the region. Data derived from the network form part of the BGS world seismological database and are held on open file.

Care must be taken in translating these data into an assessment of quantifiable risk, because more information is needed to enable accurate judgements to be made that will assist both industry and those responsible for providing design guidance regulations. To date the work has concentrated on the North Sea, but an extension of the network to the north and west of Britain is required if an adequate database is to be established.

6. GEOCHEMISTRY

The establishment of geochemical baselines is an important part of the study of the sedimentary environment of the seabed around the UK. The increased demand for monitoring of the environment, including the introduction of EEC controls on waste disposal, has highlighted the value of baselines and the need for further information. The data are also of value in identifying mineral concentrations and can be used in the early stages of mineral exploration and source identification.

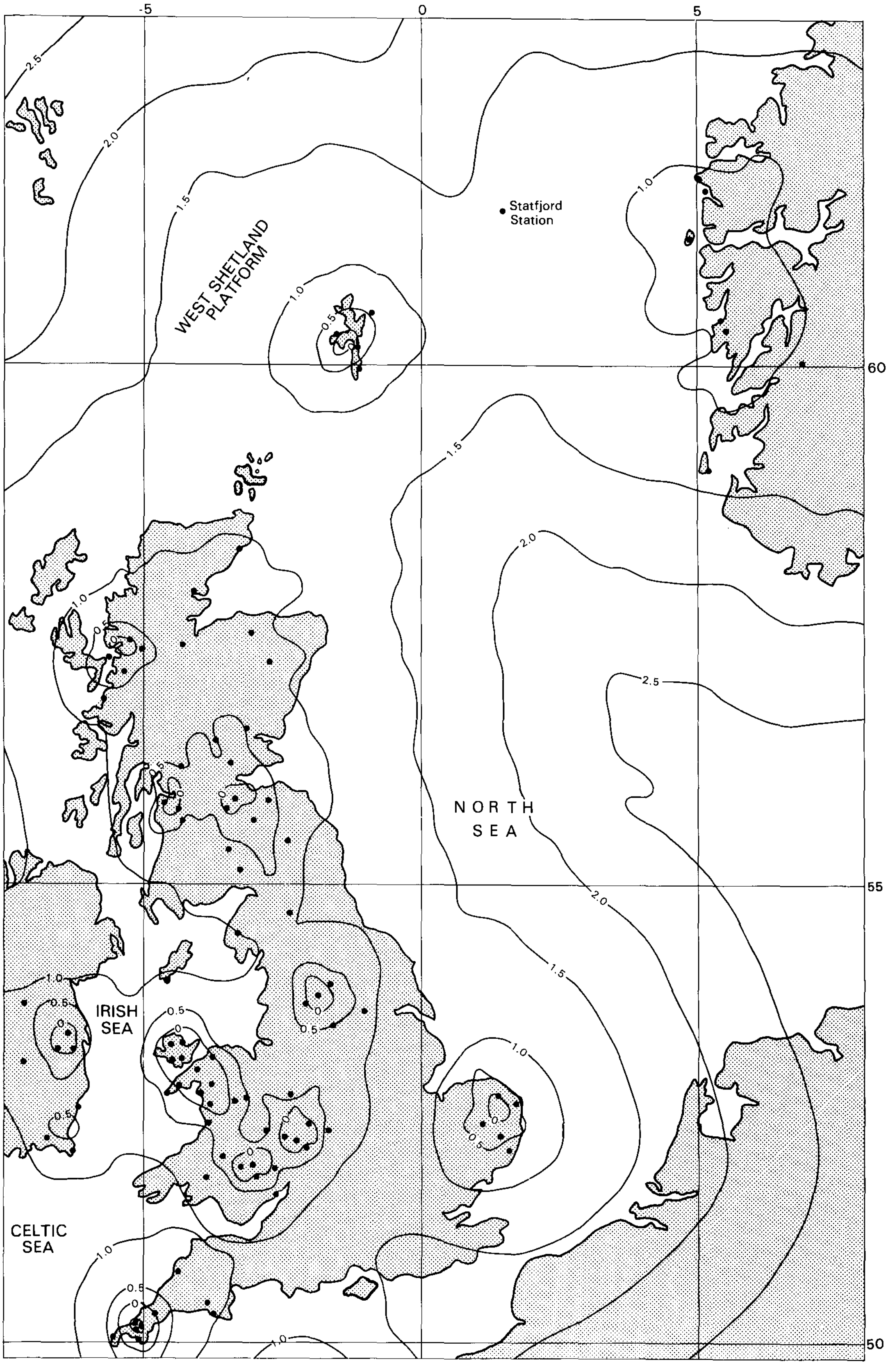

Figure 18. Seismic recording stations in the UK and surrounding areas. The contours indicate earthquake detection threshholds by the Richter local magnitude scale.

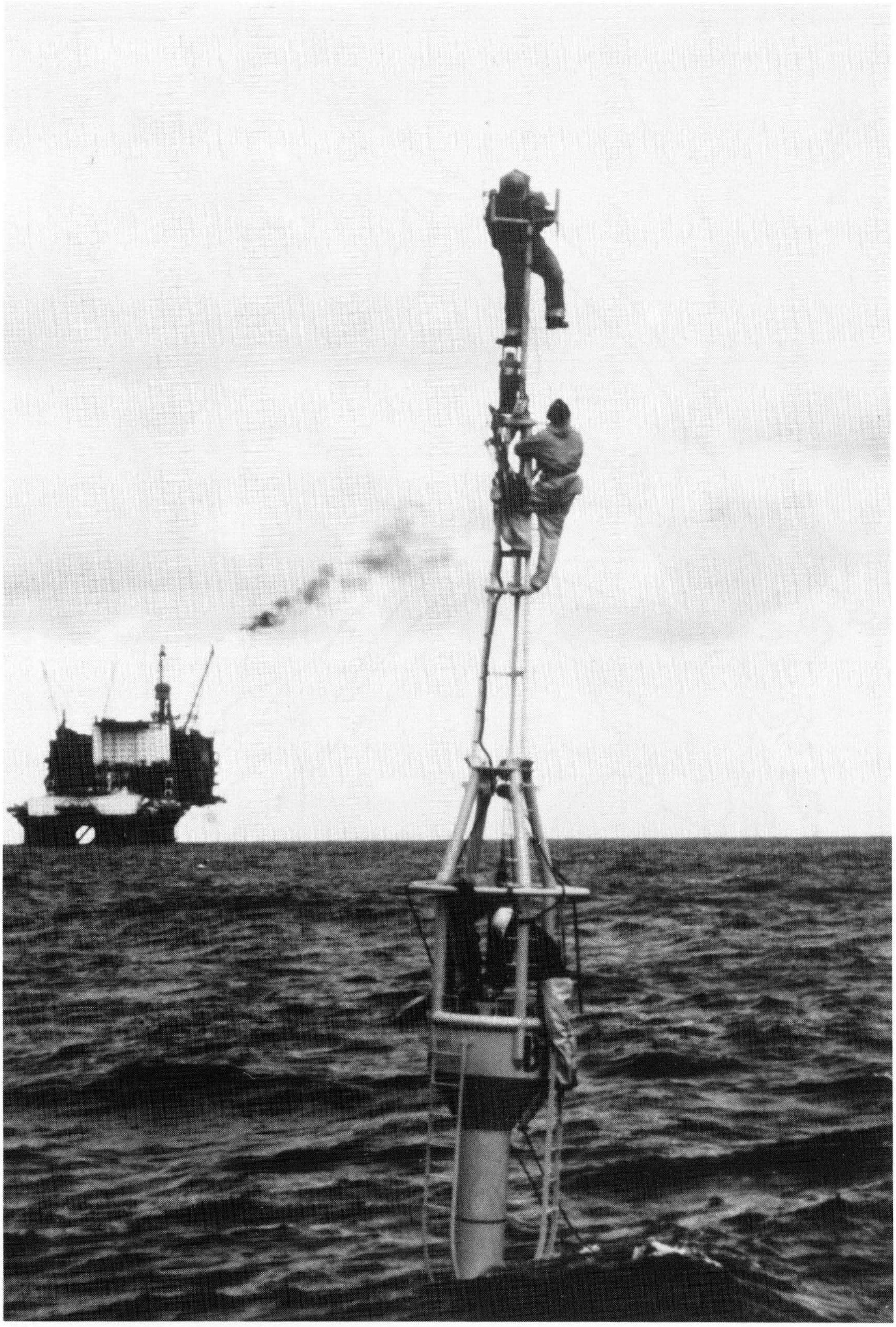

Figure 19. Installation by BGS staff of a transmitting buoy adjacent to the Statfjord Platform in August 1985. The buoy is hard-wired to the seabed seismometers, and data are transmitted to a recording station on the platform. The magnetic tapes are taken ashore for analysis every 7 days.

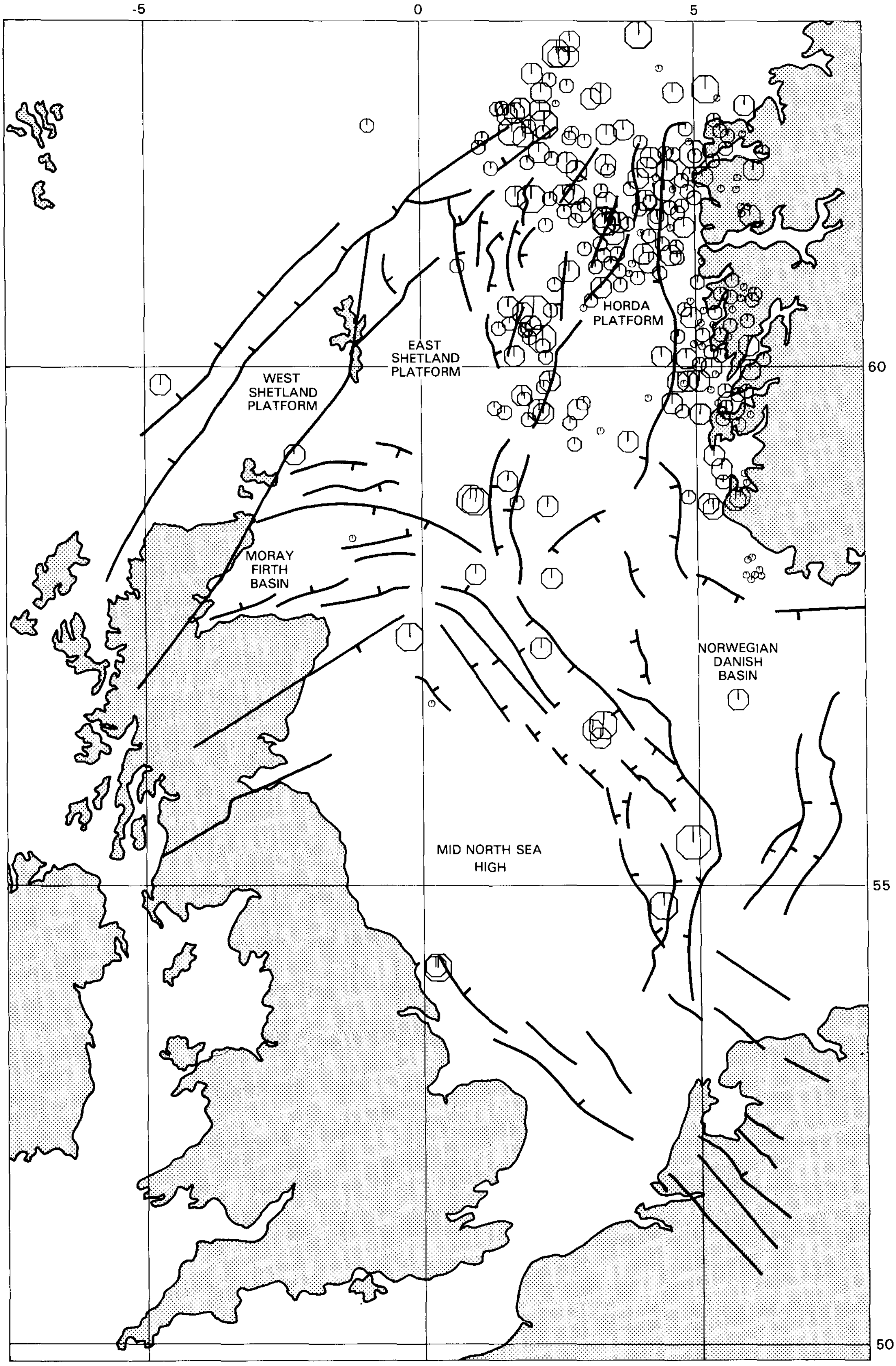

Figure 20. Seismic events in the North Sea (1980-85). Event magnitude ranging up to 4.8 ML is indicated by symbol size. Note the relationship of the epicentres with the main structural lines of the graben areas.

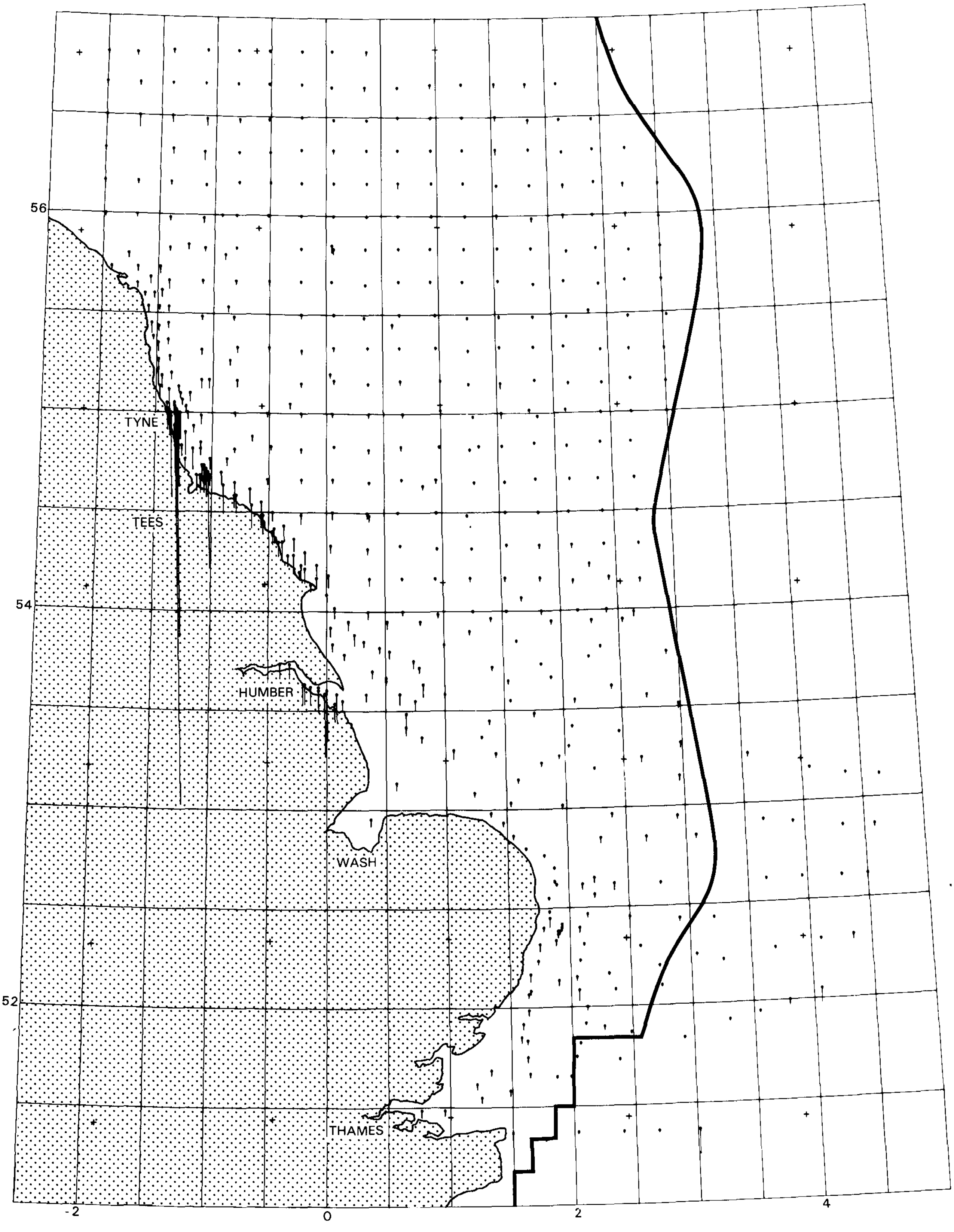

Figure 21. Zinc concentrations in seabed sediments in the southern North Sea. The concentrations are represented by the length of the line drawn at each sample point. The highest value, off the mouth of the River Tyne, represents a concentration of 2240 ppm.

BGS geochemical work began in 1971 with an investigation of heavy metal pollution extending from estuaries into the relatively enclosed basin of the southern North Sea. Seabed samples were collected on an approximate ten-mile grid and the concentration of cadmium, lead, zinc, mercury and copper were determined (Nicholson and Moore, 1981). The ships for much of this work were provided by the research vessels of the Ministry of Agriculture, Fisheries and Food and NERC. In 1975, the geochemical programme was integrated with the Regional Mapping Programme.

The preliminary southern North Sea work was completed in 1978 and the sample location data and geochemical results are held on magnetic disc. Some maps have been produced (Figure 21), and the data can be presented in a similar form to that of the land geochemical atlas (Institute of Geological Sciences, 1978). The samples were later analysed for a further twenty two elements (Nicholson and Stuart, 1985) and are available on disc.

From 1979 to 1984, sampling was completed over the remaining parts of the North Sea, and in 1985 samples were collected to the northwest of Scotland. Some 9500 samples have been collected and approximately 3500 have been analysed for 22 elements, and an additional 3500 partially analysed. Analysis is continuing on the remaining samples.

Samples are now collected using a Shipek grab. Some of the early samples were collected using a stainless steel cone dredge to avoid the possibility of heavy metal contamination, but this was shown to be unnecessary. Approximately 40 to 50 gm subsamples are freeze dried onboard ship, quartered, and passed through a 2.0 mm mesh nylon sieve and stored in sealed plastic containers for analysis. A variety of techniques have been used, but most recently the samples have been analysed using a DC arc direct-reading emission spectrometer. Mercury is determined by flameless atomic absorbtion spectrometry and uranium by delayed neutron activation analysis.

In conjunction with Harwell Laboratory (Atomic Energy Research Establishment), BGS has also been responsible for the development of a number of gamma-ray spectrometers for marine surveying (Miller and Symons, 1973; Miller and others, 1977; Thomas and others, 1984). A probe, the 'Eel', containing a gamma-ray detector is towed along the seabed (Figure 22) to measure both the natural radioactive constituents of rocks and sediments, and radionuclides introduced by man. Versions of the equipment have been developed for use from both small inshore vessels and ocean going ships. The equipment has been towed successfully for more than 15 000 km at depths up to 600 m, and in its present configuration can be operated in water depths up to 1000 m.

Measurement of the natural gamma emmitters (potassium, uranium and thorium) has been used to map solid and superficial seabed geology on some areas of the UK Continental Shelf. Uranium-bearing extensions of tin veins have been successfully identified off Cornwall and the technique can be used to explore for certain placer deposits and phosphorites (Noakes and others, 1974). The distribution of effluent from the Sellafield nuclear fuel reprocessing plant in the Irish Sea has been mapped, both on regional and detailed local scales (Miller and others, 1982).

By incorporating a neutron source into the seabed probe, transition elements can be determined from their prompt gamma-ray emissions, a technique applicable to exploration for placers, manganese nodules and cobalt-rich manganese crusts. A prototype neutron probe has been employed to map manganese nodules on the bed of Loch Fyne (Thomas and others, 1984).

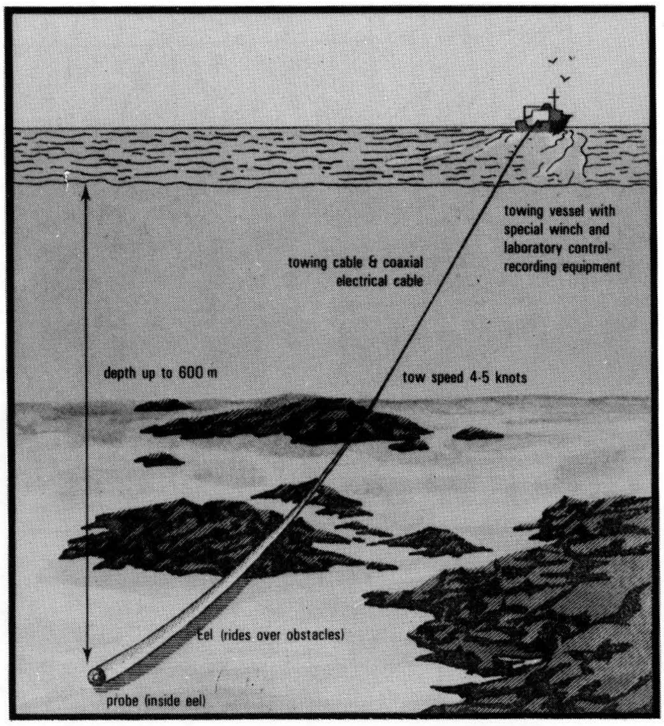

Figure 22. Towing configuration of the geochemical 'Eel' containing either gamma ray detectors or a neutron source.

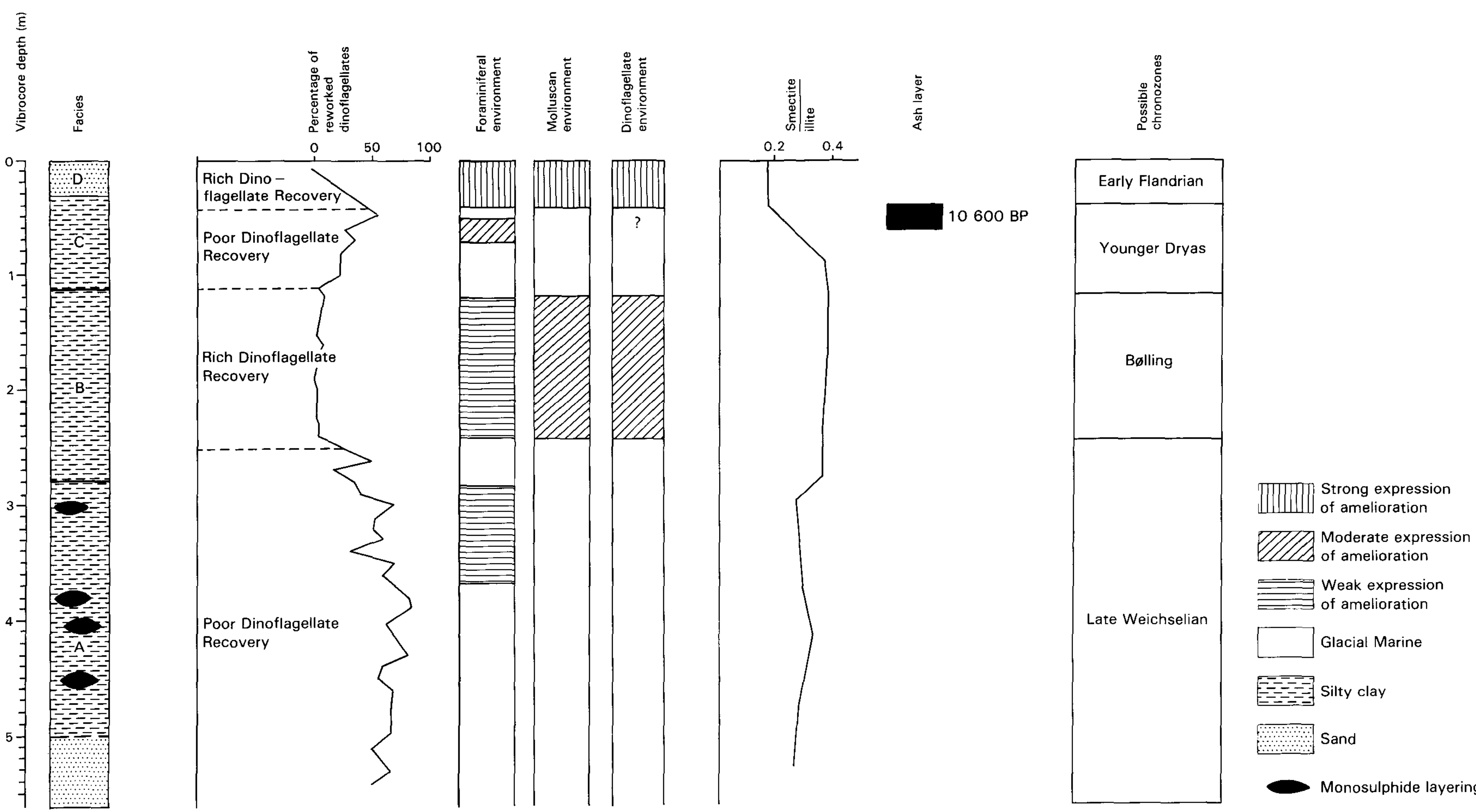

Figure 23. Integrated biostratigraphic analyses of a vibrocore, taken with other properties to indicate environmental and climatic change, and as an aid in establishing chronostratigraphy.

7. BIOSTRATIGRAPHY

Biostratigraphic support has concentrated on the late Palaeozoic, Mesozoic and Tertiary successions most relevant to the offshore industry, and some studies have been sold as biostratigraphical packages. Material is derived from cores and cuttings provided by oil companies and from the BGS drilling and seabed coring programmes. In palaeontology, common reference collections and sequences are of crucial importance if meaningful correlations are to be made, and BGS palaeontologists co-operate with universities, oil companies and commercial research organisations servicing the oil industry.

Studies have established a miospore zonation of the Carboniferous, refined from stratotype and reference sections, concentrating particularly on the late Namurian and Westphalian. The redbed and evaporitic sequences of the extensive Permian and Triassic sediments have been examined and a more detailed palynomorph succession established. This has greatly aided correlations in areas such as the Carlisle Basin, while in western Lancashire and Morecambe Bay this scheme has helped quantify rates of sedimentation and differential subsidence.

A dinoflagellate cyst zonation scheme for the Jurassic has proved useful in refining the stratigraphy of the central North Sea oil fields. Parallel studies on Late Jurassic to mid-Cretaceous ostracods and foraminifera, based on reference sections and boreholes from eastern England, have also been used to refine the currently available zonations and have facilitated extremely detailed correlations with similar deposits in the southern and central North Sea. Palynofacies models for the Carboniferous, Jurassic and Cretaceous based on the quantitative assessment of palynomorphs and detrital kerogen have been established to develop interpretations of depositional environments and post-depositional thermal histories in the central and northern North Sea and in onshore areas. Further work is in hand to improve the biostratigraphic framework of several successions where information is limited or correlation poor.

BGS has participated in the development of a joint northwest European programme to establish a unified regional zonation scheme for the Tertiary based on dinoflagellate cysts. The scheme, which is largely based on UK reference sections, now permits widespread and detailed correlations and assists palaeoenvironmental interpretation of the Tertiary on the continental shelf.

Palaeoenvironmental analyses based on foraminiferal and dinoflagellate cyst studies (Figure 23) have aided the establishment of a coherent climatostratigraphy for the offshore Quaternary regional mapping studies (Bent, 1986). Biogeographic distribution patterns of dinoflagellate cysts are being investigated and provide a useful comparison between fossil and living species. Additionally, the combination of micro- and macrofossil studies in the Quaternary has assisted palaeoclimatological interpretations and provided links with the palaeoceanographic history established in the North Atlantic.

8. MINERALOGY AND PETROLOGY

The principal aims of this work have been to establish provenance and intrabasinal dispersal patterns of clastic detritus, to establish regional and local lithostratigraphic correlations that can be tied to biostratigraphic and geophysical data, and to determine the nature of the reservoir sequences, with particular regard to diagenesis and its effects on reservoir properties.

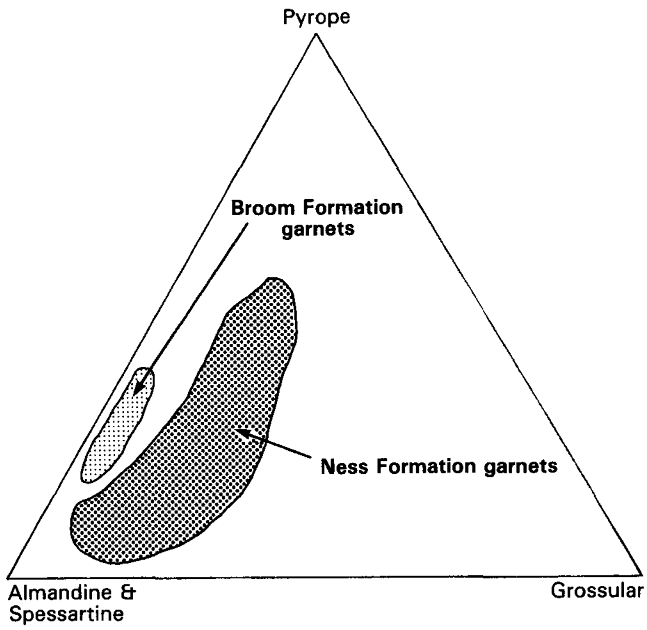

Figure 24. Detrital garnet suites from the Middle Jurassic Brent Group of the Murchison Field showing two distinct fields interpreted as evidence of deposition from separate submarine fan systems.

In the North Sea, heavy mineral suites have been profoundly affected by diagenesis. To counteract these effects on deeply buried mineral suites, a technique involving electron microprobe analysis of detrital garnet suites has been developed to produce provenance-sensitive data that are largely unaffected by diagenesis. This has been used to identify two distinct submarine fan systems in the reservoir sequence of the Palaeocene Forties Formation, and to demonstrate (Morton, 1987) several distinct sediment sources feeding the sandstones of the Middle Jurassic Brent Group (Figure 24). These studies have been extended to incorporate whole-rock geochemical and clay mineral data in order to produce more comprehensive provenance models.

A second aspect of provenance studies has involved the search for the volcanic centres that deposited early Tertiary and Quaternary tephras in the UK area. Hebridean and East Greenland/Faeroes sources have been recognised for the early Tertiary tephras (Knox and Morton, 1988), whereas the Quaternary tephras originated in Iceland.

Regional and local stratigraphic variations in petrological and mineralogical properties have been of considerable value in establishing lithostratigraphic correlations, for example in the Middle Jurassic Brent Group. Tephra layers have proved valuable for correlation in both the Tertiary (Knox, 1984) and Quaternary (Long and Morton, 1987). The tephrostratigraphy established for the early Tertiary has been integrated with the magnetostratigraphic record, allowing precise timing of North Sea Basin tectonic and sedimentary events in terms of the rifting and sea-floor spreading between Greenland and northwest Europe (Knox and Morton, 1988).

Reservoir sandstone studies also include an assessment of reservoir quality and its relationship with the response observed in downhole geophysical logs. The proportion of mud matrix (V-clay or V-shale) is measured in the laboratory from cored sections of the borehole,and used to calibrate the geophysical logs in order to extend the value of the logs in uncored sections so as to improve the quality of reservoir models. Reservoir sandstone studies include specific assessments of diagenesis, involving the use of a variety of thin section petrography, scanning electron microscopy, electron microprobe analyses, X-ray diffraction, cathodoluminescence and stable isotope analyses. Such studies contribute to facies analyses and studies of post-depositional reservoir history, and aid reservoir modelling.

9. DATA ARCHIVES

Geological information

The archives contain documents and samples, both confidential and openfile, derived from a variety of sources (Table 1). Confidential information is held by BGS on behalf of DEn, or companies who have chosen to place a dataset in the keeping of BGS, and is held under a strict level of security. On computer files, all such data are flagged as confidential and in the case of the records held on behalf of DEn, a completely separate computer system is operated. The industry derived hydrocarbon cores and samples of chippings are stored in more than 50 000 trays or cardboard boxes and protected by an identification code. All information is held in Edinburgh.

Well logs are kept for all wells drilled in UK waters, and are held in confidence until released, normally five years after they have been received by DEn (commonly six years after drilling). The information provided varies but normally includes a composite log, a short length of a strike and a dip seismic line, a location map and a variety of downhole logs. The data are available on microfiche and may be viewed at BGS Edinburgh and at DEn in London or Aberdeen.

Samples collected by companies for pipeline or site investigation studies are not included in the DEn requirement for automatic submission to BGS. An arrangement has however been made between the United Kingdom Offshore Operators Association (UKOOA) and DEn/BGS to allow these samples to be archived after engineering testing of the material is complete, to the mutual benefit of both the industry and the national archive. These samples and the associated data are held in confidence at Edinburgh, although by agreement the results are used in the compilation of offshore maps.

The non-confidential samples acquired by BGS include borehole cores, vibrocores, gravity cores and seabed samples and are held either in Edinburgh or Keyworth. The vibrocores and gravity cores are normally split longitudinally and archived in sealed plastic sleeving. Seabed samples are analysed routinely for particle size, and the dried fractions are retained with the remaining bulk samples.

Summary geological data are recorded for all BGS samples and, for those collected since 1982, a description of the sediments and some parameters

TABLE I. Geological data archive

Data type	Source	Status	Archive holdings: Raw data	Archive holdings: Supporting data	Archive holdings: Interpreted data	Access procedure
Split core samples and cuttings from exploration and development wells	Supplied to DEn/ BGS under the Petroleum (Production) Regulations	Confidential	Core samples: [$\frac{1}{2}$-$\frac{1}{4}$ vertical split of all cored sections] Chippings: representative samples of chippings recovered	Lithological logs and composite logs Palaeontology reports	Prospectivity evaluation General geological reports	Interpretations are confidential to DEn Core and composite logs released five years after receipt by DEn/ BGS. Cores held by BGS.
Well logs	As above	Confidential	Paper and film copies of well logs			Well records available from BGS, DEn and Erico Data Services Ltd. after release period
Installation site investigation soil samples and in situ measurements from field and pipeline studies.	Supplied to BGS by agreement with UKOOA	Confidential	Core samples of sediments (soils) from boreholes, vibrocores and gravity cores Bulk samples Disturbed samples after testing Undisturbed waxed sub-samples In situ penetrometer test curves	Soils investigation reports [usually include some interpretation]	Intra- and inter-field correlations Calibration of seismic data Integration with other data in 1:250 000 map series	Released by telexed permission of owner to BGS No fixed released period
Shallow drilling cores	Drilled by BGS	Non-confidential	Core samples	Lithostratigraphy Palaeontology Petrology Geochemistry Geotechnical data	Correlation with seismic interpretation Integration with other data in 1:250 000 map series and reports	By arrangement with BGS
Vibrocores and gravity cores	Cored by BGS	Non-confidential	Continuous core up to 6 m long - [commonly split longitudinally and stored in plastic sleeving]	Lithostratigraphy Palaeontology Petrology Geochemistry Geotechnical data	Correlation with seismic interpretation Palaeontological investigations Integration with other data in 1:250 000 map series and reports	By arrangement with BGS
Seabed samples	Collected by BGS	Non-confidential	Bulk seabed samples Gravel, sand and mud splits	Grain size Geochemistry Palaeontology	Integration with other data in 1:250 000 map series and reports	By arrangement with BGS

TABLE II. Geophysical data archive

Data/material type	Source	Status	Archive holding: Raw data	Supporting data	Interpreted data	Access procedure
Processed deep seismic [shot for exploration or field development] Digital sparker [shot for exploration site inspection]	Supplied to DEn/BGS under the Petroleum (Production) Regulations	Confidential	Paper copies of processed seismic lines UKOOA standard format magnetic tapes	Paper copies of track chart	1:50 000 horizon contour maps Inter-borehole correlations in field areas	Interpretations are confidential to DEn Currently no agreement for release of seismic data
Digital and analogue sparker, pinger, boomer, echosounder and sidescan sonar [shot for installation site investigations]	Supplied to BGS by agreement with UKOOA	Confidential	Film copies of processed digital sparker lines Paper copies of analogue record	Paper copies of Track charts Reports of survey investigations [may include some interpretation]	Inter-borehole correlations in field areas and along pipeline routes Integration with other data in 1:250 000 map series	Released by telexed permission of owner to BGS No fixed release period
Shallow reconnaissance mapping seismic: analogue airgun, watergun, sparker, pinger, boomer, echosounder, sidescan sonar Gravity Magnetics	Shot by BGS	Non-confidential	Magnetic tapes of reduced data [gravity, magnetics, echosounder and position]. Paper copies of analogue records [airgun, watergun, sparker,pinger, boomer, echosounder and sidescan sonar]	Film and paper copies of track charts	Posted value maps Structure and feature distribution maps Isopachyte maps Integration with other data in 1:250 000 map series	By arrangement with BGS Geological and geophysical 1:250 000 map series Reports and publications
Aeromagnetics	Commissioned or purchased by BGS	Non-confidential	Digitised data retained by survey company			By arrangement with BGS
Multichannel seismics	Commissioned by BGS	Non-confidential	Film copies of processed seismic lines	Paper copies of track charts. Reports of survey investigations		By arrangement with BGS

is available in fixed format. These data are stored on a VAX 8600 computer and accessed by the Oracle database management system so that water depth, sample type, laboratory analyses, brief lithological description or other recorded parameters can be presented as listings with sample positions or as maps. These samples are available for further study.

Geophysical information

A wide range of geophysical data are held by BGS and include both confidential and non-confidential records that are kept separately (Table II). Film copies of the deep seismic records are supplied to BGS by the companies along with track charts and, more recently, with UKOOA standard format magnetic tapes.

In recent years, digital seismic data have been collected by companies for site inspection purposes prior to drilling. These data are supplied in confidence to BGS under licence arrangements and supplement the BGS data from the top one second (two-way reflection time) of the section. This exploration site inspection information differs from the shallow seismic site investigation data which penetrate only the top few hundred metres of the section. The latter, which may include both high and medium-resolution seismic profiles as well as processed digital sparker and sidescan sonar, are supplied as part of the UKOOA/DEn/BGS agreement and are also held in confidence.

The original analogue records of BGS seismic traverses collected in the Survey's own field programmes are microfilmed for reference and security, and paper copies can be reproduced. Geophysical and track data are held on International Geophysical Exchange format magnetic tapes for most BGS surveys. The information, recorded most recently at one minute intervals, includes position, water depth, gravity and magnetic data. The data are also held on computer from which information can be retrieved for any area and displayed as posted value maps or written on to magnetic tape.

10. DATA ACCESS

Hydrocarbon information

Released well data are available through ERICO Data Services or can be viewed in microfiche form in London, Edinburgh and Aberdeen. Prices for the well record data are available from ERICO Data Services (addresses below) and the regularly updated listing of the available wells is available from HMSO Bookshops.

Viewing facilities for released well records are available at the following addresses; viewing is by appointment only.

Room 1020
Department of Energy
Library
Thames House South
Millbank
London
SW1P 4QJ

Tel: 01 211 3384
or 01 211 6758

Offshore Supplies
Office
Greyfriars House
Gallowgate
Aberdeen

Tel:0224 641242

ERICO Data Services Ltd
Lane House
233-235 Roehampton Lane
London
SW15 4LB

Tel: 01 788 1072
Telex: 946371

ERICO Incorporated
Suite 1830
One Williams Centre
Tulsa
Oklahoma 74172

Tel: (918) 599 9999
Telex: 9108453012

Released well material, or confidential data with the permission of the owner, may be viewed by appointment at the following address:

The Curator
DEn/BGS Core Store
376 Gilmerton Road
Edinburgh

Tel: 031 664 8852

BGS information

The nature and accessibility of data and samples in the BGS archive are presented in Tables I and II. Charges for data do not reflect the cost of acquisition, but attempt to recover the handling costs in making the records available to enquirers.

Non-confidential information is available directly through the BGS offices in Edinburgh and Keyworth where they are supplied at standard costs, although discretion is exercised regarding the release of very large datasets. Data with very specific and direct commercial applications are compiled for sale as packages.

Users of the archive are encouraged to discuss their requirements with the BGS geologists who are familiar with the data and who can guide the enquirer to its most effective use. Where appropriate, consultant charges are made for staff time, but special arrangements are available for students and other *bona-fide* research workers.

Laboratory facilities are available for core inspection, and bench charges are made where appropriate. Where adequate material is available, subsamples may be taken for further analyses provided copies of the results are supplied to BGS. If necessary these may be held in confidence for an agreed period before being placed on the BGS openfile. Working copies of maps and reports being prepared for publication may also be made available but are subject to additional charges.

As well as providing consultancy services, BGS can also supervise or undertake investigations on contract. Equipment and operators/ technicians may also be hired when not required for the Survey's own programmes.

Further information may be obtained from the following:

Programmes Director, Hydrocarbon and Marine Earth Sciences Directorate
Programme Manager, Hydrocarbons Programme
Programme Manager, Marine Geology Programme
Programme Manager, Marine Geophysics and Offshore Services Programme
Research Group Manager, Global Seismology Group

British Geological Survey
Murchison House
West Mains Road
Edinburgh EH9 3LA

Tel: 031 667 1000
Telex: 727343 SEISED G
Fax: 031 668 2683

Officer-in-Charge
Marine Geology Programme
British Geological Survey
Nicker Hill
Keyworth
Nottingham NG12 5GG

Tel: 06077 6111
Telex: 378173
Fax: 06077 6602

Published maps and reports are available through HMSO Bookshops and the BGS sales points listed below:

British Geological Survey
Murchison House
West Mains Road
Edinburgh EH9 3LA

Tel: 031 667 1000
Telex: 727343 SEISED G
Fax: 031 668 2683

British Geological Survey
Nicker Hill
Keyworth
Nottingham NG12 5GG

Tel: 06077 6111
Telex: 378173
Fax: 06077 6602

BGS London Information Office
Geological Museum
Exhibition Road
South Kensington
London SW7 2DE

Tel: 01 589 4090; 01 938 9056/7
Telex: 8812180 GEOSCI G
Fax: 01 584 8270

11. REFERENCES

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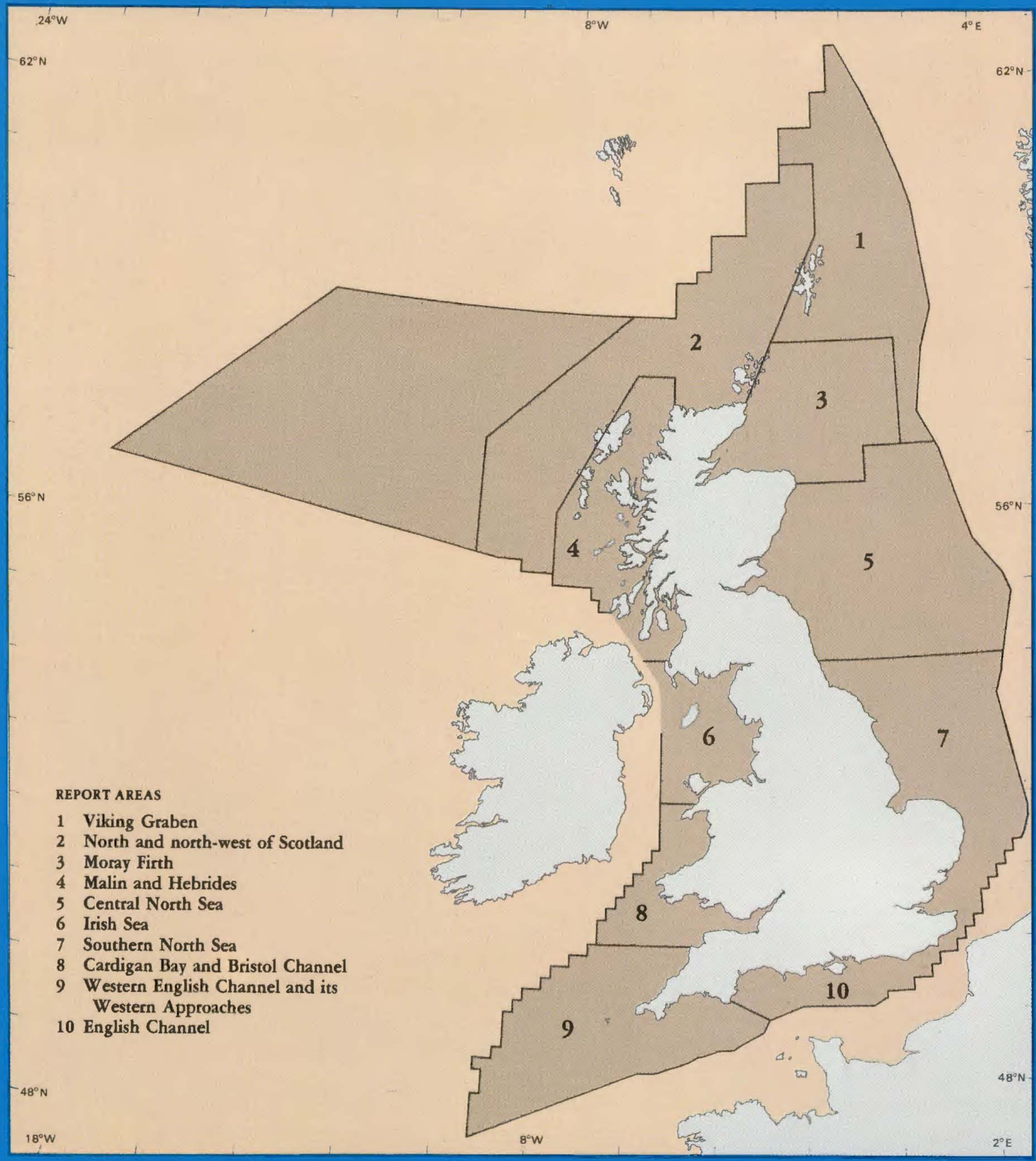

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