UK EARTHQUAKE MONITORING 1991/92

BGS Seismic Monitoring and Information Service

Third Annual Report

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BRITISH GEOLOGICAL SURVEY

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UK Earthquake Monitoring 1991/92

BGS Seismic Monitoring and Information Service

Third Annual Report

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April 1992

UK Seismic Monitoring and Information Service Year Three Report to Customer Group: April 1992

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Solar-powered earthquake-monitoring station in the North-west Highlands of Scotland (T Bain)

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The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Overseas Development Administration.

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UK EARTHQUAKE MONITORING 1991/92

1. Executive Summary

The aims of the Service are to develop and maintain a national database of seismic activity in the UK for use in seismic hazard assessment, and to provide near-immediate responses to the occurrence, or reported occurrence, of significant events. Following a history of seismic monitoring at a number of localities over the past 23 years, the British Geological Survey (BGS) has been charged with the task of developing a uniform network of seismograph stations throughout the country in order to acquire more standardised data in the future. The project is supported by a group of organisations under the chairmanship of the Department of the Environment (DOE) with a major financial input from the Natural Environment Research Council. This Customer Group is listed in Annex A.

In the third year of the project (April 1991 to March 1992), 7 new seismograph stations have been added to the network by taking advantage of existing recorders with spare channel capacity. They are in western Scotland, Exmoor and eastern England (5 stations into the Leeds recording centre). Equipment has been purchased for the most notable gap in coverage, in central southern England, through an additional, specific allocation of DOE funds. The rapid response capability following significant events has been improved further with the upgrade of the Hereford network and (possibly on a temporary basis) the North Wales network.

Despite recent additions to the UK background monitoring network, the overall coverage is still dependent on separately commissioned site-specific stations supported by Department of Energy, Nuclear Electric and British Nuclear Fuels. These seismographs are vulnerable to closure in the longer term.

Over 400 earthquakes have been located by the monitoring network in the past year, with 30 of them having magnitudes of 2.0 or greater. The largest on land had a magnitude of 3.4 and was strongly felt in the region around Peterborough in the early hours of 17 February 1992. Offshore, the largest earthquake had a magnitude of 4.2 and occurred near the Ninian and Alwyn oil fields on 25 April 1991. Smaller earthquakes have been felt in several areas of the country including Powys, Strathclyde and the Central Region of Scotland.

In addition to earthquakes, BGS receives frequent reports of seismic events, felt and heard, which on investigation prove to be sonic booms, spurious or in coalfield areas where much of the activity is probably induced by the mining. All significant felt events and some others are reported rapidly to the Customer Group through 'seismic alerts' sent by Fax and are then followed up in more detail. Monthly bulletins are issued 2 months in arrears with provisional details of all earthquakes located, and, after revision, they are compiled into an annual bulletin.

A coloured wall map showing all of the British earthquakes located by BGS in the 1980s has been published as part of the UK Seismic Monitoring and Information Service project.

As part of the programme to establish a national database and archive of British earthquakes, external collections have been transferred to BGS for curation and the digitisation of deteriorating analogue magnetic tape recordings, collected over 20 years, has commenced. The latter exercise will provide optical disk storage in the same format as that used for present-day earthquakes and duplicates will be held outside the Murchison House offices of BGS.

2. Introduction

The UK earthquake monitoring and information service has developed from the commitment of a group of organisations with an interest in the seismic hazard of the UK. The current supporters of the project are referred to as the 'Customer Group' and are listed in Annex A. The project formally started in April 1989 and the published Year 1 report includes details of the history of monitoring by BGS since 1969 and an outline of the background to the establishment of the project.

This Year 3 report to the Customer Group follows the format of the first two annual reports in reiterating the programme objectives and highlighting some of the significant seismic events in the period April 1991 to March 1992. The catalogue of earthquakes for the whole of 1991 is plotted to reflect the period for which the bulletin of revised data is produced. Progress towards the overall need to establish a uniform distribution of seismic monitoring stations with an average spacing of 70 km has been limited by the availability of resources during the year but, with new funds from DOE in January 1992, equipment has been purchased to provide a substantial improvement in southern England during 1992/93. An upgrade to the remotely-accessible digital system in Hereford in addition to the ones previously installed in Cornwall and around Edinburgh has substantially improved the identification and rapid location of seismic events. Figure 1 shows this capability with the inclusion of a fourth digital system in North Wales, supported specifically by Nuclear Electric. The last, however, may not be retained in the longer term.

All of the advances made and proposed in the effective background network of the UK can be seen by comparing the present coverage (Fig 5) with that in 1988 (Fig 2) although some reliance remains on site-specific networks which are vulnerable to closure by the bodies which have commissioned them.

3. Programme objectives

3.1 Long-term

The overall objectives of the service are:

(i) To provide a database for seismic risk assessment using existing information together with that obtained from a uniform distribution of modern seismograph stations throughout the UK landmass. A mobile network of seismograph stations would be used for specific investigations of seismic events to supplement the background network.

(ii) To provide near-immediate preliminary responses to seismic vibrations reported to have been heard or felt, or of significance to the Customer Group.

These objectives and a strategy to meet them were described more fully in a proposal from BGS dated December 1987. The higher the density of seismograph stations in the network, the more accurate will be the response and the database. In discussion with the Customer Group, a 70 km average spacing of stations (Fig 3) was agreed as a cost-effective way of achieving the main goals although it was recognised that some parameters (eg depths of focus and focal mechanisms) would not be well-determined.

3.2 Short-term

In 1988, the Customer Group agreed to a reduced initial phase of development of the monitoring network to fit the limited funds likely to become available in the first 3 years. In this strategy, the following sacrifices were made:

(i) The mobile network could not be specifically supported.

(ii) The 70 km-spacing of stations could not cover the whole country. Advantage would be taken, where possible, of site-specific networks operated for other purposes and of existing recorders with spare channel capacity to add individual stations. Priority for new networks would be in the south east of England and around the north Irish Sea. This modified coverage by the background network is shown in Figure 4.

(iii) Upgrading of the analogue stations to digital recording and direct access to remote networks (from Edinburgh) using computer or telephone links would be reduced to an opportunistic, phased level as resources became available.

The establishing of a "user-friendly" database and archive of seismicity was to be retained as a high priority element of the project.

4. Development of the monitoring network

4.1 Station distribution

The network developed by December 1991 is shown in Figure 5 with its detection capability in Figure 6. The scheduled programme for 1991/92 provided for:

(i) Installation of new seismograph stations in E Devon, Yorkshire and W Scotland.

(ii) Planning the proposed central southern England network.

(iii) Upgrading the Hereford network to the digital, remote access standard and adding an extra station in the Bishop's Castle-Shrewsbury area.

(vi) Installing a number of strong motion recorders.

All stations under (i) have been installed, with 5 covering eastern England onto the Leeds recorder. There has been no progress with planning the new central southern England network (ii) owing to a reduction in priorities pending the identification of funds for equipment purchase. In early 1992, DOE placed a contract for that purchase and the network is available for deployment later in 1992. The Hereford network has been upgraded, in August 1991, as specified in (iii) and this development played a major part in the rapidity of response to the magnitude 3.4 Peterborough earthquake of 17 February 1992. Progress under (iv) has been limited with only one strong motion system retained in the region of the Bishop's Castle earthquake until January 1992. Difficulties have been encountered in modifying some existing equipment for this purpose. However, with the support of the Jersey New Waterworks Company, instruments have been installed in Jersey for long term monitoring which, with one placed at Hunterston for Scottish Nuclear, provide 2 BGS-maintained strong motion systems in the UK.

With regard to the continuation of site-specific monitoring projects on which the present network depends:

(i) Nuclear Electric have sustained monitoring in North Wales throughout the year at a less intensive level than previously and have confirmed they are unable to continued after 31 March 1992. Unfortunately, this withdrawal results in a substantial gap in one of the more seismically active areas of the country and the Company has been invited to join the Customer Group in support of background monitoring.

(ii) The Department of Energy-sponsored monitoring of the HDR geothermal research work in Cornwall has continued and the contract has been renewed to March 1994 with no reduction in station density.

(iii) Nuclear Electric withdrew support for monitoring around Heysham on 30 September 1991 but coverage in the NW of England is likely to continue with support from BNFL. In the SW of Scotland a dense BNFL network has enhanced regional coverage in that area since its commissioning in February 1992.

(iv) The Jersey New Waterworks Company, in addition to installing a strong motion recorder, has provided an upgrade of the existing network of stations on the island together with a two-year intensive study of seismic activity.

4.2 Progress with instrumentation

Improvements to the hardware and software of the digital recording system, SEISLOG, have continued to the point where a robust, stable facility has been achieved and has been proven at four of the sub-networks in the UK. In addition to remotely accessing data, the SEISLOG telephone connection also provides a means of 'kick-starting' the system following software upgrades. Re-starts following power breaks are now initiated automatically without the need for a field visit. As often happens when a stable computer-based system is established, the manufacturers of the processor board and the suppliers of the operating system software have changed their specifications. Further efforts are being made to provide replicas of the proven system, in the short-term, and to test and harness the new systems, in the longer term.

Operation of the borehole sensor at Heysham has generated data which clearly demonstrates its benefit in areas of poor surface geology and high background noise. Plans are being made to enhance the eastern England networks with such sensors in 1992/93 in order to combat the high levels of noise experienced. The prospect of using British Coal's borehole vibration sensors has been investigated but, unfortunately, they operate outside the earthquake signal frequency band and are, therefore, unsuitable. The boreholes, themselves, are backfilled and not available for the installation of other instruments.

5. Seismic activity in Year 3

5.1 Earthquakes located for 1991

Details of all earthquakes and the larger sonic booms detected by the network have been published in monthly bulletins and, with final revision, will be provided in the BGS bulletin for 1991 scheduled for publication in July 1992. A map of the 410 events located in 1991 is reproduced here as Figure 7 and a catalogue of those with magnitudes of 2.0 or greater is given in Annex B.

5.2 Significant events

Highlights of the seismic activity during the third year of the project (April 1991 to March 1992) are given below:

(i) In the Oban area of Scotland, a magnitude 2.1 ML earthquake occurred, on 15 April 1991 close to the epicentre of the widely felt magnitude 4.1 event in September 1986 which caused some concern about the nuclear submarine bases on the Clyde.

(ii) In Newtown, Powys, a magnitude 2.8 ML earthquake was felt at intensity 3+ MSK on 16 June 1991. It is the largest Welsh earthquake during Year 3 with an epicentre close to the magnitude 3.3 ML event which was felt more strongly in this region in April 1984.

(iii) In Ardentinny, Strathclyde, a magnitude 2.0 ML event was felt at intensity 3+ MSK on 16 June 1991. This was also in the region of a strongly felt magnitude 3.3 ML earthquake in September 1985.

(iv) In Balquhidder, 30 km NW of Stirling, the largest earthquake in Scotland for the year occurred on 4 August 1991 with a magnitude of 2.8 ML and was felt with intensity 3+ MSK (Fig 8).

(v) In the Bridge of Allan, near Stirling, an earthquake with a magnitude of 1.1 ML, which is well below that normally thought to cause concern to people, was felt over a small area on 31 October 1991.

(vi) In Lancashire, near Oakenclough, a magnitude 2.7 ML earthquake occurred on 8 November 1991. Such events would normally be felt but, on this occasion, no reports were received.

(vii) In NW France, 20 km E of Boulogne, a magnitude 3.6 ML (BGS) earthquake occurred on 14 December 1991. This location places it some 60 km off the SE England coast. The French Laboratoire de Detection et de Geophysique (LDG) gave the magnitude as 4.0 ML but they consistently report magnitudes higher than those determined by BGS. An aftershock on 27 January 1992 was assigned a magnitude of 2.8 by BGS and 3.5 by LDG. Information has been received from France that the mainshock was felt but no details have been published to-date. Data exchange between Britain, Belgium and France was important in locating the event with some degree of accuracy as the locality is poorly served by local seismograph stations. This same data has been used by LDG to determine a focal mechanism which shows mainly thrust faulting with a small dextral component. One of the two possible planes of faulting deduced from this mechanism, with an orientation of 131°, is in the same direction as the principal tectonic structures of the epicentral region.

(viii) In Peterborough, an earthquake with magnitude 3.4 ML was strongly felt (locally up to intensity 5 MSK) on 17 February 1992 (Fig 9). It is the largest earthquake to have occurred in England during the year, has an epicentre 10 km south of Peterborough and was felt up to some 50 km away. Many people were awakened by it (at 01.22 in the morning) and some slight damage has been reported. Peterborough is an area of the country with little history of earthquake activity although a magnitude 4.0 event occurred some 40 km to the west in 1750.

(ix) In North Wales, aftershocks have continued from the Lleyn Peninsula, magnitude 5.4 ML earthquake of July 1984. The largest in the year had a magnitude of 1.8 ML and no felt reports of it have been received.

(x) In coalfield areas, small earthquakes were felt at Coppice Farm, Staffs (1.6 ML, 12 May 1991), Stanton Hill, Notts (1.2 ML, 28 May 1991), Morton, Derbyshire (0.7 ML, 20 June 1991), Dinnington, S Yorkshire (1.8 ML, 4 September 1991, Fig 10) and Gildingwells, S Yorkshire (1.2 ML, 22 October 1991). The above are examples of the many which are presumed to be related to present-day coalmining activity.

(xi) In the North Sea, the largest earthquake (with a magnitude of 4.2 ML) occurred on 25 April 1991 near the Ninian and Alwyn oil fields. There were, however, no reports of it being felt offshore. Several earthquakes occurred in the central North Sea with the largest, on 5 April 1991, having a magnitude of 3.1 ML.

(xii) In Essex on 12 February 1992, an event was strongly felt at Colchester and Wivenhoe when doors slammed and houses shuddered. It was also experienced at the Bradwell nuclear power station, 20 km to the south of Colchester. The cause was traced to explosions from controlled detonations on the Shoeburyness range, some 40 km to the south of Colchester. Only one of the seismograph stations of the SE England and E Anglia networks recorded a signal from the event. The explanation is likely to be that energy from the explosions was mainly in air blast, that the prevailing southerly winds influenced the direction of propagation and that multipathing from detonations separated by a few seconds may have focused the impact in the Colchester area.

(xiii) Elsewhere in the country, many 'seismic' events have been reported to be felt or heard like small earthquakes but, on analysis, have been proved to be sonic booms. Specific examples are Tyne and Wear (9 May 1991), Kent (15 May 1991), Anglesey (21 May 1991), Northumberland (5 July 1991), Fife (23 October 1991), Yorkshire (10 November 1991), Borders (20 November 1991), Norfolk (21 November 1991), The Wirral (22 January 1992) and Cumbria coast (19 February 1992).

5.3 Global earthquakes

The monitoring network detects large earthquakes elsewhere in the world. Those which dominated the News included:

(i) India on 19 October 1991 with magnitude 7.1 MS (Fig 11). This earthquake was felt throughout Northern India, western Nepal and north-eastern Pakistan. Landslides and deep fissuring occurred in the epicentral area. Over 2000 people were killed and 18000 buildings were destroyed.

(ii) Costa Rica on 22 April 1991 with a magnitude 7.6 MS this was the largest earthquake of the period (Year 3). Seventy five people were killed in Costa Rica and Panama; over 500 were injured and 10,000 left homeless. A 2 metre tsunami was generated on the Costa Rican coast.

(iii) Western Caucasus on 29 April 1991 with magnitude 7.0 MS. At least 114 people were killed, 1,000 injured and 67,000 homeless. Severe damage and landslides occurred in Georgia, USSR. It was felt throughout the western Caucasus, Georgia, northern Armenia and in eastern Turkey.

(iv) Eastern Turkey on 13 March 1992 with a magnitude of 6.9 MS. Confirmed deaths are 479 with over 2000 injured and thousands made homeless. There was extensive damage in the Erzincan area with landslides and avalanches blocking a number of roads. A magnitude 5.8 aftershock, 2 days later, added to the damage.

A moderate earthquake with magnitude 5.2 Mb, 5.6 MS, occurred in Western Romania on 2 December 1991. Ninety per cent of the houses were damaged (VIII MM) and 500 people left homeless at Voiteg. Lesser damage occurred in the Deta-Caecova and Belgrade areas. The Lleyn Peninsula earthquake in north-west Wales in 1984 had a similar magnitude, between 4.9 and 5.2 Mb (from North American and European stations). Damage in Wales was limited by the depth of

20 km compared to 10 km in Romania. Statistical analysis of the latest earthquake catalogue gives a return period for this magnitude of a little over 10 years for Britain and its surrounding waters.

5.4 Seismicity 1980-1989 and seismic hazard

A draft of a coloured, 1:1500000 scale wall map of British earthquakes in the 1980s has been produced for distribution to the Customer Group and for sale to schools, universities and other interested bodies.

The significance of such data for the estimation of seismic hazard in Britain and surrounding waters is illustrated in Figure 12. The cumulative number of earthquakes exceeding a magnitude M is plotted against M for both the instrumental seismicity catalogue for the 1980s and the historical catalogue after Musson (1990). Figure 12 shows the good agreement in the region of overlap between the two datasets and the incompleteness of the instrumental and historical catalogues below about 2.5 ML and 4.5 ML, respectively. As can be seen from the right-hand ordinate, return periods for exceedence of a given magnitude can be estimated. Statistical predictions for the probability of exceedence of a magnitude in the lifetime of an installation can be obtained although a longer monitoring period is required to reduce the uncertainties in the critical high-magnitude, region.

The statistical calculations assume that seismicity is uniform over this large area; this may not be justified but zoning is difficult with the present scant data. Future monitoring will steadily improve the prospect of zoning in the UK for seismic hazard levels.

6. Archives

6.1 Identification and cataloguing

In order to take advantage of new developments in archive cataloguing methods and with the recognition that, in some cases, curation work needs to proceed in step with it, the programme has been rescheduled for completion by October 1992.

The status of catalogues transferred from or held at other sites is currently:

Aberdeen: The seismograms and other papers from Aberdeen, which ceased recording in 1966, are kept in good conditions by Aberdeen University Department of Physics, who wish to retain them. It is informally agreed that BGS will take over responsibility if the University can no longer accommodate the records.

Bidston: The seismograms are held by BGS but are in poor condition as a result of neglect. Possible conservation solutions are being pursued.

Durham: This observatory is still functional and the records are maintained by Durham University Department of Earth Sciences.

Eskdalemuir: Records from ESK are stored by the Meteorological Office at Eskdalemuir under BGS curation.

Jersey: Smoked paper records written on the Mainka seismograph, which was installed in 1936, have been passed to BGS from the States of Jersey Meteorological Office.

Kew: All Kew material is held by BGS.

Oxford: All the Oxford seismograms bar one appear to have been destroyed some time after 1947. The one survivor is held by BGS.

Paisley: All of the Paisley seismograms and notebooks, which date back to the beginning of the century, have been passed to BGS by the Observatory (Renfrew District Council).

Shide: This observatory closed in 1913 and the records are presumed destroyed, though the Isle of Wight County Record Office has tracings of a few.

Stonyhurst: After extensive enquiries as far afield as the Vatican, it now appears more likely that the Stonyhurst seismograms were destroyed some time after 1947.

West Bromwich: No clue has been found to the fate of these records. They are presumed destroyed.

Changes in the above list since the Year 2 report are for the Jersey and Paisley collections both of which have been passed to BGS for curation, cataloguing and archiving.

6.2 Storage and inspection facilities

Custom-built archival quality shelving and storage equipment has now been installed for the seismogram and other paper archives. Measures have been taken to protect records from any potential flood hazard.

In order to protect data which has been collected over the past 20 years on deteriorating analogue magnetic tape, a programme of digitising seismic events has been initiated. These digital seismograms are stored on optical disks in the same format as for contemporary data. Copies are held outside the BGS Murchison House laboratories to enhance data protection.

7. Dissemination of results

7.1 Near-immediate response

Customer Group members have continued to receive seismic alerts by Fax (Annex C) whenever an event has been reported to be felt or heard by more than one or two individuals. In the case of series of events in coalfield areas, only the more significant ones are reported in this way with small events reported separately to British Coal. Similarly, small events near nuclear power stations are reported to Nuclear Electric because of its special interests. In all cases, copies are supplied to Dr B R Marker, DOE. Some 37 alerts have been issued to the whole Customer Group during the year.

The bulletin board, on a captive process on the VAX computer in Murchison House, has continued to be maintained on a routine basis for British and Global earthquake information. It contains continually updated seismic alert information together with the most recent 3 months, at least, of provisional data from the routine analysis of the UK network.

The additional upgrades of sub-networks in the Hereford/S Wales region and, for Nuclear Electric, in North Wales have further improved the immediate response capability for UK seismic events. Networks in the Scottish Lowlands, North Wales, Hereford and Cornwall can now be remotely accessed from Edinburgh and, in particular, from the homes of the principal seismologists. This capability, in the worst background noise conditions, is illustrated in Figure 1. Almost all of the UK can be covered for earthquakes with magnitudes of 3.0 or greater, in contrast to the situation one year ago when a large part of England and Wales was not covered for these magnitudes. The

Peterborough earthquake at 01.22 on 17 February 1992 was confirmed to be of seismic origin, with its position and magnitude reasonably well calculated, within about 2 hours of its occurrence through this increased capability.

7.2 Medium-term response

Preliminary bulletins of seismic information have continued to be produced and distributed on a routine basis to the Customer Group normally within 2 months of the end of a 1 month reporting period. This is considered to be the optimum for the present technology and resources available.

7.3 Longer term

The project aim is to publish the revised annual bulletin of UK seismic activity within 6 months of the end of a calendar year. Owing to problems of staff resources, this has not yet been achieved; the 1990 bulletin was published in March 1991. The schedule for the 1991 bulletin is, however, more optimistic and proof copies should be available in July 1991. The coloured wall map of UK seismicity in the 1980s is scheduled for publication in April 1992.

8. Programme for 1992/93

During the year, the project team (Annex D) will continue to detect, locate and understand natural seismicity and man-made events in and around the UK and to supply timely information to the Customer Group. Further progress will be made in the provision of a 'user-friendly' database and archive of UK seismicity and in extending the background, 70 km-spacing, seismograph coverage of the country. Specific advances anticipated for 1992/93 are:

(i) Installation of a new seismograph network in central southern England to fill the most evident gap in the present coverage. This will have remote access from Edinburgh.

(ii) Upgrading to digital, remote access standard, existing networks in western Scotland and SE England.

(iii) Installation of a borehole system to reduce background in the Keyworth network and, possibly, in SE England.

(iv) Checking the geographic locations of most of the existing seismograph stations using new satellite-based positioning systems.

(v) Installation of 2 or 3 of the triggered strong motion recorders.

(vi) Completion of the digitising of seismic events collected on analogue magnetic tape over the past 20 years.

(vii) Maintaining a watching brief on archives held by other organisations with a view to seeking the transfer to Edinburgh of any considered to be at risk.

Acknowledgements

We particularly wish to thank the Customer Group (listed in Annex A) for their participation, financial support, and input of data and equipment to the project. Station operators and landowners throughout the UK have made an important contribution and the technical and scientific staff in BGS (listed in Annex D) have been at the sharp end of the operation. The work is supported by the Natural Environment Research Council and is published with the approval of the Director of the British Geological Survey (NERC).

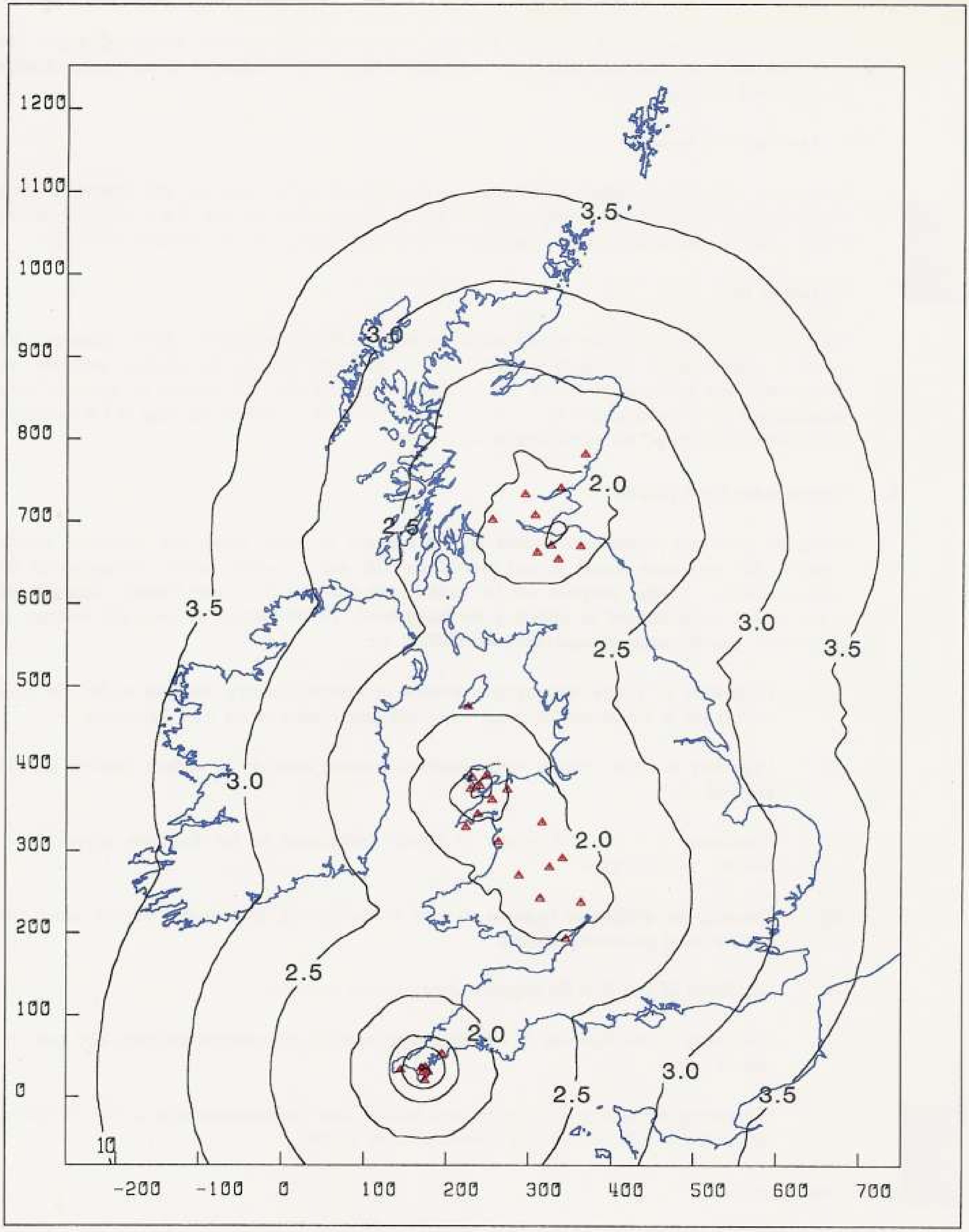

Figure 1. Detection capability of the Lowlands, North Wales, Hereford and Cornwall seismograph networks to which rapid access is available (SEISLOG). Contours show the magnitude (ML) of an earthquake which would be detected by 5 stations in the presence of background noise of 20 nanometres at 10 Hz. That is, the worst case when local vibrations, against which the signal must be detected, are high.

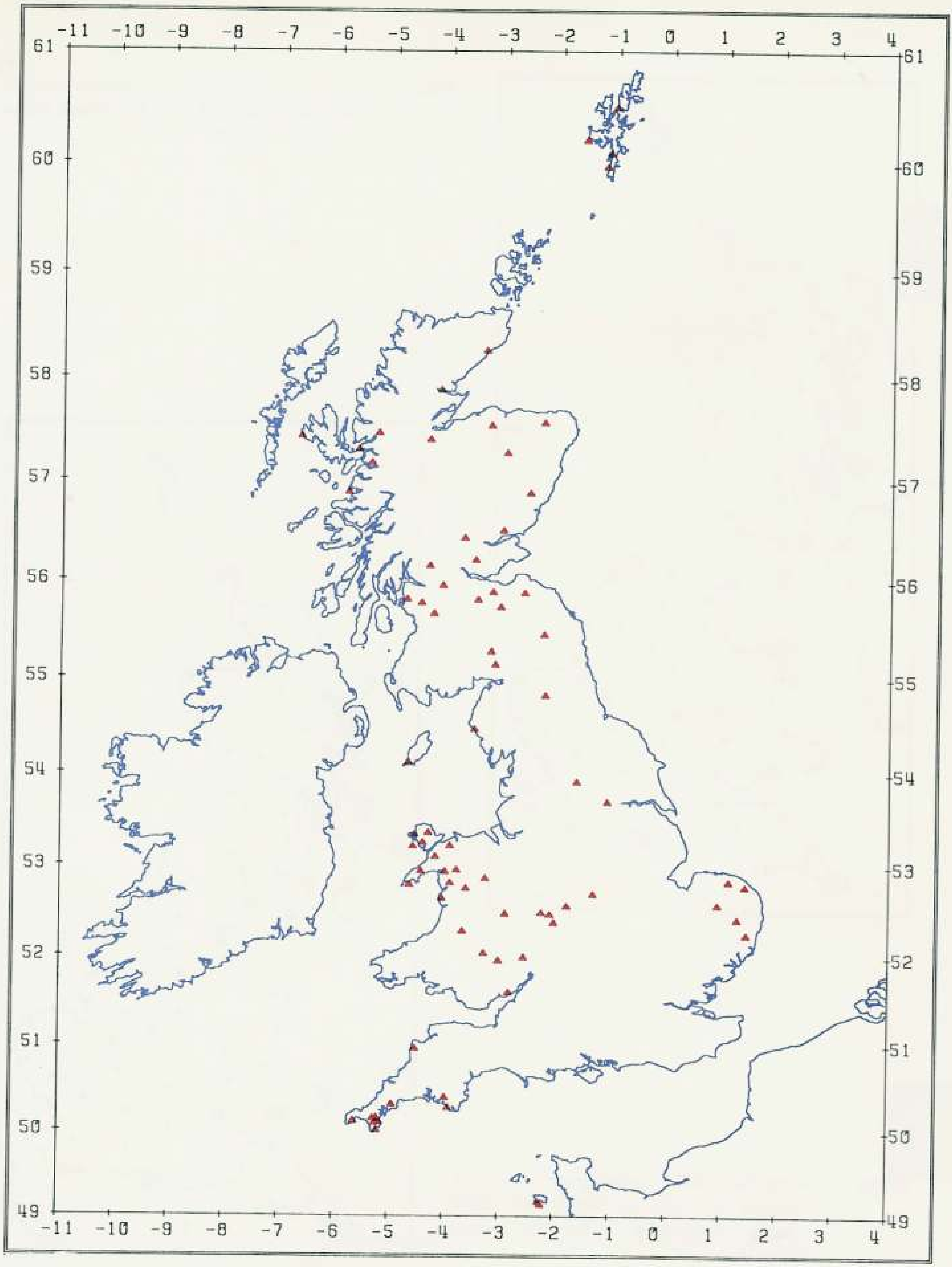

Figure 2. BGS seismograph network in 1988 prior to the commencement of the UK monitoring enhancement project.

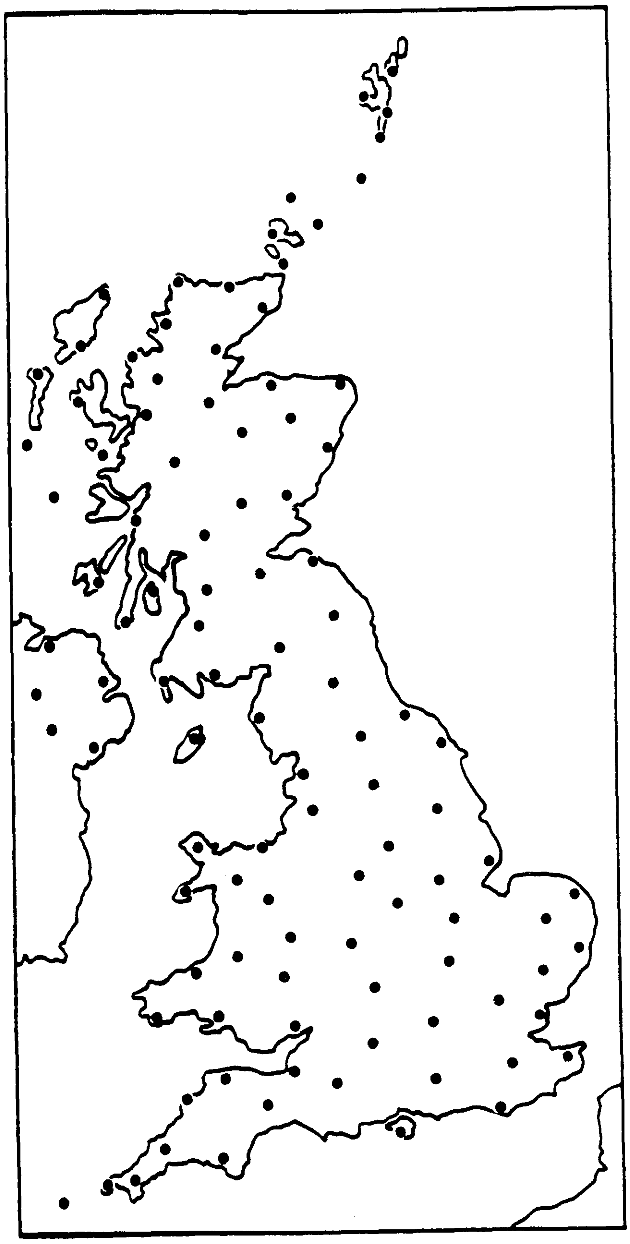

Figure 4. Proposed UK seismograph network coverage for 1992 at background station spacing discounting site-specific dense networks.

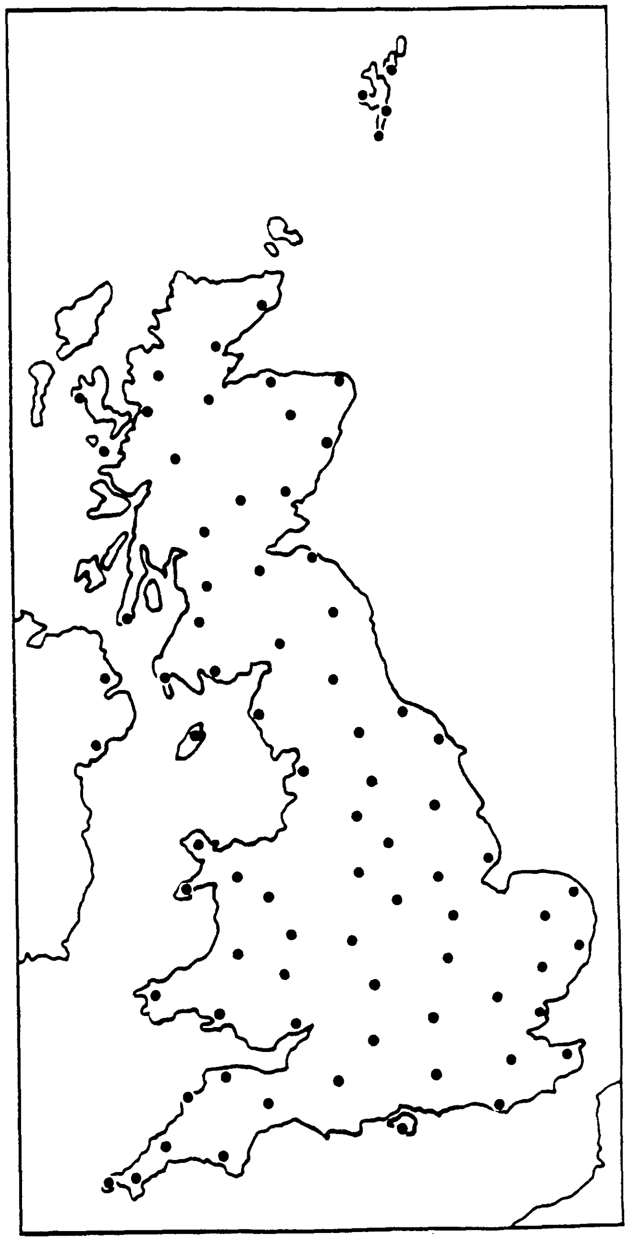

Figure 3. Proposed long-term UK background seismic monitoring network with an average station spacing of 70 km.

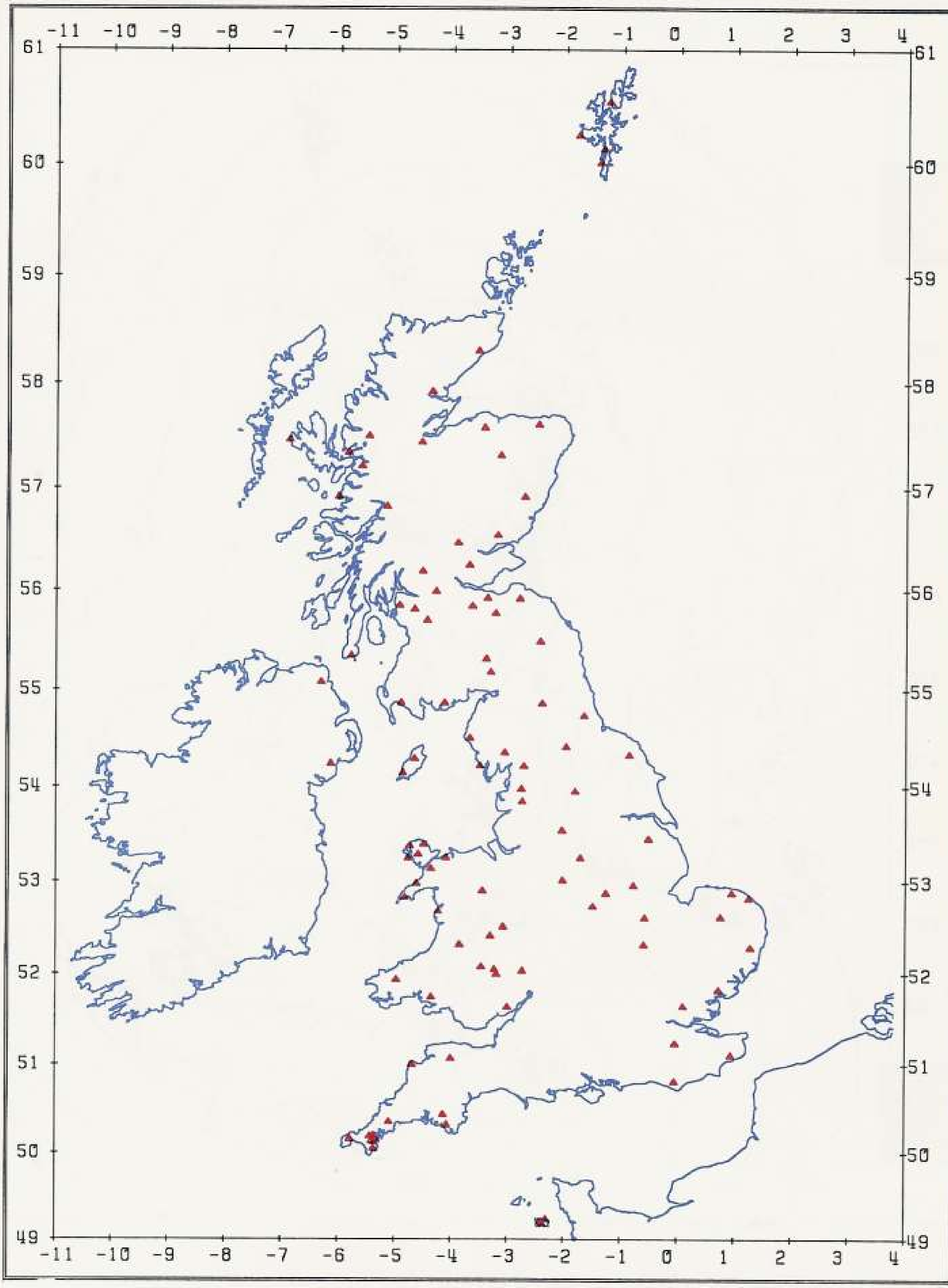

Figure 5. BGS seismograph network operational in December 1991.

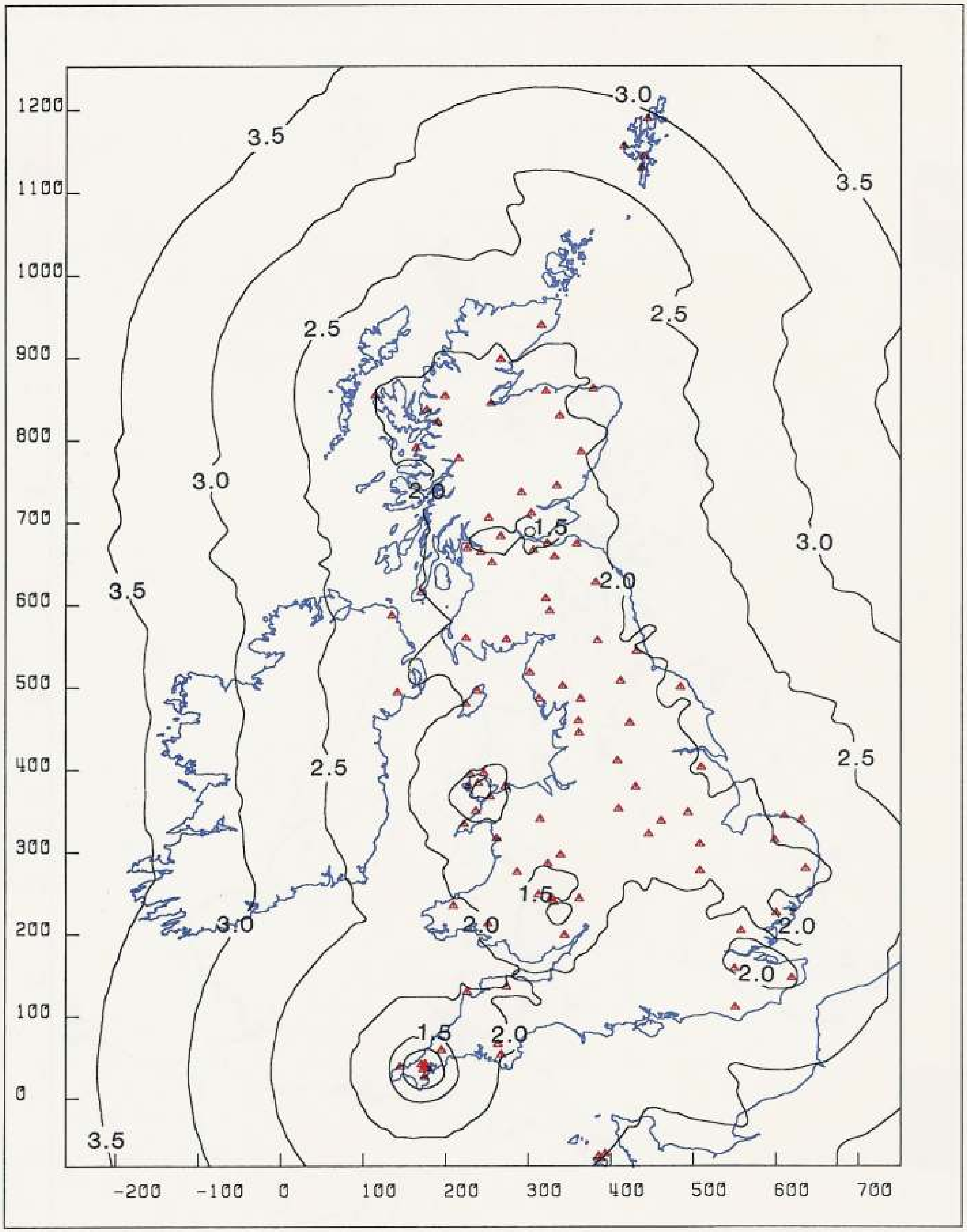

Figure 6. Earthquake identification capability. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitudes twice that at the fifth nearest station.

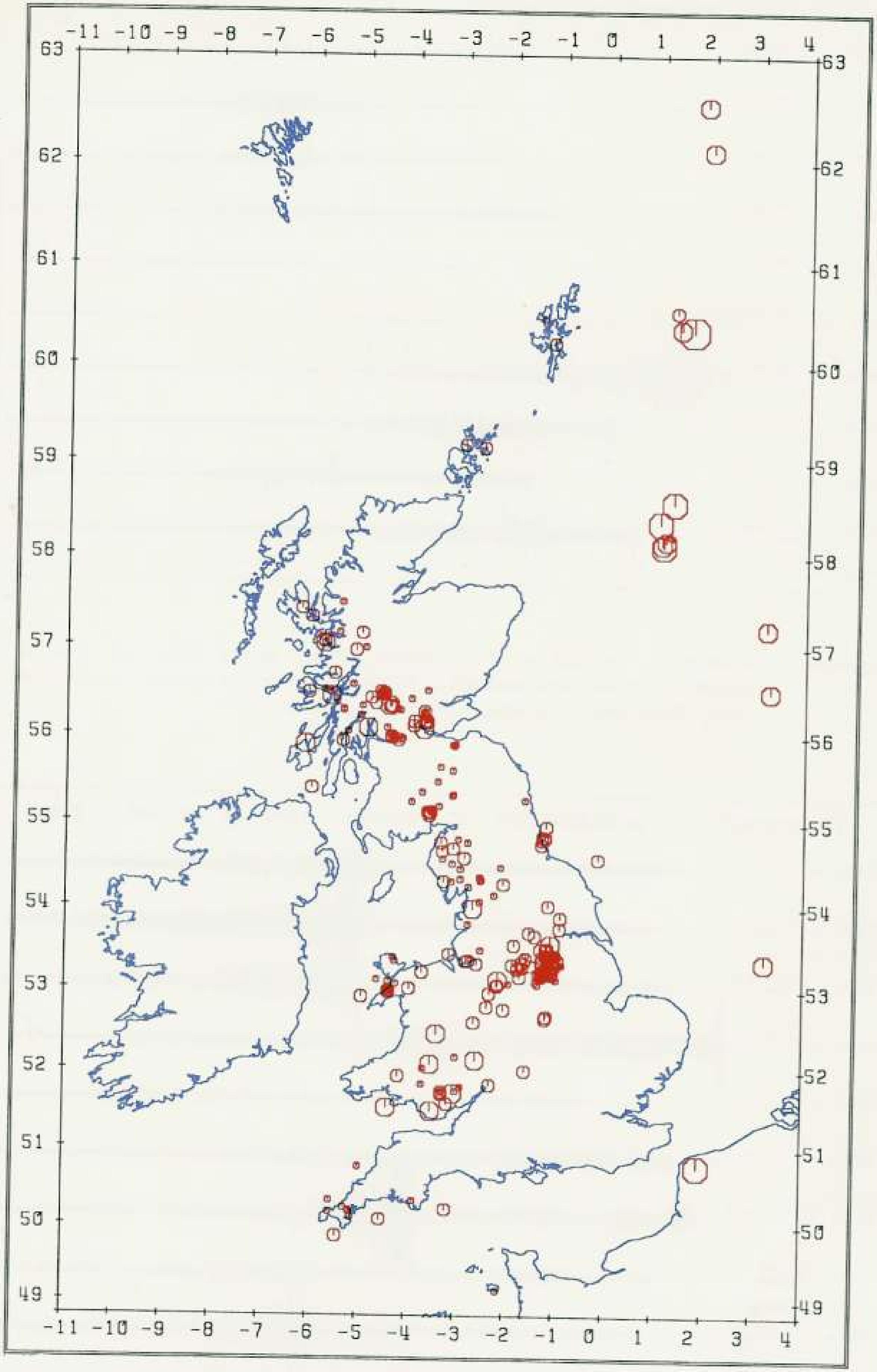

Figure 7. Epicentres of all UK earthquakes located in 1991.

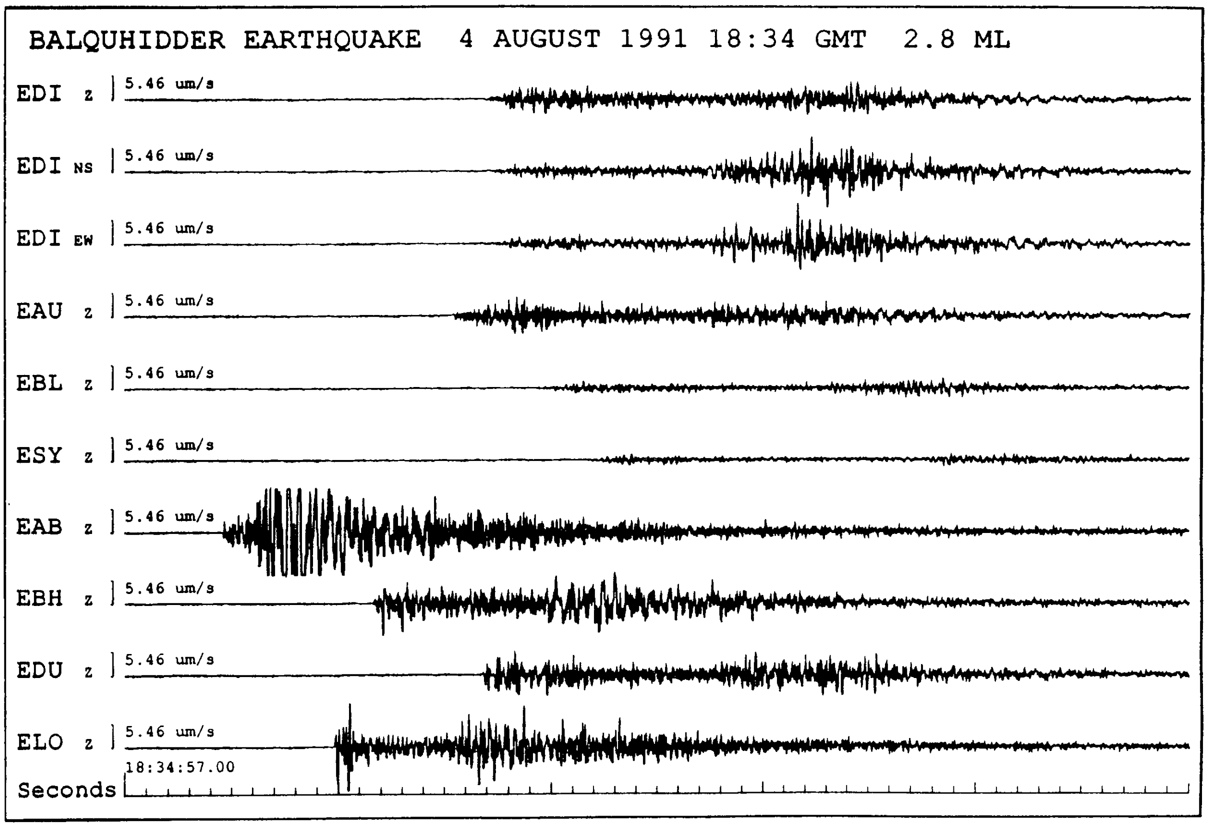

Figure 8. Seismograms recorded on the Lowlands network around Edinburgh, from a magnitude 2.8 ML earthquake felt at Balquhidder in central Scotland on 4 August 1991. Three letter codes refer to stations listed in Annex E.

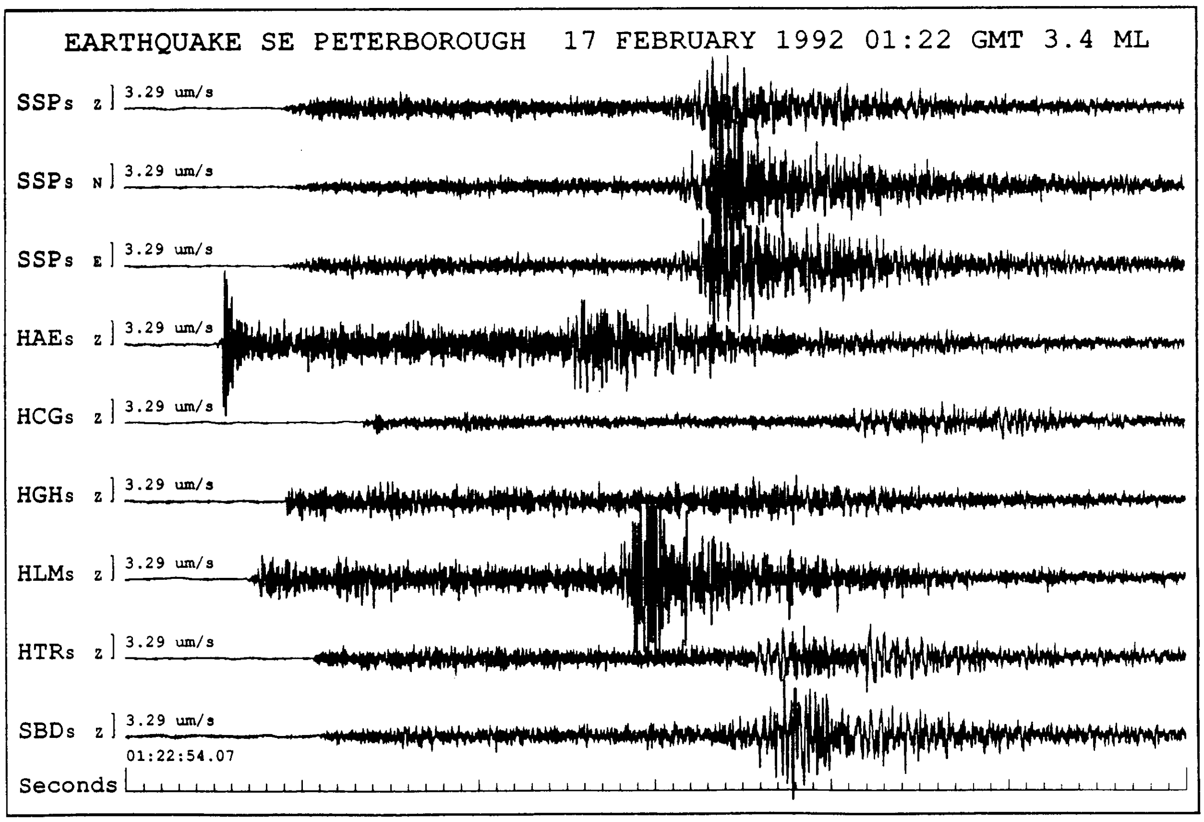

Figure 9. Seismograms recorded on the Hereford network from a magnitude 3.4 ML earthquake which was felt in the Peterborough region on 17 February 1992. Three letter codes refer to stations listed in Annex E.

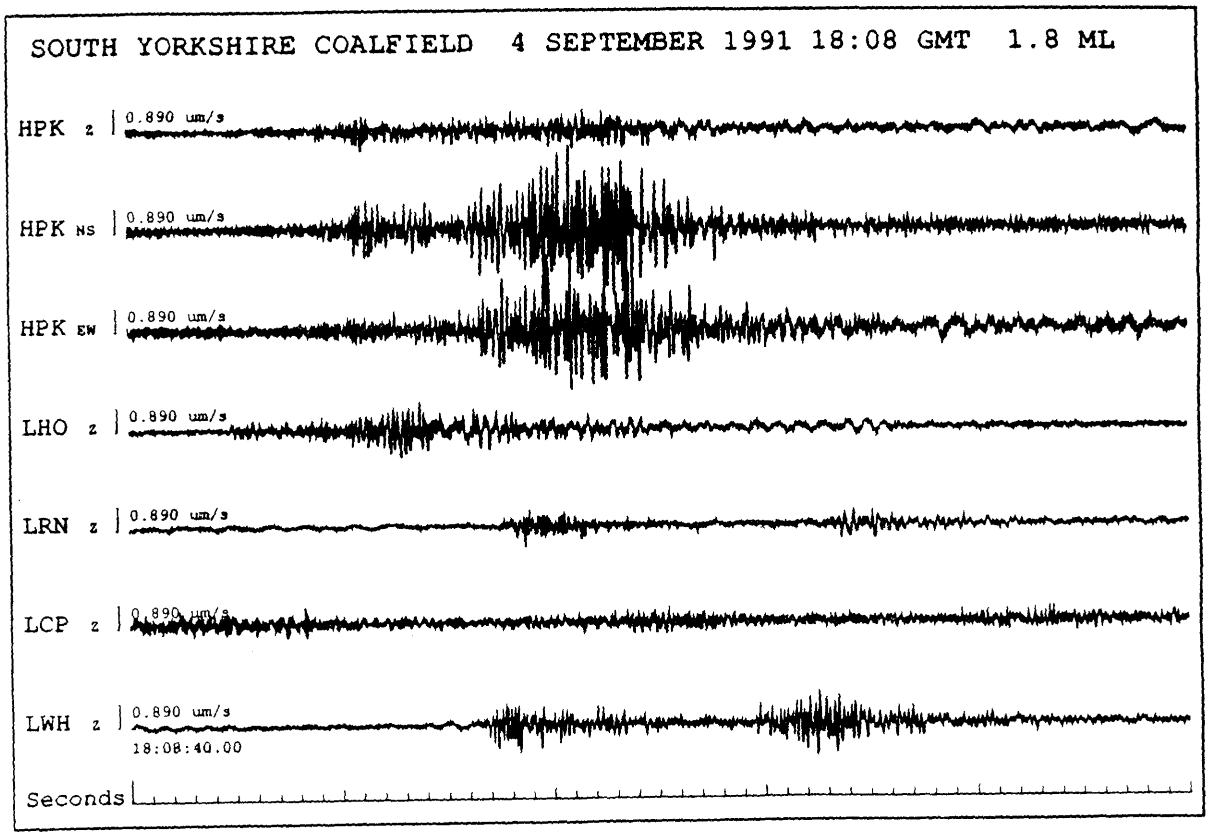

Figure 10. Seismograms recorded on the Leeds network from a magnitude 1.8 ML earthquake felt near Dinnington in the south Yorkshire coalfield on 4 September 1991. Three letter codes refer to stations listed in Annex E.

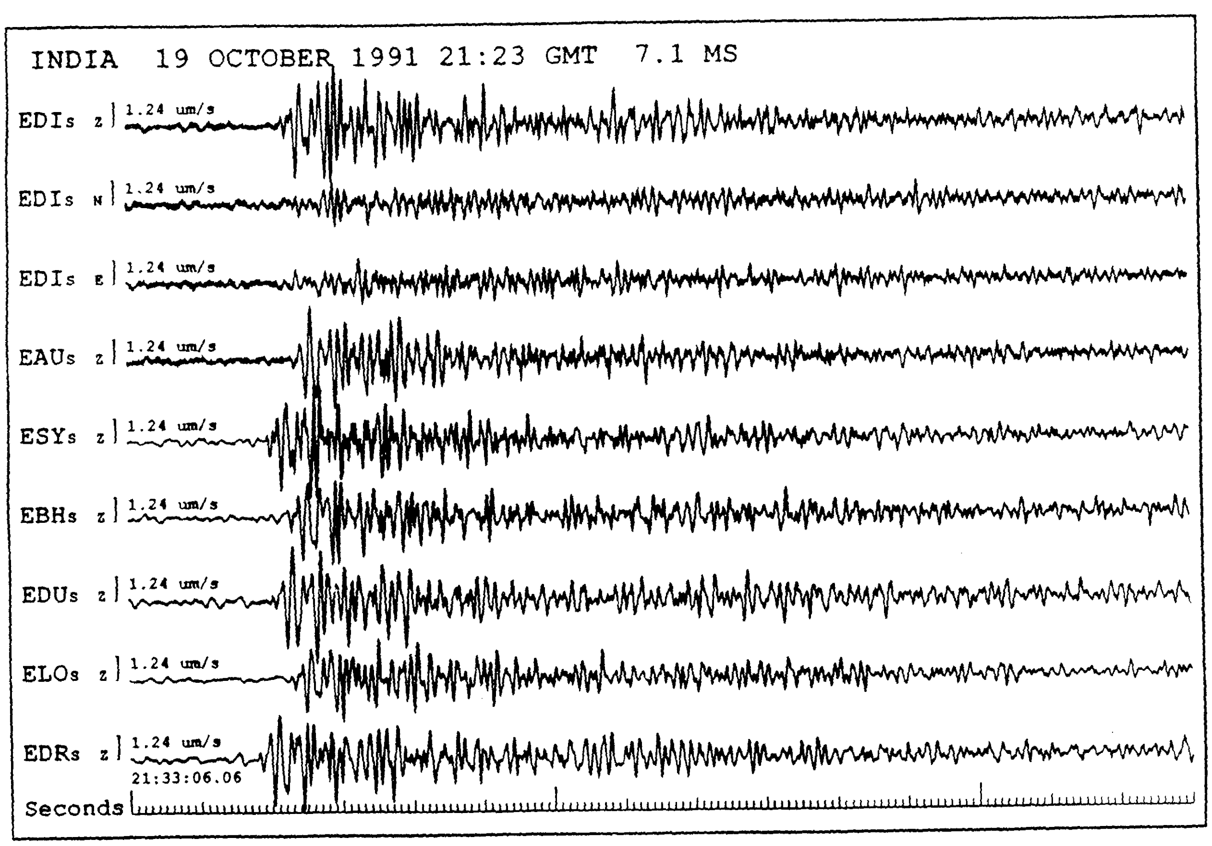

Figure 11. Seismograms recorded on the Lowlands network around Edinburgh, from the magnitude 7.1 MS earthquake in India on 19 October 1991. Three letter codes refer to stations listed in Annex E.

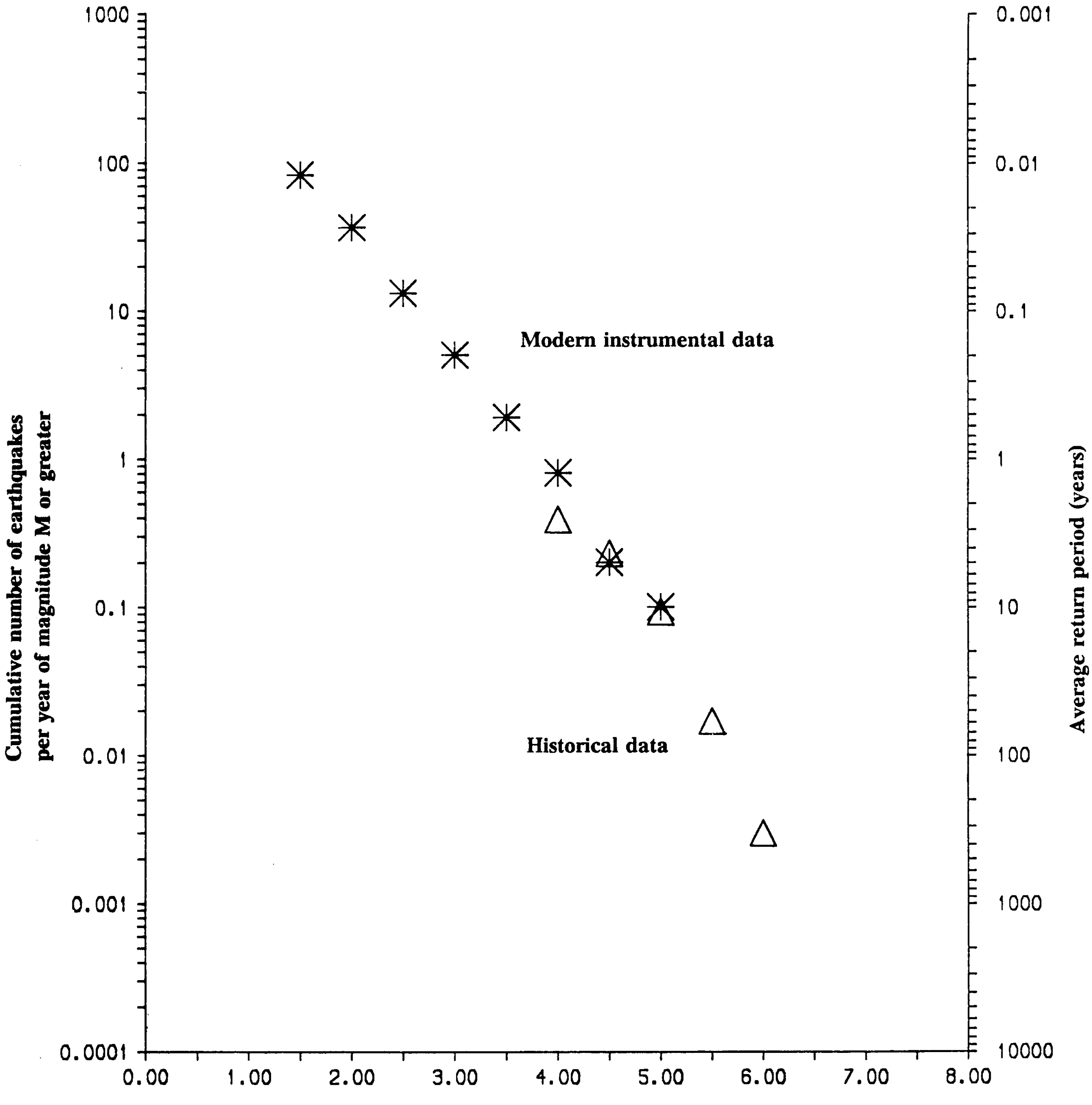

Figure 12. The recurrence relationship for British seismicity in an area 49°N to 62°N and 12°W to 4°E from the BGS instrumental catalogue for 1980 to 1989, and the historical catalogue above 4 ML after Musson (1990); both normalised to one year.

CONTRIBUTORS TO THE PROJECT

Department of the Environment
British Nuclear Fuels plc
AEA Technology
Department of Economic Development (N Ireland)
Department of the Environment (N Ireland)
Nuclear Installations Inspectorate
Scottish Hydroelectric plc
Scottish Nuclear plc
British Coal
Renfrew District Council
Welsh Office
Natural Environment Research Council

Nuclear Electric plc	Data
Ministry of Defence	Data
Department of Energy	Data and equipment

Customer Group Members (not contributing in Year Three)

British Gas
Nirex
Health and Safety Executive
Department of Trade and Industry
Scottish Development Department
International Seismological Centre

EARTHQUAKES WITH MAGNITUDES ≥ 2.0 RECORDED IN THE UK AND OFFSHORE WATERS: 1991

EVENTS ≥ 2.0 ONSHORE UK AND NORTH SEA REGION

Date	HrMnSecs	Lat	Lon	KmE	KmN	Dep	Mag	Locality	Int	No	DM	Gap	RMS	ERH	ERZ	Q	SQD	Comments...
150291	163013.4	53.32	3.22			0.4	2.4	SOUTHERN NORTH SEA		6	131	335	0.11	6.9	3.1	D	D*D	
170291	180643.7	53.09	-2.17	388.6	354.6	9.0	2.3	STOKE-ON-TRENT,STAFFS		28	23	154	0.31	1.0	1.9	C	C*C	9 KM NW STOKE-ON-TRENT
210391	024504.6	58.09	1.07	581.2	914.7	9.9	3.2	CENTRAL NORTH SEA		24	207	234	0.19	1.8	1.8	C	B*D	
210391	131743.0	58.11	1.04	579.3	917.1	14.1	2.8	CENTRAL NORTH SEA		24	206	233	0.48	4.6	4.9	D	C*D	
230391	004656.6	53.53	-1.11	458.7	404.3	0.2	2.0	DONCASTER,S YORKSHIRE		15	41	202	0.27	1.3	1.2	C	B*D	
280391	015059.2	51.46	-3.51	295.1	174.8	9.6	2.2	BRISTOL CHANNEL		18	53	123	0.18	0.7	2.0	C	B*D	
290391	092748.0	55.88	-6.15	140.4	673.4	3.2	2.1	ISLAY,STRATHCLYDE		23	69	248	0.26	2.0	2.9	C	B*D	
040491	041642.5	51.68	-3.06	326.5	198.3	0.2	2.1	PONTYWAUN,GWENT		25	18	128	0.40	0.6	1.0	C	C*C	
050491	183612.0	58.34	1.00	575.5	943.4	9.5	3.1	CENTRAL NORTH SEA		24	211	238	0.25	2.6	2.6	D	C*D	
140491	152848.4	62.53	1.85	598.1	1411.6	25.0	2.2	NORTHERN NORTH SEA		6	270	355	0.27			D	D*D	
150491	003354.6	56.43	-5.63	176.4	732.1	6.0	2.1	OBAN,STRATHCLYDE		20	84	306	0.31	3.2	5.2	D	C*D	
240491	103249.5	57.19	3.20	713.8	822.7	5.0	2.3	CENTRAL NORTH SEA		7	384	349	0.47			D	D*D	WEAKLY RECORDED
250491	162747.2	60.34	1.62	600.0	1167.2	10.6	4.2	NORTHERN NORTH SEA		24	151	129	0.54	2.4	4.4	D	D*D	
060691	214550.4	58.15	1.12			8.2	2.5	CENTRAL NORTH SEA		22	211	243	0.17	1.9	1.8	C	B*D	
160691	055415.8	52.43	-3.41	304.0	282.7	13.1	2.8	NEWTOWN,POWYS	3+	29	37	64	0.29	0.7	1.1	C	B*C	FELT NEWTON AREA
160691	083711.3	56.07	-4.88	221.0	690.7	4.0	2.0	ARDENTINNY,STRATHCLYDE	3+	13	27	210	0.15	1.2	1.3	C	B*D	FELT CLYNDER (3 MSK)
160691	182945.1	50.28	-4.12	249.0	44.3	3.0	2.3	EDDYSTONE LIGHTHOUSE		14	18	176	0.23	1.2	3.6	C	B*C	UNDERWATER EXPLOSION ?
270691	162553.8	52.10	-2.61	358.4	244.6	14.7	2.2	WESTHIDE,HER & WORC		18	8	80	0.15	0.5	0.6	B	B*A	8KM NORTHEAST OF HEREFORD
040891	183457.1	56.32	-4.44	249.4	717.1	3.3	2.8	BALQUHIDDER,CENTRAL	3+	27	16	125	0.15	0.4	0.8	B	A*C	FELT BALQUHIDDER,TYNDRUM,
110891	230747.1	60.36	1.37	585.8	1169.0	1.0	2.1	NORTHERN NORTH SEA		6	136	336	0.29	12.2	5.2	D	D*D	
140891	132241.2	52.05	-3.53	294.7	240.3	14.9	2.3	BRECON,POWYS		20	18	135	0.17	0.6	0.5	B	B*B	15KM NORTHWEST OF BRECON
240891	070253.4	62.10	1.97	607.2	1364.6	1.0	2.1	NORTHERN NORTH SEA		6	238	353	0.08	8.1	6.5	D	D*D	
270991	081844.4	57.02	-5.78	170.3	798.7	5.7	2.2	LOCH NEVIS,HIGHLAND		13	12	180	0.11	0.8	1.0	B	A*C	SMALL AFTERSHOCKS @ 08:20
201091	024209.7	56.49	3.28	725.2	745.1	5.0	2.9	CENTRAL NORTH SEA		12	325	215	0.35	11.4	9.0	D	D*D	
081191	063720.1	53.96	-2.70	354.3	451.8	13.2	2.7	OAKENCLOUGH,LANCS		33	70	78	0.41	0.9	1.7	D	C*D	
131191	213311.9	56.69	5.16			0.2	2.6	CENTRAL NORTH SEA		6	480	352	1.86			D	D*D	
141191	220239.9	56.05	-3.74	291.6	685.4	0.8	2.1	LETHAM,CENTRAL		9	88	279	0.54	3.2	2.5	D	D*D	
181191	091300.1	58.55	1.27	590.3	967.0	11.6	3.7	NORTHERN NORTH SEA		24	291	335	0.42			D	D*D	
301191	144151.1	51.50	-4.41	232.9	180.8	17.2	2.2	BRISTOL CHANNEL		23	33	131	0.18	0.7	1.0	B	B*B	
141291	133055.1	50.75	1.91			0.1	3.6	BOULOGNE, FRANCE		21	67	170	0.87	3.5	3.0	D	D*D	

FAX

BRITISH GEOLOGICAL SURVEY
MURCHISON HOUSE
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FAX: 031 667 1877 GSRG BGS

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J COLLOFF	- BNFL	T JONES	- NIREX
H TUR	- BNFL	C HEATLIE	- SCOTTISH HOME & HEALTH DE
C WILSON	- DED	J P McFARLANE	- SCOTTISH NUCLEAR
D J MALLARD	- NUCLEAR ELEC	M WILKES	- UKAEA
C F ALLEN	- NUCLEAR ELEC	M J ALLEN	- BRITISH COAL
W P ASPINALL	- AA	P J BUCKLEY	- H&S EXEC
C BEAK	- HYDROBOARD	F D KANE	- DOE(NI)
R J STUBBS	- NII, LONDON	A W B JACOB	- DIAS
C PATCHETT	- NII, BOOTLE	H PAYNE	- WELSH OFFICE
J E INKESTER	- NII, BOOTLE		
		DIRECTOR	- BGS
		M RAINES	- BGS, KEYWORTH
		B TAYLOR	- BGS, INFO SERVICES
		S BRACKELL	- BGS, LONDON INFO OFFICE
		B STEPHENSON	- BGS, MARKETING

FROM: A B WALKER/C W A BROWITT

DATE: 18 FEBRUARY 1992

TIME: 18:25

PAGES TO FOLLOW: NONE

SEISMIC ALERT: FOLLOW UP

FELT EARTHQUAKE SE PETERBOROUGH 17 FEBRUARY 1992 01:22 GMT 3.4 ML

FURTHER TO OUR FAX OF 17 FEBRUARY WE HAVE RECEIVED DATA TAPES FROM NETWORKS IN EAST ANGLIA AND KEYWORTH AND THE FOLLOWING LOCATION PARAMETERS HAVE BEEN OBTAINED:

DATE:	17 FEBRUARY 1992
ORIGIN TIME:	01:22 33.0 GMT
LAT & LONG:	52.50 N 0.19 W
GRID REFERENCE:	523 KME 290 KMN
LOCALITY:	SE PETERBOROUGH
DEPTH:	10 km
MAGNITUDE:	3.4 ML
INTENSITY:	4 MSK

THIS IMPROVED LOCATION HAS DETERMINED THE DEPTH AND HAS MOVED THE EPICENTRE 7 KM TO THE SOUTH OF THE PROVISIONAL SOLUTION.

A MACROSEISMIC SURVEY HAS BEEN INITIATED IN LOCAL NEWSPAPERS TO OBTAIN DETAILS AND LIMITS OF THE FELT AREA WHICH AT PRESENT APPEAR TO BE FROM UPPINGHAM TO WISBECH AND BOSTON TO HUNTINGDON: SOME 60 KM BY 70 KM.

FAX

BRITISH GEOLOGICAL SURVEY
MURCHISON HOUSE
WEST MAINS ROAD
EDINBURGH EH9 3LA

TEL: 031 667 1000
TLX: 727343 SEISED G
FAX: 031 667 1877 GSRG BGS

TO: B R MARKER	- DOE	T B KAM	- BRITISH GAS
J COLLOFF	- BNFL	T JONES	- NIREX
H TUR	- BNFL	C HEATLIE	- SCOTTISH HOME & HEALTH DE
C WILSON	- DED	J P McFARLANE	- SCOTTISH NUCLEAR
D J MALLARD	- NUCLEAR ELEC	M WILKES	- UKAEA
C F ALLEN	- NUCLEAR ELEC	M J ALLEN	- BRITISH COAL
W P ASPINALL	- AA	P J BUCKLEY	- H&S EXEC
C BEAK	- HYDROBOARD	F D KANE	- DOE(NI)
R J STUBBS	- NII, LONDON	A W B JACOB	- DIAS
C PATCHETT	- NII, BOOTLE	H PAYNE	- WELSH OFFICE
J E INKESTER	- NII, BOOTLE		
		DIRECTOR	- BGS
		M RAINES	- BGS, KEYWORTH
		B TAYLOR	- BGS, INFO SERVICES
		S BRACKELL	- BGS, LONDON INFO OFFICE
		B STEPHENSON	- BGS, MARKETING

FROM: D W REDMAYNE

DATE: 20.2.92

TIME: 19.10

PAGES TO FOLLOW: NONE

SEISMIC ALERT: FOLLOW UP

REPORTED TREMORS 19 FEBRUARY 1992 19:00-21:45 GMT CUMBRIA

FOLLOWING AN EARLIER FAX ON THIS SUBJECT, THE ANALOGUE SEISMIC TAPE FROM THE ESKDALEMUIR NETWORK HAS BEEN ANALYSED. NO EARTHQUAKE OR GROUND BASED EXPLOSION HAS BEEN DETECTED AT THE TIMES OF THE REPORTS. HOWEVER, FIVE SIGNALS CONSISTENT WITH EVENTS OF ATMOSPHERIC ORIGIN HAVE BEEN RECORDED ON ONE STATION (XDE, NEAR WHITEHAVEN) AT 18:57 GMT, 19:39 GMT, 19:49 GMT, 20:44 GMT, 21:33 GMT. THESE TIMES AGREE WELL WITH THE REPORTED TIMES OF THE 'TREMORS'. THE NATURE OF THE RECORDED SIGNALS IS CONSISTENT WITH ATMOSPHERIC OR ACOUSTIC EVENTS, PROBABLY SONIC BOOMS, AND WE CONCLUDE THAT THIS IS THE CAUSE.

ANNEX C

BGS STAFF WITH INPUT TO THE PROJECT

Dr C W A Browitt
Mr P S Day
Mr G D Ford
Mr C J Fyfe
Mr D D Galloway
Mr P H O Henni
Mr D J Houliston
Mr N S Hunt
Mr J Laughlin
Mr P C Marrow
Mr A Miller
Mr S N Morgan
Mrs A I Muir
Dr R M W Musson
Mr D L Petrie
Mr M G Raines
Mr D W Redmayne
Mrs M E A Ritchie
Mr B A Simpson
Mr D A Stewart
Mrs J H Shaw
Mr T Turbitt
Mr W A Velzian
Miss A B Walker
Mr R J Wallace
Mrs F Wright
Mr R M Young

GEOGRAPHICAL CO-ORDINATES OF BGS SEISMOGRAPH STATIONS: DECEMBER 1991

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (m)	Yrs Open	Comp	Agency
SHETLAND									
LRW	LERWICK	60.1360	-1.1779	445.66	1139.27	100	78-	4R	BGS
YEL	YELL	60.5509	-1.0830	450.29	1185.55	200	79-	1	BGS
WAL	WALLS	60.2576	-1.6133	421.40	1152.60	170	80-	1	BGS
SAN	SANDWICK	60.0176	-1.2386	442.44	1126.05	155	85-	1	BGS
MORAY									
MCD	COLEBURN DISTIL	57.5827	-3.2541	325.02	855.41	280	81-	4R	BGS
MDO	DOCHFOUR	57.4412	-4.3633	258.17	841.43	366	81-	1R	BGS
MLA	LATHERON	58.305	-3.364	320.1	935.9	190	81-	1	BGS
MME	MEIKLE CAIRN	57.315	-2.965	341.9	825.3	455	81-	1	BGS
MVH	ACHVAICH	57.9232	-4.1816	270.79	894.70	198	84-	1	BGS
MFI	FISHRIE	57.6116	-2.2953	382.36	857.97	220	88-	1R	BGS
KYLE									
KAC	ACHNASHELLACH	57.4999	-5.2982	202.40	850.29	330	83-	1R	BGS
KAR	ARISAIG	56.9175	-5.8302	166.90	787.20	225	83-	1	BGS
KSB	SHIEL BRIDGE	57.2098	-5.4230	193.30	818.39	70	83-	1R	BGS
KPL	PLOCKTON	57.3391	-5.6527	180.21	833.50	36	86-	4R	BGS
KSK	SCOVAL	57.4653	-6.7020	118.09	851.40	250	89-	1R	BGS
KNR	NEVIS RANGE	56.8219	-4.9714	218.68	773.97	1118	91-	1R	BGS
LOWNET									
EAB	ABERFOYLE	56.1881	-4.3400	254.80	701.95	250	69-	1R	BGS
EAU	AUCHINOON	55.8444	-3.4547	308.92	662.20	350	69-	1R	BGS
EBH	BLACK HILL	56.2481	-3.5081	306.56	707.19	375	69-	1R	BGS
EBL	BROAD LAW	55.7733	-3.0436	334.54	653.82	365	69-	1R	BGS
EDI	EDINBURGH	55.9233	-3.1861	325.89	670.66	125	69-	4R	BGS
EDU	DUNDEE	56.5475	-3.0142	337.65	739.95	275	69-	1R	BGS
ELO	LOGIEALMOND	56.4706	-3.7119	294.55	732.24	495	69-	1R	BGS
ESY	STONEYPATH	55.9177	-2.6144	361.60	669.57	328	81-	1R	BGS
EDR	DRUMTOCHTY	56.9184	-2.5404	367.18	780.96	388	89-	1R	BGS
PAISLEY									
PCA	CARROT	55.700	-4.255	258.3	647.5	305	83-	1	BGS
PCO	CORRIE	55.988	-4.097	269.2	679.2	274	83-	1	BGS
PMS	MUIRSHIEL	55.846	-4.744	228.2	664.8	351	83-	1	BGS
PGB	GLENIFFERBRAES	55.810	-4.478	244.5	660.5	200	84-	3	BGS
ESKDALEMUIR									
ESK	ESKDALEMUIR	55.3167	-3.2050	323.54	603.18	263	65-	4R	BGS
ECK	CAULDKAINE HILL	55.1812	-3.1271	328.24	588.02	337	81-	1R	BGS
XAL	ALLENDALE	54.8617	-2.2147	386.22	551.91	462	83-	1R	BGS
XDE	DENT	54.5058	-3.4897	303.55	513.31	291	83-	1R	BGS
XSO	SOURHOPE	55.4925	-2.2511	384.13	622.11	495	83-	1R	BGS
GALLOWAY AND N IRELAND									
GAL	GALLOWAY	54.8664	-4.7114	226.02	555.78	105	89-	4	BGS
GCD	CASTLE DOUGLAS	54.8638	-3.9417	275.40	553.85	189	89-	1R	BGS
GCL	CUSHENDALL	55.076	-6.130	136.4	583.7	275	89-	1R	BGS
GIM	N ISLE OF MAN	54.2923	-4.4670	239.46	491.35	366	89-	1R	BGS
GMK	MULL OF KINTYRE	55.3459	-5.5936	172.18	611.65	160	89-	1R	BGS
GMM	MTNS OF MOURNE	54.239	-5.951	142.6	489.8	140	89-	1R	BGS
LANCASHIRE									
LBO	BOWLAND	53.9790	-2.5728	362.44	453.83	320	89-	1R	BGS
LCK	CROOK	54.3595	-2.8715	343.37	496.36	200	89-	1R	BGS
LKL	KIRKBY LONSDALE	54.2185	-2.5345	365.15	480.46	396	89-	3R	BGS

GEOGRAPHICAL CO-ORDINATES OF BGS SEISMOGRAPH STATIONS: DECEMBER 1991

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (m)	Yrs Open	Comp	Agency
LLO	LONGRIDGE	53.8503	-2.5598	363.18	439.51	247	89-	3R	BGS
LMI	MILLOM	54.2206	-3.3070	314.79	481.35	140	89-	3R	BGS
LBH	MORECAMBE B102	54.0259	-2.9058	340.68	460.00	-85	90-	1	BGS
LEEDS									
HPK	HAVERAH PARK	53.9554	-1.6240	424.67	451.12	227	78-	3R	BGS
LCP	CASSOP	54.7368	-1.4741	433.86	538.12	185	91-	1	BGS
LWH	WHINNY NAB	54.3335	-0.6714	486.38	493.94	265	91-	1R	BGS
LRN	RICHMOND	54.4167	-1.7858	413.90	502.40	300	91-	1R	BGS
LMK	MARKET RASEN	53.4569	-0.3266	511.10	396.90	130	91-	1	BGS
LHO	HOLMEFIRTH	53.5451	-1.8548	409.62	405.42	460	91-	1	BGS
NORTH WALES									
YRC	RHOSCOLYN	53.2506	-4.5741	228.28	375.74	24	84-	1R	BGS
YRE	YR EIFL	52.9810	-4.4254	237.19	345.42	197	84-	1R	BGS
YLL	LLANBERIS	53.1402	-4.1704	254.84	362.57	162	84-	1R	BGS
YRH	RHIW	52.8335	-4.6289	222.93	329.49	300	84-	1R	BGS
WCB	CHURCH BAY	53.3782	-4.5465	230.63	389.86	135	85-	4	BGS
WFB	FAIRBOURNE	52.6830	-4.0378	262.27	311.47	325	85-	1R	BGS
WIM	ISLE OF MAN	54.1472	-4.6735	225.41	475.70	365	85-	1R	BGS
WLF	LLYNFAES	53.2893	-4.3966	240.27	379.64	65	85-	1	BGS
WME	MYNDD EILIAN	53.3966	-4.3034	246.86	391.37	130	85-	1R	BGS
WPM	PENMAENMAWR	53.2583	-3.9049	272.94	375.20	350	85-	1R	BGS
KEYWORTH									
CWF	CHARNWOOD FST	52.7382	-1.3071	446.78	315.88	185	75-	3R	BGS
KBI	BIRLEY GRANGE	53.2546	-1.5278	431.50	373.20	270	88-	1	BGS
KEY	KEYWORTH	52.8774	-1.0751	462.24	331.54	75	88-	1	BGS
KSY	SYSTON	52.9642	-0.5873	494.88	341.73	123	88-	1R	BGS
KTG	TILBROOK GRANGE	52.3261	-0.4007	508.98	271.03	78	88-	1	BGS
KUF	UFFORD	52.6175	-0.3895	509.02	303.45	35	88-	1R	BGS
KWE	WEAVER FARM	53.0163	-1.8435	410.50	346.60	320	88-	1R	BGS
EAST ANGLIA									
AWH	WHINBURGH	52.6299	0.9512	599.70	307.70	60	80-	1R	BGS
ABA	BACONSTHORPE	52.8875	1.1471	611.70	336.90	13	82-	1	BGS
AWI	WITTON	52.8324	1.4460	632.09	331.69	35	83-	1	BGS
APA	PACKWAY	52.2999	1.4779	637.10	272.60	35	84-	1	BGS
HEREFORD									
MCH	MICHAELCHURCH	51.9977	-2.9983	331.47	233.77	233	78-	4	BGS
SBD	BRYN DU	52.9055	-3.2588	315.35	335.01	497	80-	1	BGS
HCG	CRAIG GOCH	52.3224	-3.6567	287.10	270.70	511	80-	1R	BGS
HGH	GRAY HILL	51.6380	-2.8064	344.20	193.64	210	80-	1R	BGS
HAE	ALDERS END	52.0376	-2.5475	362.45	237.88	224	82-	1R	BGS
HTR	TREWERN HILL	52.0790	-3.2697	313.00	243.10	329	82-	1R	BGS
HLM	LONG MYND	52.5169	-2.8878	339.76	291.41	259	84-	1	BGS
SSP	STONEY POUND	52.4177	-3.1119	324.39	280.59	417	90-	3	BGS
HBL2	BONNYLANDS	52.0508	-3.0384	328.80	239.72	440	91-	1R	BGS
SOUTH EAST ENGLAND									
TFO	FOLKSTONE	51.1136	1.1406	619.79	139.67	188	89-	4	BGS
TEB	EASTBORNE	50.8188	0.1459	551.14	104.40	70	89-	1R	BGS
TSA	SEVENOAKS	51.2427	0.1558	550.46	151.55	170	89-	1	BGS
TBW	BRENTWOOD	51.6549	0.2911	558.47	197.66	82	89-	1R	BGS
TCR	COLCHESTER	51.8349	0.9215	601.26	219.23	40	89-	1R	BGS

GEOGRAPHICAL CO-ORDINATES OF BGS SEISMOGRAPH STATIONS: DECEMBER 1991

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (m)	Yrs Open	Comp	Agency
CORNWALL									
CCA	CARNMENELLIS	50.1864	-5.2277	169.62	36.87	213	81-	1	BGS
CBW	BUDOCK WATER	50.1482	-5.1144	177.53	32.29	98	81-	1	BGS
CCO	CONSTANTINE	50.1357	-5.1960	171.64	31.15	183	81-	1	BGS
CGH	GOONHILLY	50.0508	-5.1649	173.47	21.61	91	81-	1	BGS
CPZ	PENZANCE	50.1560	-5.5835	144.07	34.66	198	81-	1R	BGS
CR2	ROSEMANOWES 2	50.1669	-5.1687	173.74	34.53	152	81-	3	BGS
CRQ	ROSEMANOWES	50.1672	-5.1728	173.45	34.57	165	81-	4R	BGS
CSA	ST AUSTELL	50.3528	-4.8936	194.18	54.39	113	81-	1	BGS
CST	STITHIANS	50.1952	-5.1635	174.24	37.66	139	81-	1	BGS
CTR	TROLVIS QUARRY	50.1665	-5.1624	174.18	34.47	191	82-	3	BGS
CME	MENERDUE FARM	50.1760	-5.1903	172.24	35.61	178	82-	3R	BGS
CRA	RAME	50.1648	-5.1921	172.06	34.36	198	82-	3	BGS
DEVON									
HTL	HARTLAND	50.9944	-4.4850	225.64	124.67	91	81-	4R	BGS
DCO	COMBE FARM	50.3200	-3.8724	266.72	48.42	410	82-	1R	BGS
DYA	YADSWORTHY	50.4352	-3.9309	262.89	61.33	280	82-	3R	BGS
HSA	SWANSEA	51.7478	-4.1543	251.30	207.70	274	87-	1R	BGS
HPE	PEMBROKE	51.9371	-4.7745	209.27	230.18	355	90-	1R	BGS
HEX	EXMOOR	51.0668	-3.8025	273.72	131.32	278	91-	1R	BGS
JERSEY									
JLP	LES PLATONS	49.2428	-2.1039			131	81-	1R	BGS
JSA	ST AUBINS	49.1879	-2.1709			21	81-	1R	BGS
JRS	MAISON ST LOUIS	49.1924	-2.0917			53	81-	4R	BGS
JVM	VAL DE LA MARE	49.2169	-2.2068			64	81-	1R	BGS
JQE	QUEENS EAST	49.200	-2.038			56	91-	1	BGS
JQW	QUEENS WEST	49.196	-2.057			73	91-	1	BGS
JQS	QUEENS SOUTH	49.180	-2.063			62	91-	1	BGS

Notes

1. The UK seismograph network is divided into a number of subnetworks, named Cornwall, Devon, etc, within which data is transmitted, principally by radio, from each seismometer station to a central recorder where it is registered against a common, accurate time standard.
2. From left to right the column headers stand for Latitude, Longitude, Easting, Northing, Height, Year station opened, number of seismometers at the station and the agency operating the station (in this list they are all BGS).
3. The 'R' against some station components indicates that station details have been registered with international agencies for data exchange purposes.

BGS Seismology reports

1991

WL/90/52	Browitt, C.W.A. Transfrontier Research in Low Seismicity areas, Report to European Community Natural Hazards Programme.
WL/91/26	Browitt, C.W.A. and Turbitt, T. BGS Seismic Monitoring and Information Service, Second Annual Report.
WL/91/28	Musson, R.M.W. The 17 March 1871 Appleby earthquake.
WL/91/30	Ritchie, M.E.A. and Wright, F. The Newtown earthquake of 16 June 1991 (2.8 ML).
WL/91/31	Ritchie, M.E.A. and Wright, F. The 1988 Hay-on-Wye earthquake sequence.
WL/91/34	Turbitt, T. (Ed.), Galloway, D.D., Ford, G.D., Hunt, N.S., Marrow, P.C., Musson, R.M.W., Redmayne, D.W., Richards, J.A., Ritchie, M.E.A., Simpson, B., Towell, J.H., Walker, A.B. and Wright F. Bulletin of British Earthquakes 1990.
WL/91/36	Walker, A.B. SW England seismic monitoring for the HDR Geothermal programme in Cornwall 1989 to September 1991.

In addition, 9 confidential reports were prepared for commercial customers and bulletins of seismic activity were produced monthly, up to 2 months in arrears for the Customer Group sponsoring the project.

External Publications

Marrow, P.C., 1992. Seismic Monitoring of the North Sea. *Health and Safety Executive - Offshore Technology Report OTH 90 323.*

Musson, R.M.W., 1991. The use of the MSK intensity scale in the study of historical British earthquakes, *Proc. of the Third International Symposium on Historical Earthquakes in Europe, Liblice, April, 1990,* 5-12.

Musson, R.M.W., 1991. Pictorial representations of damage in historical British earthquakes, *Proc. of the Third International Symposium on Historical Earthquakes in Europe, Liblice, April, 1990,* 161-174.

Redmayne, D.W. and Turbitt, T., 1991. Ground velocity attenuation associated with the Lockerbie air crash impact. In: *Earthquake, Blast and Impact - Measurement and Effects of Vibration,* (Edited by The Society for Earthquake and Civil Engineering Dynamics), Elsevier Applied Science, 352-362.

Walker, A.B., 1991. The Jersey Earthquake of 30 April 1990, *Société Jersiaise Annual Bulletin 1991,* **25(3),** 529-538.

TRANSFRONTIER RESEARCH IN LOW SEISMICITY AREAS

C W A Browitt

It has become widely recognised in recent years that areas of low seismicity contain a definite risk for industrialised countries which engage in 'high consequence' activities (eg nuclear power and reprocessing, offshore and onshore hydrocarbon exploitation, chemical works and large engineered structures such as bridges and tunnels). Understanding the earthquake hazard and identifying the causative faults in such areas is difficult because of the infrequency of the larger earthquakes and the relatively short period of instrumental monitoring. Recognising that 8 of the north-western Member States of the European Community fall into the category outlined above, the Commission contracted research under the Second Framework Agreement for those States to improve, enhance and harmonise their capabilities in this area. Emphasis was to be placed on tackling the problems of free and rapid data exchange, particularly in transfrontier areas.

Notable gaps in the seismographic coverage of the region have been identified and, during the period of this work, some of them have been filled and plans laid for further improvement. Specifically, new stations have been installed in northern France, south-east England, Belgium, Ireland and Luxembourg.

Methods of rapid access to earthquake information in one Member State by any other participant has been pursued with the use of Fax machines, computer bulletin boards, 'dial-up' seismograph stations and, where possible, the real-time transmission of data across borders by radio and land-line.

The largest natural earthquake to have occurred during the project had a magnitude of 5.1 ML (Richter), was centred near the England-Wales border and caused some damage in the epicentral area. It was felt over Wales, most of England and into Ireland and Scotland. In Germany, a strong mining-induced 'earthquake' occurred near Merkers with a magnitude of 5.4 Mb. It was felt widely in Germany and in parts of France, Czechoslovakia, Switzerland and Austria with damage to many buildings in the epicentral area. Elsewhere, earthquakes with magnitudes of about 3.5 ML have been felt in the Netherlands, Belgium, Jersey and Germany with one felt offshore on oil platforms near the Denmark-UK-Norway borders in the central North Sea.

BGS SEISMIC MONITORING AND INFORMATION SERVICE: SECOND ANNUAL REPORT

C W A Browitt and T Turbitt

The UK earthquake monitoring and information service project has developed from the commitment of a group of organisations, the 'Customer Group', with an interest in the seismic hazard of the UK. The project formally started in April 1989 and the published Year 1 report includes details of the history of monitoring by BGS since 1969 and an outline of the background to the establishment of the project.

This Year 2 report to the Customer Group follows the format of the first annual report in reiterating the programme objectives and highlighting some of the significant seismic events in the period April 1990 to March 1991. The catalogue of earthquakes for the whole of 1990 is plotted to reflect the period for which the bulletin of revised data is produced. Progress towards the overall need to establish a uniform distribution of seismic monitoring stations with an average spacing of 70 km is reviewed. With insufficient funds available to move to this situation in the short term, reliance is placed on some of the site-specific networks commissioned by some members of the Customer Group who have made the data collected in this way openly available. Low cost ways of adding individual monitoring stations to the network have been pursued and, on an opportunistic basis, upgrades to more modern digital systems are being implemented.

The effect of these upgrades is to make immediately available, data outside the Edinburgh region with a consequent increase in response time for felt earthquakes in many parts of England and Wales.

THE 17 MARCH 1871 APPLEBY EARTHQUAKE

R M W Musson

This earthquake, formerly referred to as a Kendal event, is one of the larger earthquakes to have affected the North of England. Its epicentre was between Appleby and Alston, and its magnitude is estimated as 4.9 ML. This report provides a full study of the event, its foreshocks and aftershocks.

THE NEWTOWN EARTHQUAKE OF 16 JUNE 1991 (2.8 ML)

M E A Ritchie and F Wright

A small, solitary earthquake occurred on 16 June 1991 at 05:54 GMT and it was felt by several people in the Newtown and Kerry areas of mid Wales. It is one of the 10, or so, events of this size which occur every year somewhere in Britain.

The nature of the station distribution allowed a focal mechanism to be obtained, thereby adding to the increasing number of fault plane solutions available for small events in Britain. The mechanism represents dominant reverse faulting on either an ESE or NE striking plane.

THE 1988 HAY-ON-WYE EARTHQUAKE SEQUENCE

M E A Ritchie and F Wright

Seventeen small earthquakes occurred near Hay-on-Wye in Hereford over a period of 37 days during 1988. Initially, epicentres of these events showed an alignment in a NNE-SSW direction over a distance of 8 km; one of the few instances when a lineation has been observed in British swarm activity. The data was re-examined in detail using additional phase data, a more appropriate velocity model for the area and error evaluation techniques in order to improve and assess the location accuracy. The apparent lineation in epicentre distribution was found to be an artefact of poor station distribution around the epicentres and the lineation cannot be sustained as a real feature. Focal mechanisms obtained for the two largest earthquakes in the series are in agreement with the regional stress field observed in Britain.

BULLETIN OF BRITISH EARTHQUAKES 1990

T Turbitt (Editor)

The largest earthquake for 6 years (magnitude 5.1 ML) occurred on 2 April near Bishop's Castle in Shropshire. Minor damage occurred in Shrewsbury and Wrexham and the earthquake was felt from Ayrshire to Cornwall and Dublin to Kent. Only 7 aftershocks were detected in contrast to the magnitude 5.4 ML Lleyn event of 1984 which generated several hundred. Those aftershocks have continued with 13 located during 1990; one being felt.

A magnitude 3.5 ML earthquake was felt throughout Jersey and on Guernsey on 30 April; an area which experienced strong shaking on many occasions in the earlier part of this century. In the North Sea, the largest earthquake, magnitude 4.4 ML, occurred 60 km north-east of the Magnus oil field on 10 November; no felt reports were received.

Coalfield areas throughout Britain have experienced many small earthquakes with a high proportion of them felt locally. Stoke-on-Trent was the centre of 10 such events of which 6 were felt and the largest had a magnitude of 2.8 ML.

In Carrickfergus, Northern Ireland, a strong seismic signal was reported on 19 October throughout the recently installed North Irish Sea network. It originated from the collapse of an abandoned salt mine which left a depression 200 metres diameter and 7 metres deep.

A swarm of small earthquakes, similar to those in 1986, occurred at Crianlarich, central Scotland, mainly during April and August. Thirty eight events were detected, including some which were too small to locate accurately. The largest had a magnitude of 1.7 ML.

A series of small events (up to 0.6 ML) occurred near Constantine in Cornwall, during November, at the site of a 3.5 ML earthquake in 1981, a large aftershock series and further activity in 1986.

SW ENGLAND SEISMIC MONITORING FOR THE HDR GEOTHERMAL PROGRAMME IN CORNWALL: 1989 TO SEPTEMBER 1991

A B Walker

The potential for earthquakes to be triggered by fluid injected into boreholes has been recognised for 25 years and natural earthquakes in Cornwall have been reported for over 250 years. As a result, the Geothermal Steering Committee advising the Hot Dry Rock (HDR) project recommended that background seismic monitoring be undertaken around the HDR experimental site at Rosemanowes. A network of seismographs was established for this purpose by the British Geological Survey (BGS) in late 1980 and has been operated continuously through September 1991. The primary aim of the network has been to provide an independent, continuous assessment of all vibrational transients in order to discriminate between those caused by the Hot Dry Rock experiments and those of natural origin or from other man-made sources. In this respect, the work provides an insurance against claims that extraneous seismic activity is related to those experiments.

Throughout 1989 to September 1991, 65 natural earthquakes have been located by the network, 23 of which located south of Constantine with magnitudes ranging from -0.8 to 0.6 ML. A study of their focal mechanisms has provided information on the principal stress directions in the crustal rocks of the region. The maximum stress acts horizontally with a NW-SE orientation in contrast to that in North Wales where small earthquakes have given an orientation of NNW-SSE; a clockwise rotation of some 25 degrees from Cornwall to North Wales.

Over the ten-year monitoring period, some 450 natural seismic events have been located by the Cornwall network. It has proved to be an area of moderate seismicity within the UK, with six natural earthquakes felt. Five of those where in the Constantine series and the other near Liskeard, with magnitudes ranging from 1.9 to 3.5 ML.

SEISMIC MONITORING OF THE NORTH SEA

P C Marrow

In 1979, the British Geological Survey and the Department of Energy embarked on a programme of North Sea earthquake monitoring to improve the database for assessment of seismic risk to oil-field installations. The study involved the deployment of new seismograph stations in Shetland, NE Scotland, Norway, E Anglia and on the bed of the northern North Sea. This report summarises the results of that programme and is the final report for the formal contract.

New data has been obtained on the seismicity of the North Sea including earthquake epicentres with accuracies of a few kilometres. Although based on a short time period, some deductions can be made. It appears that the axial grabens of the North Sea are seismically active and are bounded by relatively aseismic structural highs; a conclusion which has implications for seismic hazard assessments which, in the past, have been forced to adopt the assumption of uniform seismicity. The association of the low levels of North Sea seismicity with the graben systems is consistent with other recent observations, worldwide, on the seismicity of "stable continental interiors". In such regions, 70-75% of seismicity is spatially associated with structural lows (such as the axial grabens) and with passive margins. In addition, the rare, large ($M \simeq 7.0$) earthquakes in these regions are all associated with structural lows and passive margins. Spectral studies suggest that the present rate of seismicity can account for only a few per-cent of observed rates of Quaternary subsidence, the majority must be by aseismic creep and/or crustal warping which in turn represent a hazard for structures with very long design lives.

Numbers of earthquakes detected per year in the North Sea region and catalogued by BGS have increased from approximately 5 per year before the DEn monitoring programme commenced, to approximately 150 per year since 1980. The improved monitoring capability and data exchange have enabled BGS to respond quickly with independant quantitative data when earthquakes or other vibrations have been felt offshore. A detailed study of an earthquake that was felt on the Ekofisk field, using advanced, recently developed techniques, found a focal depth of 16 $\pm$2km.

Although the seismic monitoring network was not specifically designed for the purpose, events have been located on or near the break-in-slope at the passive margin to the north and northwest of Scotland. Such events have implications for the triggering of slides on low-angled slopes, of which the giant Storegga slides, off western Norway, are the most significant historical examples in the region. Such slides may generate tsunami.

THE USE OF THE MSK INTENSITY SCALE IN THE STUDY OF HISTORICAL BRITISH EARTHQUAKES

R M W Musson

The MSK intensity scale is considered in the light of how well its arrangement matches the data to be found in studying British earthquakes, with remarks on which details of the scale appear to be more, or less, reliable in indicating intensity.

PICTORIAL REPRESENTATIONS OF DAMAGE IN HISTORICAL BRITISH EARTHQUAKES

R M W Musson

Since British earthquakes rarely cause photogenic damage, illustrations of their effects are few. This study lists all the events, starting in 1839, for which drawings or photographs of damage are known, up to the period for which British earthquakes were actively monitored by the BGS (1970). The archive is dominated by the 1884 Colchester earthquake, which is very well illustrated.

GROUND VELOCITY ATTENUATION ASSOCIATED WITH THE LOCKERBIE AIR CRASH IMPACT

D W Redmayne and T Turbitt

On 21 December 1988, as the result of a terrorist bomb attack, Pan Am flight 103, a Boeing 747 aircraft, crashed on the Scottish border town of Lockerbie. The impact of the largest portion of the fragmented aircraft was detected by British Geological Survey seismometers in the Eskdalemuir network as a magnitude 1.3 ML event.

Seismometers at 17 and 24 kilometres gave direct measurement of the ground velocity at their locations. Ground motions nearer to the impact site were, however, unknown and estimation from damage was complicated by air blast effects. To allow a full appraisal of the effect on buildings near the impact site, velocity attenuation data from a variety of sources, including measured velocities at seismometers, were extrapolated back to the impact site. The likely damage effects could then be predicted from the estimated peak velocities. Results indicate that the impact was likely to be perceptible (peak particle velocities over 1 mm/s) with a radius of 1.1 kilometres and that structural damage was possible within 150 metres of the epicentre (peak particle velocities over 100 mm/s).

These results, together with the crucial information about the precise time of the impact have been presented to the crash investigation team and at the subsequent Public Inquiry.

A comparison is made with a number of other aircraft crashes detected by seismometer networks and efficiency and directionality effects are noted.

THE JERSEY EARTHQUAKE OF 30 APRIL 1990

A B Walker

On 30 April, 1990, an earthquake with a Richter magnitude of 3.5 ML was felt throughout the island of Jersey; in many places with an intensity sufficient to awaken people and dislodge unstable objects. Elsewhere, it was experienced with intensities like a heavy object falling and with doors, windows and the walls of houses shaking, but there was no structural damage. It was also felt in Guernsey, 45 km to the north-west, at a lower, less alarming, intensity but there were no reports from the French coast, a similar distance to the east.

The magnitude, precise time and location of the event were determined using the Jersey seismograph network which was installed in 1981 by the Jersey Meteorological Department, Jersey New Waterworks Company and the British Geological Survey. The earthquake, together with a number of aftershocks had epicentres approximately 8 km south of St Aubins bay at depths of around 8 km. The aftershocks were much smaller with magnitudes in the range -0.8 to 1.2 ML and were not felt by the people of Jersey.

An interpretation of the focal mechanism of the mainshock and the larger aftershocks shows that movement was thrust faulting with a component of strike-slip on a plane either striking approximately NW and dipping 35° to the WSW, or striking ENE and dipping 76° to the NNW. The result is consistent with the approximately NW-SE compressive stress direction determined for other localities in the UK and France.

Natural Environment Research Council

Decade of UK seismicity for earthquakes with magnitudes greater than 1.5 ML: available as a wall map