# UK EARTHQUAKE MONITORING 1993/94

# BGS Seismic Monitoring and Information Service

## Fifth Annual Report


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

Tel: 0131-667-1000
Fax: 0131-667-1877
Internet: http://www.gsrg.nmh.ac.uk/

# BRITISH GEOLOGICAL SURVEY

## TECHNICAL REPORT WL/94/10

## Global Seismology Series

# UK Earthquake Monitoring 1993/94

## BGS Seismic Monitoring and Information Service

## Fifth Annual Report

**A B Walker and C W A Browitt**

**June 1994**

**UK Seismic Monitoring and Information Service Year Five Report to Customer Group: June 1994**

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

*Bibliographic reference*
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**Edinburgh British Geological Survey 1994**

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# UK EARTHQUAKE MONITORING 1993/94

## 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 25 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 (NERC). This Customer Group is listed in Annex A.

In the fifth year of the project (April 1993 to March 1994), a seven-station network has been installed to cover the gap in central southern England and the rapid response capability has been significantly improved with 5 sub-networks added to the 9 previously upgraded to the new digital standard.

There still remain some gaps in coverage; notably in NW Scotland and in Northern Ireland. Other areas, covered by site-specific networks in SW England, North Wales, Cumbria and the Scottish Borders are vulnerable to closure as funds are withdrawn by the commissioning bodies.

Some 360 earthquakes have been located by the monitoring network in 1993 with 39 of them having magnitudes of 2.0 or greater. The largest on land, in the reporting year (April 1993 to March 1994), had a magnitude of 4.0 and was strongly felt in the epicentral area, around Norwich, on 15 February 1994. Offshore, the largest felt earthquake also had a magnitude of 4.0 and located some 400 km east of Newcastle in the Central North Sea. It was felt on the Gorm hydrocarbons field. The largest was in the northern North Sea on 27 December with a magnitude of 4.3 ML. Smaller earthquakes have been felt in several areas of the country including Grange-over-Sands, Cumbria, Stoke-on-Trent, Staffordshire, Betws-y-Coed and Bangor, North Wales, Bristol Channel, and Newtown, mid-Wales. 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 (Ranskill, Nottinghamshire). Controlled explosions are also recorded; in particular the Glasgow flats demolition on 12 September, which killed one person and injured several others, was detected by the monitoring network. Some 10 significant explosions and 10 sonic events throughout the reporting period have been processed following Media attention or public concern.

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 now issued 6 weeks in arrears with provisional details of all earthquakes located, and, after revision, they are compiled into an annual bulletin to be published in 6 months. In all these reporting areas, scheduled targets have been met or surpassed. The network coverage has been extended as scheduled but there has been some slippage in completing the check on station locations and in the programme of digitising (and thereby safeguarding) past seismograms.

## 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 and the immediate effects of felt or damaging vibrations on people and structures. 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.

Earthquake monitoring information is required to refine our understanding of the level of seismic risk in the UK. This helps in assessment of the level of precautionary measures which should be taken in respect of existing and new buildings and constructions, and installations which could prove hazardous in the event of damage or disruption. In addition, seismic events cause public concern and there is a need to be able to give objective information as soon as possible after significant events in order to allay any unnecessary worries. Most seismic events occur naturally, but some are triggered by human activities such as mining subsidence and other tremors (eg. sonic booms and explosions) are often mistaken for small earthquakes.

This Year 5 report to the Customer Group follows the format of the first four annual reports in reiterating the programme objectives and highlighting some of the significant seismic events in the period April 1993 to March 1994. The catalogue of earthquakes for the whole of 1993 is plotted to reflect the period for which revised data is available and to be consistent with the annual bulletin produced as a separate volume. For the first time, this report also contains a map of earthquakes with magnitudes $\geq$ 2.5 ML for the period 1979 to March 1994. The data set is considered to be almost complete for this period. Seven seismic monitoring stations have been installed during the year towards the specific objective of establishing a uniform distribution with an average spacing of 70 km. Meanwhile, monitoring stations in Shetland, East Anglia, south east England, north Devon and central England have been upgraded to the remotely-accessible digital standard. This is, in addition to those previously installed in Cornwall, Hereford, North Wales, around Edinburgh, Kyle, Keyworth, Cumbria, Borders and Jersey. These have substantially improved the identification and rapid location of seismic events and Figure 6 shows their present combined detection capability.

All of the advances made and proposed in the effective background network of the UK can be seen by comparing the present coverage (Fig 1) 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 few 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.

(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 to March 1994, with rapid access upgrades, is shown in Figure 1 with its detection capability in Figure 5. The scheduled programme for 1993/94 had as its aims:

(i) Completion of the new seismograph network in central southern England to fill the most evident gap in the present coverage.

(ii) Upgrading to digital, remote access standard, most of the existing networks in the UK.

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

(iv) Completing the check on geographic locations of the existing seismograph stations using new satellite-based positioning systems.

(v) Installation of additional triggered strong motion recorders as opportunities arise.

(vi) Completion of the digitising of the final few percent of seismic events collected on analogue magnetic tape over the past 20 years except, possibly, those for which there are technical problems with the tapes.

(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.

The installation of the new network in central southern England (i) has been completed. The programme of extending the remote access capability of the network (ii) has met the expectations, with a total of 101 of the 129 stations in the UK now being in that category. There is now considerably improved geographical coverage for rapid access (Fig 6). The introduction of borehole systems (iii) has been accomplished at two sites in Nottinghamshire. Experiments with these shallow boreholes, however, have proved to be inconclusive and it may be necessary to go to greater depths in order to obtain improved noise characteristics in the local earthquake frequency band. Although not yet completed, there has been substantial progress with the programme of checking station locations using GPS (iv). A further 74 sites have been completed making 85 in total. The development of the strong motion network (v) has resulted in the installation of instruments in Hereford, south east England and Kyle where signals are recorded onto the 'remote access systems', this is in addition to other strong motion systems under contracts with the Jersey New Waterworks Company, BNFL, MOD, ETSU/DTI and Scottish Nuclear (installed in Jersey, Chapelcross, Faslane, Cornwall and Hunterston). The total distribution of strong motion instruments together with the low gain instruments and microphones is shown in Figure 4. Five of the eight strong motion station generate open-file data; the other three will require some negotiation to ensure data will be freely available. The digitising project (vi) has progressed more slowly than anticipated due to the reorganisation of the tape storage facility, and it is anticipated that this project will be completed in 1994/95. The watching brief on archives (vii) is continuing. Contact has been made with a private researcher who is working on a biography of J J Shaw (West Bromwich Observatory) and is searching for local records.

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

(i) Nuclear Electric have continued to permit the North Wales instrumentation to be left in place during the year, following its withdrawal of maintenance funds in March 1992. This proved to be particularly valuable in monitoring the felt earthquakes near Betws-y-Coed, Bangor and Newtown. The network's long-term continuation, however, will depend on Nuclear Electric's future position and on obtaining additional funding for its operation.

(ii) The ETSU/DTI-sponsored monitoring in SW England for the HDR Geothermal project has continued but, from April 1994, the level will be reduced to supporting only Cornwall stations; leaving those in Devon without operating funds.

(iii) BNFL is continuing the intensive microseismic monitoring study in Cumbria. This is being conducted through a local enhancement of the UK background network with more detailed interpretation of the results. All seismicity data is being made available to the UK monitoring programme on an open-file basis. Its sponsorship of a similar network in the Scottish Borders, however, will be withdrawn or reduced.

(iv) The Jersey New Waterworks Company has continued to support the monitoring network on Jersey.

(v) The installation of a free-field strong motion system for Scottish Nuclear at Torness has been delayed.

In summary, 17 existing stations crucial to the background network are at risk owing to site-specific project support. Some £200k of additional annual support would be required to cover these losses.

### 4.2 Progress with instrumentation

New faster Motorola modems have been installed at several locations throughout the country to permit fast transfer of data from the remote access networks to Edinburgh (up to three times faster). A new ILI (Interpolating Line Interface Unit) has been developed to record digital information onto the SEISLOG systems. This gives 16-bit data in digital form, eliminating FM demodulators and analogue-to-digital converters and hence increasing the dynamic range to 96 db.

Larger capacity, one gigabyte disks have been installed in five locations to replace 40 and 400 megabyte units. They give a three-day window of continuous data together with extra storage for event files which would be needed during significant aftershock sequences such as that experienced following the Lleyn earthquake of 1984. Further software improvements have been made in the data acquisition system.

A self-contained triggering seismograph has been modified to permit high sensitivity recording near Manaccan in Cornwall to enhance coverage of the Constantine swarm activity. As a stand-alone system, it obviates the need for line-of-sight radio communication although with a penalty at the data analysis end.

The digitising system used for conversion of the archive of analogue tapes had become too old, unreliable and time-consuming for the job. A new, PC-based unit has been designed, assembled and commissioned during the year and is being used for the remaining analogue stations in the network and to tackle the outstanding backlog.

## 5. Seismic activity in Year 5

### 5.1 Earthquakes located for 1993

Details of all earthquakes, and felt explosions and sonic booms, detected by the network have been published in monthly bulletins and, with final revision, are provided in the BGS bulletin for 1993 published in March 1994. A map of the 358 events located in 1993 is reproduced here as Figure 7 and a catalogue of those with magnitudes of 2.0 or greater is given in Annex B. Six in that magnitude category are known to have been felt. In the period since BGS commenced modern seismic monitoring in the UK (1979 to March 1994), almost all of the earthquakes with magnitudes $\geq$ 2.5 ML are believed to have been detected. The distribution of such events for that period (Fig 8) is, therefore, largely unbiased by the distribution of seismic monitoring stations for the onshore region. Accuracy of individual locations, however, will vary across the country.

### 5.2 Significant events

Highlights of the seismic activity during the fifth year of the project (April 1993 to March 1994) are given below:

(i) Near Grange-over-Sands, Cumbria, a magnitude 3.0 ML earthquake occurred on 26 June 1993. It was felt over an area of 9000 $km^2$ (Isoseismal 2), 2700 $km^2$ (Isoseismal 3), and a macroseismic survey throughout the region showed that it was felt in the epicentral area with a maximum intensity of 5 MSK (just below the damaging level).

(ii) At Talke Pits in the Potteries, on 29 June, a small event (magnitude 2.0 ML) was felt strongly and it was reported that unstable objects were overturned indicating an intensity of at least 5 MSK.

(iii) In the Central North Sea, an earthquake with magnitude 4.0 ML, was felt at the Gorm hydrocarbons field on 7 July. The felt reports described "a shuddering" on the Gorm complex and on a nearby standby vessel resulting in a production stoppage of 2 hours. It locates in a similar area to the magnitude 4.0 ML event on 10 June 1985 which was felt on the Gorm and Tyra platforms and on a standby vessel.

(iv) Near Coniston in Cumbria, a magnitude 1.5 ML earthquake was detected on 8 July 1993. A single felt report was received from the village of Kirkby-in-Furness describing "a noise like a freight train passing outside". It locates some 18 km from the Grange-over-Sands earthquake two weeks before.

(v) At Betws-y-Coed and nearby Nantbh, a magnitude 2.3 ML earthquake was felt by several people on 11 October 1993. It located at a depth of 9.3 km and the fault plane solution shows dominant normal faulting with a small component of strike-slip.

(vi) In the Bristol Channel in the early hours of New Years day, a magnitude 2.8 ML earthquake was felt by local residents in north Devon. Although the epicentre located some 5 km from the coast of south Wales, no felt reports were received from that area. A fault plane solution of the event shows dominant normal faulting.

(vii) Near Wallingford in Oxfordshire, a magnitude 2.2 ML earthquake was detected by the network on 8 January. This event, together with one other, some 10 km away, represents the only seismicity detected in the area over the past 20 years.

(viii) Near Bangor, North Wales, a magnitude 2.9 ML earthquake was felt by local residents in the early hours of 10 February. A macroseismic survey was initiated and some 600 replies were received. This showed the felt area to be approximately 10,000 km$^2$ and the maximum intensity 5 MSK. The fault plane solution of the event shows near vertical movement on a near vertical plane or near horizontal movement on a near-horizontal plane. A seismogram of the earthquake recorded on the Hereford network is shown in Figure 9.

(ix) The largest onshore earthquake of the reporting year, occurred near Norwich, Norfolk on 15 February with a magnitude of 4.0 ML and was felt over an area of approximately 31,000 km□. A macroseismic survey throughout the region showed that it was felt in the epicentral area with a maximum intensity of 5 MSK. A seismogram of the earthquake recorded on the North Wales network is shown in Figure 10. An hour later at 11:18 UTC a small aftershock (2.8 ML) was felt with intensities of at least 3 MSK.

(x) In mid-Wales, approximately 8 km WNW of Newtown, Powys, a magnitude 3.1 ML earthquake was felt by local residents on 17 March. It was felt over an area of approximately 4,000 km$^2$ and locates some 30 km from the widely felt Bishops' Castle earthquake (magnitude 5.1 ML) on 2 April 1990. Two aftershocks were located a few hours after the main shock with magnitudes of 1.0 and 0.8 ML.

(xi) In North Wales, four events with magnitudes ranging from 0.0 to 0.7 ML were located on the Lleyn Peninsula, in the same area as the Lleyn Peninsula earthquake of 19 July 1984, (magnitude 5.4 ML).

(xii) A series of twenty-two events near Mallaig, in the north-west of Scotland, were detected in August and September with magnitudes ranging from -0.2 to 2.7 ML. The largest was felt with intensities of at least 3 MSK in the town of Mallaig where residents reported a noise "like a small blast". The event locates in the same general area as the magnitude 3.7 ML Mallaig earthquake of 1 December 1985 which was felt with intensities up to 4 MSK.

(xiii) In the reporting year, 12 small events were detected near Johnstonebridge, Dumfries and Galloway, with magnitudes ranging between -0.2 and 0.6 ML. They locate in the same general area as the felt Johnstonebridge earthquake of 27 February 1992 (magnitude 2.7 ML).

(xiv) Some 81 small earthquakes were located near the village of Constantine in Cornwall during the reporting year; none were felt and the largest had a magnitude of 1.8 ML. They form part of a continuing series which has been instrumentally recorded since 1981 and which has produced five felt earthquakes. There is some indication of cyclical behaviour of this source (5-6 years) with strongest activity in 1981, 1986 and 1992/93.

(xv) Near Ranskill, Nottinghamshire, a magnitude 2.2 ML coal mining event was detected on 11 November. It was felt strongly in the village of Ranskill where residents ran out of their houses into the streets indicating at least an intensity of 5 MSK. A seismogram of the event recorded on the Hereford network is shown in Figure 11.

(xvi) Some 30 coalfield events, with magnitudes ranging from -0.1 to 1.6 ML, were located in the Clackmannan area of Scotland; one of which was felt by local residents in the village of Forest Mill with a magnitude of 1.6 ML and an intensity of at least 3 MSK.

(xvii) In other coalfield areas, small earthquakes were located in the Lothian coalfields (ten events with magnitudes ranging from -0.2 to 0.7 ML), Clay cross, Derbyshire (1.6 ML, 22 June 1993), Amble, Northumberland (1.7 ML, 11 August 1993 and 1.5 ML, 14 December 1993), Oxton, Nottinghamshire (1.7 ML, 6 September 1993), Bilsthorpe, Nottinghamshire (1.3 ML, 22 September 1993), Maltby, south Yorkshire (1.5 ML, 20 October 1993), Bargoed, Mid Glamorgan (1.3 ML, 15 December 1993), Matlock, Derbyshire (0.6 ML, 31 December 1993 and 1.7 ML, 18 February 1994) and Mansfield, Nottinghamshire (three events in January 1994 with magnitudes between 0.4 and 1.4 ML). These events are presumed to be related to present-day coalmining activity.

(xviii) 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 Suffolk (24 May 1993), Norfolk (21 June 1993), Fife (two events, 11 August 1993 and 27 October 1993), Swansea (two events, 22 and 24 October 1993), Northumberland (27 October 1993), Cumbria (two events on 26 January 1994), north Yorkshire (9 February 1994) and Swansea (10 February 1994). A seismogram of a sonic event felt in the Workington area, Cumbria, is shown in Figure 12.

(xix) A number of felt reports have been received concerning World War II mine detonations and other man-made events which have received Media attention. Specific examples are: a Hercules air crash on 27 May 1993; three ordnance detonations of WWII German mines on 30 July near Scarborough, in the North Channel, and 23 September 1993, near Stranraer; a suspected meteorite on 20 September 1993; a contraband explosion off Fraserburgh on 5 November 1993. On 12 September 1993 at 13:13 UTC a block of flats in the centre of Glasgow was destroyed using a controlled explosion. The demolition did not go to plan and flying debris from the blast killed one person and injured several others. The BGS network in the area recorded the blast and a seismogram of the event is shown in Figure 13. In October 1993, a nuclear explosion from the Lop Nur test site in China, was recorded throughout the country. It was readily identified as a nuclear test due to its prominent first motion arrival and absence of other phases. A seismogram of the event recorded on the Cornwall network is shown in Figure 14.

### 5.3 Global earthquakes

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

(i) An earthquake with a moderate magnitude by World standards (6.3 Ms) had a disastrous impact on an unprepared community in Mararashtra/Khilari, southern India, on 29 September 1993. It resulted in the loss of some 10,000 lives and injured approximately 30,000, in an area with no previous history of events. A seismogram recorded on the Lowlands network is shown in Figure 15. Many buildings were destroyed during this earthquake an example of which is shown in Plate 1.

(ii) An earthquake of magnitude 6.5 Mb on 11 October, was felt strongly in Tokyo. It was located offshore, some 450 km SSW of Tokyo at a depth of 365 km. No damage was caused but Media interest was aroused owing to the contrast with the Indian earthquake, above, and speculation about the impact of Japanese earthquakes on the World's financial systems.

(iii) The most costly natural disaster in USA history occurred in Los Angeles on 17 January 1994 (some $30 billion). Despite the scale of damage and consequential losses, the death toll of between 60 and 70 people is a reflection of the competence of Californian engineering in the face of moderate earthquakes (6.8 Ms). There were some 6,500 injured and 15,000 made homeless. A number of free-field acceleration records were recorded for the earthquake with peak horizontal/vertical accelerations in downtown LA of 0.19g/0.10g to 1.82g/1.18g (the latter in Tarzana, close to the epicentre, which is known to produce high values of accelerations during earthquakes). A seismogram of the earthquake recorded on the Borders network is shown in Figure 16 with a photograph of damage in Plate 2.

## 6. Archives

### 6.1 Identification and cataloguing

There has been no change in the status of collections held by BGS and detailed in the Year 4 report to the Customer Group.

Considerable progress has been made with the drafting of a catalogue of textural material held in the archives. In the process, the curation requirements of some of it have been identified more clearly and, for the more vulnerable records a curation process has been started.

Contact has been made with a private researcher who is working on a biography of J J Shaw (West Bromwich Observatory) and is searching for local records.

### 6.2 Storage and Inspection facilities

The new accommodation in Murchison House is now fully organised and has already been used by some 20 visiting scientists for the inspection of data held in the archive. The new external store at Loanhead (near Edinburgh) is fully operational and the analogue magnetic tape collection is now stored there, together with less valuable textual records.

### 6.3 Digital records

Problems with the old digitising equipment coupled with a hiatus in tape accessibility during the archive storage moves has led to little progress this year.

## 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. Some 50 alerts have been issued to the 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.

Networks in the Scottish Lowlands, North Wales, Hereford, Cornwall, Keyworth, Borders, Cumbria, Kyle, Jersey, central England, Shetland, East Anglia, south east England and north Devon can now be remotely accessed from Edinburgh and, in particular, from the homes of the principal seismologists. That is, 80% of the monitoring stations. They have further improved the immediate response capability for UK seismic events (Fig 1) so that almost all of the UK can now be covered in this way for earthquakes with magnitudes of 2.5 or greater.

### 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 within 6 weeks of the end of a 1 month reporting period. This improved target (rather then the 8 weeks previously) has been met on all occasions during the year.

### 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. In 1993 problems with printers resulted in the delay of the annual bulletin but the 1993 bulletin was published in April 1994, 2 months ahead of schedule.

## 8. Programme for 1994/95

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 1993/94 are:

(i) Minor additions to the seismograph network coverage: more substantial ones (eg. for NW Scotland, Northern Ireland) require new funding.

(ii) Completion of the upgrade to the remote access, digital standard for all UK stations.

(iii) Further experimentation with borehole systems to advance capabilities in noise reduction. Those to-date have been inconclusive.

(iv) Completion of the check on geographic locations of existing seismograph stations using the Global Positioning System (GPS).

(v) Installation of 3 or 4 additional strong motion stations recording on the SEISLOG systems. This new direction for a strong motion network follows the proving of the technology, with Scottish Nuclear sponsorship, for application at Torness.

(vi) Completion of the programme of digitising the remaining analogue magnetic tape data except for those tapes which have technical problems.

(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).

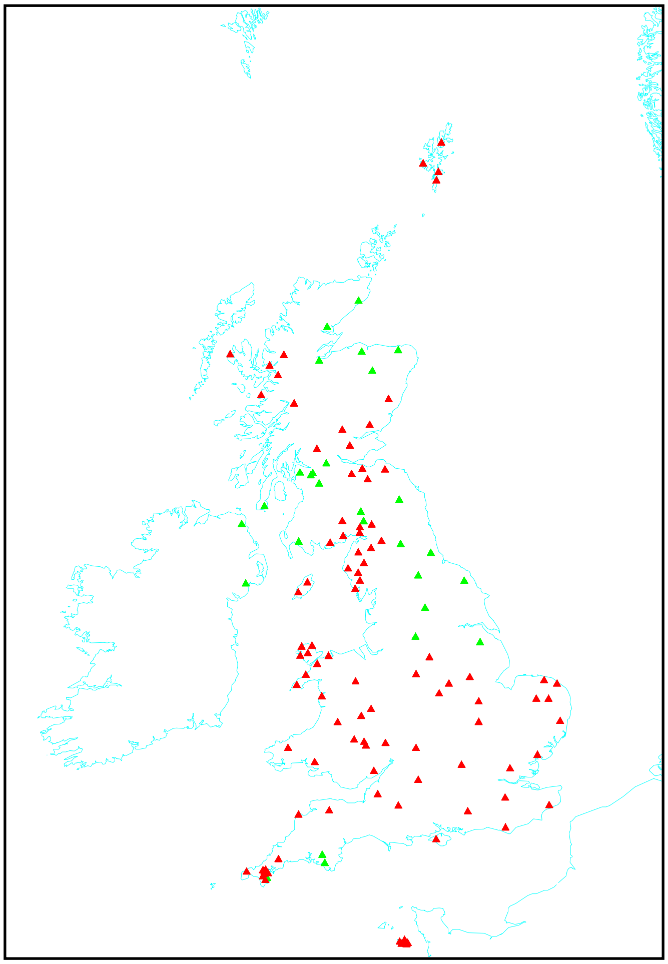


**Figure 1.** **BGS seismograph network operational in March 1994. Colour coding shows the standard stations (green) and those upgraded to rapid access (red).**

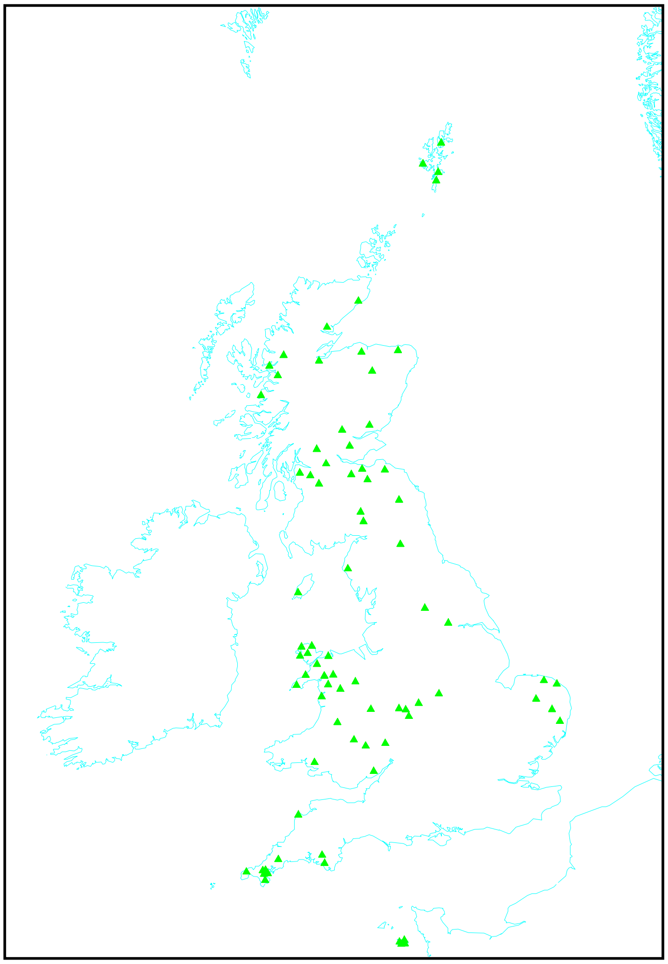


**Figure 2.** **BGS seismograph network in 1988 prior to the commencement of the UK monitoring enhancement project.**

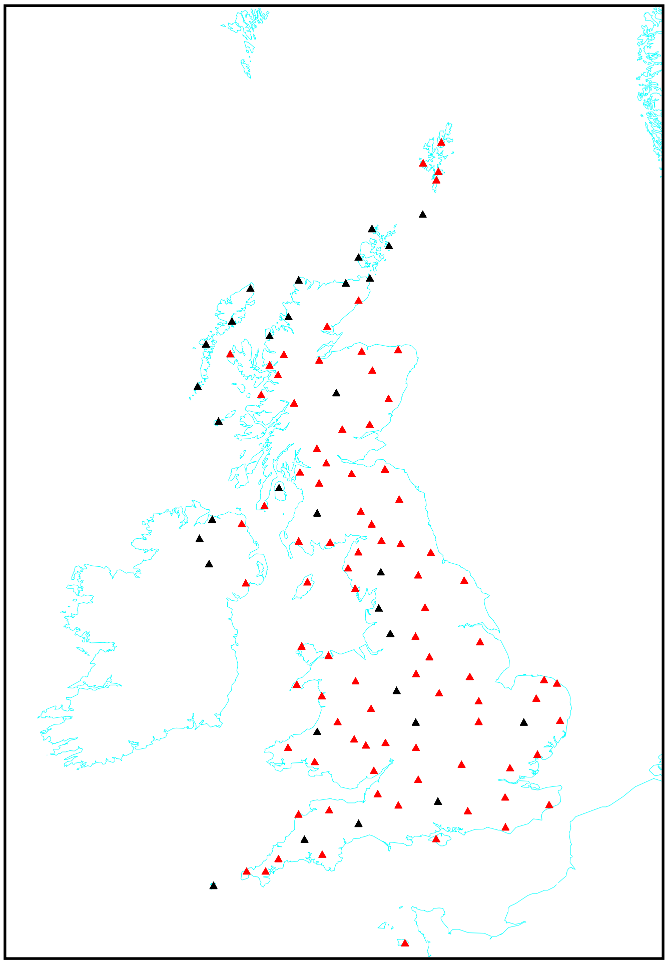


**Figure 3.** **Proposed long-term background seismic monitoring network with an average station spacing of 70 km. Colour coding shows existing coverage (red) and proposed stations (black).**

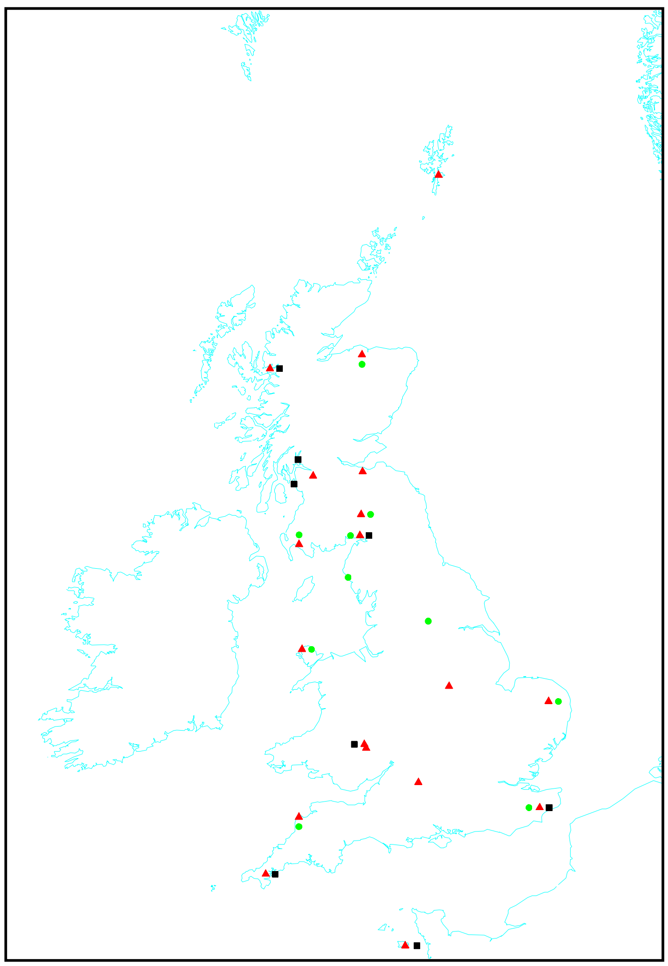


**Figure 4.** **BGS network of strong-motion instruments (black), low sensitivity (red) and microphones (green) by March 1994.**

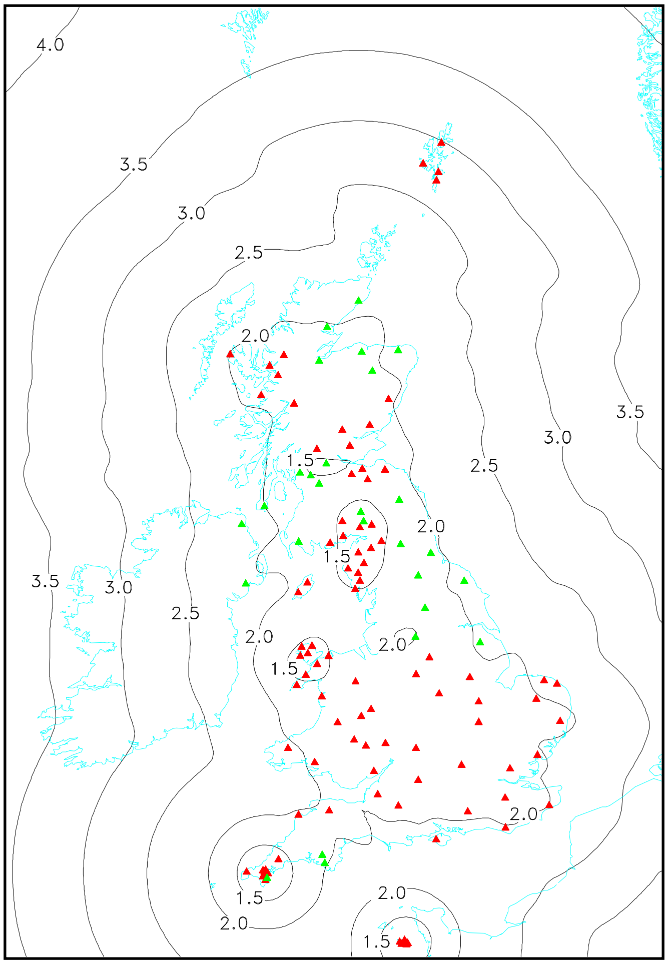



**Figure 5.** **Earthquake identification capabilty. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.**

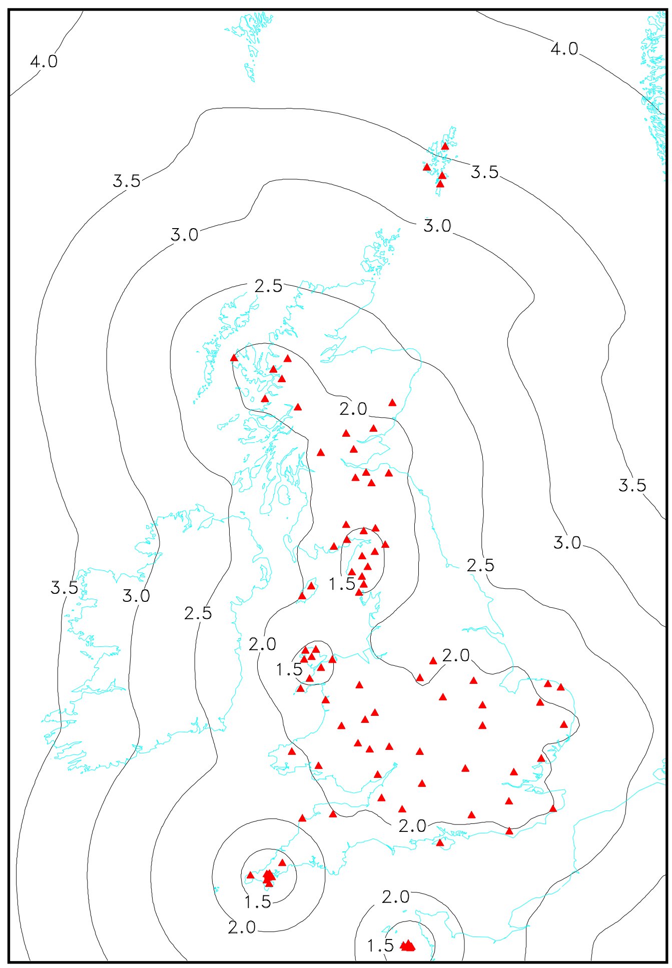



**Figure 6.** **Detection capability of the rapid access networks. Contours show the magnitude (ML) of an earthquake which would be detected by 5 stations in the presence of 20 nanometres of background noise at 10 Hz.**

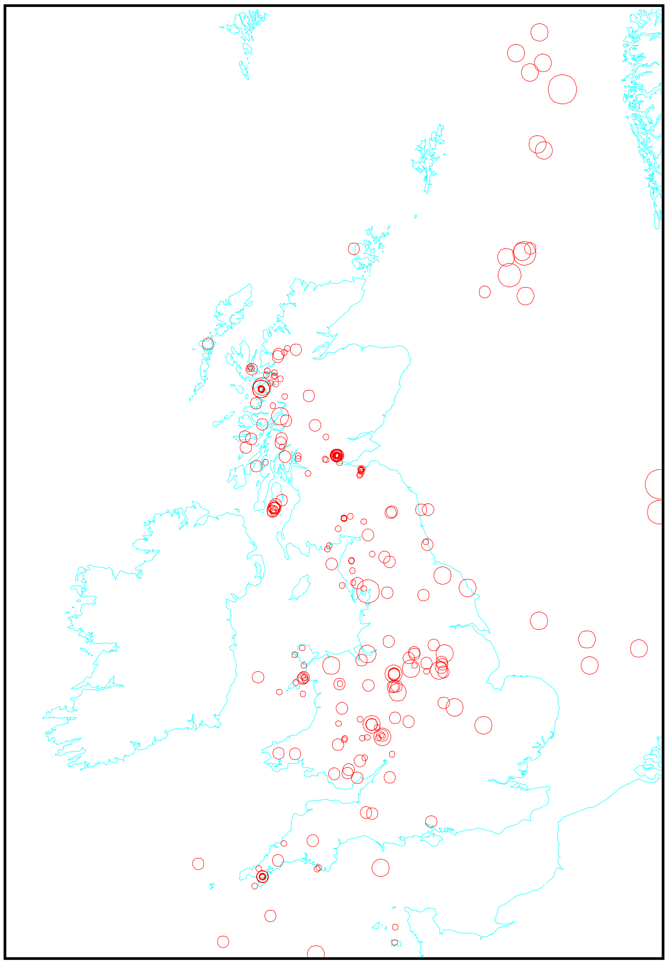


**Figure 7.** **Epicentres of all UK earthquakes located in 1993.**

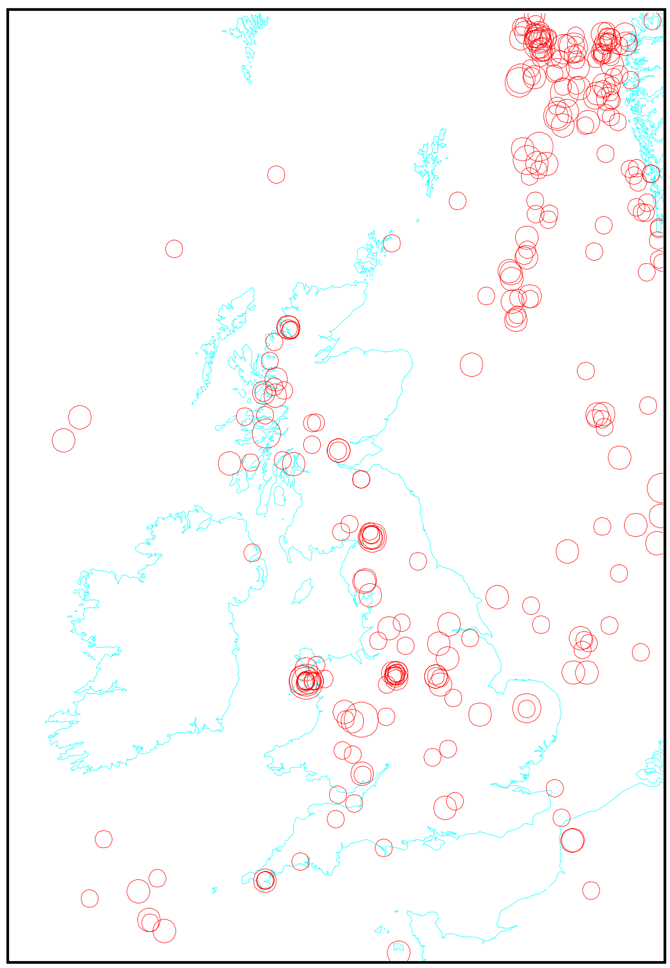


**Figure 8.** **Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 1994.**

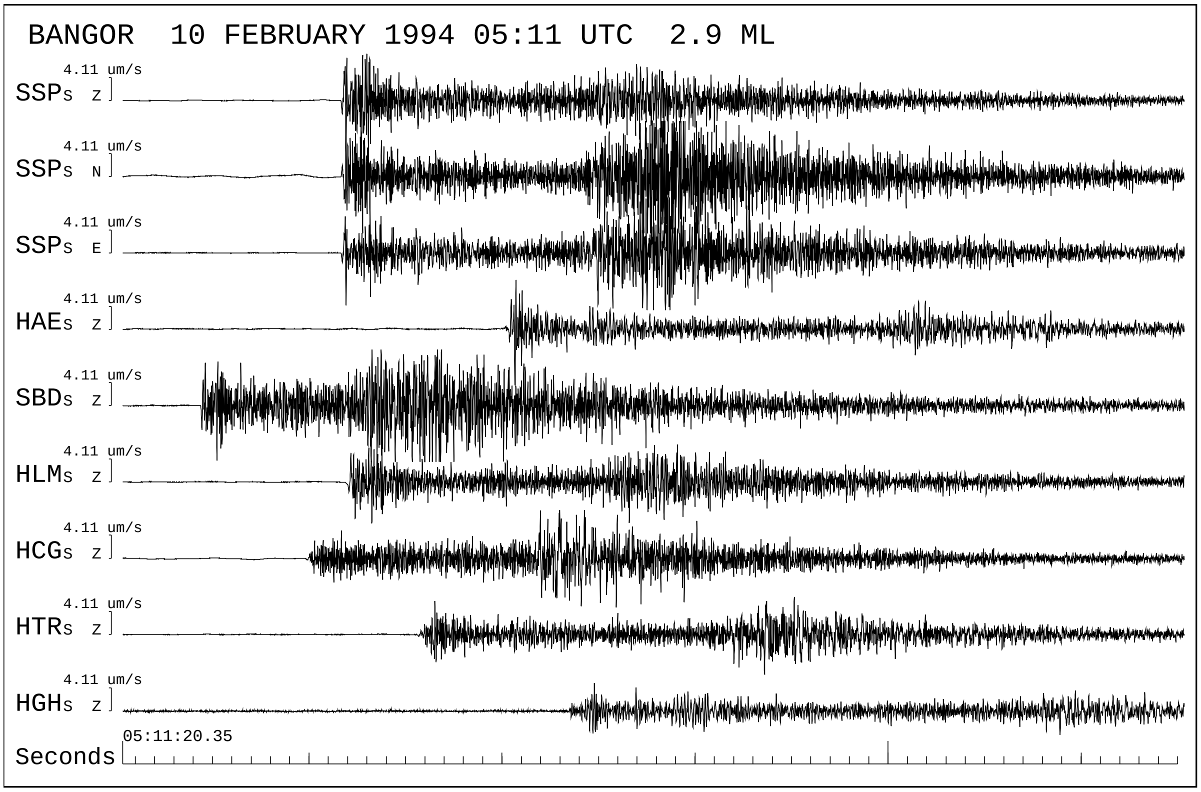



**Figure 9.** Seismograms recorded on the Hereford network from a magnitude 2.9 ML earthquake felt in the Bangor region of North Wales on 10 February 1994 . Three letter codes refer to stations in Annex E.

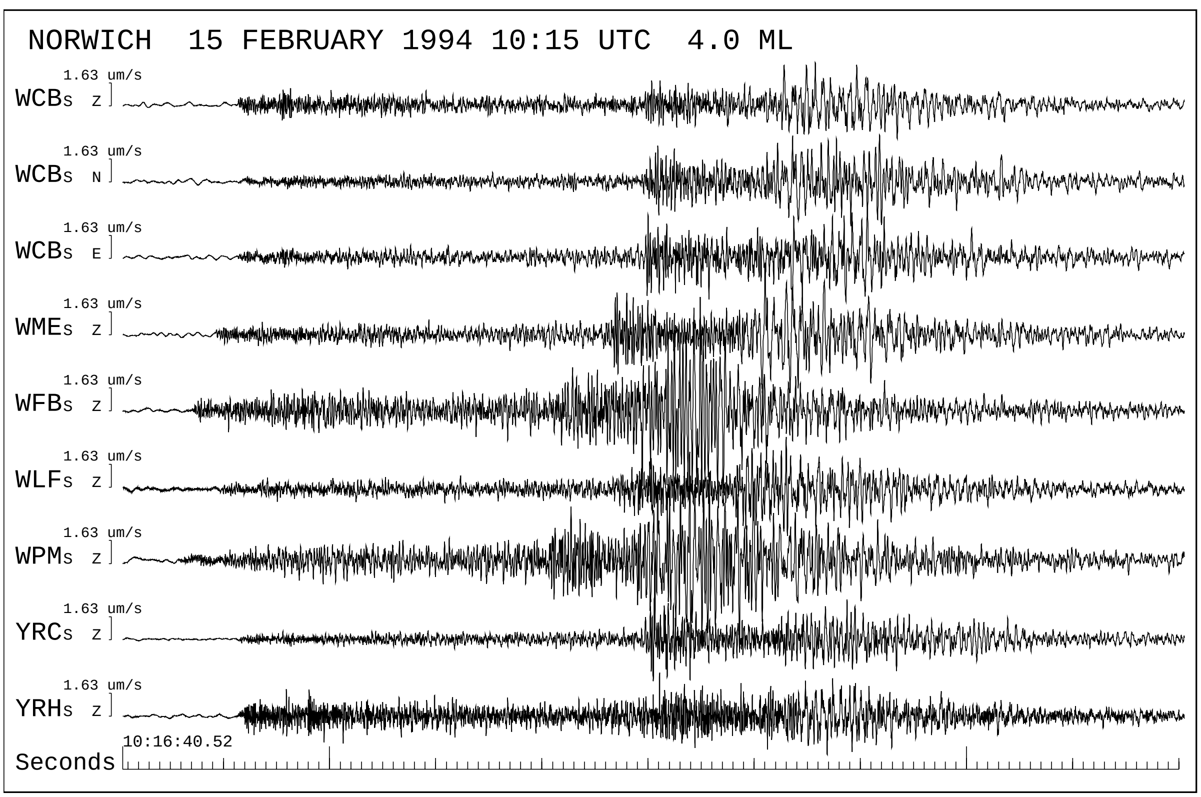



**Figure 10.** Seismograms recorded on the North Wales network from a magnitude 4.0 ML earthquake felt in the East Anglia region on 15 February 1994. Three letter codes refer to stations in Annex E.

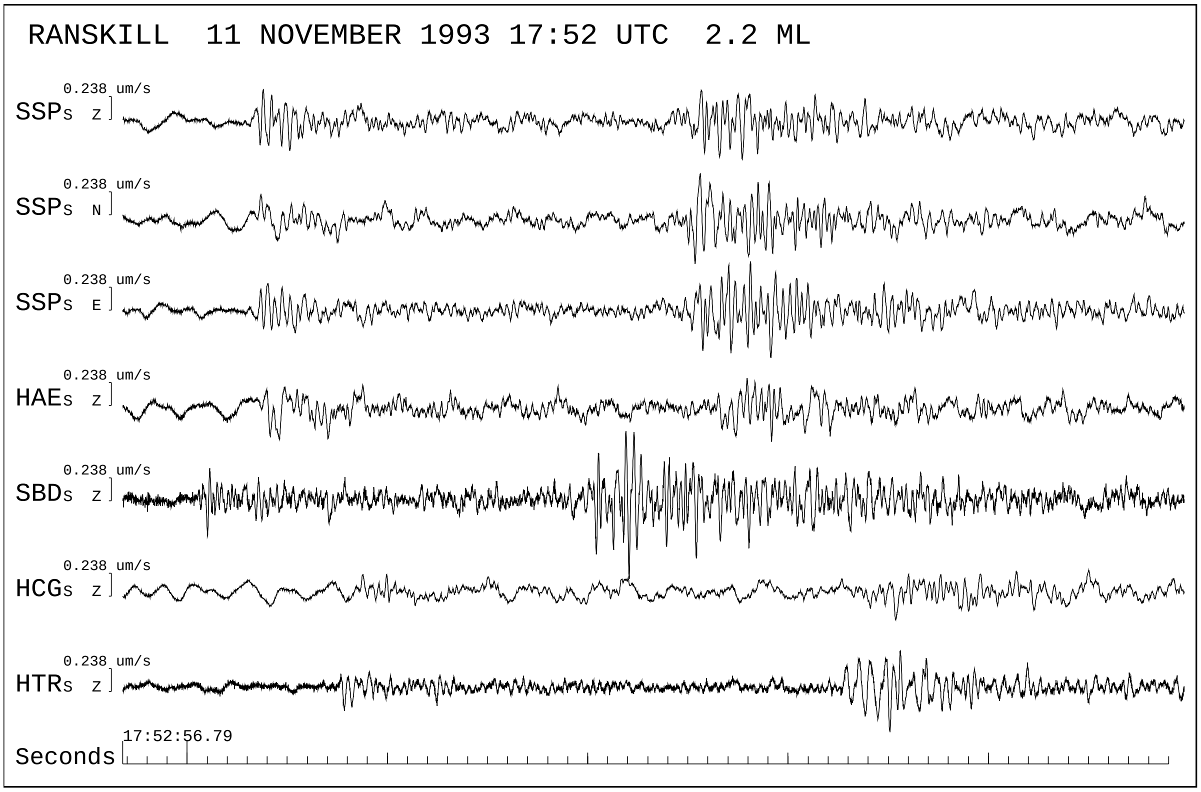



**Figure 11.** Seismograms recorded on the Hereford network from a magnitude 2.2 ML coalfield event felt in the village of Ranskill, Nottinghamshire on 11 November 1993 . Three letter codes refer to stations in Annex E.

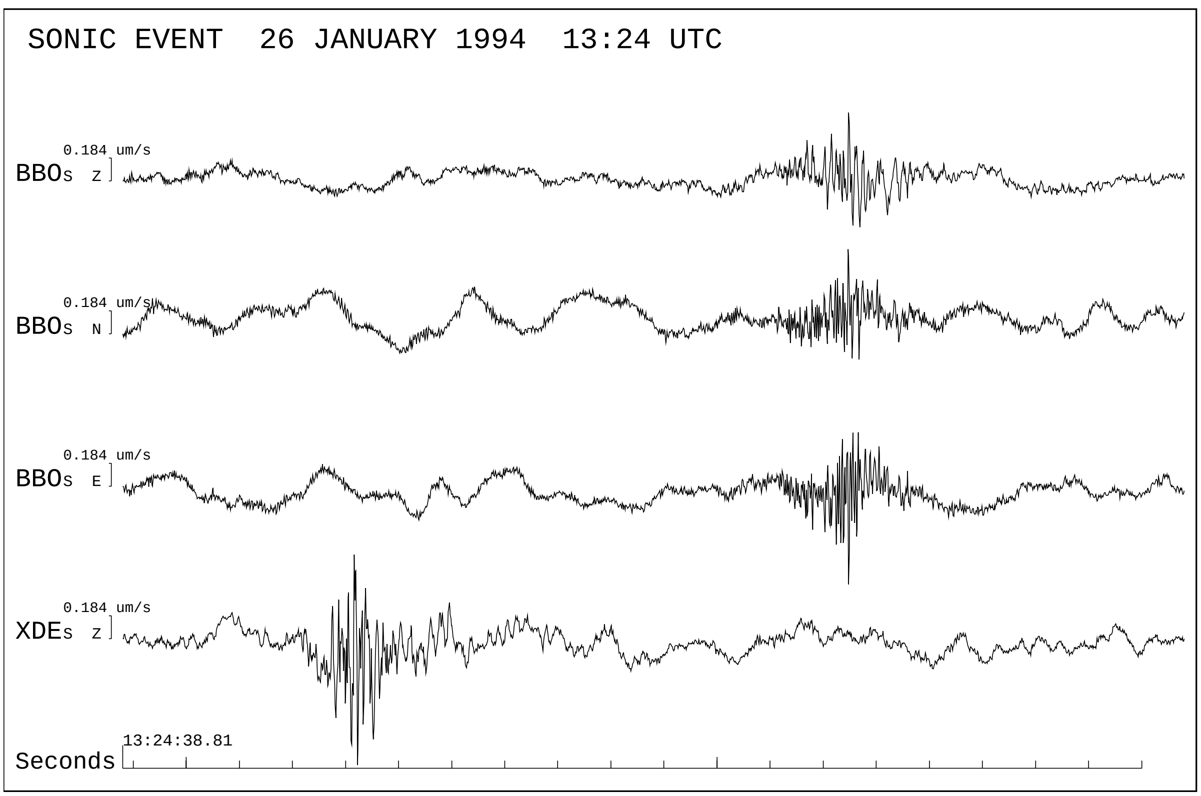



**Figure 12.** Seismograms recorded on the Cumbria network from a sonic event felt in the Workington area, Cumbria, on 26 January 1994. Three letter codes refer to stations in Annex E.

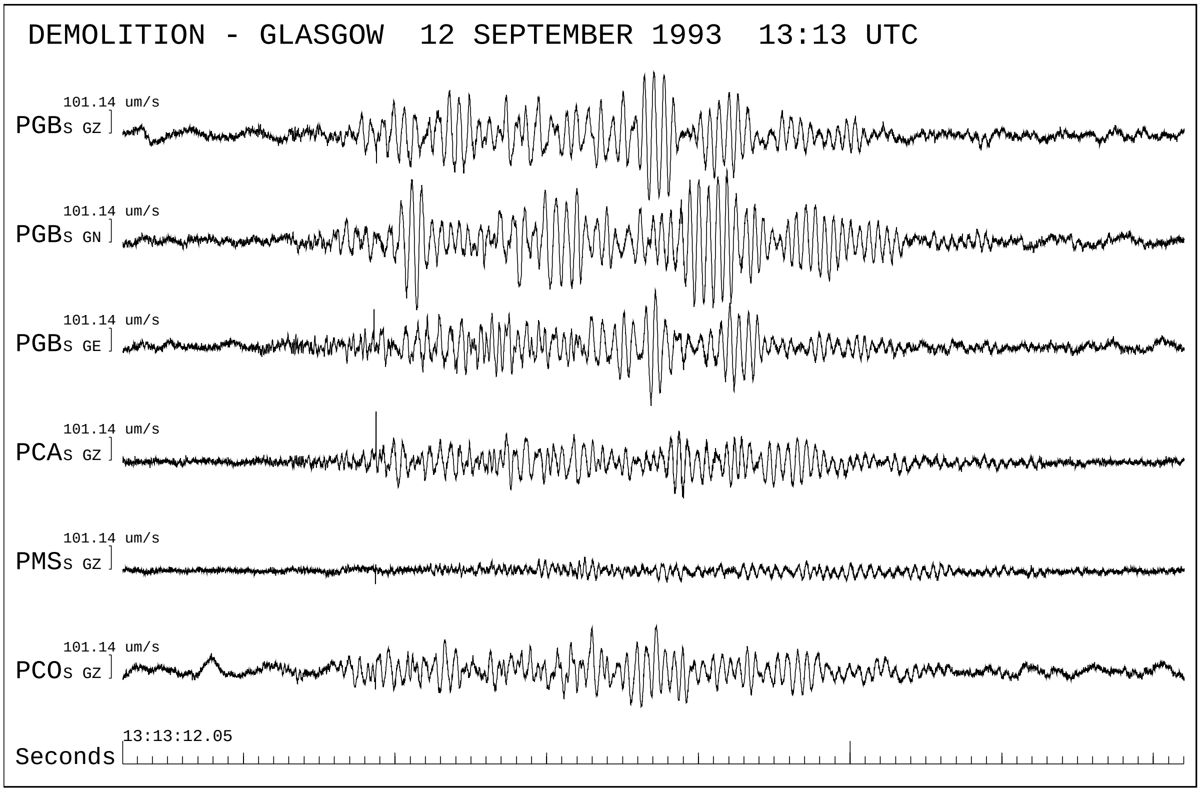



**Figure 13.** Seismograms recorded on the Paisley network from the Glasgow flat demolition on 12 September 1993. Three letter codes refer to stations in Annex E.

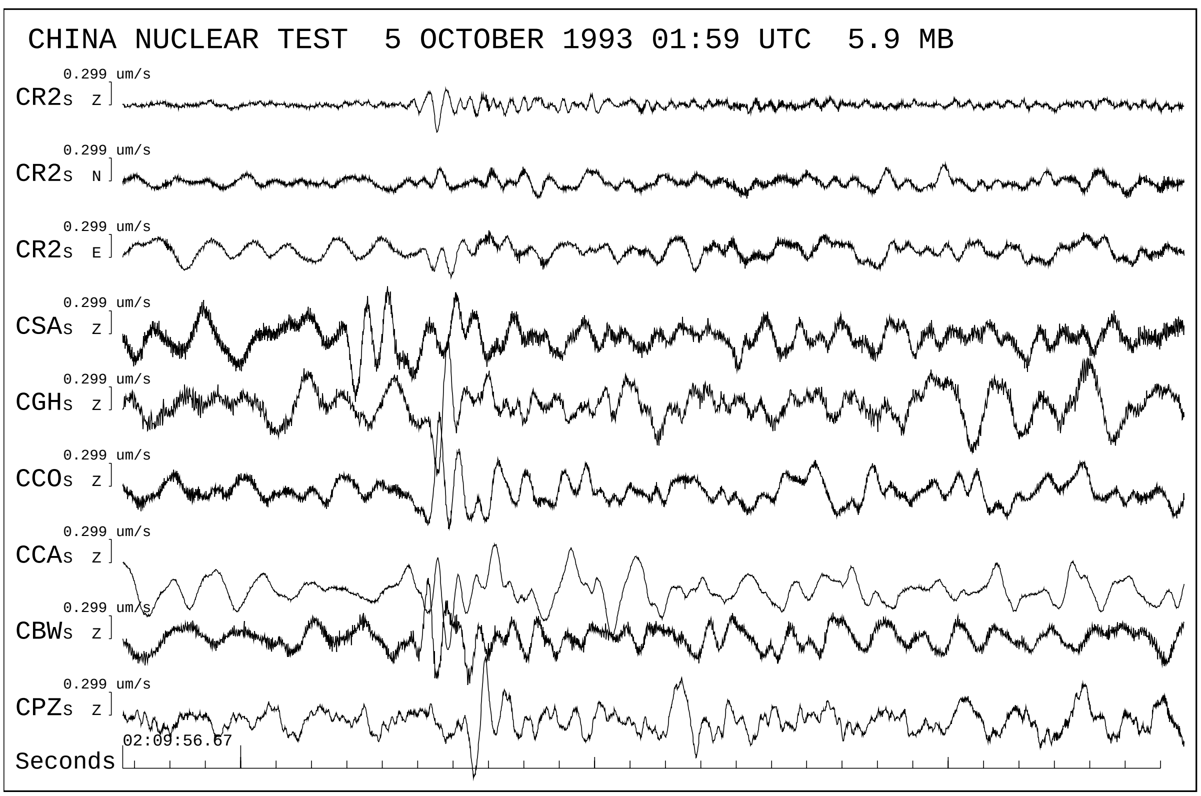



**Figure 14.** Seismograms recorded on the Cornwall network from the magnitude 5.9 MB China nuclear test on 5 October 1993. Three letter codes refer to stations in Annex E.

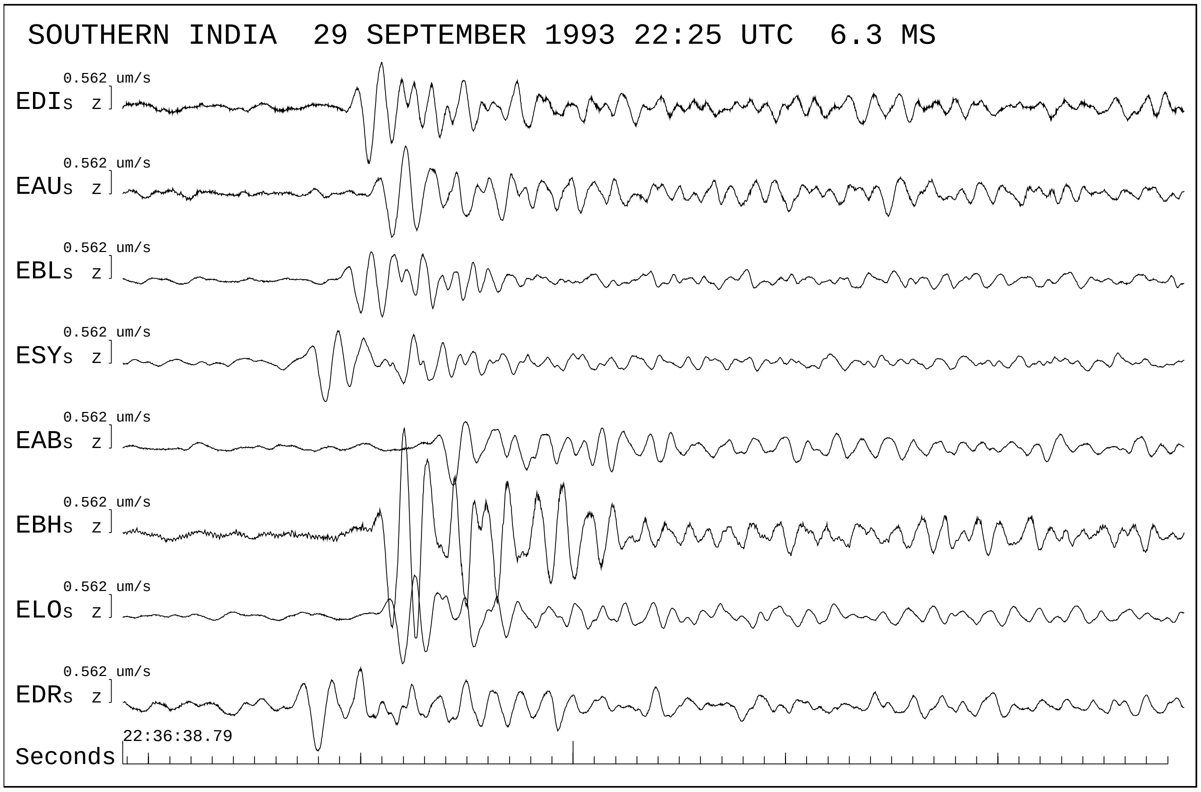



**Figure 15.** Seismograms recorded on the Lowlands network around Edinburgh from the magnitude 6.3 MS earthquake in southern India on 29 September 1993. Three letter codes refer to stations in Annex E.

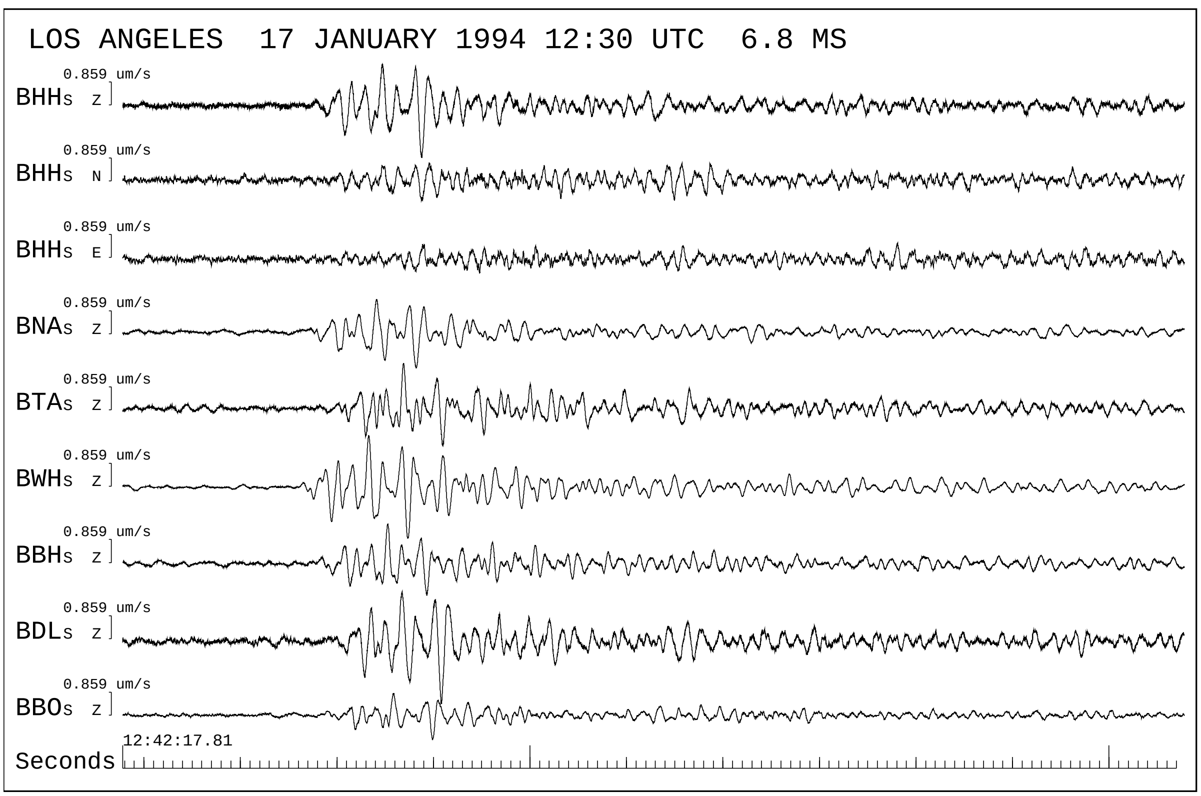



**Figure 16.** Seismograms recorded on the Borders network from the magnitude 6.8 MS earthquake in Los Angeles on 17 January 1994. Three letter codes refer to stations in Annex E.

ANNEX A

## CONTRIBUTORS TO THE PROJECT

Department of the Environment
British Nuclear Fuels plc
Department of Economic Development (N Ireland)
Nuclear Installations Inspectorate
Scottish Hydro-Electric plc
Scottish Nuclear Ltd
Renfrew District Council
Welsh Office
Natural Environment Research Council

| | |
|---|---|
| Ministry of Defence | Data |
| Department of Trade and Industry | Data |
| Nirex | Data |

**Customer Group Members (not contributing in Year Five)**
British Gas
Health and Safety Executive
British Coal
International Seismological Centre
Nuclear Electric plc
AEA Technology
Scottish Office Environment Department

## EARTHQUAKES WITH MAGNITUDE 2.0 AND ABOVE, RECORDED IN THE UK AND OFFSHORE WATERS: 1993

| YearMoDy | HrMnSecs | Lat | Lon | kmE | kmN | Dep | Mag | Locality | Int | No | DM | Gap | RMS | ERH | ERZ | SQD | Comments... |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19930211 | 194612.6 | 58.97 | 1.45 | 598.3 | 1013.8 | 6.4 | 3.8 | NORTHERN NORTH SEA | | 36 | 192 | 159 | 0.39 | 1.1 | 2.1 | C*D | |
| 19930309 | 132209.4 | 56.65 | -5.24 | 201.6 | 756.2 | 2.5 | 2.0 | LOCH LINNHE,HIGHLAND | | 22 | 25 | 120 | 0.23 | 0.7 | 1.1 | B*C | |
| 19930314 | 024857.2 | 54.43 | -0.99 | 465.4 | 504.3 | 1.8 | 2.4 | WESTERDALE,N YORKSHIRE | | 43 | 23 | 137 | 0.21 | 0.5 | 0.9 | B*C | |
| 19930315 | 142329.1 | 53.08 | -1.11 | 459.6 | 354.2 | 0.1 | 2.4 | FARNSFIELD,NOTTS | | 23 | 23 | 162 | 0.22 | 0.7 | 1.0 | B*C | C/F |
| 19930406 | 064106.2 | 58.67 | 1.01 | 574.4 | 979.5 | 25.8 | 3.5 | NORTHERN NORTH SEA | | 34 | 197 | 181 | 0.24 | 1.2 | 2.3 | B*D | |
| 19930415 | 213003.4 | 52.55 | -0.75 | 484.9 | 295.9 | 4.7 | 2.3 | GREAT EASTON,LEICS | | 23 | 25 | 77 | 0.40 | 1.3 | 2.8 | C*C | |
| 19930502 | 190825.8 | 58.92 | 0.93 | 568.6 | 1007.6 | 15.0 | 2.3 | NORTHERN NORTH SEA | | 17 | 173 | 264 | 0.39 | 7.0 | 7.8 | D*D | |
| 19930504 | 142025.9 | 52.29 | -0.06 | 531.9 | 267.5 | 0.2 | 2.4 | HUNTINGDON,CAMBS | | 19 | 43 | 101 | 0.25 | 1.0 | 1.2 | B*C | 9KM SE OF HUNTINGDON |
| 19930505 | 140738.1 | 62.08 | 2.27 | 622.9 | 1363.3 | 10.8 | 2.2 | NORWEGIAN SEA | | 15 | 175 | 212 | 0.42 | 2.8 | 3.9 | C*D | |
| 19930507 | 125043.0 | 52.14 | -2.47 | 367.5 | 249.0 | 11.5 | 2.3 | BROMYARD,HER & WOR | | 29 | 12 | 133 | 0.18 | 0.6 | 0.6 | B*B | 6KM SE OF BROMYARD |
| 19930519 | 072412.7 | 60.50 | 2.00 | 619.6 | 1186.3 | 22.3 | 2.1 | NORTHERN NORTH SEA | | 10 | 163 | 156 | 0.13 | 1.0 | 2.0 | A*D | |
| 19930522 | 220227.9 | 50.28 | -2.49 | 364.9 | 42.0 | 6.9 | 2.2 | ENGLISH CHANNEL | | 28 | 104 | 96 | 0.33 | 0.8 | 2.9 | C*D | 40KM SOUTH OF WEYMOUTH |
| 19930529 | 174341.4 | 61.52 | 1.90 | 607.4 | 1299.7 | 16.7 | 2.7 | NORWEGIAN SEA | | 16 | 167 | 192 | 0.28 | 2.2 | 3.5 | B*D | |
| 19930613 | 150055.7 | 49.03 | -3.92 | 259.7 | -94.8 | 11.1 | 2.2 | ENGLISH CHANNEL | | 15 | 127 | 240 | 0.28 | 3.9 | 5.6 | C*D | |
| 19930614 | 073730.8 | 60.41 | 2.18 | 630.0 | 1176.4 | 19.8 | 2.3 | NORTHERN NORTH SEA | | 13 | 167 | 149 | 0.38 | 2.2 | 3.9 | C*D | |
| 19930615 | 090600.7 | 54.93 | 5.68 | 891.5 | 586.5 | 15.0 | 3.0 | SOUTHERN NORTH SEA | | 15 | 506 | 331 | 0.42 | | | D*D | |
| 19930615 | 163436.7 | 57.06 | -5.75 | 172.5 | 803.1 | 5.7 | 2.3 | KNOYDART,HIGHLAND | | 35 | 17 | 175 | 0.20 | 1.3 | 1.3 | B*C | |
| 19930626 | 054220.0 | 54.21 | -2.86 | 344.1 | 479.3 | 8.3 | 3.0 | GRANGE-O-SANDS,CUMBRIA | 5 | 44 | 26 | 36 | 0.19 | 0.4 | 0.6 | B*C | FELT GRANGE-OVER-SANDS.. |
| 19930628 | 172723.8 | 61.65 | 2.31 | 628.3 | 1314.8 | 10.2 | 2.1 | NORWEGIAN SEA | | 10 | 146 | 228 | 0.39 | 7.8 | 7.0 | D*D | |
| 19930629 | 004558.2 | 58.99 | 1.39 | 594.8 | 1016.4 | 21.8 | 2.8 | NORTHERN NORTH SEA | | 22 | 188 | 135 | 0.39 | 1.4 | 3.1 | C*D | |
| 19930629 | 040348.8 | 53.04 | -2.21 | 385.7 | 348.8 | 4.1 | 2.0 | STOKE-ON-TRENT,STAFFS | 5+ | 27 | 25 | 86 | 0.16 | 0.4 | 1.1 | B*C | FELT TALKE PITS AREA |
| 19930630 | 055956.8 | 53.31 | -2.85 | 343.2 | 380.0 | 8.9 | 2.2 | ELLESMERE PRT,CHESHIRE | | 51 | 53 | 50 | 0.27 | 0.4 | 1.1 | B*D | |
| 19930707 | 114806.6 | 55.55 | 4.63 | 818.1 | 648.6 | 0.3 | 4.0 | CENTRAL NORTH SEA | 4+ | 37 | 301 | 90 | 0.24 | 0.7 | 0.9 | B*D | FELT GORM PLATFORM |
| 19930712 | 042039.5 | 53.11 | -1.79 | 414.0 | 356.9 | 18.9 | 2.2 | HARTINGTON,DERBYSHIRE | | 29 | 11 | 90 | 0.22 | 0.6 | 0.8 | B*A | |
| 19930712 | 215305.4 | 53.74 | 1.37 | 622.2 | 432.6 | 7.4 | 2.9 | SOUTHERN NORTH SEA | | 31 | 156 | 270 | 0.35 | 3.9 | 4.1 | C*D | |
| 19930727 | 060735.9 | 53.26 | 3.76 | 784.2 | 388.8 | 0.3 | 2.9 | SOUTHERN NORTH SEA | | 31 | 163 | 178 | 0.36 | 1.7 | 2.2 | C*D | |
| 19930904 | 071455.1 | 57.03 | -5.78 | 170.4 | 799.5 | 2.7 | 2.7 | MALLAIG,HIGHLAND | 3+ | 14 | 13 | 119 | 0.08 | 0.3 | 0.7 | A*C | FELT MALLAIG |
| 19930905 | 094819.3 | 57.03 | -5.78 | 170.6 | 799.2 | 2.7 | 2.0 | MALLAIG,HIGHLAND | | 14 | 13 | 117 | 0.08 | 0.3 | 0.8 | A*C | |
| 19930906 | 022831.8 | 53.07 | 2.55 | 704.4 | 362.2 | 3.8 | 2.3 | SOUTHERN NORTH SEA | | 16 | 78 | 313 | 0.08 | 1.1 | 1.2 | B*D | |
| 19930916 | 014910.1 | 53.44 | 2.52 | 700.1 | 403.3 | 7.8 | 2.8 | SOUTHERN NORTH SEA | | 14 | 145 | 231 | 0.08 | 0.8 | 1.1 | A*D | |
| 19930917 | 013954.4 | 52.32 | -2.73 | 350.3 | 269.0 | 14.5 | 2.3 | LUDLOW,SHROPSHIRE | | 29 | 25 | 94 | 0.15 | 0.4 | 0.4 | B*B | 6KM SOUTH OF LUDLOW |
| 19930928 | 125936.5 | 58.36 | 1.42 | 600.0 | 946.4 | 11.2 | 2.0 | NORTHERN NORTH SEA | | 15 | 239 | 179 | 0.23 | 1.0 | 1.9 | B*D | |
| 19931004 | 202148.0 | 61.81 | 1.51 | 584.9 | 1330.4 | 1.4 | 2.2 | NORWEGIAN SEA | | 12 | 189 | 210 | 0.26 | 3.6 | 3.3 | C*D | |
| 19931005 | 020514.8 | 52.77 | -2.11 | 392.3 | 319.6 | 8.6 | 2.2 | STAFFORD,STAFFORDSHIRE | | 20 | 33 | 101 | 0.09 | 0.4 | 0.7 | A*C | |
| 19931011 | 094334.0 | 53.14 | -3.73 | 284.6 | 361.9 | 9.3 | 2.3 | BETWS-Y-COED,GWYNEDD | 3+ | 32 | 18 | 115 | 0.22 | 0.6 | 0.9 | B*B | FELT BETWS-Y-COED... |
| 19931111 | 175246.4 | 53.32 | -0.97 | 468.7 | 381.1 | 0.0 | 2.2 | RANSKILL,NOTTS | 5+ | 16 | 45 | 77 | 0.32 | 1.4 | 2.2 | C*C | C/F,FELT RANSKILL |
| 19931115 | 004855.8 | 54.25 | -0.37 | 506.1 | 484.9 | 31.0 | 2.0 | SCARBOROUGH,N YORKS | | 10 | 22 | 242 | 0.08 | 1.3 | 0.7 | B*D | |
| 19931213 | 085953.9 | 55.16 | 4.55 | 816.7 | 604.7 | 20.4 | 3.4 | CENTRAL NORTH SEA | | 24 | 415 | 216 | 0.27 | 1.8 | 2.7 | B*D | |
| 19931227 | 052045.9 | 61.25 | 2.85 | 660.0 | 1273.1 | 17.9 | 4.3 | NORTHERN NORTH SEA | | 48 | 123 | 169 | 0.38 | 1.0 | 1.9 | C*D | |

**ANNEX C**

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 | | |
| P A MERRIMAN | BNFL | T A F WILLIS | SCOTTISH POWER |
| H TUR | BNFL | J P McFARLANE | SCOTTISH NUCLEAR |
| C WILSON | DED | P W WINTER | UKAEA |
| P MACDONALD | ETSU | P J BUCKLEY | HSE |
| D J MALLARD | NUCLEAR ELEC | M J A THOMPSON | HSE OFFSHORE |
| C F ALLEN | NUCLEAR ELEC | V KATHIGAYAN | HSE OFFSHORE |
| W P ASPINALL | AA | A W B JACOB | DIAS |
| C BEAK | HYDROBOARD | H PAYNE | WELSH OFFICE |
| C PATCHETT | NII, BOOTLE | DIRECTOR | BGS |
| J E INKESTER | NII, BOOTLE | M RAINES | BGS, KEYWORTH |
| A ACTON | BRITISH GAS | A WHITTAKER | BGS, KEYWORTH |
| U M MICHIE | NIREX | S BRACKELL | BGS, LONDON INFO OFFICE |
| G HERBERT | SCOT H & H | H J HEASON | BGS, MARKETING |

**FROM:** D D GALLOWAY
**DATE:** 7/7/93
**TIME:** 17:30 BST
**PAGES TO FOLLOW:** NONE

SEISMIC ALERT: CENTRAL NORTH SEA - 7 JULY 1993 11:48 UTC, 4.1 ML

BGS have located a magnitude 4.1 ML earthquake in the central North Sea area at 11:48 UTC on 7 July 1993.

A preliminary location, using data from rapid access networks in nothern Scotland, southern Scotland, the Scottish Borders and N Wales, follows:

| | |
|---|---|
| **Date** | : 7 July 1993 |
| **Origin time** | : 11:48 03.5s UTC |
| **Lat/Lon** | : 55.45°N 5.29°E |
| **Depth** | : 15 km |
| **Magnitude** | : 4.1 ML |

A seismogram of the event recorded on our LOWNET (southern Scotland) network is attached.

This provisional location puts the epicentre approximately 10 km ESE of the Dan field, 30 km ESE of the Gorm field and 20 km east of a magnitude 4.0 earthquake which was felt on the Gorm and Tyra platforms and on a standby vessel on 10 June 1985. The latter was reported as "violent shaking" for 5-6 seconds on the 5-platform Gorm complex. No damage to instruments nor structures was reported and production was not stopped. Today's event (7 July 1993) has not been reported felt at this stage but enquiries will be made.

[Author's note: The following day, it was established that the 7 July earthquake was felt on the Gorm platform and on a standby vessel and that production was stopped for two hours].

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 | | |
| P A MERRIMAN | BNFL | T A F WILLIS | SCOTTISH POWER |
| H TUR | BNFL | J P McFARLANE | SCOTTISH NUCLEAR |
| C WILSON | DED | P W WINTER | UKAEA |
| P MACDONALD | ETSU | P J BUCKLEY | HSE |
| D J MALLARD | NUCLEAR ELEC | M J A THOMPSON | HSE OFFSHORE |
| C F ALLEN | NUCLEAR ELEC | V KATHIGAYAN | HSE OFFSHORE |
| W P ASPINALL | AA | A W B JACOB | DIAS |
| C BEAK | HYDROBOARD | H PAYNE | WELSH OFFICE |
| C PATCHETT | NII, BOOTLE | DIRECTOR | BGS |
| J E INKESTER | NII, BOOTLE | M RAINES | BGS, KEYWORTH |
| A ACTON | BRITISH GAS | A WHITTAKER | BGS, KEYWORTH |
| U M MICHIE | NIREX | S BRACKELL | BGS, LONDON INFO OFFICE |
| G HERBERT | SCOT H & H | H J HEASON | BGS, MARKETING |

**FROM:** CHRIS BROWITT/A B WALKER
**DATE:** 10 FEBRUARY 1994
**TIME:** 09:30 UTC
**PAGES TO FOLLOW:** FOUR

SEISMIC ALERT: BANGOR EARTHQUAKE, NORTH WALES, 10 FEBRUARY 1994 05:11 UTC

An earthquake has been felt in NW Wales and Anglesey this morning. Provisional details are as follows:

| | |
|---|---|
| **Date** | : 10 February 1994 |
| **Origin time** | : 05:11 13.3s UTC |
| **Lat/Lon** | : 53.1950 N 4.1407 W |
| **Grid Ref** | : 257.0 kmE 368.6 kmN |
| **Depth** | : 9.4 km |
| **Magnitude** | : 2.9 ML |
| **Locality** | : 5 km SW of Bangor |
| **Intensity** | : 4 |

Felt reports have been received from Holyhead (30 km NW), Bangor (5 km NE), Caernarvon (10 km SW), Llanberis (10 km S), Blaenau Ffestiniog (25 km SE), Penygroes (20 km SE).

No damage has been reported to date.

In recent years, there have been many earthquakes felt in this region including: 29 July 1992 (3.5, Caernavon), 19 July 1984 (5.4, Lleyn mainshock), 29 July 1984, 6 and 18 August 1984 (3.6-4.3, Lleyn aftershocks), 23 January 1974 (3.5, Bala).

A macroseismic survey has been initiated.

## BGS STAFF WITH INPUT TO THE PROJECT

Dr C W A Browitt
Mr J A Bolton
Mr P S Day
Mrs J Exton
Mr G D Ford
Mr C J Fyfe
Mr D D Galloway
Mr P H O Henni
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 D W Redmayne
Mrs J A Richards
Ms M E A Ritchie
Mr B A Simpson
Mr D A Stewart
Mr T Turbitt
Miss S J Van Barneveld
Mr W A Velzian
Mr A B Walker
Mr G J Webster
Mrs F Wright
Mr R M Young

## GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1994

| 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 |
| LRWS | LERWICK (SM) | 60.1397 | -1.1831 | 445.37 | 1139.69 | 80 | 96- | 3 | BGS |
| SAN | SANDWICK | 60.0176 | -1.2386 | 442.44 | 1126.05 | 155 | 85- | 1 | BGS |
| WAL | WALLS | 60.2576 | -1.6133 | 421.40 | 1152.60 | 170 | 80- | 1 | BGS |
| YEL | YELL | 60.5509 | -1.0830 | 450.29 | 1185.55 | 200 | 79- | 1 | BGS |
| **MORAY** | | | | | | | | | |
| MCD | COLEBURN DISTIL | 57.5827 | -3.2541 | 325.02 | 855.41 | 280 | 81- | 4Rm | BGS |
| MDO | DOCHFOUR | 57.4413 | -4.3633 | 258.17 | 841.43 | 366 | 81- | 1R | BGS |
| MFI | FISHRIE | 57.6116 | -2.2953 | 382.36 | 857.97 | 220 | 88- | 1R | BGS |
| MLA | LATHERON | 58.3050 | -3.3640 | 320.07 | 935.93 | 190 | 81- | 1 | BGS |
| MME | MEIKLE CAIRN | 57.3150 | -2.9650 | 341.88 | 825.33 | 455 | 81- | 1 | BGS |
| MVH | ACHVAICH | 57.9232 | -4.1816 | 270.80 | 894.70 | 198 | 84- | 1 | BGS |
| **KYLE** | | | | | | | | | |
| KAC | ACHNASHELLACH | 57.4999 | -5.2982 | 202.40 | 850.30 | 330 | 83- | 1R | BGS |
| KAR | ARISAIG | 56.9175 | -5.8302 | 166.90 | 787.20 | 225 | 83- | 1 | BGS |
| KNR | NEVIS RANGE | 56.8219 | -4.9714 | 218.68 | 773.97 | 1118 | 91- | 1 | BGS |
| KPL | PLOCKTON | 57.3391 | -5.6527 | 180.21 | 833.50 | 36 | 86- | 4R | BGS |
| KSB | SHIEL BRIDGE | 57.2098 | -5.4230 | 193.30 | 818.40 | 70 | 83- | 1R | BGS |
| KSK | SCOVAL | 57.4653 | -6.7020 | 118.10 | 851.41 | 250 | 89- | 1R | BGS |
| **LOWNET** | | | | | | | | | |
| EAB | ABERFOYLE | 56.1881 | -4.3400 | 254.80 | 701.95 | 250 | 69- | 1R | BGS |
| EAU | AUCHINOON | 55.8454 | -3.4474 | 309.38 | 662.30 | 359 | 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 |
| EDR | DRUMTOCHTY | 56.9190 | -2.5394 | 367.16 | 780.97 | 401 | 89- | 1R | 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 |
| EMN | MONKTONHALL | 55.9295 | -3.0889 | 331.97 | 671.24 | 52 | 96- | 3 | BGS |
| ENH | NEWHAILES | 55.9401 | -3.0795 | 332.58 | 672.42 | 25 | 96- | 1 | BGS |
| ENC | NEWCRAIG HALL | 55.9318 | -3.1050 | 330.97 | 671.52 | 45 | 96- | 3 | BGS |
| **PAISLEY** | | | | | | | | | |
| PCA | CARROT | 55.7000 | -4.2550 | 258.30 | 647.48 | 305 | 83- | 1 | BGS |
| PCO | CORRIE | 55.9880 | -4.0970 | 269.20 | 679.21 | 274 | 83- | 1 | BGS |
| PGB | GLENIFFERBRAES | 55.8100 | -4.4780 | 244.73 | 660.58 | 200 | 84- | 3 | BGS |
| PMS | MUIRSHIEL | 55.8461 | -4.7441 | 228.22 | 664.83 | 351 | 83- | 1 | BGS |
| POB | OBSERVATORY | 55.8458 | -4.4299 | 247.88 | 664.06 | 34 | 92- | 1 | 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 |
| XSO | SOURHOPE | 55.4925 | -2.2511 | 384.13 | 622.11 | 495 | 83- | 1R | BGS |
| **GALLOWAY & N IRELAND** | | | | | | | | | |
| GAL | GALLOWAY | 54.8664 | -4.7114 | 226.02 | 555.78 | 105 | 89- | 4m | BGS |
| GCL | CUSHENDALL | 55.0783 | -6.1263 | 136.66 | 583.77 | 278 | 89- | 1R | BGS |

**GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1994**

| Code | Name | Lat | Lon | GrE (Kms) | GrN (Kms) | Ht (M) | Yrs Open | Comp | Agency |
|---|---|---|---|---|---|---|---|---|---|
| GMK | MULL OF KINTYRE | 55.3459 | -5.5936 | 172.18 | 611.65 | 160 | 89- | 1R | BGS |
| GMM | MTNS OF MOURNE | 54.2377 | -5.9498 | 142.66 | 489.67 | 155 | 89- | 1R | BGS |
| **BORDERS** | | | | | | | | | |
| BBH | BRUNTSHEIL | 55.1332 | -2.9299 | 340.72 | 582.50 | 207 | 92- | 1 | BGS |
| BNA | NEW ABBEY | 54.9659 | -3.6244 | 296.02 | 564.70 | 78 | 92- | 1 | BGS |
| BHH | HOWATS HILL | 55.0928 | -3.2187 | 322.23 | 578.28 | 198 | 92- | 3 | BGS |
| BTA | TALKIN | 54.9057 | -2.6841 | 356.14 | 557.00 | 276 | 92- | 3 | BGS |
| BDL | DOBCROSS HALL | 54.8030 | -2.9390 | 339.65 | 545.76 | 132 | 92- | 1 | BGS |
| BWH | WARDLAW | 55.1757 | -3.6551 | 294.61 | 588.08 | 275 | 92- | 1 | BGS |
| BBO | BOTHEL * | 54.7367 | -3.2465 | 319.75 | 538.70 | 205 | 92- | 3 | BGS |
| BCM | CHAPELCROSS | 55.0151 | -3.2212 | 321.92 | 569.64 | 78 | 92- | m | BGS |
| BCC | CHAPELCROSS | 55.0154 | -3.2202 | 321.98 | 569.67 | 68 | 92- | 1 | BGS |
| **CUMBRIA** | | | | | | | | | |
| CKE | KESWICK | 54.5878 | -3.1062 | 328.52 | 521.98 | 296 | 92- | 1 | BGS |
| CSF | SCAFELL | 54.4478 | -3.2431 | 319.40 | 506.55 | 548 | 92- | 1 | BGS |
| CDU | DUNNERDALE | 54.3363 | -3.1950 | 322.31 | 494.09 | 362 | 92- | 1 | BGS |
| CSM | SELLAFIELD | 54.4183 | -3.4913 | 303.24 | 503.58 | 50 | 92- | m | BGS |
| LMI | MILLOM* | 54.2206 | -3.3070 | 314.79 | 481.35 | 140 | 89- | 3R | BGS |
| GIM | ISLE OF MAN (N)* | 54.2923 | -4.4670 | 239.46 | 491.34 | 366 | 89- | 3R | BGS |
| GCD | CASTLE DOUGLAS* | 54.8638 | -3.9417 | 275.39 | 553.85 | 189 | 89- | 1R | BGS |
| XDE | DENT * | 54.5058 | -3.4897 | 303.55 | 513.31 | 291 | 83- | 1R | 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 | HOLMFIRTH | 53.5451 | -1.8548 | 409.62 | 405.42 | 460 | 91- | 1 | BGS |
| LDU | LEEDS | 53.8025 | -1.5553 | 429.35 | 434.45 | 230 | 83- | 2Rm | BGS |
| **NORTH WALES** | | | | | | | | | |
| WCB | CHURCH BAY | 53.3782 | -4.5465 | 230.63 | 389.87 | 135 | 85- | 4m | BGS |
| WFB | FAIRBOURNE | 52.6830 | -4.0378 | 262.26 | 311.47 | 325 | 85- | 1R | BGS |
| WIM | ISLE OF MAN (S) | 54.1472 | -4.6735 | 225.41 | 475.70 | 365 | 85- | 1R | BGS |
| **NORTH WALES continued** | | | | | | | | | |
| WLF | LLYNFAES | 53.2893 | -4.3966 | 240.27 | 379.64 | 65 | 85- | 1 | BGS |
| WME | MYNDD EILIAN | 53.3966 | -4.3034 | 246.87 | 391.36 | 130 | 85- | 1R | BGS |
| WPM | PENMAENMAWR | 53.2583 | -3.9049 | 272.95 | 375.20 | 350 | 85- | 1 | BGS |
| 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 |
| **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 |

**GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1994**

| Code | Name | Lat | Lon | GrE (Kms) | GrN (Kms) | Ht (M) | Yrs Open | Comp | Agency |
|---|---|---|---|---|---|---|---|---|---|
| **EAST ANGLIA** | | | | | | | | | |
| ABA | BACONSTHORPE | 52.8875 | 1.1471 | 611.70 | 336.90 | 13 | 82- | 1 | BGS |
| AEA | E.ANGLIA UNIV. | 52.6208 | 1.2403 | 619.30 | 307.53 | 45 | 84- | m | BGS |
| APA | PACKWAY | 52.2999 | 1.4779 | 637.10 | 272.60 | 35 | 84- | 1 | BGS |
| AWH | WHINBURGH | 52.6299 | 0.9512 | 599.70 | 307.70 | 60 | 80- | 1R | BGS |
| AWI | WITTON | 52.8324 | 1.4460 | 632.10 | 331.70 | 35 | 83- | 1 | BGS |
| AEU | E.ANGLIA | 52.6201 | 1.2347 | 618.93 | 307.44 | 15 | 94- | 4 | BGS |
| **HEREFORD** | | | | | | | | | |
| SBD | BRYN DU | 52.9055 | -3.2588 | 315.35 | 335.01 | 497 | 80- | 1 | BGS |
| MCH | MICHAELCHURCH | 51.9977 | -2.9983 | 331.47 | 233.77 | 233 | 78- | 4 | BGS |
| HAE | ALDERS END | 52.0376 | -2.5475 | 362.45 | 237.88 | 224 | 82- | 1R | 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 | 193.60 | 210 | 80- | 1R | BGS |
| HLM | LONG MYND | 52.5184 | -2.8807 | 340.25 | 291.57 | 429 | 84- | 1 | BGS |
| HTR | TREWERN HILL | 52.0790 | -3.2697 | 313.00 | 243.10 | 329 | 82- | 1R | 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 |
| **SWINDON** | | | | | | | | | |
| SWN | SWINDON | 51.5130 | -1.8005 | 413.85 | 179.42 | 192 | 93- | 4 | BGS |
| SMD | MENDIPS | 51.3082 | -2.7174 | 350.00 | 156.87 | 300 | 93- | 1 | BGS |
| SSW | STOW-ON-WOLD | 51.9667 | -1.8499 | 410.31 | 229.85 | 291 | 93- | 1 | BGS |
| SWK | WARMINSTER | 51.1483 | -2.2471 | 382.72 | 138.87 | 279 | 93- | 1 | BGS |
| SFH | HASELMERE | 51.0604 | -0.6911 | 491.71 | 129.88 | 260 | 93- | 1 | BGS |
| SIW | ISLE OF WIGHT | 50.6711 | -1.3747 | 444.18 | 85.97 | 162 | 93- | 1 | BGS |
| SKP | KOPHILL | 51.7215 | -0.8099 | 482.20 | 203.25 | 215 | 93- | 1 | BGS |
| **SOUTH EAST ENGLAND** | | | | | | | | | |
| TFO | FOLKESTONE | 51.1136 | 1.1406 | 619.79 | 139.67 | 188 | 89- | 4m | BGS |
| TEB | EASTBOURNE | 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 |
| **CORNWALL** | | | | | | | | | |
| CMA | MANACCAN | 50.0819 | -5.1273 | 176.30 | 24.96 | 50 | 93- | 1 | BGS |
| 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 | 31.14 | 183 | 81- | 1 | BGS |
| CGH | GOONHILLY | 50.0508 | -5.1649 | 173.46 | 21.61 | 91 | 81- | 1 | BGS |
| CPZ | PENZANCE | 50.1560 | -5.5835 | 144.07 | 34.66 | 198 | 81- | 1R | BGS |
| CR2 | ROSEMANOWES2 | 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 |
| CGW | GWEEK | 50.1003 | -5.2224 | 169.58 | 27.29 | 76 | 93- | 1 | BGS |
| **DEVON** | | | | | | | | | |
| 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 |
| HTL | HARTLAND | 50.9944 | -4.4850 | 225.64 | 124.67 | 91 | 81- | 4Rm | BGS |

**GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1994**

| Code | Name | Lat | Lon | GrE (Kms) | GrN (Kms) | Ht (M) | Yrs Open | Comp | Agency |
|---|---|---|---|---|---|---|---|---|---|
| HSA | SWANSEA | 51.7478 | -4.1543 | 251.30 | 207.70 | 274 | 87- | 1R | BGS |
| HPE | PEMBROKE | 51.9371 | -4.7745 | 209.30 | 230.20 | 355 | 90- | 1R | BGS |
| HEX | EXMOOR | 51.0668 | -3.8025 | 273.72 | 131.32 | 278 | 91- | 1R | BGS |
| **JERSEY** | | | | | | | | | |
| JQE | QUEENS EAST | 49.2000 | -2.0384 | | | 58 | 91- | 1 | BGS |
| JLP | LES PLATONS | 49.2428 | -2.1039 | | | 131 | 81- | 1R | BGS |
| JRS | MAISON ST LOUIS | 49.1924 | -2.0917 | | | 53 | 81- | 4R | BGS |
| JSA | ST AUBINS | 49.1879 | -2.1709 | | | 21 | 81- | 1R | BGS |
| JVM | VALLE D.L.MARE | 49.2169 | -2.2068 | | | 64 | 81- | 1R | BGS |

Notes

1. The UK seismograph network is divided into a number of sub-networks, named Cornwall, Devon etc, within which data are 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 (Comp) and the agency operating the station (in this list they are all BGS).

3. Qualifying symbols indicate the following:

   R in Comp column : station details have been registered with international agencies for data exchange.

   m in Comp column : low frequency microphone also deployed.

   * after Name : station removed from original network to be transmitted to a new centre.

   ** after Name : station transmitting to both the Cumbria and Borders network centres.

## PROJECT PUBLICATIONS ANNEX F

### BGS Seismology reports

| | |
|---|---|
| WL/93/06 | Walker, A.B. SW England seismic monitoring for the HDR Geothermal Programme in Cornwall, April 1992 to March 1993. |
| WL/93/08 | Browitt, C.W.A. and Walker, A.B., 1993. UK Earthquake Monitoring 1992/93, BGS Seismic Monitoring and Information Service, Fourth Annual Report. |
| WL/93/10 | Musson, R.M.W. Earthquakes in the Isle of Man. |
| WL/93/11 | Walker, A.B. (Ed.), Ford, G.D., Galloway, D.D., Redmayne, D.W., Richards, J.A., Ritchie, M.E.A., Simpson, B.A., Turbitt, T., Wallace, R.J. and Wright F. Bulletin of British earthquakes 1992. |
| WL/93/13 | Musson, R.M.W. Macroseismic magnitude and depth for British earthquakes. |
| WL/93/21 | Walker, A.B. Earthquake Guidelines. |
| WL/94/4 | Musson, R.M.W. A catalogue of British earthquakes. |
| WL/94/9 | Walker, A.B. (Ed.), Ford, G.D., Galloway, D.D., Lovell, J.H., Redmayne, D.W., Richards, J.A., Simpson, B.A., and Wright, F. Bulletin of British earthquakes 1993. |
| WL/94/11 | Wright, F., Richards, J.A., Musson, R.M.W. and Henni, P.H.O. The Grange over Sands earthquake of 26 June 1993, 3.0 ML. |

In addition, 5 confidential reports were prepared for commercial customers and bulletins of seismic activity were produced monthly, up to 6 weeks in arrears for the Customer Group sponsoring the project.

### External Publications

Browitt, C.W.A., 1993. The Khilari earthquake disaster, *SECED Newsletter,* Oct 1993 **7:4**.

Browitt, C.W.A., 1993. Earthquake impact reduction, *SECED Newsletter,* Oct 1993 **7:4**.

Browitt, C.W.A. and Musson, R.M.W., 1993. Earthquake hazards and risk, *Earthwise,* **1:3,** 34-35.

Musson, R.M.W. and Winter, P., 1993. Seismic hazard methodology for a hazard map of the UK, *AEA Technology Consultancy Services (SRD)* Report No GNSR (DTI), p(93)149.

Musson, R.M.W., 1993. Comrie: a historical Scottish earthquake swarm and its place in the history of seismology, *Terra Nova,* **5,** 477-480.

Musson, R.M.W., 1993. Discovery of a curious seismological monument from 19th century Scotland, *Terra Nova,* **5,** *p513.*

Redmayne, D.W., 1993. Recent Notable Earthquakes (1980-1983), *SECED Newsletter,* Oct 1993, 7:4.

Redmayne, D.W., 1994. 1993 - A Summary of the Earthquakes, *SECED Newsletter,* Jan 1994, **8:1**.

## SW ENGLAND SEISMIC MONITORING FOR THE HDR GEOTHERMAL PROGRAMME IN CORNWALL: APRIL 1992 TO MARCH 1993

**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 March 1993. 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.

In the period April 1992 to March 1993, 67 natural earthquakes have been located with magnitudes between -0.3 and 3.2 ML; the largest locating south west of the Scilly Isles on 29 June 1992. The 52 events which located within 10 km of the HDR site, occurred near Constantine with magnitudes ranging from -0.3 to 1.0 ML and form part of the continuing series of instrumentally located events in that area since 1981.

Since 1981, Cornwall has proved to be an area of moderate seismicity within the UK with five events felt by people from epicentres near the village of Constantine, 6 km south of the HDR site, and one felt near Liskeard near the Cornwall-Devon border. The magnitudes of these events ranged from 1.9 to 3.5 ML. Some 500 smaller earthquakes, which were imperceptible to people, have been located in the region, including many aftershocks of the larger Constantine events.

## BGS SEISMIC MONITORING AND INFORMATION SERVICE: FOURTH ANNUAL REPORT

**C W A Browitt and A B Walker**

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 4 report to the Customer Group follows the previous format in reiterating the programme objectives and highlighting some of the significant seismic events in the period April 1992 to March 1993. The catalogue of earthquakes for the whole of 1992 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 improvement in response time for felt earthquakes in many parts of England and Wales.

## EARTHQUAKES IN THE ISLE OF MAN

**R M W Musson**

An account is given of the principal earthquakes felt or reported to have been felt in the Isle of Man. Reported earthquakes in 1171, 1788 and 1910 are shown not to be genuine. An event in 684 is of uncertain status, probably genuine. Other events occurred in 1893 and 1987.

## BULLETIN OF BRITISH EARTHQUAKES 1992

**A B Walker (Editor)**

Some 291 earthquakes have been located by the monitoring network in the year, with 50 of them having magnitudes 2.0 or greater. Eight in that magnitude category are known to have been felt together with a few smaller ones.

The largest earthquake of the year, onshore, occurred in Caernarvon Bay on 29 July with a magnitude of 3.5 ML and was felt over an area of approximately 10,000 $km^2$. A macroseismic survey throughout the region showed that it was felt around Caernarvon with a maximum intensity of 5 MSK (just below damaging level). The focal mechanism shows reverse faulting with a small-component of strike-slip faulting.

In the North Sea, the largest offshore earthquake in 1992, with magnitude 4.7 ML, occurred on 8 November in the north Viking Graben, approximately 230 km NE of Shetland. A single felt report was received from the More region of western Norway but there were no reports from the North Sea platforms nor other land areas probably owing to the poor weather conditions at the time of the event.

Twenty-five small events with magnitudes ranging from 0.3 to 1.7 ML were detected in the coalfield areas of Fife; six were reported felt. In other coalfield areas some 14 events were detected, one of which was felt.

## MACROSEISMIC MAGNITUDE AND DEPTH FOR BRITISH EARTHQUAKES

**R M W Musson**

In order to produce numerate catalogues of historical earthquakes, it is necessary to be able to estimate earthquake magnitude from macroseismic effects. The recommended method is to correlate magnitude with the area enclosed within one of the outer isoseismals, usually 3 or 4 MSK. In this study, the largest dataset of instrumental and macroseismic details ever assembled for the UK is studied, and equations deduced for estimating magnitude for historical earthquakes.

The critical equations are:

$$ML = 1.03 \log A3 - 0.19$$
$$ML = 0.92 \log A4 + 0.71$$

where A3 and A4 are the areas enclosed by isoseismals 3 and 4 MSK, respectively.

Focal depth can also be estimated by macroseismic methods; the method developed by Sponheuer is adapted in a new computer program for estimating depth from isoseismal areas and this is applied to all UK earthquakes for which the macroseismic data are sufficient. Analysis of the results shows that for the larger earthquakes ( $\geq$ 4 ML) the depth range is from 3 to 26 km, with a mean at 15 km.

**EARTHQUAKE GUIDELINES**

**A.B Walker**

These UK guidelines give the analysis procedures which are followed in the event of a local earthquake or sonic boom. They contain sufficient detail for a novice to be able to extract data from remote stations of the seismic monitoring network, using any suitable terminal, and to transfer that information to the Murchison House VAX. Following this data capture, the guidelines cover procedures necessary to locate earthquakes, determine magnitudes, search the BGS database, edit the bulletin board and despatch faxes.

**A CATALOGUE OF BRITISH EARTHQUAKES**

**R M W Musson**

This report contains a catalogue of earthquakes felt in the UK, with the following restrictions: from the earliest times to 1700, only earthquakes believed to be 4 ML or greater are included. From 1700 to 1993, all known earthquakes of magnitude 3 ML and greater are included, plus a selection of smaller events where these are of some interest (eg those that were strongly felt). Short descriptive paragraphs of all the earthquakes are included, except for those modern earthquakes that were not felt.

**BULLETIN OF BRITISH EARTHQUAKES 1993**

**A B Walker (Editor)**

There have been 358 earthquakes located by the monitoring network in the year, with 39 of them having magnitudes of 2.0 or greater. Six in that magnitude category are known to have been felt together with a further seven smaller ones, bringing the total to 13 felt earthquakes in 1993.

The largest onshore earthquake of the year occurred in Grange-Over-Sands, Cumbria, on 26 June with a magnitude of 3.0 ML and a felt area of 2700 km$^2$. A macroseismic survey throughout the region showed that it was felt in the epicentral area with a maximum intensity of 5 MSK (just below the damaging level). The focal mechanism interpretation shows two possibilities; strike-slip with a small component of reverse faulting or reverse faulting with a small component of strike-slip faulting.

The largest felt offshore earthquake in 1993, (magnitude 4.0 ML), occurred on 7 July and was felt at the Gorm hydrocarbons field. The felt reports described "a shuddering" on the Gorm complex and on a nearby standby vessel resulting in a production stoppage of 2 hours. It locates in a similar area to the magnitude 4.0 ML event on 10 June 1985 which was felt on the Gorm and Tyra platforms and on a standby vessel.

On 29 June, a small event (magnitude 2.0 ML) was located in the Potteries, Stoke-on-Trent. It was felt in the Talke Pits area and it was reported that unstable objects were overturned indicating an intensity of at least 5 MSK.

Near Coniston in Cumbria, a magnitude 1.5 ML earthquake was detected on 8 July 1993. A single felt report was received from the village of Kirkby-in-Furness describing "a noise like a heavy lorry passing outside". It locates some 18 km from the Grange-Over-Sands earthquake two weeks before.

In Wales five events were located on the Lleyn Peninsula and form part of the earthquake series which was detected following the magnitude 5.4 ML earthquake of 19 July 1984. Three events near Ludlow located at mid-crustal depths of around 14 km and a magnitude 2.3 ML earthquake was felt by a few people in Betws-y-Coed and Nantbh.

Several series of earthquakes have been detected throughout the year; namely, south of Arran (12 events), Mallaig (22 events), Johnstonebridge (11 events) and near Constantine in Cornwall (89 events).

Some 53 coalfield events with magnitudes ranging between -0.2 and 2.4 ML have been detected in 1993, six of which were felt. Thirty of them were located in the Clackmannan area in the central region of Scotland, where 3 events were felt by local residents in the village of Forest Mill; the largest (1.6 ML) had an intensity of at least 3 MSK.

Near Ranskill, Nottinghamshire, a magnitude 2.2 ML coal-mining event was detected on 11 November. It was felt strongly in the village of Ranskill where residents ran out of their houses into the streets, indicating an intensity of at least 5 MSK. The largest coalfield event during the year near Farnsfield in Nottinghamshire had a magnitude of 2.4 ML but was not reported to be felt.

## THE GRANGE-OVER-SANDS EARTHQUAKE 26 JUNE 1993 (3.0 ML)

**F Wright, J A Richards, R M W Musson and P H O Henni**

On 26 June 1993 at 05:42 UTC, a magnitude 3.0 ML earthquake occurred approximately 3 km ENE of Grange-over-Sands, Cumbria. It was felt over an area of 9,000 $km^2$ (Isoseismal 2), 2,700 $km^2$ (Isoseismal 3) and had a maximum intensity of 5 MSK near the epicentre. The focal depth was 8.3 km.

Analysis of the focal mechanism of the event produced a large number of possible solutions, ranging from strike-slip faulting with a small component of reverse faulting, to reverse faulting with a small component of strike-slip faulting. All of the possible mechanisms were consistent with a NW-SE maximum compressive stress direction, in agreement with the stress regime observed for other locations in the UK.

**THE KHILARI EARTHQUAKE DISASTER**

**C W A Browitt**

India has a long history of earthquakes, most of which are confined to the Himalayan seismic belt in the north. Away from this area, a magnitude 6.5 earthquake, near the Koyna dam, caused 180 deaths in 1967 and has been attributed to the filling of that reservoir. This was 270 km to the west of the epicentre of the magnitude 6.3 Khilari earthquake of 29 September 1993 which was a natural event resulting from the slow build-up of strain within a plate of the Earth's crust. These conditions produce infrequent, but potentially damaging earthquake; examples of which have also occurred in Australia and in Britain.

Many thousands of people died in the Khilari earthquake due to poor building standards. Simple techniques for strengthening and protecting ordinary rural housing against earthquake damage exist and should be taken into account for the reconstruction programme in the state of Maharashtra. The mission of the International Decade for Natural Disaster Reduction is to help vulnerable communities such as this to be better protected by the transfer of expertise and knowledge and the encouragement of greater funding.

**EARTHQUAKE IMPACT REDUCTION**

**C W A Browitt**

In the past few decades, there has been a significant increase in disasters and losses due to earthquakes (and tsunami) as the world's population and urbanisation has increased, and this will continue unless appropriate measures are taken to assess and minimise the risk. This involves a lengthy programme of hazard assessment. The first steps should be the identification of the likely sites and magnitudes of earthquakes, and a prediction of their effects on local rocks and man-made structures, which involves extensive programmes of seismic monitoring, geological mapping and engineering studies. The protection of public utilities and lines of communication is vital, and finally, the level of public awareness needs to be raised by training programmes, so that the populace can react appropriately. The Society for Earthquake and Civil Engineering Dynamics (SECED) provides the UK forum for discussion of all these matters.

**EARTHQUAKE HAZARDS AND RISK**

**C W A Browitt and R M W Musson**

Although the UK is situated a long way from those areas of the world from which large and very damaging earthquakes are reported, earthquakes do occur here, and have reached around magnitude 6 and caused damage. Seismic risk to 'high-consequence' structures is therefore low but not negligible. The development by BGS of an earthquake catalogue, and seismic monitoring networks covering the UK has led to the acquisition of a large data set which can be used for the quantification of earthquake effects both on- and off-shore.

**SEISMIC HAZARD METHODOLOGY FOR A HAZARD MAP OF THE UK**

**R M W Musson and P Winter**

This reports considers the methodological problems involved in hazard mapping exercises in general, and for the UK in particular, and outlines the approach that will be taken in a commissioned study currently being undertaken by BGS and AEA Consultancy Services, in partnership, for the Department of Trade and Industry. A new hazard mapping computer program, based on the USGS program SEISRISK III, but incorporating "logic-tree" modelling of parametric uncertainties, is described.

**COMRIE: A HISTORICAL SCOTTISH EARTHQUAKE SWARM AND ITS PLACE IN THE HISTORY OF SEISMOLOGY**

**R M W Musson**

Comrie, Perthshire, suffered from pronounced earthquake swarm activity in the years 1795-1801 and again in 1839-1846; probably earlier around 1605-1622 as well. Between these periods small shocks also occurred with lesser frequency. The activity that started in 1839 attracted the attention of the British Association for the Advancement of Science, who set up a committee to study the earthquakes. The result of this work is of importance for the early development of seismology. It included the first use of the inverted-pendulum seismometer and the first local instrumental network, among other innovations.

**DISCOVERY OF A CURIOUS SEISMOLOGICAL MONUMENT FROM 19TH CENTURY SCOTLAND**

**R M W Musson**

A curious stone pillar with an inscription recording an earthquake in 1841 was recently unearthed in the grounds of Fingask Castle, Perthshire. Research shows that the event so memorialised has escaped the attention of previous earthquake catalogues. It is conjectured that the pillar was originally erected in the grounds of Stanley House, north of Perth and is now the property of Perth museum.

**RECENT NOTABLE EARTHQUAKES (1980 - 1993)**

**D W Redmayne**

Notable earthquakes of the world for the fourteen years, 1980 to 1993, were reviewed with particular regard to their impact on human activity. Over this period, earthquakes have occurred with rather less than the average frequency noted earlier this century; however, the death toll and economic consequences of earthquakes have risen over the years as populations have increased worldwide, not least in earthquake prone areas.

The greatest loss of life occurred in the Iran earthquake (magnitude 7.7 Ms) of 20 June 1990 with between 40,000 and 50,000 fatalities. Other earthquakes which caused very high death tolls occurred in Algeria, Italy, southern Iran, Mexico, Armenia and southern India. A number of earthquakes occurring in areas previously not regarded as having a significant earthquake hazard caused fatalities. The most notable example of this was the magnitude 6.3 Ms, Maharashtra, southern India, earthquake of 29 September 1993. Over 9,000 people were killed in this earthquake which occurred in an area with no previous earthquake history. Earthquakes in developed countries, although causing great economic loss, generally caused far fewer casualties due to well enforced building codes.

During the period there were four earthquakes over magnitude 8.0 Ms, only one of which caused casualties, and an average of 11 per annum between 7.0 and 7.9 Ms, as compared to a long term average of eighteen. In the United Kingdom there were two earthquakes over magnitude 5.0 ML and three between 4.0 and 4.9 ML. Over 120,000 people died worldwide in earthquakes during the period reviewed, averaging 8,700 per annum. This figure could be significantly reduced if the understanding and technical knowledge available in the world were applied where it is most needed.

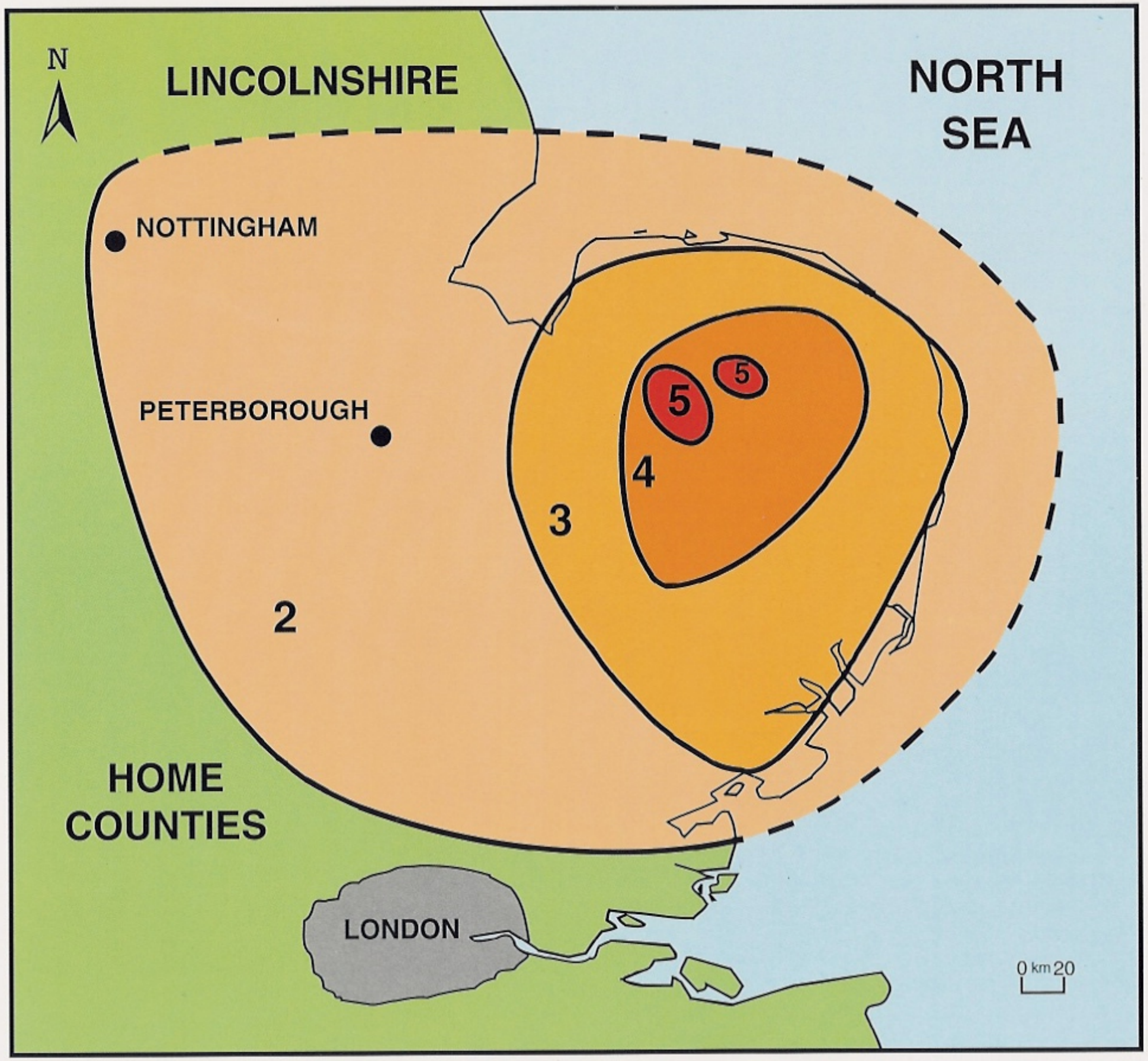
**1993 - A SUMMARY OF THE EARTHQUAKES**

**D W Redmayne**

The year 1993 was not exceptional in terms of the earthquakes which occurred worldwide, with generally fewer large earthquakes than the long term average. It was only in fatalities caused by earthquakes that 1993 proved to be higher than average. Most of the 10,039 earthquake deaths that occurred were caused by the 29 September, Khilari, earthquake of southern India. This earthquake, which caused 9,478 fatalities, had a magnitude of 6.3 Ms and occurred in an area with no previous earthquake history. One earthquake with a magnitude over 8.0 Ms occurred during 1993; on 8 August with an epicentre south of the Marianas Islands. It caused damage to property and port facilities on the island of Guam.

The number of earthquakes in the UK was also below average during the year. The strongest onshore UK earthquake, magnitude 3.0 ML, occurred near Grange-over-Sands on 26 June and was felt in southern Cumbria and northern Lancashire. A magnitude 4.0 ML earthquake was felt in the Gorm oil production complex in the central North Sea on 7 July.

Natural Environment Research Council




Norwich Earthquake 15th February 1994, 10:15 UTC (4.0 ML) - MSK intensities