UK EARTHQUAKE MONITORING 1994/95

BGS Seismic Monitoring and Information Service

Sixth Annual Report

British Geological Survey
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UK Earthquake Monitoring 1994/95

BGS Seismic Monitoring and Information Service

Sixth Annual Report

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June 1995

UK Seismic Monitoring and Information Service Year Six Report to Customer Group: June 1995

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

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UK EARTHQUAKE MONITORING 1994/95

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 26 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 sixth year of the project (April 1994 to March 1995), the rapid response capability has been improved with 3 sub-networks added to the 14 previously upgraded to the new digital standard, leaving only three on the old standard. There are, however, some remaining gaps in station 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 following the withdrawal of, or dependency on, funds from commissioning bodies. Two additional low sensitivity and two strong motion instruments have been installed.

Some 360 earthquakes have been located by the monitoring network in 1994 with 42 of them having magnitudes of 2.0 or greater and 23 known to be felt. The largest on land, in the reporting year (April 1994 to March 1995), had a magnitude of 3.1 ML and was felt in Arnisdale, near Kyle of Lochalsh, and in the Duisdalemore area of Skye. The largest offshore event was in the Central North Sea, magnitude 4.0 ML and was felt on the Dan oil platform. Smaller earthquakes have been felt in several areas of the country including Stratford-Upon-Avon, Constantine, Kilmelford, Coniston, Skye, Bargoed, and Stoke-on-Trent. 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 mining (eg Stillingfleet, North Yorkshire). Controlled explosions are also recorded. During the reporting period, data on two explosions and on five sonic events have been processed and reported upon following public concern or media attention.

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 programme of digitising old analogue records has achieved capture of all known events above magnitude 2.5 since 1979.

In order to explore the further potential of the network's data links and computing capabilities, an environmental monitoring capacity has been proved at one remote station alongside the seismic sensor.

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 6 report to the Customer Group follows the format of the first five annual reports in reiterating the programme objectives and highlighting some of the significant seismic events in the period April 1994 to March 1995. The catalogue of earthquakes for the whole of 1994 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. An updated map of epicentres since 1979 is also included for earthquakes with magnitude $\geq$ 2.5 ML; the threshold above which the data set is probably complete.

There has been no further progress in achieving the overall objective of a minimum station spacing of 70 km for the whole of the UK and some gaps remain. However, advances have been made in the capabilities of the existing facility. Monitoring stations in the sub-networks of Leeds, Galloway and Eskdalemuir have been upgraded to the remotely-accessible digital standard. These are, in addition to those previously installed in Cornwall, Hereford, North Wales, around Edinburgh, Kyle, Keyworth, Cumbria, Borders, Jersey, East Anglia, central England, Shetland, south east England and north Devon. Only the Devon, Moray and Paisley networks remain to be upgraded. Figure 6 shows the present combined detection capability of the digital, rapid-access stations.

To improve the capacity of the network to deliver on-scale data for the larger earthquakes and to more effectively calculate their magnitudes, low-gain and strong motion instruments have been installed in Norwich. A further strong motion system has been established at Torness for Scottish Nuclear Ltd (Fig 4). Traditionally, strong motion and high sensitivity networks have been treated separately for technical reasons. The new digital hardware and software developed in collaboration with the University of Bergen, has permitted a convergence of the technologies and the strategy now is to collect the two types of data in the one computer system. This produces a cost benefit, greater reliability and, more importantly, ensures there is a pool of analysts familiar with extracting and processing data despite the infrequency of strong motion earthquakes.

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 (at present, only three sub-networks remain to be upgraded, Devon, Paisley and Moray).

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 1995, with rapid access upgrades, is shown in Figure 1 with its detection capability in Figure 5. The scheduled programme for 1994/95 had as its aims:

(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.

Minor additions (i) have been made in Leeds and East Anglia where low-gain instruments have been installed; the completion of the digital upgrading (ii) has been held up due to a shortage of equipment, although half of the outstanding stations were converted (13 remain). No further progress has been made with experimental boreholes (iii) owing to a shortage of funds and staff resources. The check on geographic locations of stations using GPS (iv) has been completed except for the Kyle network which is expected to be conducted in May 1995; all significant position changes have been implemented in the station list. The development of the strong motion network (v) has resulted in the installation of two strong motion stations at Torness and Norwich which are being recorded onto rapid access systems. The digitising project (vi) has been completed for all earthquakes above 2.5 ML for the period 1979 to present. A large number of smaller magnitude events have also been recovered and that work is continuing; difficulties with older tapes are being examined. A watching brief (vii) is continuing.

The present distribution of strong motion instruments together with the low-gain instruments, microphones and the environmental station in the Lowlands of Scotland is shown in Figure 4. Seven of the 11 strong motion stations generate open-file data; the other 3 still require some negotiation before the data could be considered available.

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. 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 throughout the year at a reduced level, resulting in the removal of three stations around the HDR site. With the cessation of funding at the end of March 1995, the equipment from the project has been transferred to the UK Earthquake monitoring programme.

(iii) BNFL is continuing the intensive microseismic monitoring study in Cumbria through the 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.

(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 completed and it is fully operational.

In summary, 17 existing stations crucial to the background network are at risk owing to the withdrawal of present or recent 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 four locations throughout the country bringing the total to nine. They permit fast transfer of data from the remote access networks to Edinburgh (up to three times faster). A 16-bit ILI (Interpolating Line Interface Unit) has been integrated into the system to permit the direct recording of digital data on the SEISLOG units. This gives 16-bit data in digital form, eliminating FM demodulators and analogue-to-digital converters and hence increases the dynamic range to 96 db. A 24-bit ILI has been purchased for evaluation and is designed to cover (dynamic range up to 140 db) all possible ground motions expected from earthquakes in Britain.

Larger capacity, one gigabyte disks have been installed in 4 new locations to replace 40 and 400 megabyte units thereby bringing the total to nine for the network. They give a three-day window of continuous data together with extra storage for event files which would be needed during aftershock sequences such as that experienced following the felt Constantine earthquakes in 1994. It is expected to upgrade all 400 megabyte disks to this standard as time and funding permit. A trial with a 4 gigabyte disk has successfully recorded 7 days of continuous data and the development of a Digital Audio Tape (DAT) continuous back-up recorder is progressing. Both of these initiatives will help prevent potential losses as the old analogue Geostore recorders are

decommissioned and reliance swings to the event-triggered systems which can miss spurious events, small earthquakes and sonic booms. Further software improvements have been made in the data acquisition system; particularly with regard to the acquisition of other environmental data in parallel with that from the seismometers (see below). At Torness, new software is recording data using multi-parameter files, which are designed, in this case, to trigger on acceleration levels. This has been successfully running throughout the year and has recorded several local quarry blasts in the vicinity of Torness.

4.3 Environmental monitoring

The infrastructure provided by the UK nationwide seismic monitoring network, comprising remote sensing stations linked to computers, is ideal for expansion into a full-spectrum environmental monitoring network (including pollution, radioactivity and weather). To this end, an experimental station (Plate 1) has been established 35 km from Edinburgh where air and ground temperature, together with radioactivity data are being transmitted to a base station, at present, although the station has the capacity to transmit data from 16 environmental sensors simultaneously. An agreement has been reached with the Met Office with regard to the meteorological elements of a proposed programme for which additional funding is being sought. Broadening the customer base in this way would help the sustainability of the seismic monitoring network.

5. Seismic activity in Year 6

5.1 Earthquakes located for 1994

Details of all earthquakes, 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 1994 published and distributed in March 1995. A map of the 357 events located in 1994 is reproduced here as Figure 7 and a catalogue of those with magnitudes of 2.0 or greater is given in Annex B. Eighteen in that magnitude category, together with 5 smaller ones, are known to have been felt. In the period since BGS commenced modern seismic monitoring in the UK (1979 to March 1995), 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 sixth year of the project (April 1994 to March 1995) are given below:

(i) Near Stratford-upon-Avon on 12 May, a magnitude 3.0 ML earthquake was felt by local residents in Stratford-Upon-Avon, Evesham, Worcester and the surrounding small villages with intensities of at least 4 MSK. A macroseismic survey was carried out and showed it was felt in the epicentral region with intensities of 5 MSK (just below damaging level). It was unusual in that there have not been any previous events in this area for 20 years. A seismogram of the event recorded on the Hereford network is shown in Figure 9.

(ii) Some 68 events, (two in April the other 66 in June) were located near the village of Constantine in Cornwall with magnitudes ranging between -0.6 and 2.2 ML; two were felt (magnitudes 2.2 and 1.6 ML), the former, with intensities of at least 4 MSK in the Constantine area of Cornwall. They form part of the continuing series which has been instrumentally recorded since 1981 and which has now produced seven felt earthquakes.

(iii) Near the village of Kilmelford, 12 km south of Oban, on 14 July, a magnitude 2.1 ML earthquake was felt on the Island of Seil and at Lerags, Strathclyde. Local residents described a noise "like a muffled explosion lasting 4-5 seconds" indicating an intensity of at least 3 MSK. The earthquake located some 25 km south east of the magnitude 4.1 ML earthquake near Oban on 29 September 1986, which was felt over an area of 2400 km^2 (Isoseismal 3).

(iv) Near Coniston in Cumbria, a magnitude 2.2 ML earthquake on 18 July, was felt by local residents in Coniston, Elterwater and Torver where it was reported that "windows and doors rattled and a rumble was heard" indicating intensities of at least 3 MSK. It locates some 7 km north-east of the three felt Ambleside earthquakes in September 1988, magnitudes 3.0, 3.2 and 1.8 ML, and 11 km north of the felt Coniston earthquake in July 1993, magnitude 1.5 ML.

(v) An earthquake with magnitude 3.1 ML was felt by residents in the Duisdalemore region of the Isle of Skye and on the mainland at Arnisdale, Strathclyde, on 17 August. It located in a remote area and resulted in only a few felt reports.

(vi) Near Bargoed, Mid Glamorgan, a magnitude 2.1 ML earthquake on 17 August, was felt by local residents who described "the building shaking and a noise like a rumble". It located some 2 km from the magnitude 2.2 ML event on 17 August 1992 which was felt with intensities of 5 MSK and which resulted in the overturning of perfume, sauce, milk bottles and cracked windows.

(vii) Some 40 km south east of Harwich, on 15 September, a magnitude 3.2 ML earthquake was felt by coastguards at Walton-on-the-Naze. It locates in an area where no previous seismicity has been detected in the past 20 years and some 62 km east of the Colchester earthquake of 1884, one of Britain's most damaging events.

(viii) The largest offshore earthquake in the reporting period, was in the Central North Sea, on 18 October, with a magnitude of 4.0 ML. It was felt on the Dan oil platform. It was located some 35 km south-east of the Dan field and 70 km east-south-east of the magnitude 4.0 ML event on 7 July 1993 which resulted in the loss of oil production for approximately 2 hours.

(ix) Near Mansfield in Nottinghamshire, seven events have been detected throughout the reporting year with magnitudes ranging between 0.2 and 2.1 ML; two of these were felt strongly by local residents, where it was reported that people ran into the streets (19 April, 1.2 ML, 25 November, 2.1 ML). With shallow depths of less than 1 km they are believed to be of coal-mining origin.

(x) Three events have been located near the border of Northern Ireland with magnitudes ranging between 1.5 and 2.1 ML. One was felt (magnitude 2.0 ML) by local residents (21 November 1994), indicating a maximum intensity of 4 MSK.

(xi) An earthquake with magnitude 2.2 ML near Stillingfleet (N Yorks), on 5 December, was felt by residents in Stillingfleet, Riccall and in the nearby collieries. It was located at a depth of less than 1 km and has the characteristics of a mining-induced event.

(xii) A swarm of earthquakes was located in the Stoke-on-Trent area in February 1995. They had magnitudes ranging between 1.6 and 2.5 ML and six were felt by local residents. From the available data (nearest station some 25 km away) many of these events had characteristics typical of natural earthquakes with some showing characteristics typical of mining-induced earthquakes. Similar swarms in the area were detected in the mid 70's, early 80's and early 90's. A seismogram of the largest felt event in this recent sequence is shown in Figure 10.

(xiii) Near Newcastle-Under-Lyme, on 22 February 1995, a magnitude 2.3 ML event was felt by local residents, in Newcastle-Under-Lyme, Madeley and Stoke-on-Trent, who reported strong shaking. The signal recorded by the BGS Keyworth network showed that the source was shallow (presence of surface waves in Figure 11) and possibly related to the nearby mines in the region.

(xiv) Some 70 coalfield events with magnitudes ranging between -0.2 and 2.2 ML have been detected in the reporting period, four of which were felt. Fifty-three of them located in the Clackmannan area in the central region of Scotland where the magnitudes ranged from 0.3 to 1.9 ML; none were felt by local residents.

(xv) In other coalfield areas, small earthquakes were located in the Lothian coalfields (five events with magnitudes ranging from -0.2 to 0.8 ML), Rotherham, south Yorkshire (1.2 ML, 15 October 1994 and 1.4 ML, 28 October 1994), Amble, Northumberland (1.5 ML, 27 January 1995). These events are presumed to be related to present-day coal-mining activity.

(xvi) Elsewhere in the country, many seismic events have been reported felt or heard like small earthquakes but, on analysis, have been proved to be sonic booms (Fig 12). Specific examples are: Pontypridd (17 and 18 August 1994), County Durham (2 September 1994), Hampshire (28 September 1994) and Selby (24 November 1994).

(xvii) 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: Southend (29 September 1994) and Port Seton, near Edinburgh (3 October 1994). A seismogram of the Port Seton WWII mine explosion is shown in Figure 13. On 7 October 1994, 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 compressional first motion arrivals (ground up) and the absence of other phases. A seismogram of the event recorded on the Hereford 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 in Bolivia on 9 June 1994 with a magnitude of 7.0 Mb (8.2 Mw) was felt throughout South America, in the Caribbean, North America, including Los Angeles, Omaha, Chicago, Minneapolis and Toronto over 6,000 km from the epicentre. It was one of the deepest earthquakes (630 km) to have been recorded in recent years. Minor damage was reported and unconfirmed reports of five deaths in Peru, resulted from this large earthquake. A seismogram of the event is shown in Figure 15.

(ii) The Kobe earthquake in Japan on 16 January 1995 was one of the most destructive earthquakes since the one which struck southern India in 1993. It measured 6.8 Ms, and caused the death of some 5,300 people, injured 27,000 and resulted in the loss of $96 billion in damages. A seismogram recorded on the LOWNET network is shown in Figure 16. Many buildings were destroyed by this earthquake, examples of which are shown in Plate 2.

(iii) A few kilometres offshore Cyprus, on 23 February 1995, a magnitude 5.8 Mb earthquake was felt throughout the island and in northern Israel and caused extensive damage in the district of Paphos, where two people were killed. An example of the damage is shown in Plate 3. With a magnitude similar to that of the Dogger Bank earthquake of 1931, the affects of this event have comparative significance in the prediction of the long term risk from such earthquakes in the UK.

6. The National Seismological Archive

6.1 Identification, curation and cataloguing

Significant progress has been made with the organisation and collation of original seismograms held by BGS. A program of microfilming of these records has been started using curation priority as the criteria for selection. The possibilities of digital image storage generated from microfilm are being investigated. If practical, this will allow for easier access to, and viewing of, seismogram material held by BGS.

Jersey Mainka' Seismograms: have now been collated and microfilmed prior to full archival storage in the Seismogram Archive in Murchison House.

Bidston Seismograms: have now been collated and are currently being microfilmed prior to full archival storage as above.

Eskdalemuir Seismograms: have been passed to BGS by the Meteorological Office at Eskdalemuir, where they will be integrated into the existing collection of KEW/ESK material and subsequently microfilmed.

West Bromwich Seismograms: one surviving record has been found.

6.2 Storage and Inspection facilities

The designated Seismogram Archive Store in Murchison House is now being monitored to ensure correct storage conditions are maintained.

This National Seismological Archive has been used by some 10 visiting scientists and many data requests have been answered from scientists and researchers worldwide. The use of the Internet as a medium for making available listings of archive holdings is being investigated. This would reduce time required for responses to academic enquiries.

Slow, but steady, progress has been made with the cataloguing of BGS held material. It is hoped that with a reassignment of staff duties this can be prioritised and a final catalogue produced. There has been no change in the status of collections held by BGS and detailed in the Year 4 report to the Customer Group.

6.3 Digital records

The programme of digitising old analogue tapes has achieved capture of all known events above magnitude 2.5 ML since 1979. A number of smaller magnitude events have also been recovered and this work is continuing.

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 two individuals. In the case of series of events in coalfield areas, only the more significant ones are reported in this way. Some 39 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. This year, it has also been made available through an Internet home page.

Remote telephone access to 90% of UK seismic stations is now available and six of the principal BGS seismologists can obtain data directly from their homes. These advances have resulted in considerable improvements in the immediate response capability for UK and global events including enquiries which prove to be spurious or of non-earthquake phenomena. Most of the UK is now covered in this way for earthquakes with magnitudes of 2.0 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 than 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. For 1994, it was issued within 3 months.

8. Programme for 1995/96

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 1995/96 are:

(i) Extension of coverage to Orkney, Outer Hebrides and north-west Scotland.

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

(iii) Focal mechanism studies using data collected from the project to establish a general stress direction for the UK.

(iv) Initiate a programme to establish seismic attenuation characteristics for the UK based on UK data: valuable for refining seismic hazard assessments.

(v) Completion of the programme of digitising the remaining analogue magnetic tape data.

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

(vii) Further experimentation with borehole systems to advance capabilities in noise reduction as resources permit.

(viii) Introduction of at least 3 new strong motion systems at sub-network digital acquisition centres.

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

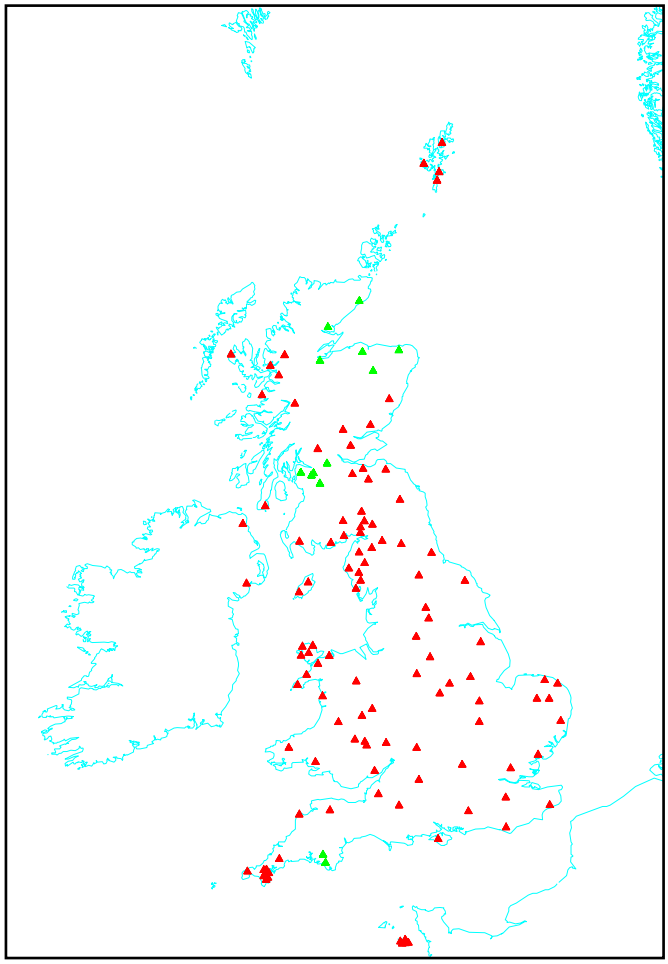


Figure 1. **BGS seismograph network operational in March 1995. Colour coding shows the standard stations (green) and those upgraded to rapid access (red).**

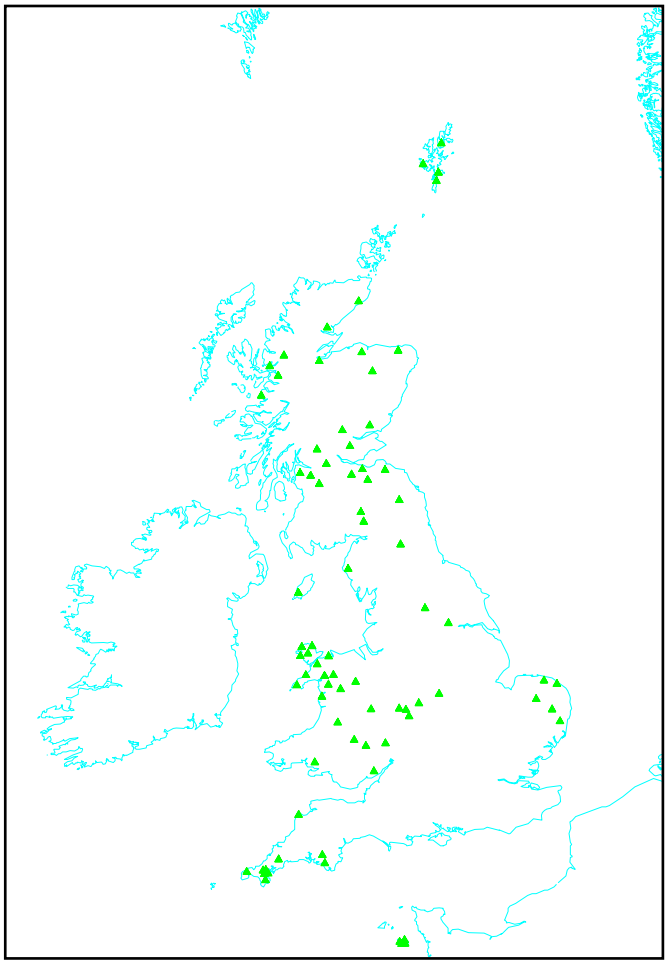


Figure 2. **BGS seismograph network in 1988 prior to the commencement of the UK monitoring enhancement project.**

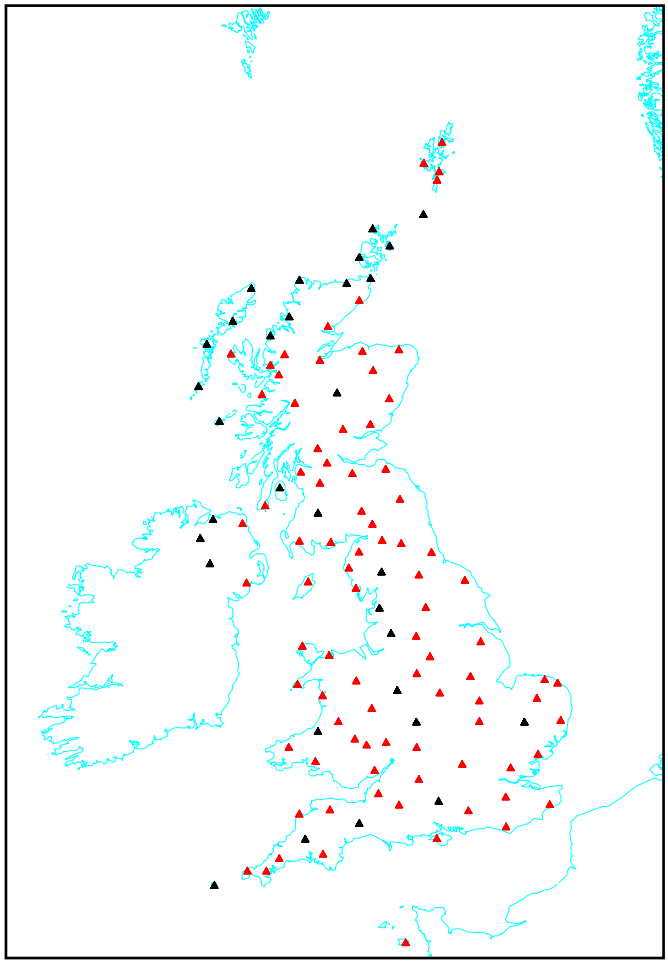


Figure 3. **Proposed long-term background seismic monitoring network with an average station spacing of 70 km. Colour coding shows existing coverage (red) and proposed stations (black).**

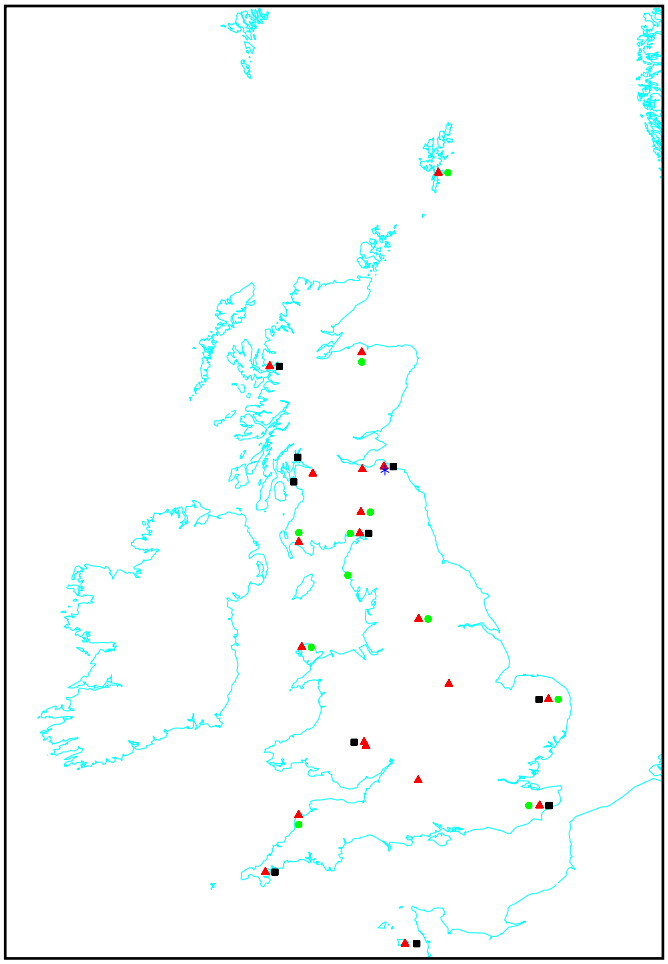


Figure 4. **BGS maintained network of strong-motion instruments (black), low sensitivity (red), microphones (green) and enviromental station (star) by March 1995.**

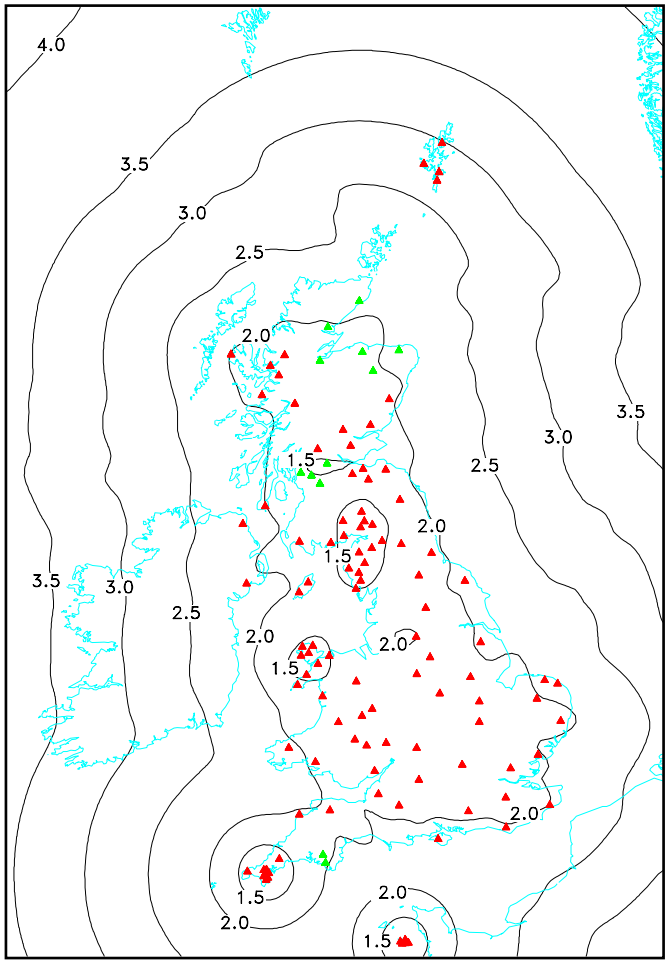


Figure 5. Earthquake identification capabilty. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.

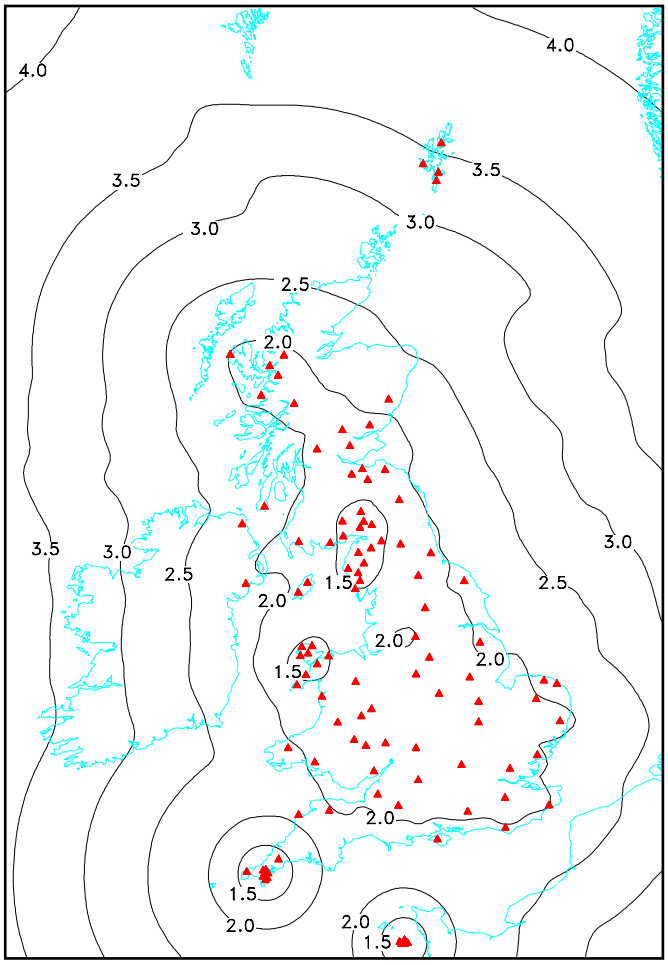


Figure 6. Detection capability of the rapid access networks. Contours show the magnitude (ML) of an earthquake which would be detected by 5 stations in the presence of 20 nanometres of background noise at 10 Hz.

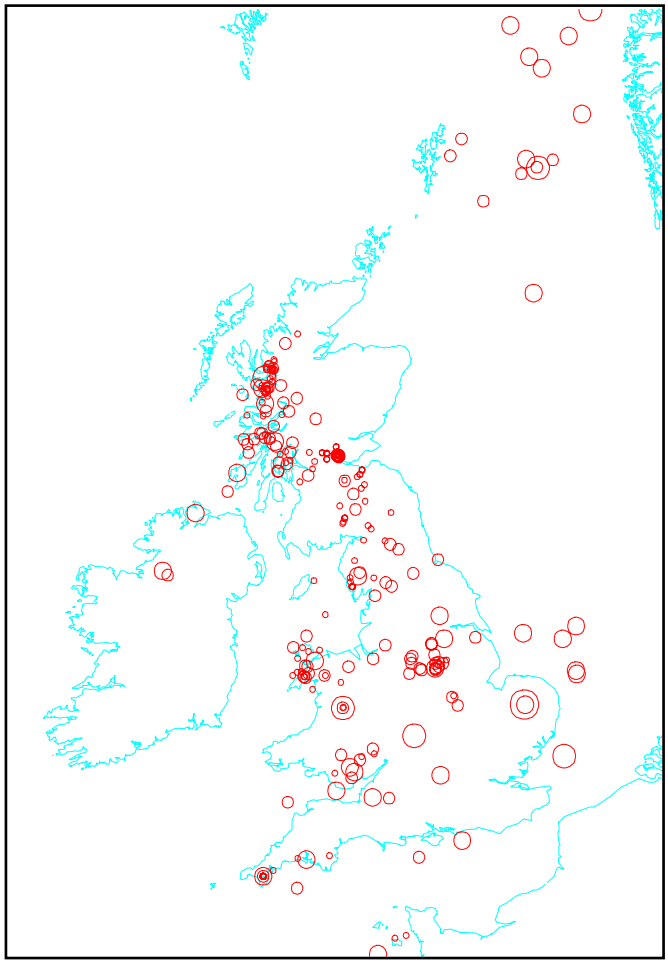


Figure 7. Epicentres of all UK earthquakes located in 1994.

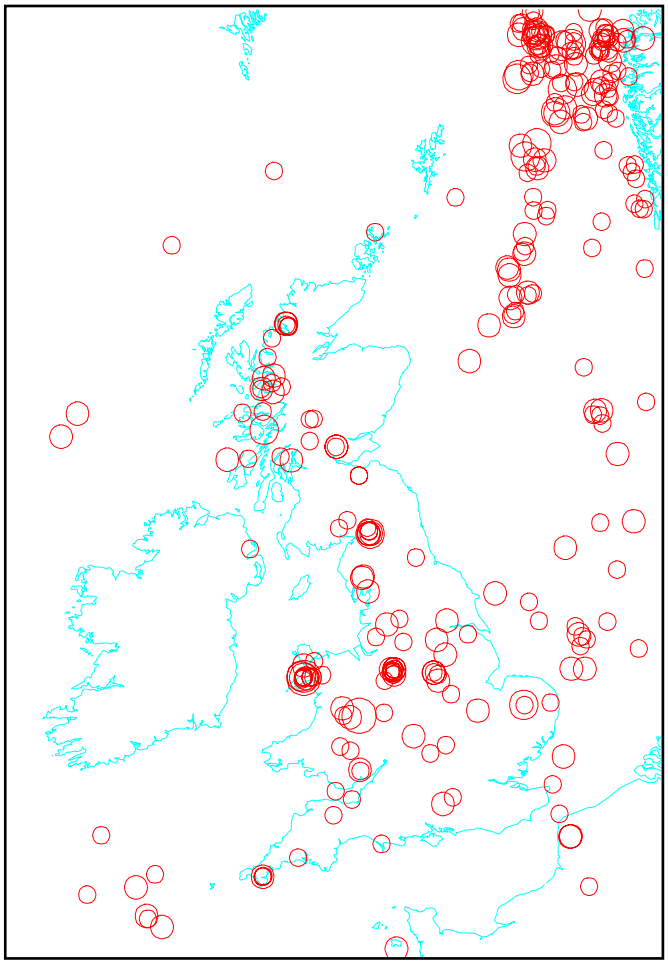


Figure 8. Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 1995.

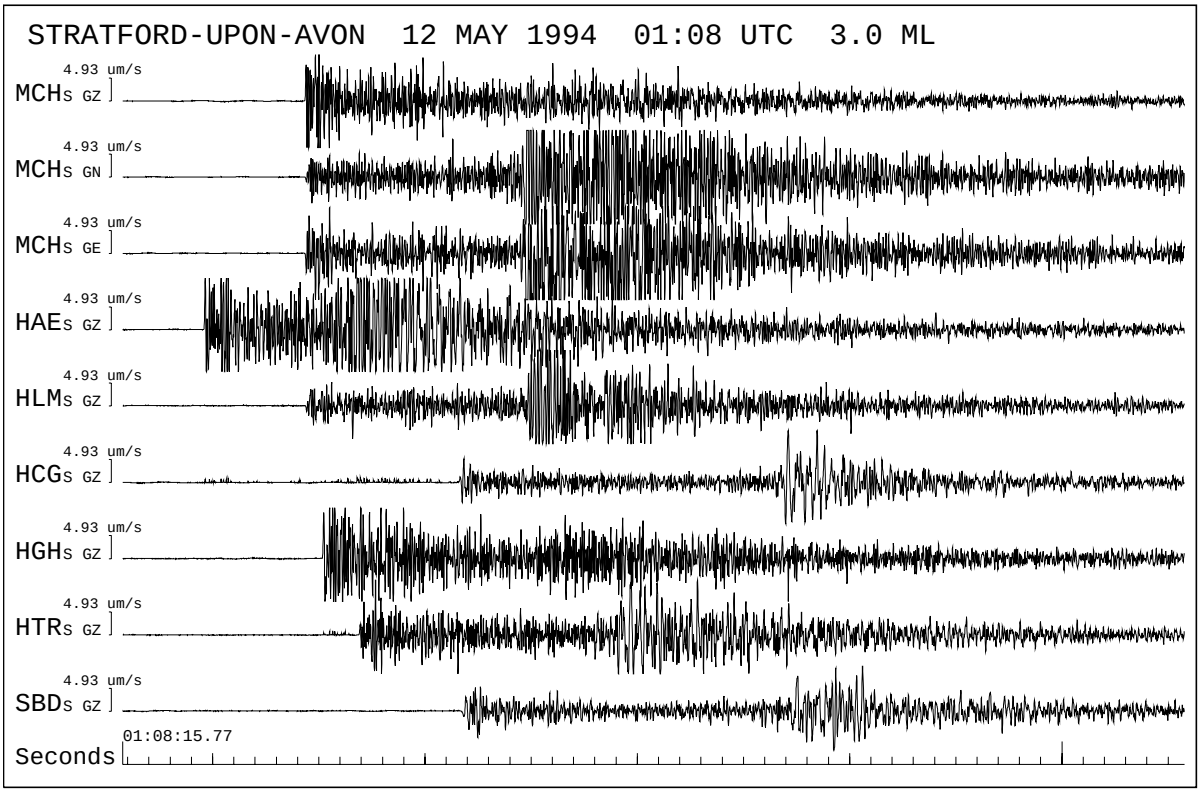


Figure 9. Seismograms recorded on the Hereford network from a magnitude 3.0 ML earthquake felt in the Stratford-Upon-Avon area on 12 May 1994 01:08 UTC. Three letter codes refer to stations in Annex E.

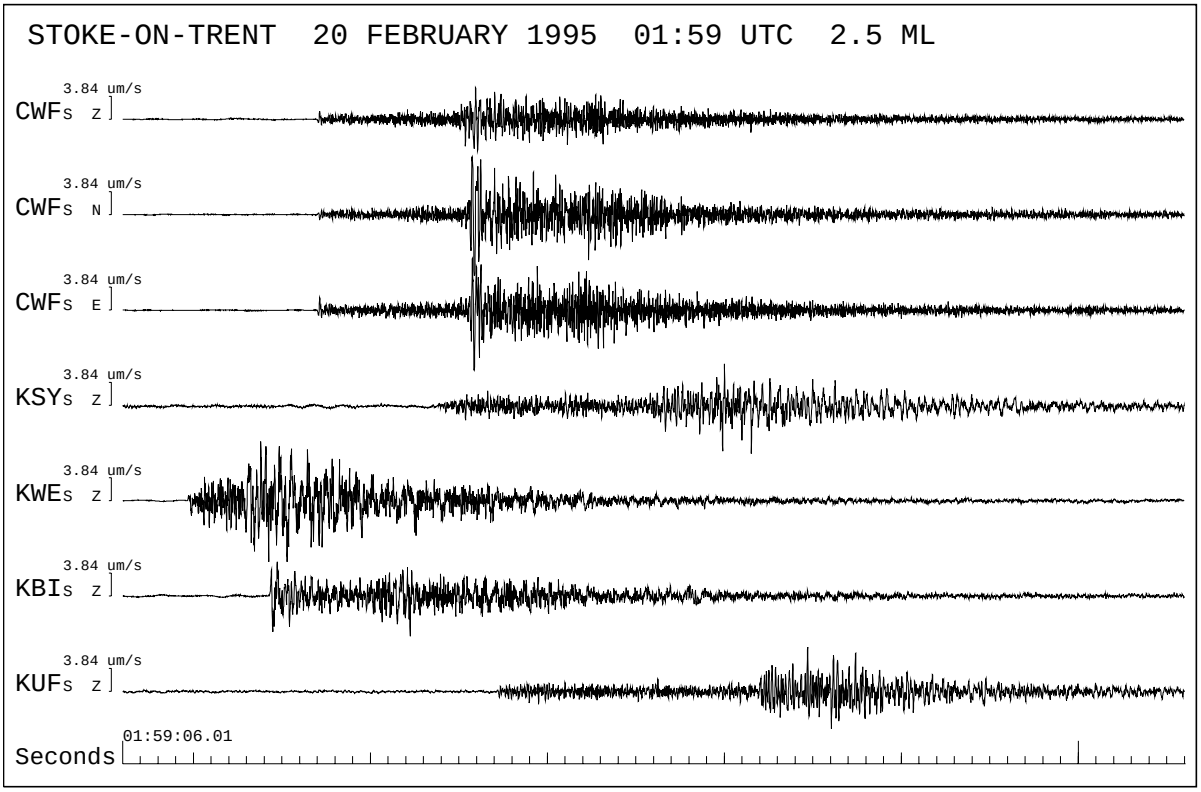


Figure 10. Seismograms recorded on the Keyworth network from a magnitude 2.5 ML earthquake felt in the Stoke-on-Trent area on 20 February 1995 01:59 UTC. Three leter codes refer to stations in Annex E.

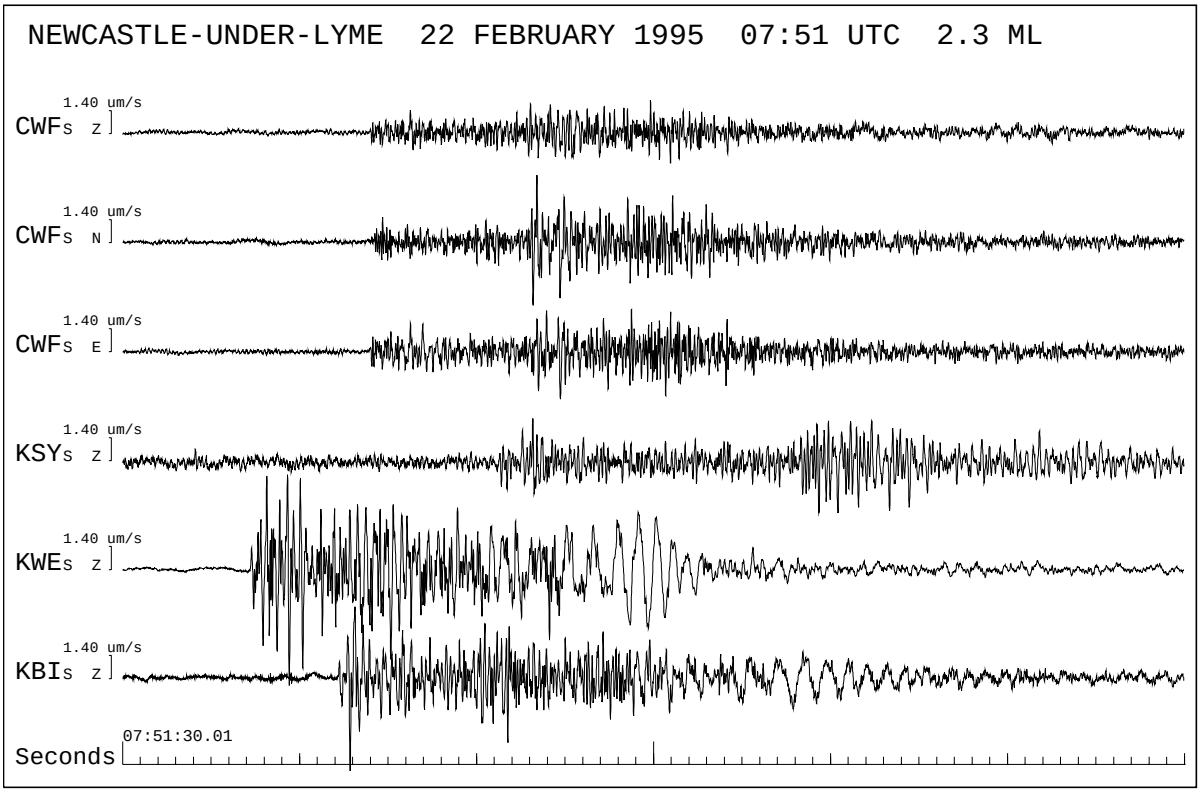


Figure 11. Seismograms recorded on the Keyworth network from a magnitude 2.3 ML coalfield event felt in the Newcastle-Under-Lyme area on 22 February 1995 07:51 UTC. Three letter codes refer to stations in Annex E.

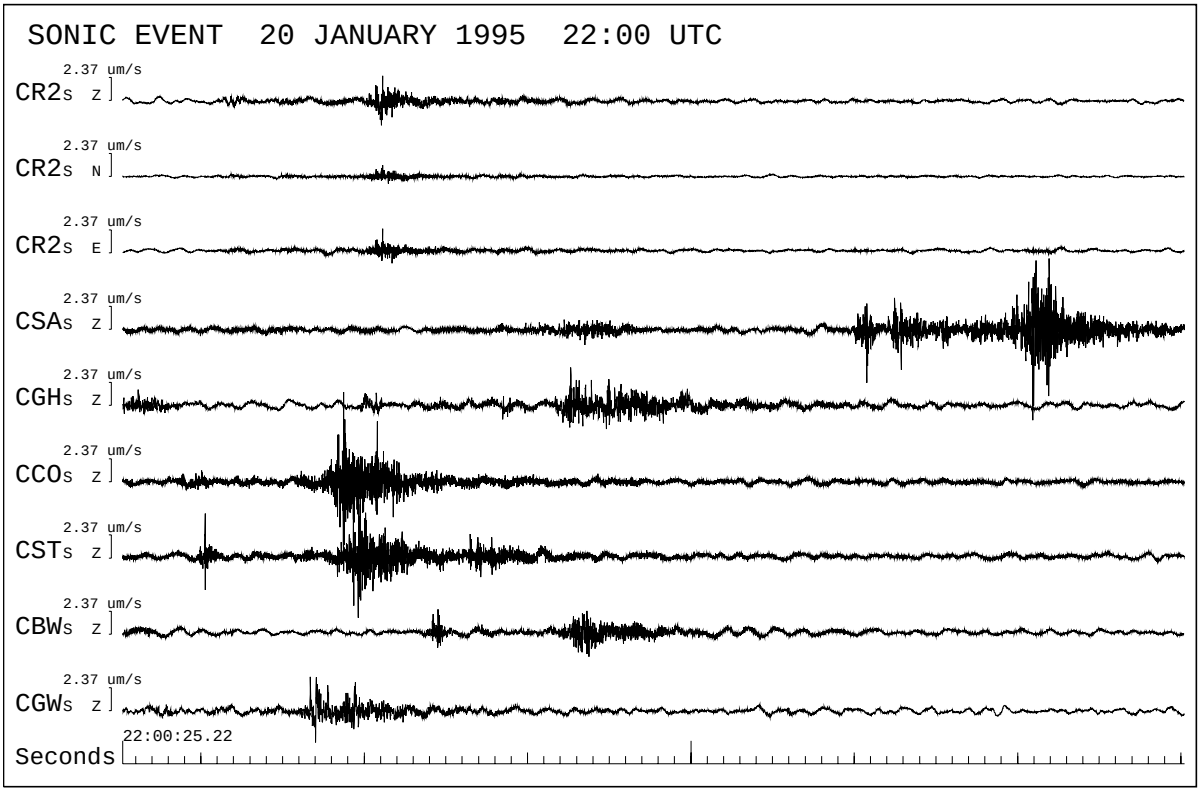


Figure 12. Seismograms of sonic event 20 January 1995 22:00 UTC recorded on the Cornwall network. Three letter codes refer to stations in Annex E.

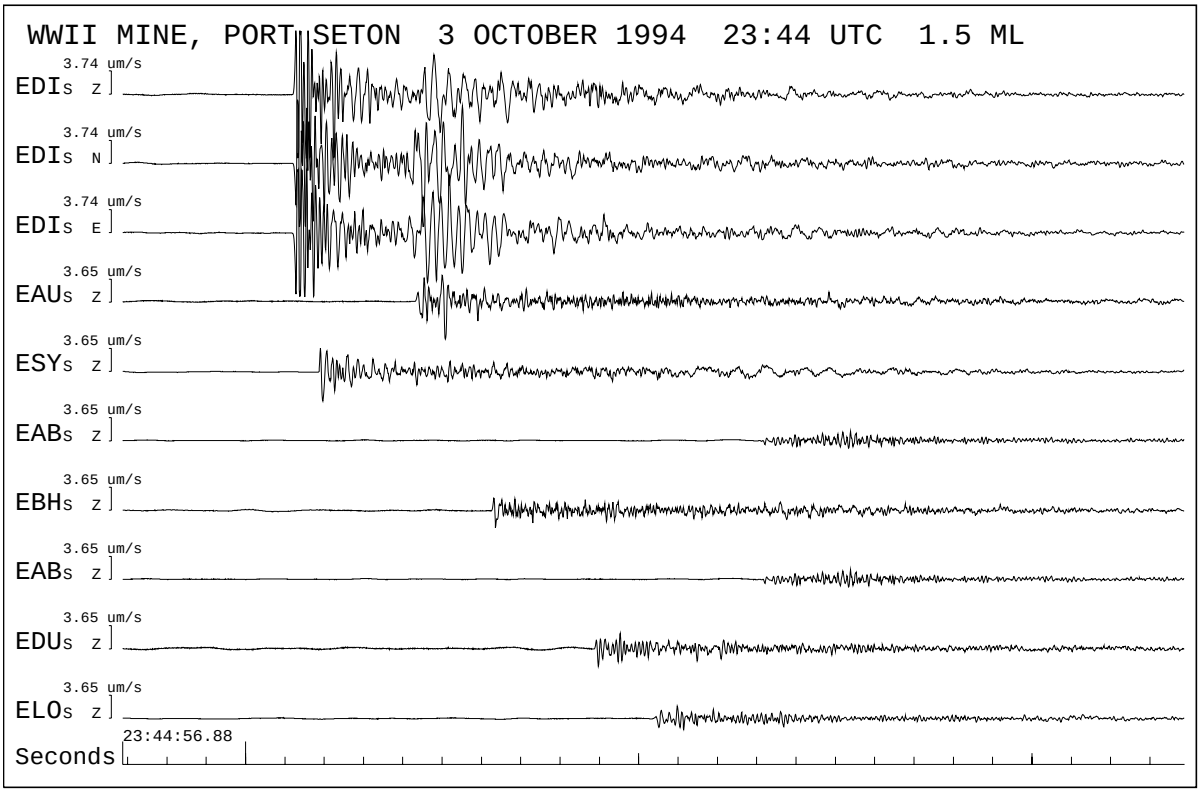


Figure 13. Seismograms recorded on the Lowlands network around Edinburgh from the magnitude 1.5 ML Port Seton WWII mine explosion on 3 October 1994 23:44 UTC. Three letter codes refer to stations in Annex E.

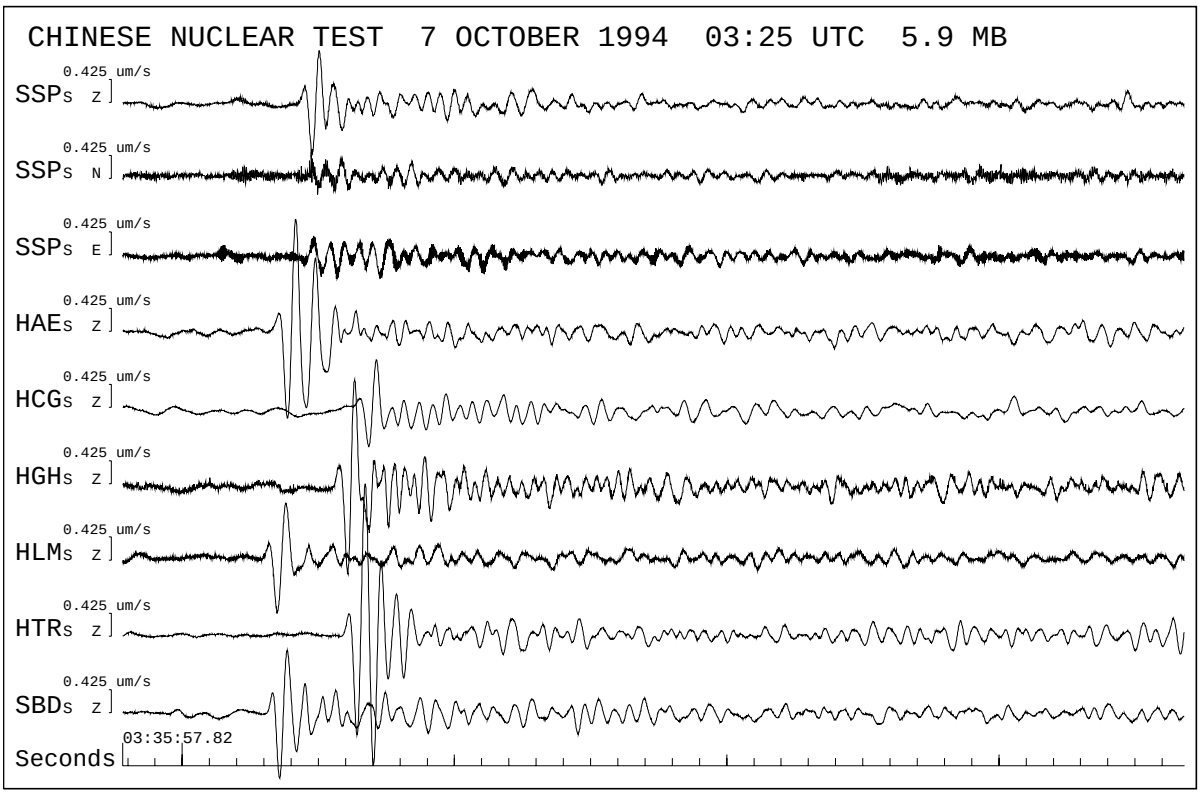


Figure 14. Seismograms recorded on the Hereford network from the magnitude 5.9 MB China nuclear test on 7 October 1994 03:25 UTC. Three letter codes refer to stations in Annex E.

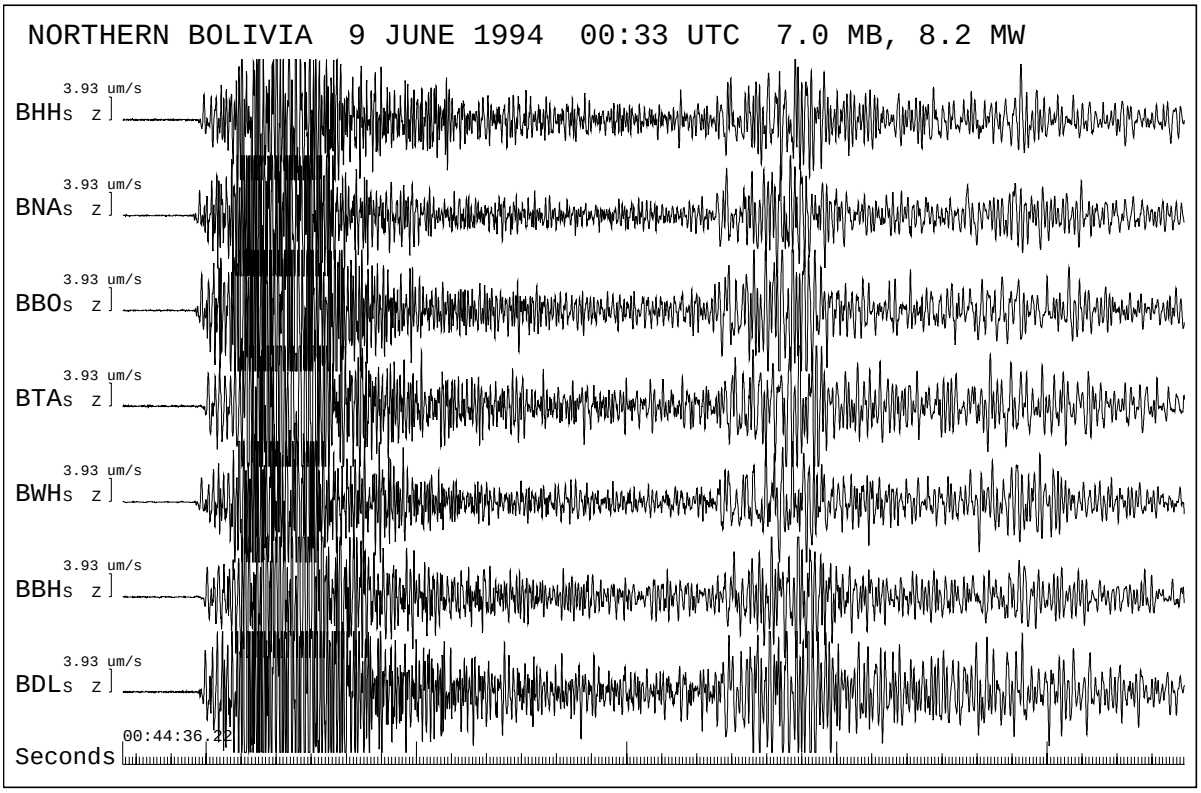


Figure 15. Seismograms recorded on the Borders network from the magnitude 7.0 MB (8.2 MW) earthquake in northern Bolivia on 9 June 1994 00:33 UTC. Three letter codes refer to stations in Annex E.

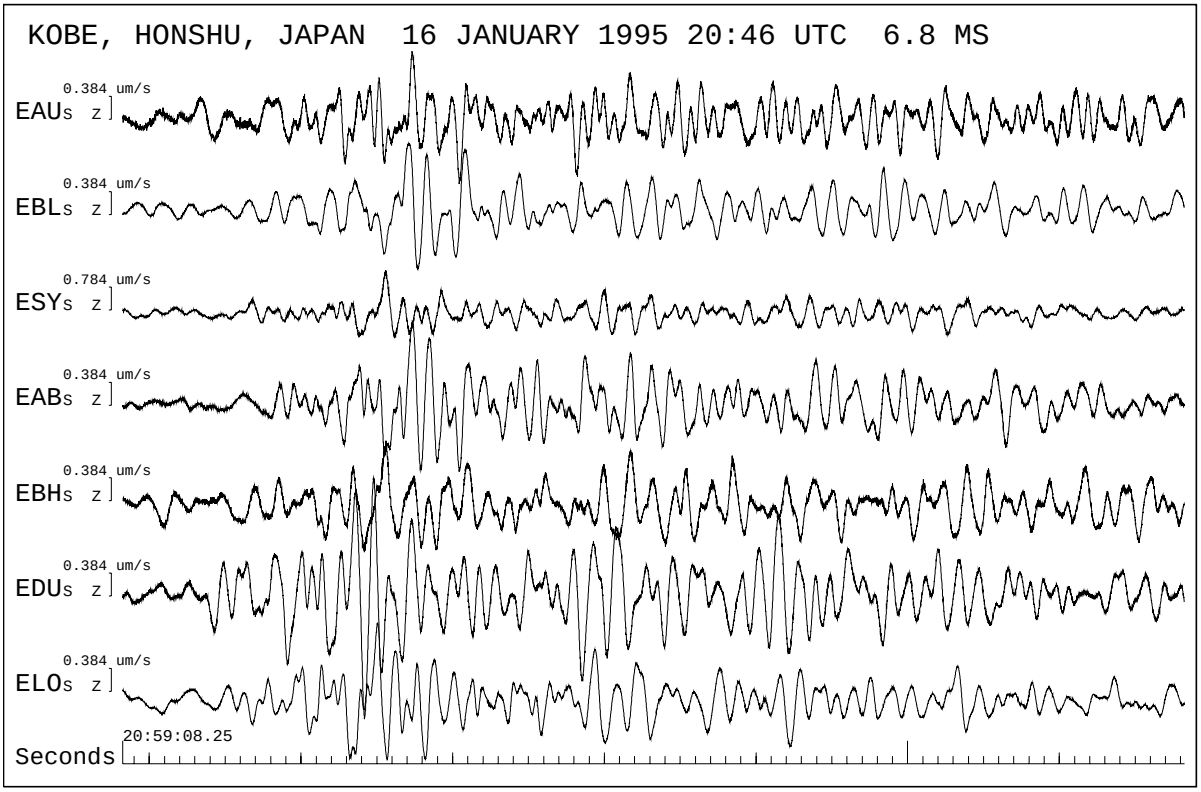
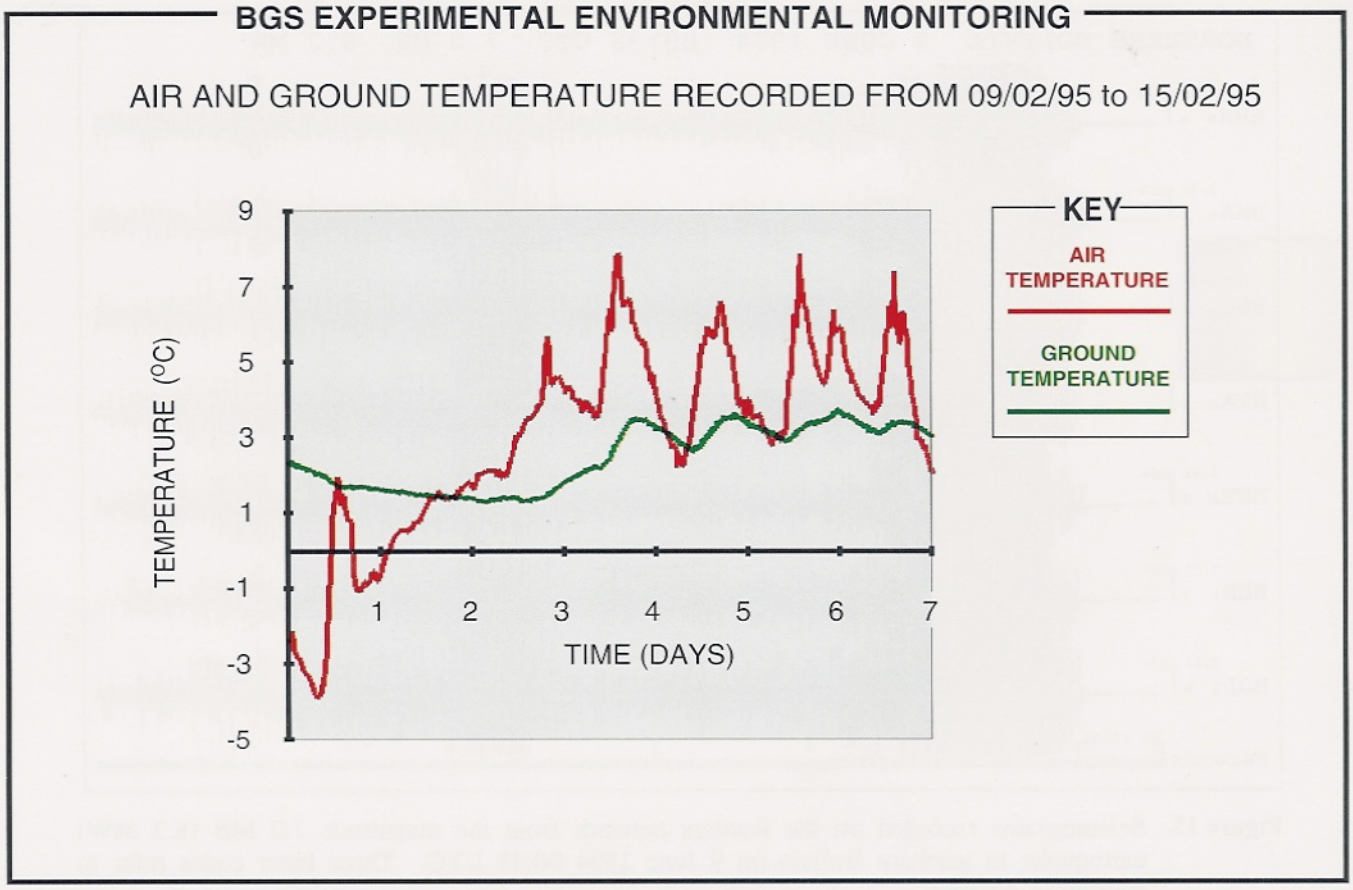


Figure 16. Seismograms recorded on the Lowlands network around Edinburgh from the magnitude 6.8 MS earthquake in Kobe, Honshu Japan on 16 January 1995 20:46 UTC. Three letter codes refer to stations in Annex E.



Test temperature data from the experimental environmental monitoring site 'ESY'.

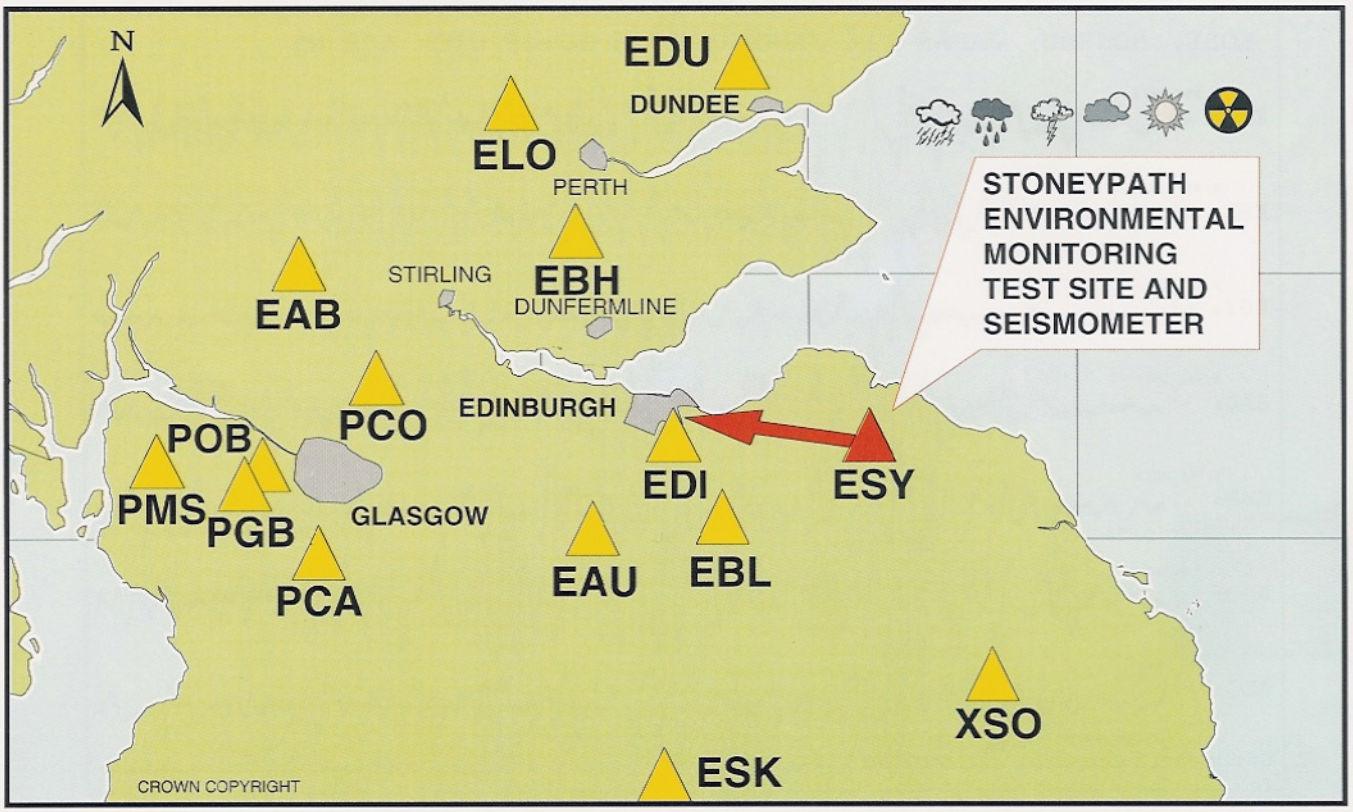


Plate1: Location of site 'ESY', one of the Edinburgh 'LOWNET' network sites.

Plate 2. Damage caused by the magnitude 6.8 MS Kobe earthquake of 16 January 1995 which resulted in the death of some 5,300 people. (Photograph supplied by W McMartin, International Rescue).

Plate 3. Damage caused by the magnitude 5.8 MB Cyprus earthquake of 23 February 1995 which caused the death of 2 people. (Photograph supplied by K Solomi, Cyprus Geological Survey).

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 only)
Department of Trade and Industry (Data only)
Nirex (Data only)

Customer Group Members (not contributing in Year Six)
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: 1994

YearMoDy	HrMnSecs	Lat	Lon	kmE	kmN	Dep	Mag	Locality	Int	No	DM	Gap	RMS	ERH	ERZ	SQD	Comments
19940101	031727.4	51.36	-3.56	291.4	163.3	17.6	2.8	BRISTOL CHANNEL	4+	36	27	69	0.18	0.4	1.6	B*B	FELT MINEHEAD.....
19940108	204605.2	51.59	-1.12	461.1	187.9	12.5	2.2	WALLINGFORD,OXON		18	26	98	0.10	0.4	0.7	A*C	
19940207	163911.0	55.81	-6.31	130.3	666.0	4.2	2.0	ISLAY,STRATHCLYDE		111	15	278	0.07	2.2	2.3	B*D	
19940210	051113.3	53.20	-4.15	256.5	368.8	11.1	2.9	BANGOR,GWYNEDD	5	22	18	85	0.10	0.3	0.7	A*B	FELT BANGOR...
19940215	101558.9	52.56	0.91	597.4	299.7	7.3	4.0	NORWICH,NORFOLK	5	15	37	77	0.24	0.8	4.4	B*C	FELT NORWICH...
19940215	111847.3	52.56	0.93	598.5	299.4	2.5	2.8	NORWICH,NORFOLK	4	13	40	105	0.26	1.0	3.5	B*C	FELT NORWICH...
19940221	220346.7	51.27	-2.71	350.5	152.7	14.6	2.0	CHEDDAR,SOMERSET		31	4	60	0.18	0.4	0.4	B*A	
19940317	162156.2	52.54	-3.44	302.3	294.2	21.4	3.1	NEWTOWN,POWYS	4	17	26	76	0.06	0.2	0.6	A*B	FELT NEWTOWN....
19940512	010809.9	52.15	-1.74	418.1	250.4	15.9	3.0	STRATFORD-U-AVON,WAR	5	18	22	98	0.10	0.3	1.6	A*B	FELT STRATFORD-U-AVON...
19940514	080431.2	58.39	1.63	612.2	950.7	8.4	2.5	NORTHERN NORTH SEA		212	28	180	0.29	1.4	1.9	B*D	VIKING GRABEN AREA
19940527	213208.0	60.88	3.36	690.9	1233.9	14.8	2.8	NORTHERN NORTH SEA		232	46	311	0.18	13.6	18.8	D*D	EAST SHETLAND BASIN AREA
19940611	031610.9	50.11	-5.18	172.7	27.9	7.4	2.2	CONSTANTINE,CORNWALL	4+	10	3	86	0.01	0.1	0.2	A*A	FELT HELSTON,PENRYN...
19940622	221650.3	51.63	-3.14	321.1	193.1	13.9	2.1	ABERCARN,GWENT		29	19	48	0.17	0.5	0.5	B*B	
19940626	164033.7	53.53	-0.99	466.9	404.0	6.8	2.2	DONCASTER,S YORKSHIRE		18	45	87	0.26	0.7	3.2	B*C	
19940710	194931.8	53.01	2.19	681.3	353.6	1.3	2.2	SOUTHERN NORTH SEA		17	54	301	0.39	5.5	3.8	D*D	
19940714	012308.9	56.29	-5.37	191.6	715.9	6.9	2.1	KILMELFORD,STRATHCLYDE	2+	36	63	187	0.12	0.5	0.8	A*D	FELT SEIL ISLAND...
19940714	125306.5	50.65	-0.64	496.2	84.6	5.4	2.3	ENGLISH CHANNEL		8	46	277	0.24	4.6	11.3	C*D	14KM S OF BOGNOR REGIS
19940714	215044.3	62.21	1.36	574.7	1374.2	10.0	2.2	NORTHERN NORTH SEA		82	26	354	0.08			D*D	200KM NE OF SHETLAND
19940718	122924.2	54.41	-3.13	326.9	502.7	12.5	2.2	CONISTON,CUMBRIA	3+	28	8	84	0.10	0.3	0.4	A*A	FELT CONISTON,TORVER....
19940727	094244.6	62.35	3.89	704.7	1399.6	15.0	3.3	NORWEGIAN SEA	2+	211	79	265	0.32	3.0	3.6	C*D	FELT FORDE,NORWAY
19940809	062557.3	60.30	1.62	600.1	1162.7	10.0	2.0	NORTHERN NORTH SEA		81	52	338	0.07	18.3		D*D	
19940809	065723.6	60.17	1.95	619.2	1148.8	13.3	3.6	NORTHERN NORTH SEA		381	73	281	0.18	2.8	3.7	C*D	NORTH VIKING GRABEN AREA
19940817	045726.4	57.19	-5.73	174.5	816.7	3.0	3.1	ISLE OF SKYE,HIGHLAND	4	60	18	107	0.13	0.2	0.4	A*C	FELT SKYE,ARNISDALE...
19940817	235050.9	51.70	-3.25	313.6	200.5	1.9	2.1	BARGOED,MID GLAMORGAN	3+	21	31	69	0.11	0.3	1.3	A*C	C/F,FELT BARGOED...
19940913	054746.7	53.47	1.91	659.6	403.7	6.1	2.1	SOUTHERN NORTH SEA		8	77	294	0.10	2.0	1.7	B*D	
19940915	063656.3	51.80	1.80	662.0	218.0	8.0	3.2	OFFSHORE HARWICH,ESSEX	2+	18	60	141	0.31	2.2	2.6	C*D	FELT WALTON-ON-THE-NAZE
19940915	114136.4	52.95	2.21	682.6	347.9	1.4	2.4	SOUTHERN NORTH SEA		11	53	305	0.25	4.0	2.7	C*D	
19940917	060504.7	49.04	-2.56	359.2	-95.4	0.6	2.0	JERSEY,CHANNEL ISLANDS		15	32	277	0.17	4.5	3.0	C*D	30KM SW OF JERSEY
19940920	204542.3	53.64	2.26	681.4	423.9	9.6	2.9	SOUTHERN NORTH SEA		211	5	314	0.49	7.4	4.3	D*D	
19941001	160828.8	57.03	-5.78	170.7	799.9	4.1	2.3	LOCH NEVIS,HIGHLAND		19	13	179	0.11	0.7	0.9	A*C	4KM NW OF MALLAIG
19941003	020201.8	63.25	3.11	656.2	1496.6	15.0	3.2	NORWEGIAN SEA		83	73	356	0.19			D*D	
19941013	215017.4	56.82	-5.67	175.9	775.4	13.6	2.2	LOCHAILORT,HIGHLAND	2+	41	15	166	0.22	1.6	1.9	B*C	FELT KENTRA
19941017	042649.8	61.57	2.25	625.7	1306.5	10.1	2.8	NORTHERN NORTH SEA		92	13	333	0.14			D*D	EAST SHETLAND BASIN AREA
19941018	183821.3	55.35	5.25	859.2	630.5	11.0	4.0	CENTRAL NORTH SEA	4+	434	14	194	0.56	2.4	2.7	D*D	FELT IN THE DAN OILFIELD
19941105	055558.4	61.75	1.89	605.1	1324.5	12.8	2.4	NORTHERN NORTH SEA		62	8	353	0.05			D*D	EAST SHETLAND BASIN AREA
19941105	221349.8	53.57	0.95	595.3	412.6	2.7	2.4	SOUTHERN NORTH SEA		37	77	209	0.38	2.3	2.9	C*D	
19941121	020048.2	55.20	-7.30	62.6	602.7	11.9	2.0	CLONMANY,DONEGAL	4	22	76	240	0.11	0.6	0.6	A*D	FELT CLONMANY...
19941125	171029.1	53.11	-1.22	452.1	357.0	1.0	2.1	MANSFIELD,NOTTS	3+	25	26	54	0.27	0.7	1.5	B*C	C/F,FELT MANSFIELD
19941126	100658.6	62.00	3.15	669.3	1357.5	15.0	2.2	NORTHERN NORTH SEA		62	78	354	0.05			D*D	
19941130	215951.7	54.35	-8.01	9.3	511.2	9.4	2.1	NORTH LEITRIM,EIRE		18	88	260	0.27	1.9	1.6	B*D	
19941205	220516.7	53.85	-1.09	459.6	440.0	0.0	2.2	STILLINGFLEET,N YORKS	3+	13	37	104	0.11	0.4	0.7	A*C	C/F,FELT STILLINGFLEET
19941230	155839.4	50.37	-4.21	242.8	54.4	4.4	2.1	TORPOINT,CORNWALL		11	21	145	0.14	1.7	5.9	C*C	

BRITISH GEOLOGICAL SURVEY
MURCHISON HOUSE
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TO:	B R MARKER	- DOE	T A F WILLIS	- SCOTTISH POWER
	C WARBURTON	- DOE	G HERBERT	- SCOT H & H
	P A MERRIMAN	- BNFL	J P McFARLANE	- SCOTTISH NUCLEAR
	H TUR	- BNFL CAPEN	P W WINTER	- AEA
	G F McCULLOUCH	- DED	P J BUCKLEY	- HSE
	J CRAIG	- ETSU	R ADAMS	- ISC
	D J MALLARD	- NUCLEAR ELEC	C V KATHIGAYAN	- HSE OFFSHORE
	C F ALLEN	- NUCLEAR ELEC	A W B JACOB	- DIAS
	W P ASPINALL	- AA	H PAYNE	- WELSH OFFICE
	C BEAK	- HYDROBOARD	DIRECTOR	- BGS
	C PATCHETT	- NII, BOOTLE	M RAINES	- BGS KEYWORTH
	J E INKESTER	- NII, BOOTLE	A WHITTAKER	- BGS KEYWORTH
	A ACTON	- BRITISH GAS	S BRACKELL	- BGS, LONDON INFO OFF
	U M MICHIE	- NIREX	H J HEASON	- BGS MARKETING
	H GULVANESSIAN	- BRE		

FROM: B A SIMPSON
DATE: 19 October 1994
TIME: 12:30 UTC
PAGES TO FOLLOW: ONE

SEISMIC ALERT: CENTRAL NORTH SEA - 18 OCTOBER 1994 18:38 UTC, 4.0 ML

BGS has received a report of "shaking" from the Dan field at approximately 18:40 UTC last night (18 October 1994). An event was recorded on our networks at 18:38 UTC.

The following preliminary information is available for this earthquake:

DATE	:	19 October 1994
ORIGIN TIME	:	18:38 19s UTC
LAT/LONG	:	55.16° North 5.55° East
DEPTH	:	15 Km
MAGNITUDE	:	4.0 ML
LOCALITY	:	Central North Sea

This provisional location puts the epicentre approximately 35 km SE of the Dan field and 72 km ESE of the magnitude 4.0 ML event on 7 July 1993 which resulted in the loss of production for 2 hours.

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

BRITISH GEOLOGICAL SURVEY
MURCHISON HOUSE
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TO:	B R MARKER	- DOE	H PAYNE	- WELSH OFFICE
	H TUR	- BNFL	H GULVANESSIAN	- BRE
	P A MERRIMAN	- BNFL	J P McFARLANE	- SCOTTISH NUCLEAR
	G McCULLOUGH	- DED	P W WINTER	- AEA
	U M MICHIE	- NIREX	PJ BUCKLEY	- HSE
	J CRAIG	- ETSU	R ADAMS	- ISC
	D J MALLARD	- NUCLEAR ELEC	V KATHIGAYAN	- HSE OFFSHORE
	C F ALLEN	- NUCLEAR ELEC	A W B JACOB	- DIAS
	W P ASPINALL	- AA	H J HEASON	- BGS MARKETING
	C BEAK	- HYDRO ELEC	DIRECTOR	- BGS
	C PATCHETT	- NII, BOOTLE	M RAINES	- BGS KEYWORTH
	J E INKESTER	- NII, BOOTLE	A WHITTAKER	- BGS KEYWORTH
	A ACTON	- BRITISH GAS	S BRACKELL	- BGS, LONDON INFO OFF
	M WILSON	- SCOT H&H		

FROM: G D Ford
DATE: 20 February 1995
TIME: 09:45 UTC
PAGES TO FOLLOW: TWO

SEISMIC ALERT: STOKE-ON-TRENT, STAFFORDSHIRE 20 FEBRUARY 1995 01.59 UTC

BGS have received reports of an event in the early hours of the morning from the Stoke-on-Trent area. The following preliminary information is available for this earthquake:

DATE	:	20 February 1995
ORIGIN TIME	:	01:59 05.3s UTC
LAT/LONG	:	53.03 North 2.21 West
GRID REF	:	385.8 kmE 348.2 kmN
DEPTH	:	7.0 km
MAGNITUDE	:	2.5 ML
LOCALITY	:	Stoke-on-Trent, Staffordshire
INTENSITY	:	3+

The Stoke-on-Trent area has a history of earthquake activity. There were a large number of events in the early 1980s which were felt. The most recent felt event in this general area was on 29 June 1993 in the Talke Pits area and had a magnitude of 2.0 ML. Some past events in this area are believed to have been induced by coal mining, however, today's event is thought to be of a tectonic origin .

A seismogram of the event recorded on the BGS Keyworth network and map of past seismicity within 50 km of today's earthquake is attached.

ANNEX C

ANNEX D

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 H Lovell
Mr J Laughlin
Mr P C Marrow
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
Ms A B Walker
Mr A Miller
Mr G J Webster
Mrs F Wright
Mr R M Young

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1995

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 1995

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 1995

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 1995

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/94/10 Walker, A.B. and Browitt, C.W.A. UK Earthquake monitoring 1993/94, BGS Seismic Monitoring and Information Service, Fifth Annual Report. April 1994.

WL/94/14 Walker, A.B. HDR Seismic Monitoring: Annual Report 1993-1994.

WL/94/25 Miller, A., & Turbitt, T. UK Strong Motion Seismic Network Version 1: Status to May 1994.

WL/94/31 Simpson, B.A. and Lovell, J. October, 1994. Seismic Monitoring of Jersey 1992-93. Contract report to the Jersey New Waterworks Company.

WL/94/32 Musson, R.M.W. The Seismicity of Sutherland, Caithness & the Orkneys. October 1994.

WL/94/36 Lovell, J.H., and Ford, G.D. The Betws-y-Coed Earthquake of 11 October 1993 (2.3 ML). November 1994.

WL/94/37 Marrow, PC and Henni, P.H.O. Earthquake focal mechanisms and crustal stress in the UK. December 1994.

WL/94/38 Lovell, J.H., Henni, P.H.O. and Musson, R.M.W. The 2.9 ML Bangor Earthquake of 10 February 1994. December 1994.

WL/95/4 Walker, A.B. (Ed.), Ford, G.D., Galloway, D.D., Lovell, J.H., Redmayne, D.W., Richards, J.A., Ritchie, M.E.A., Simpson, B.A., van Barneveld, S.J., Webster, G.J. and Wright, F. Bulletin of British earthquakes 1994.

In addition, 13 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

Vogt, J., Musson, R.M.W. and Stucchi, M., 1994. Seismological and hydrological criteria for the new European Macroseismic Scale (MSK-92), Natural Hazards, vol 10, pp1-6.

Redmayne, D.W., 1995. 1994- A summary of the Earthquakes, SECED Newsletter, Jan 1995.

UK EARTHQUAKE MONITORING 1994/95 BGS SEISMIC MONITORING AND INFORMATION SERVICE: FIFTH ANNUAL REPORT

A B Walker and C W A Browitt

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 5 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 1993 to March 1994. The catalogue of earthquakes for the whole of 1993 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.

HDR SEISMIC MONITORING ANNUAL REPORT : 1993 - 1994

A B Walker

The potential for earthquakes to be triggered by fluid injected into boreholes has been recognised for 30 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 1994. 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 1993 to March 1994, 90 natural earthquakes have been located with magnitudes between -0.2 and 2.8 ML; the largest locating in the Bristol Channel on 1 January 1994. Of the 82 events which located within 10 km of the HDR site, 81 occurred near Constantine with magnitudes ranging from -0.8 to 1.8 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 600 smaller earthquakes, which were imperceptible to people, have been located in the region, including many aftershocks of the larger Constantine events.

UK STRONG MOTION SEISMIC NETWORK, VERSION 1: STATUS TO MAY 1994

A Miller and T Turbitt

There are no near-field three-component strong-motion data in the UK, as earthquakes above magnitude 5 ML are very infrequent. Consequently, seismic hazard assessments for civil engineering projects are based on imported data.

The UK network of strong-motion instruments is currently being extended, to improve the prospects of capturing such data. Strong-motion instruments are being integrated into the UK high-gain networks. The equipment is described and contoured maps show the maximum earthquake which can be recorded without saturating.

Currently a magnitude 6 ML anywhere in the UK will remain on-scale. The report will be updated as the network expands.

SEISMIC MONITORING OF JERSEY 1992-1993

B A Simpson and J H Lovell

This contract report to The Jersey New Waterworks Company discusses the seismicity around Jersey for the period January 1992 to December 1993. The BGS network in Jersey was augmented in late 1991 by the addition of three stations in the southeast of the Island, in connection with the expansion of the water industry and the impoundment of new reservoirs. The enhanced network detected eight natural earthquakes with magnitudes between 0.3 and 2.5 ML within 100 km of the Island, although no events above the detection threshold of approximately 0.0 ML were detected on the Island itself.

THE SEISMICITY OF SUTHERLAND, CAITHNESS & THE ORKNEYS.

Musson R M W

A field study has been undertaken to investigate the seismicity of the extreme north of Scotland, comprising the old counties of Sutherland, Caithness and the Orkneys. Results confirm that the seismicity is low in historical times as well as in the recent monitoring period. For the western part of the area, written documentation is poor and events may have been missed as late as the 1920's. For the Caithness- east Sutherland- Orkneys area the situation is much better and one may be reasonably confident that no significant earthquakes have occurred in this area since 1960.

THE BETWS-Y-COED EARTHQUAKE OF 11 OCTOBER 1993 (2.3 ML)

J H Lovell and G D Ford

At 09:43 UTC on Monday 11 October 1993 a 2.3 ML earthquake was felt by a few people in the vicinity of Betws-y-Coed, Gwynedd, with an intensity of at least 3 MSK. Its epicentre was 9 km northeast of Betws, and the focal depth, 10.6 km. A macroseismic survey was not initiated. The fault plane solution suggests dominant normal faulting, with a strike-slip component, on either an eastward dipping plane striking approximately northwest, or on a westward dipping plane striking south-southeast. Both mechanisms are consistent with a generally northwest direction of maximum compressive stress in Britain and much of Europe.

EARTHQUAKE FOCAL MECHANISMS AND CRUSTAL STRESS IN THE UK

P C Marrow and P H O Henni

This report examines fifty earthquake focal mechanisms (fault plane solutions, FPS) following some of the ideas used in The World Stress Map Project of the International Lithosphere Program. A map of the trend of the horizontal component of the P-axes (centre of dilatational quadrant) of the fifty FPS in the UK area is presented, together with some circular statistics of their scatter. The mean azimuth of the horizontal projection of the 50 P-axes is $N152^{o}E \pm 29^{o}$. Some suggestions for practical application of these UK data are made together with recommendations for future improvements and additions to the database.

THE 2.9 ML BANGOR EARTHQUAKE OF 10 FEBRUARY 1994

J H Lovell, P H O Henni and R M W Musson

At 05:11 UTC on Thursday 10 February 1994, a magnitude 2.9 ML earthquake caused widespread public and media interest over a large part of North Wales. The epicentre was located at a depth of 11.1 km about 4 km southwest of Bangor, Gwynedd. Slight damage occurred close to the epicentre. Maximum intensity was initially estimated as in excess of 4, and a macroseismic survey was initiated which indicated that a maximum intensity of 5 was reached in the epicentral area. There is excellent agreement between the instrumentally- and macroseismically-determined locations and magnitudes.

The focal mechanism for this earthquake suggests almost pure reverse faulting with a small strike-slip component. Movement took place either on a plane striking approximately east-west and dipping steeply southwards at about 70^{o}, or on a plane striking approximately southwest-northeast and dipping northwestwards at about 30^{o}. The mechanism is consistent with a generally NW-SE compressive stress direction determined for most of Britain and NW Europe.

BULLETIN OF BRITISH EARTHQUAKES 1994

A B Walker (Editor)

There have been 357 earthquakes located by the monitoring network in the year, with 42 of them having magnitudes of 2.0 or greater. Of these, 18 are known to have been felt, together with a further 5 smaller ones, bringing the total to 23 felt earthquakes in 1994.

The largest onshore earthquake occurred near Norwich, Norfolk, on 15 February with a magnitude of 4.0 ML and a had wide felt area in Norfolk, Suffolk and parts of Cambridgeshire . A macroseismic survey throughout the region showed that it was felt in the epicentral area with a maximum intensity of 5 MSK. The largest offshore earthquake was located in the Central North Sea on 18 October, with a magnitude of 4.0 ML, and was felt on the Dan oil platform with an intensity of at least 4 MSK.

Several events of interest have been recorded throughout the year, in the Bristol Channel, Bangor, Newtown, Stratford-upon-Avon, Constantine, Kilmelford, Coniston, Isle of Skye, Bargoed and Northern Ireland.

Some 74 coalfield events with magnitudes ranging between -0.2 and 2.2 ML have been detected in 1994, seven of which were felt. Fifty-one of them located in the Clackmannan area in the central region of Scotland where the magnitudes ranged from 0.3 to 1.9 ML; none were felt by local residents. Near Mansfield, Nottinghamshire, 11 events with magnitudes ranging from 0.2 to 2.1 ML have been located, five of which were felt by residents in Mansfield who ran into the streets in alarm. At a shallow depth of 1 km they are believed to be of coal-mining origin. An earthquake, on 5 December, with magnitude 2.2 ML near Stillingfleet, North Yorkshire was felt by residents with an intensity of at least 3 MSK, in Stillingfleet, Riccall and in the nearby collieries. It was located at a depth of 1 km and has the characteristics of a mining induced event.

SEISMOLOGICAL AND HYDROLOGICAL CRITERIA FOR THE NEW EUROPEAN MACROSEISMIC SCALE (MSK-92)

J Vogt, R M W Musson and M Stucchi

The casual inclusion of intensity diagnostics relating to seismological and hydrological phenomena in traditional intensity scales has led to many errors of assessment. The new European Macroseismic Scale recognises the problem and provides an approach which takes into account the considerable variation in intensities over which such effects as ground cracking can occur, depending on local geological and hydrological conditions.

1994 - A SUMMARY OF THE EARTHQUAKES

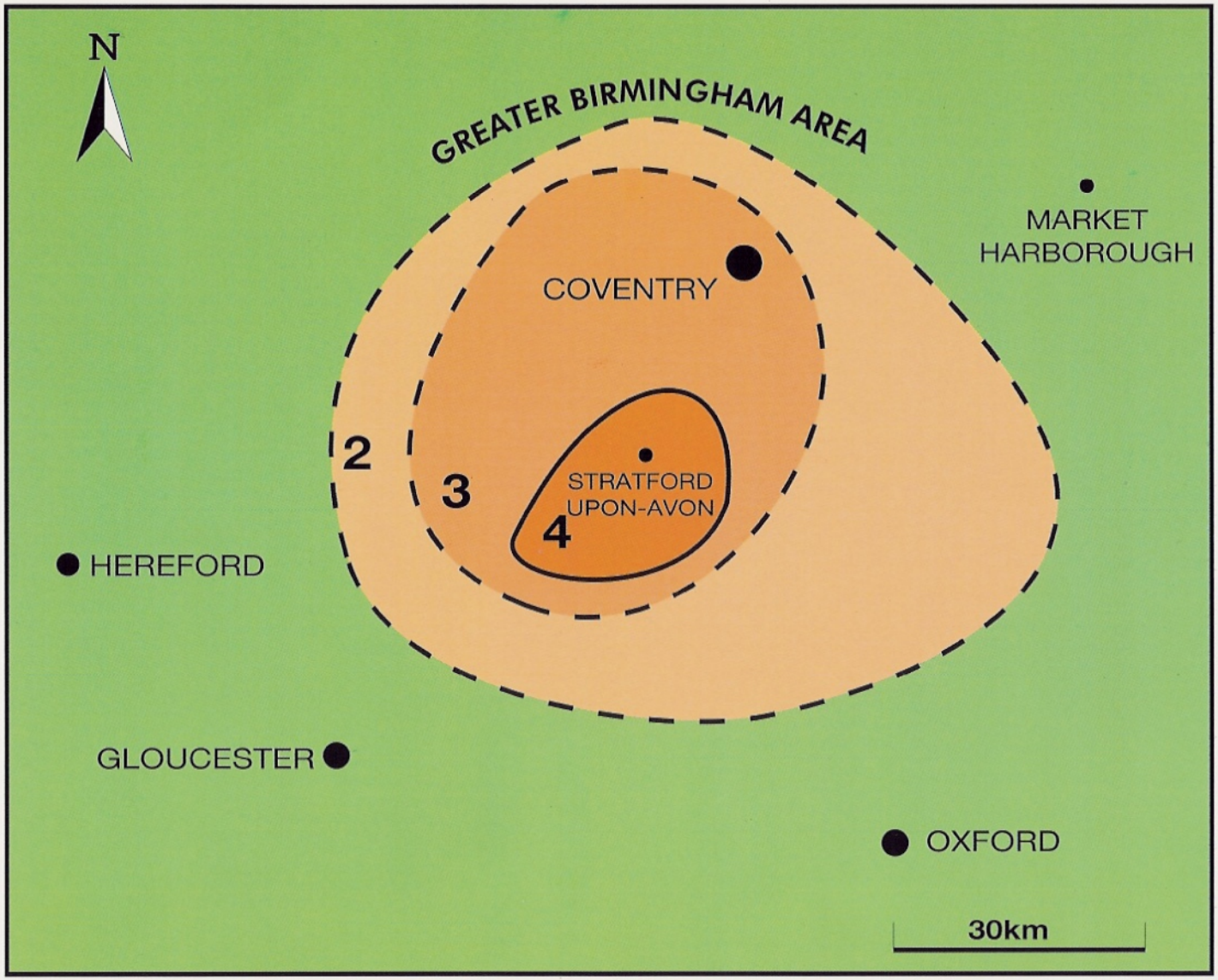
D W Redmayne

One 'great earthquake', with a magnitude over 8.0 Ms, occurred in 1994. Numbers of larger earthquakes were generally less than average and the number of fatalities due to earthquakes was also well down on the long-term average. There were, however, a number of damaging earthquakes during the year. Los Angeles was struck by a magnitude 6.8 Ms earthquake on 16

January which caused extensive damage and killed 60 people. Indonesia, Colombia, Japan and the Philippines were also affected by large damaging earthquakes during the year. Smaller, but also damaging, events caused casualties in Haiti, Mexico, Iran and Algeria. A powerful deep earthquake in Bolivia on 9 June caused damage in parts of Peru and Brazil and was felt as far away as Toronto, Canada. Its depth was 630 km and magnitude, 7.0 Mb, 8.2 Mw.

The British Geological Survey recorded 357 earthquakes in the British Isles and surrounding continental shelf during 1994. Forty-two of these had magnitudes over 2.0 ML and 23 were felt by people. Earthquake activity in the UK was a little over average during 1994. The largest onshore event occurred near to Norwich on 15 February and had a magnitude of 4.0 ML. It was felt over a wide area of Norfolk, Suffolk and in parts of Cambridgeshire. Minor damage occurred near to the epicentre. The largest offshore event, also magnitude 4.0 ML, was felt in the Dan oilfield on 18 October as 'shaking' on a production platform. There was earthquake swarm activity in Cornwall during June and several coalfield areas throughout Britain were affected.

Natural Environment Research Council



Stratford-upon-Avon Earthquake 12th May 1994, 01:08 UTC (3.0ML) - MSK Intensities