UK EARTHQUAKE MONITORING 1996/97

BGS Seismic Monitoring and Information Service

Seventh Annual Report

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UK Earthquake Monitoring 1995/96

BGS Seismic Monitoring and Information Service

Seventh Annual Report

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UK Seismic Monitoring and Information Service Year Seven Report to Customer Group: June 1996

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

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CONTENTS

UK EARTHQUAKE MONITORING 1995/96

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 27 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 seventh year of the project (April 1995 to March 1996), the rapid response capability has been improved with 3 sub-networks added to the 17 previously upgraded to the new digital standard, leaving only two on the old analogue standard. Two additional low sensitivity and two strong motion instruments have been installed. There are, however, some remaining gaps in station coverage; notably in Northern Ireland. Other areas, covered by site-specific networks in Cumbria, northern Scotland, Outer Hebrides and the Orkney Islands are vulnerable to closure owing to their dependency on funds from commissioning bodies.

Some 225 earthquakes have been located by the monitoring network in 1995, with 38 of them having magnitudes of 2.0 or greater, of which ten are known to have been felt. The largest onshore felt earthquake in the reporting year (April 1995 to March 1996), with a magnitude of 3.4 ML occurred near Shrewsbury on 7 March 1996. The earthquake was felt over approximately 3000 km^2 and the maximum intensity in the epicentral region was 5 EMS (European Macroseismic Scale, Annex H, equivalent to MSK). The largest offshore events were in the northern North Sea with magnitudes of 3.6 ML. None were felt. 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). During the reporting period, data on one controlled explosion in Anglesey and seven sonic events have been processed and reported upon following public concern or media attention. A number of underwater explosions in the North Channel between Scotland and Northern Ireland have attracted media attention in relation to the Beaufort's Dyke munitions dump and the construction of a British Gas pipeline.

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 seismic bulletins are issued 6 weeks in arrears and, following revision, are compiled into an annual bulletin. 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 2.0 since 1977.

In order to explore the further potential of the network's data links and computing capabilities, an environmental monitoring capacity has been proved at a remote station, some 35 km south east of Edinburgh, using additional sensors.

2. Introduction

The UK earthquake monitoring and information service has developed as a result of 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 programme, drawn from industry and central and local Government, 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 seismic monitoring by BGS since 1969, as well as 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. Although seismic hazard/risk is low by world standards it is by no means negligible, particularly in respect to potentially hazardous installations and sensitive structures. This helps in assessment of the level of precautionary measures which should be taken to prevent damage and disruption to new buildings, 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 7 report to the Customer Group follows the format of the first six annual reports in reiterating the programme objectives and highlighting some of the significant seismic events in the period April 1995 to March 1996. The catalogue of earthquakes for the whole of 1995 is plotted to reflect the period for which revised data are available and to be consistent with the annual bulletin, which is produced as a separate volume. An updated map of epicentres since 1979 is also included for earthquakes with magnitude ≥2.5 ML; the threshold above which the data set is probably complete.

There has been considerable progress in achieving the overall objective of a minimum station spacing of 70 km for the whole of the UK although gaps still remain. An oil company and Health and Safety Executive consortium (the Western Frontier Association) has promoted the extension of coverage to the Outer Hebrides, northern Scotland and the Orkneys. Further advances have been made in the capabilities of the existing facility; in particular, monitoring stations in the Moray sub-network 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, Jersey, East Anglia, central England, Shetland, south east England, north Devon, Leeds, Galloway and Eskdalemuir. Only the Paisley and south Devon 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. Low-gain instruments employ standard seismometers recording ground velocity but with the electronic amplifier gain reduced by a factor of 50. Strong motion instruments record ground acceleration for the larger felt earthquakes in the range 0.015% g to 0.1% g. Two strong motion systems have been established at Swindon and NW Scotland and two low-gain instruments in northern Scotland and NW Scotland (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 now the strategy 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 data contributed from separately funded, site-specific networks. These are vulnerable to closure when the commissioning organisations have completed the work for which these were installed.

3. Programme objectives

3.1 Long-term

The initial overall objectives of the service were:

(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 the determination of some parameters (eg depths of focus and focal mechanisms) could only be approximate.

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 from Edinburgh to remote networks using computer or telephone links would be reduced to an opportunistic, phased level as resources became available (at present, only two sub-networks remain to be upgraded, Paisley and south Devon and these are expected to be completed by September 1996).

The establishment 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 1996, with rapid-access upgrades, is shown in Figure 1 with its detection capability in Figure 5. The scheduled programme for 1995/96 had as its aims:

(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) Initiation of 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.

The extension of the network has been completed (i) with the installation of thirteen stations in the north-west and northern Scotland, the Orkney Islands and the Outer Hebrides; one sub-network has been upgraded to remote access but two still remain on the old standard (ii). The analysis of focal mechanisms for UK earthquakes (iii) has produced preliminary results which show that the larger earthquakes in Britain are consistent with a maximum horizontal stress direction of NW-SE; further interpretation shows there may be a relationship between focal depth and heat flow and that mechanisms with dominant reverse faulting are more common than originally thought. Work on the attenuation in Britain (iv) has been held up due to a shortage of staff and funds. It is, however, expected to begin in May 1996. The digitisation project (v) has been completed for all earthquakes above 2.0 ML, except those where tape supplies were of poor quality in the period 1979 to 1980. A large number of smaller magnitude events have also been recovered and that work is continuing; the process of digitising older tapes (1970-77) has been initiated and modification of the existing equipment is in progress to enable the old 1" tapes from that period to be processed. The check on geographic locations of stations using GPS (vi) has been completed. Surface seismometers were installed at the two borehole sites in the Keyworth network (vii) and comparison of signals resulted in the conclusion that, for this area, 40m/10m boreholes do not significantly improve the signal-to-noise and therefore deeper boreholes should be considered for future installations in similar geological environments. The development of the strong motion network (viii) has resulted in the installation of two strong motion stations, at Swindon and in north-west Scotland, both being recorded onto rapid-access systems. This brings the total number to twelve. Contact with archives outside BGS has been maintained (ix): The Coats Observatory (Paisley) and Durham University have transferred their collections to BGS, Aberdeen is considering this step and the West Bromwich Observatory records are confirmed to be well-curated by Lapworth museum, Birmingham.

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. Nine of the 12 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 has transferred its equipment to the project (including the North Wales instrumentation in place) and are welcomed to the Customer Group as paying members from 1995.

(ii) Nirex is continuing its seismicity studies, incorporating results from the Cumbria microseismic network. Formerly this work was jointly funded by Nirex and BNFL.

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

(iv) The free-field strong motion system for Scottish Nuclear at Torness has continued to operate and a formal maintenance contract is under negotiation. A proposal to upgrade the Hunterston equipment to the standard SEISLOG system has been submitted.

(v) The enhancement of the UK network in north-west and northern Scotland, the Orkney Islands and the Outer Hebrides with 13 new stations, has been funded by a consortium of oil companies and HSE, working with BGS on a wide range of offshore hazard issues (the Western Frontier Association).

In summary, coverage of the country is almost complete with the aid of these site-specific networks. In the longer-term, however, they represent areas of vulnerability owing to the prospect of the withdrawal of funding.

4.2 Progress with instrumentation

New and faster Motorola modems have been installed at seven locations throughout the country bringing the total to sixteen. They permit fast transfer of data from the rapid-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. A system has been running successfully on the Borders network for nine months. This gives 16-bit data in digital form, eliminating FM demodulators and analogue-to-digital converters and hence increases the dynamic range to 96dB. A 24-bit ILI, with a dynamic range of 140dB, has been purchased for evaluation and is designed to cover all possible ground motions expected from earthquakes in Britain. This would remove the traditional distinction between high sensitivity and strong motion systems.

Larger capacity, one gigabyte disks have been installed in five new locations to replace the 400 megabyte units, thereby bringing the total to fifteen 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 intended to upgrade all 400 megabyte disks to this standard or better 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

Environmental monitoring is becoming increasingly important in modern life. Many city centres now have air pollution monitoring equipment but the background control and wide area effects are often not so well studied due to the high cost of collecting data from a wide-spread network. The costs are especially acute where the data is required on-line, due to the extra expense of telemetry equipment. The existing infrastructure of the UK seismograph monitoring network with its remote stations giving continuous on-line data from the Shetland Islands to Jersey, can potentially provide a cost-effective environmental monitoring network. Users can inspect the data in real-time or transfer it at intervals via modem or the Internet. In principle any environmental sensor can be interfaced and sampled at, say, once per minute. To this end, an experimental station has been operating 35 km from Edinburgh where air and ground temperature, together with radioactivity data are being transmitted to a base station (Fig 19). The station has the capacity to transmit data from 16 environmental sensors simultaneously. Hardware and software have been upgraded during the 12-month trial period to improve the reliability and efficiency of data collection. Graphical display software has been developed for the PC and SEISLOG computers and pollution sensors have been evaluated for future integration. Selected potential users of the system will be given demonstrations of the monitoring possibilities with a view to seeking further support for its development. A

Memorandum of Understanding with the Meterological Office has been signed to explore possible avenues of collaboration.

5. Seismic activity in Year 7

5.1 Earthquakes located for 1995

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 1995 published and distributed in April 1996. A map of the 225 events located in 1995 is reproduced here as Figure 7 and a catalogue of those with magnitudes of 2.0 or greater is given in Annex B. Ten in that magnitude category, together with eleven smaller ones, are known to have been felt. In the period since BGS extended its modern seismic monitoring in the UK (1979 to March 1996), 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 seventh year of the project (April 1995 to March 1996) are given below:

(i) Near Johnstonebridge, Dumfries and Galloway, a magnitude 2.1 ML earthquake was detected on 6 July, the largest of eight events in that area during the year. It was not felt by local residents. These form part of the continuing sequence of events in this area, the largest of which occurred on 27 February 1992 with a magnitude of 2.7 ML. It was felt with intensities of at least 4 EMS (European Macroseismic Scale) in the towns of Newton and Sandyford and at lower levels throughout the Johnstonebridge area.

(ii) The largest offshore earthquakes in the period, with magnitudes of 3.6 ML, were both located in the northern North Sea on 28 June and 13 November. Some 19 earthquakes were located in the North Sea; none of them were reported to have been felt.

(iii) In the English Channel, 55 km south of Plymouth, a magnitude 3.1 ML earthquake occurred on 17 August. No felt reports were received owing to its distance from the shore.

(iv) Near Aviemore, Highland, on 28 August, an earthquake with a magnitude of 2.7 ML was felt by local residents in Boat of Garten, Aviemore, Grantown-on-Spey, Carrbridge and many of the surrounding villages. Felt reports described "a bang, a rumble, the building shaking" and one person reported that "ornaments moved and glasses shook"; a few reports of minor damage were also received. The earthquake was felt over approximately 1300 km^2 and was located in an area where no previous seismicity had been recorded. A macroseismic survey throughout the region showed that it was felt in the epicentral area with a maximum intensity of 4 EMS. A seismogram of the event recorded on the Kyle of Lochalsh network is shown in Figure 9.

(v) Some 9 km south of Mansfield, Nottinghamshire on 11 October, an earthquake with a magnitude of 2.4 ML, was felt by local residents in South Normanton with intensities of at least 3 EMS. It was preceded by a smaller event (magnitude 1.9 ML), one minute before.

(vi) In Stoke-On-Trent, on 26 April and 27 November 1995, two events with magnitudes of 1.4 and 1.6 ML were located in the same area as the six felt events in February 1995. In this area, coal mining was abandoned in the late 1980s, but since that time sporadic outbursts of seismicity have occurred.

(vii) In Loch Fyne, Strathclyde, an earthquake with a magnitude of 1.9 ML was felt by residents who reported "a rumble and shuddering" on 3 February 1996.

(viii) On 7 March 1996, a magnitude 3.4 ML earthquake was located some 9 km north of Shrewsbury. It was felt throughout Shrewsbury, Telford and Oswestry and felt reports described "a rumble and shuddering" and "felt the settee move sideways". A macroseismic survey revealed that the maximum intensity was 5 EMS and the felt area was approximately 3000 km^2. A seismogram of the event recorded on the Hereford network is shown in Figure 10.

(ix) An event with a magnitude of 2.1 ML, occurred near Stillingfleet, North Yorkshire on 1 November. It was felt with intensities of at least 2 EMS by residents in Stillingfleet and in the nearby collieries. It was located at a depth of less than 1 km and had the characteristics of a mining-induced event. This event located in the same area as the felt Stillingfleet event on 5 December 1994 which had a magnitude of 2.2 ML.

(x) Near Newcastle-under-Lyme, four shallow events, with magnitudes of 2.0, 1.9, 1.9 and 2.3 ML were felt by local residents. The largest, on 16 March 1996, was felt by people in the Keele area. The signals recorded by the Keyworth network showed that the source was shallow (presence of surface waves in Figure 11) and it is thought to be related to nearby mines in the epicentral region. A smaller, magnitude 1.5 ML, event occurred in the same area on 14 October and was not reported to be felt.

(xi) Some 47 coalfield events with magnitudes ranging between 0.5 and 2.3 ML have been detected in the reporting period; fourteen of them were felt. Twenty-three of them were located in the Clackmannan area in the Central region of Scotland, where the magnitudes ranged from 0.5 to 1.8 ML and five were reported to be felt by local residents.

(xii) In other coalfield areas, small events were located near Knottingley, West Yorkshire (1.3 ML, 21 April 1995), Nottingham, Nottinghamshire (1.3 ML, 25 April 1995), Rotherham, South Yorkshire (four events with magnitudes ranging from 1.1 to 1.9 ML; none were reported felt), Worksop, Nottinghamshire (0.8 ML, 13 May 1995), Mansfield, Nottinghamshire (six events with magnitudes ranging from 0.7 to 1.7 ML; one was reported felt by local residents in the Mansfield area on 16 July 1995, 1.7 ML), Leigh, Greater Manchester (1.5 ML, 11 August 1995, felt in Lowton Common), Maltby, South Yorkshire (two events were felt; 2.0 ML, 11 October 1995, felt Stainton and 1.7 ML, 22 October 1995, felt Maltby), Hoyland, South Yorkshire (1.9 ML, 11 October 1995) and Sheffield, South Yorkshire (1.8 ML, 18 January 1996). These events are presumed to be related to present-day coal-mining activity.

(xiii) 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: Fife/Tayside (5 June 1995), Norfolk (22 June 1995), Isle of Man (26 July 1995), central Fife (2 November 1995), Anglesey, North Wales (2 November 1995), Moray Firth (18 January 1996) and Norfolk (16 February 1996).

(xiv) Reports have been received of man-made events which were the focus of media attention. Near Penmon, Anglesey, on 22 June 1995, an explosion to destroy the local pier was felt by local residents. Following the appearance of phosphor sticks on Ayrshire beaches in early summer 1995, BGS analysts started to register explosions in the North Channel between Scotland and Ireland owing to their potential interest and the presence of a large munitions dump in Beaufort's Dyke. Normally, such offshore explosions (which are common around the UK) would not be registered in computer files although raw data is retained. Many of the 1995 Beaufort's Dyke explosions have been confirmed to be part of controlled operations including civil engineering works for a British Gas pipeline. Owing to the proximity of the munitions dump, media interest has continued. Seismograms of the Penmon explosion and a confirmed North Channel explosion are shown in Figures 13 and 14, respectively.

(xv) Throughout the year, a number of nuclear explosions were detonated in the Pacific atolls of Fangataufa and Muroroa in the Tuamota Archipelago. The BGS network, although capable of detecting nuclear explosions, did not record these events due to the distance and position of Britain on the Globe (in the shadow zone). On 17 August 1995, a nuclear explosion (magnitude 6.1 MB) 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 15.

5.3 Rock concert events

On Saturday and Sunday, 4 and 5 November, BGS received reports of seismic events from Scotland Yard and the Kensington, Chelsea and Fulham police. They had received several calls from concerned residents who reported "buildings shaking, candlesticks rocking and a chandelier swinging". On the Saturday, events occurred at about 21:00, 21:30 and 22:13 UTC; on the Sunday, at 21:30 UTC. The Oasis rock group were playing a concert at Earl's Court Exhibition Centre at the time and it was estimated that 20,000 people attended the all-standing concert. BGS attributed these felt effects to the rock concert; no earthquakes nor explosions were detected on the BGS seismograph network. One report was about 1 km from Earl's Court and, on the Sunday, there were 15 calls from an area of 1 square mile.

There are similarities between these events and those of 8 and 9 August 1992, when buildings were evacuated around Finsbury park, north London, at the time of a Madness concert, and on two occasions during the 1980s when rock group U2 were playing in Brussels.

5.4 Belgian earthquake

An earthquake with a magnitude of 4.5 ML, occurred in Belgium on 20 June 1995 at 01:54 UTC, near the village of Le Roeulx in the province of Hainaut. Data were exchanged between 10 participating members of the CEC Transfrontier Project to provide phase arrivals to enhance the location parameters. The event was felt throughout Belgium, northern France and the Netherlands but damage was confined to fallen chimneys (less than 10) and wall cracking in the epicentral area. For an event of this size, more damage was expected, but due to its focal depth of some 23 km, little occurred. This focal depth was unusual; previous seismicity in the area has been located between 5 and 10 km. However, such depths were observed in the United Kingdom during the 1984 Lleyn Peninsula earthquake (magnitude 5.4 ML) and its many aftershocks. A seismogram of the Belgian earthquake from the south east England network is shown in Figure 16.

5.5 Global earthquakes

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

(i) An earthquake in the Gulf of Corinth, on 15 June 1995 at 00:15 UTC, with a magnitude of 6.5 Ms, resulted in the deaths of twenty-six people and injuries to 60 in the Aiyion area of Greece. Extensive damage occurred at Aiyion and Eratini; damage also occurred at Corinth, Patras and Pirgos. Preliminary estimates of damage costs were around $660 million. The earthquake was felt in Athens, Ioanuina, Kalamata, Kardhitsa and Kozani and on the island of Kefallinia. A seismogram of the event recorded on the Cornwall network is shown in Figure 17 and Plate 1 shows the extent of damage in the Aigio, Peloponnese area.

(ii) An earthquake in the Gulf of Aqaba, Egypt, on 22 November 1995 at 04:15 UTC with a magnitude of 7.3 Ms, killed at least eight people and injured some 100. Damage was reported in Egypt, Israel, Jordan and Saudi Arabia. A hotel was destroyed at Nuwaiba in Egypt. A seismogram recorded on the Lowlands network around Edinburgh is shown in Figure 18 and damage which occurred in the Cairo area is shown in Plate 2.

(iii) In Lijiang, China on the western edge of the Himalayas, an earthquake with a magnitude of 6.5 Ms devastated the local area on 3 February 1996, killing some 250 people and injuring many others. Approximately 1 million people were left homeless after the destruction of many houses in the province.

6. The National Seismological Archive (NSA)

6.1 Identification, curation and cataloguing

The collation, cataloguing, curation and microfilming of original seismograms held by BGS continues to progress. There follows an updated synopsis of the status of major known seismological archival materials:

Aberdeen: This collection is still maintained by the University of Aberdeen. Arrangements for seismogram microfilming and possible transfer of this material to the NSA are in hand.

Bidston: Records have now been collated and microfilmed prior to full archival storage in the NSA.

Coats Observatory, Paisley: This material has now been transferred to the NSA for collation, cataloguing, curation and microfilming.

Durham: These seismograms have now been transferred to the NSA for collation, cataloguing, curation and microfilming.

Eskdalemuir: These seismograms have now been integrated into the existing collection of KEW/ESK material held in the NSA for curation, cataloguing and microfilming. (The original Worldwide Standard Seismograph Network seismograms continue to be stored at Eskdalemuir, with microfilm copies available for inspection in the NSA.)

Jersey: These seismograms have now been collated, microfilmed and added to the NSA in Murchison House.

Kew: All existing material has been integrated into the NSA for collation, cataloguing, curation and microfilming.

Oxford: These records are presumed destroyed except one seismogram held in the NSA.

Royal Observatory, Edinburgh: All existing material has been integrated into the NSA for collation, cataloguing, curation and microfilming.

Shide: The records are presumed destroyed, although the Isle of Wight County Record Office has tracings of a few.

Stonyhurst: These records are presumed destroyed.

West Bromwich: The surviving papers and records from West Bromwich Observatory (JJ Shaw) have now been located in Birmingham. They are in good condition and are well curated by Lapworth museum, Birmingham, although the number of actual seismograms is very small. A preliminary inventory of the material has been made and published (Musson 1995, BGS Report WL/95/20). In due course, arrangements will be made for the copying of the surviving seismograms.

P L Willmore: Professor Patrick L. Willmore, who was Head of BGS Global Seismology Unit from 1963 to 1981, died in 1995. Mrs Willmore has given permission for his papers to be incorporated into the NSA and a preliminary inventory has been made.

6.2 Storage and Inspection facilities

The National Seismological Archive has been used this year by at least eight visiting scientists and around 30 data requests have been answered from scientists and researchers worldwide.

Monitoring of temperature and humidity has been extended to cover the BGS external store at Loanhead (near Edinburgh), where the analogue magnetic tape collection and secondary textual records are stored and BGS material at Eskdalemuir, where Worldwide Standard Seismograph Network (WWSSN) seismograms and tertiary material are stored.

The cataloguing of BGS-held material continues, with about 90% of it now preliminarily indexed and a final catalogue nearing completion. Information has been published on the Internet home page (address: http://www.gsrg.nmh.ac.uk/), abstracted from the ongoing cataloguing, to allow enquirers access to information and to submit data requests via e-mail.

6.3 Digital records

The programme of digitising old analogue tapes has achieved capture of all known events above magnitude 2.0 ML since 1977. 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 50 alerts have been issued to the Customer Group during the year.

The bulletin board, on a captive process on the central computer in Murchison House, has continued to be maintained on a routine basis for UK 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. In addition, throughout the year, an updated catalogue listing of recent earthquakes (1 month) and seismic alerts, giving details of UK and global earthquakes has been available through an Internet home page (address: http://www.gsrg.nmh.ac.uk/).

Remote telephone access to 95% of UK seismic stations is now available and eight 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 ML 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 reporting 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 1995, it was issued within 4 months.

8. Programme for 1996/97

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. The specific advances anticipated for 1996/97, subject to the continuation of funding at, at least, the current level and without any unexpected closures of site specific network are:

(i) Completion of the upgrade to the remote access, digital standard for all UK stations by September 1996.

(ii) Extension of the network in Northern Ireland (resources permitting).

(iii) Installation of an Automatic Data Request Manager (AutoDRM) to facilitate rapid data exchange with neighbouring countries.

(iv) Enhance the multi-functional environmental potential of the network.

(v) Continue a programme to improve seismic attenuation characteristics for the UK based on UK data: valuable for refining seismic hazard assessments.

(vi) Completion of the programme of digitising the 1" analogue magnetic tape data.

(vii) Installation of additional 4 gigabyte disks to increase the continuous recording capability to 14 days.

(viii) Introduction of at least three 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.

(x) A final catalogue of material held in the NSA will be published.

9. 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).

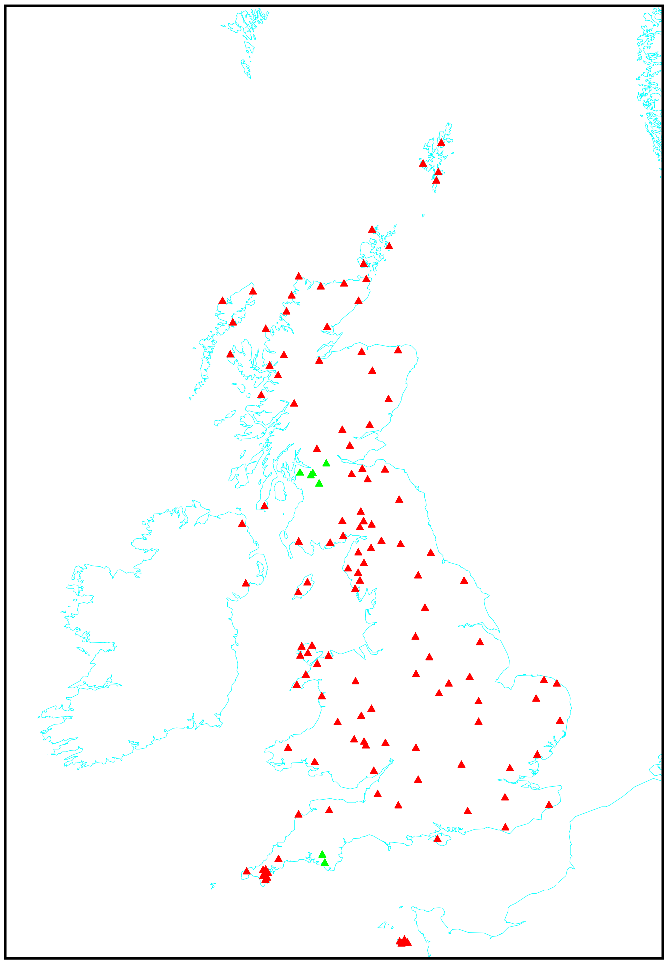

Figure 1. **BGS seismograph network operational in March 1996. Colour coding shows the standard stations (green) and those upgraded to rapid access (red).**

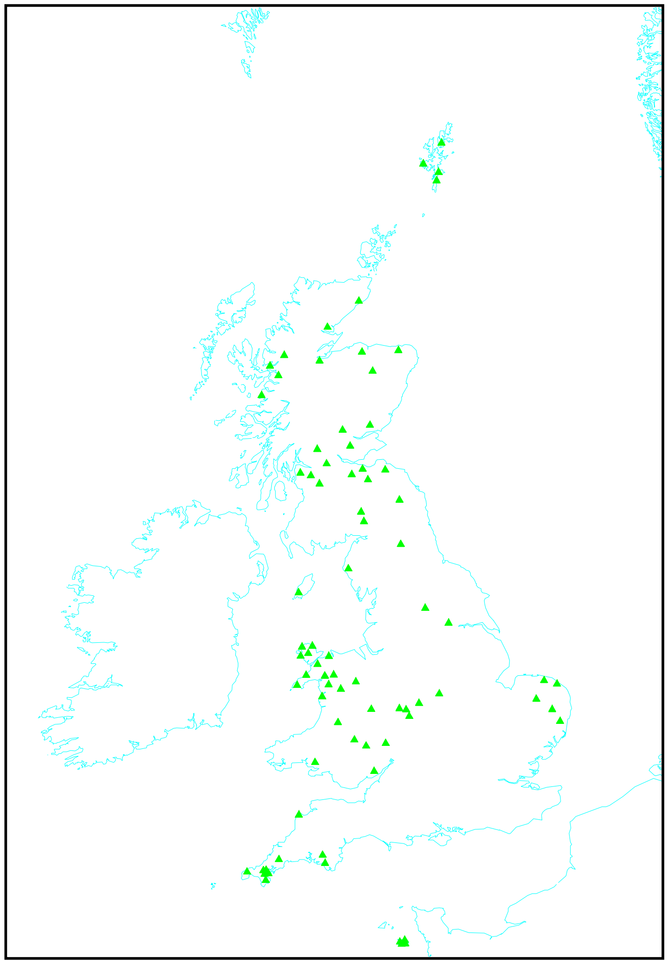

Figure 2. **BGS seismograph network in 1988 prior to the commencement of the UK monitoring enhancement project.**

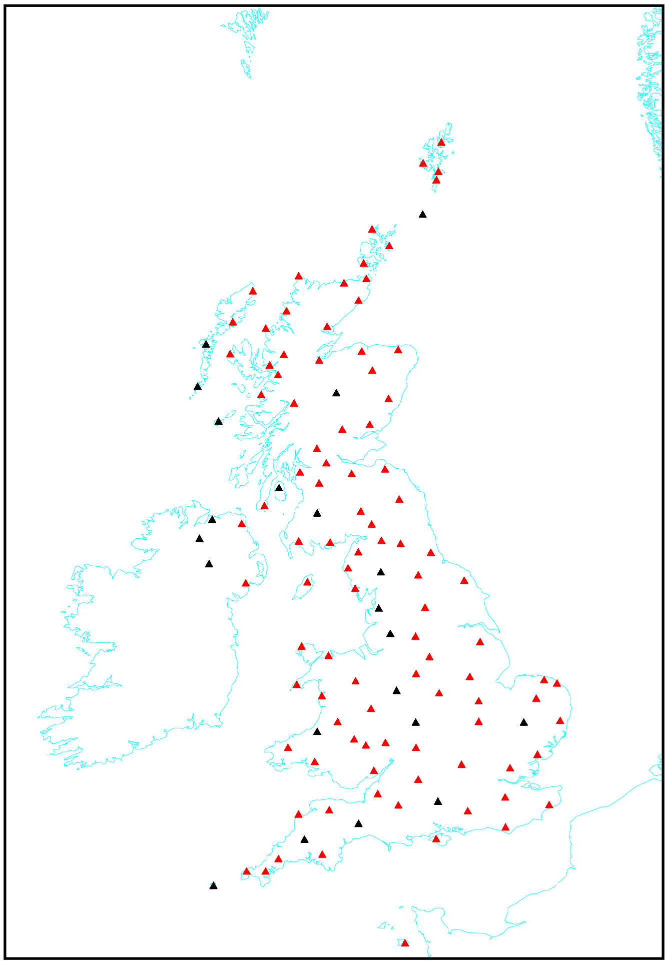

Figure 3. Proposed long-term background seismic monitoring network with an average station spacing of 70 km. Colour coding shows existing coverage (red) and proposed stations (black).

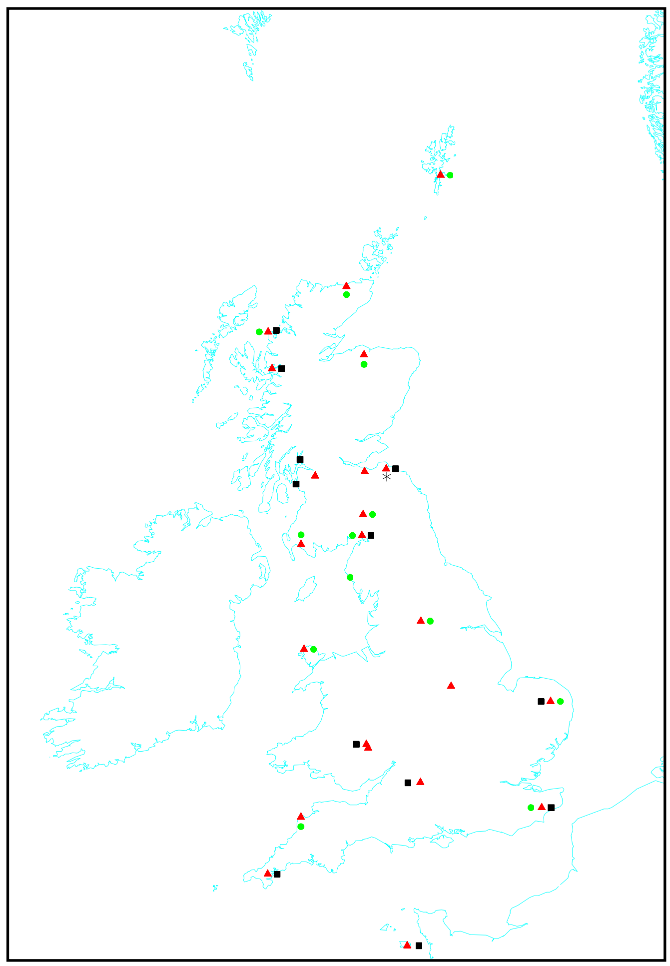

Figure 4. BGS network of strong-motion instruments (black), low sensitivity (red), microphones (green) and environmental station (star) in March 1996.

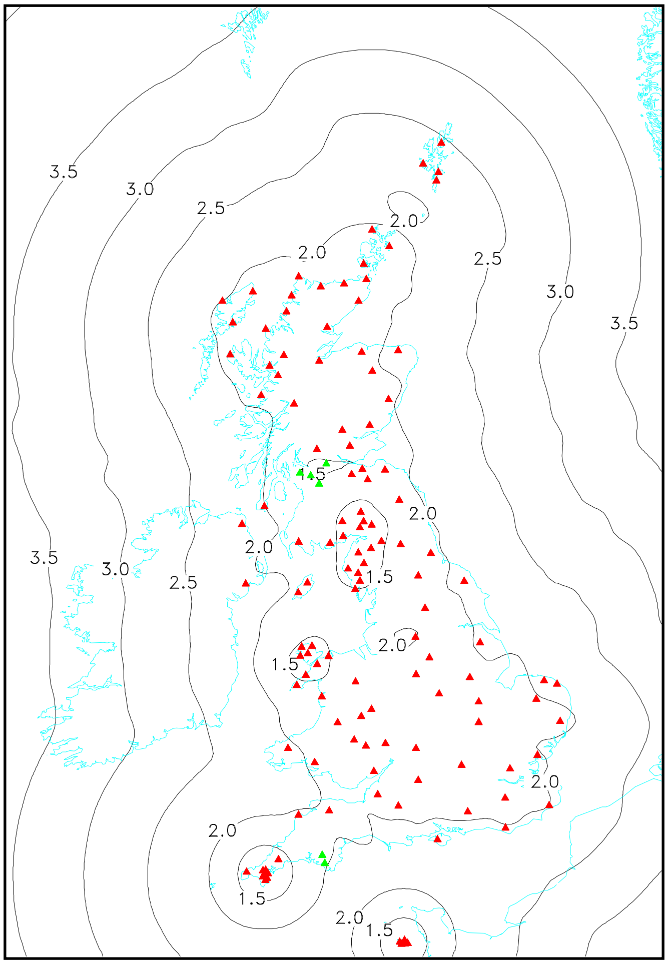

Figure 5. **Earthquake identification capabilty. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.**

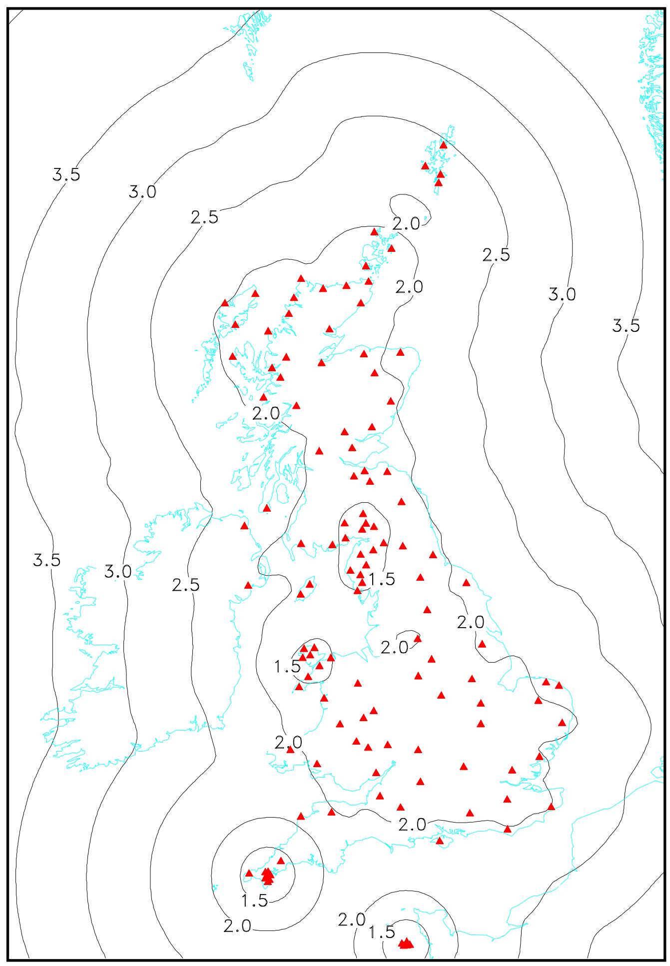

Figure 6. **Detection capability of the rapid access networks (excluding the green stations in west, central Scotland and Devon). Contours show the magnitude (ML) of an earthquake which would be detected by 5 stations in the presence of 20 nanometres of background noise at 10 Hz.**

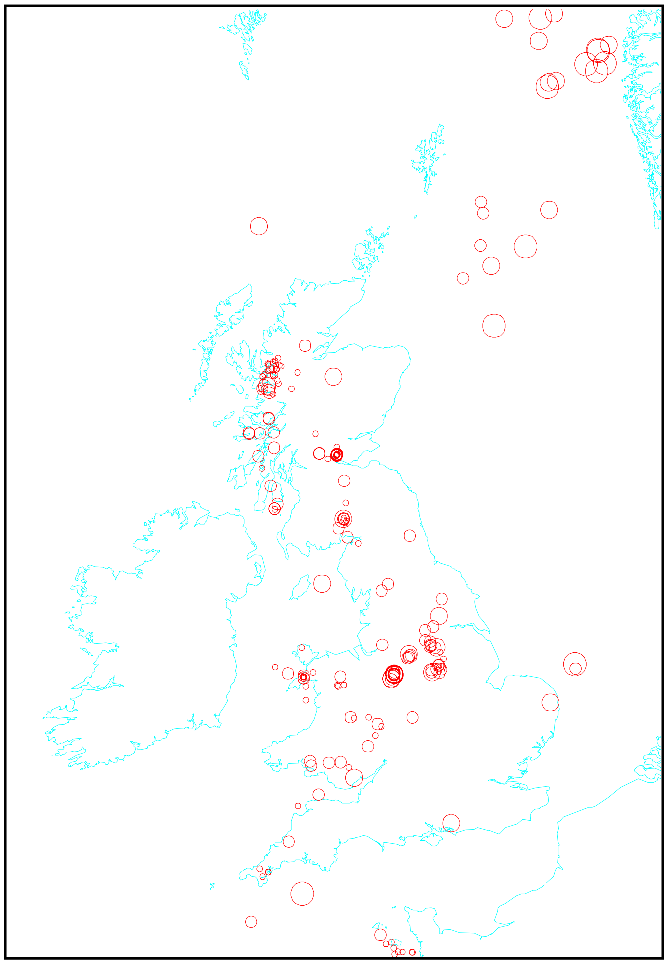

Figure 7. **Epicentres of all UK earthquakes located in 1995.**

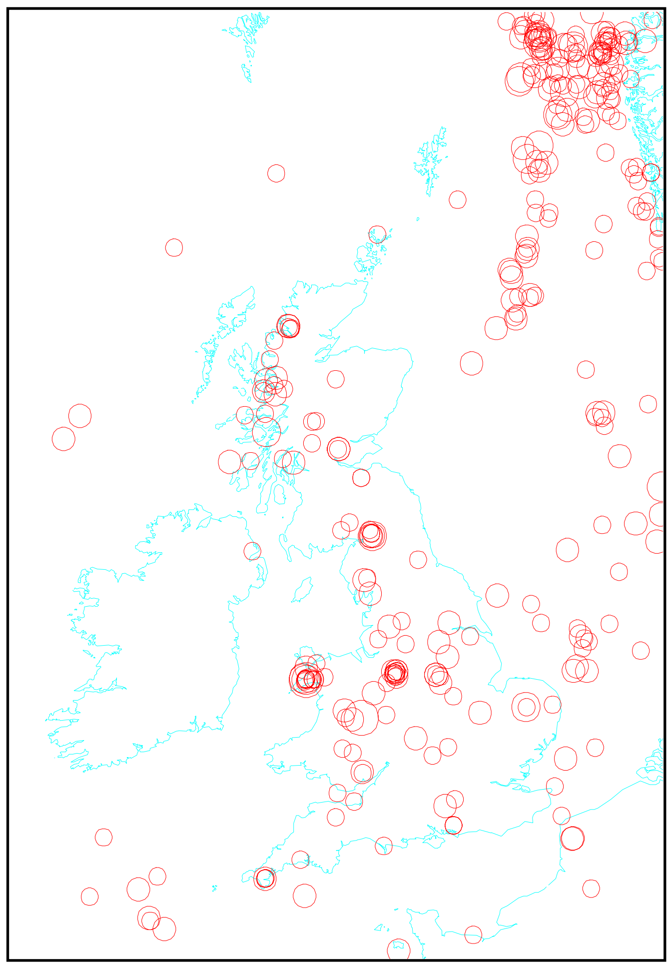

Figure 8. **Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 1996.**

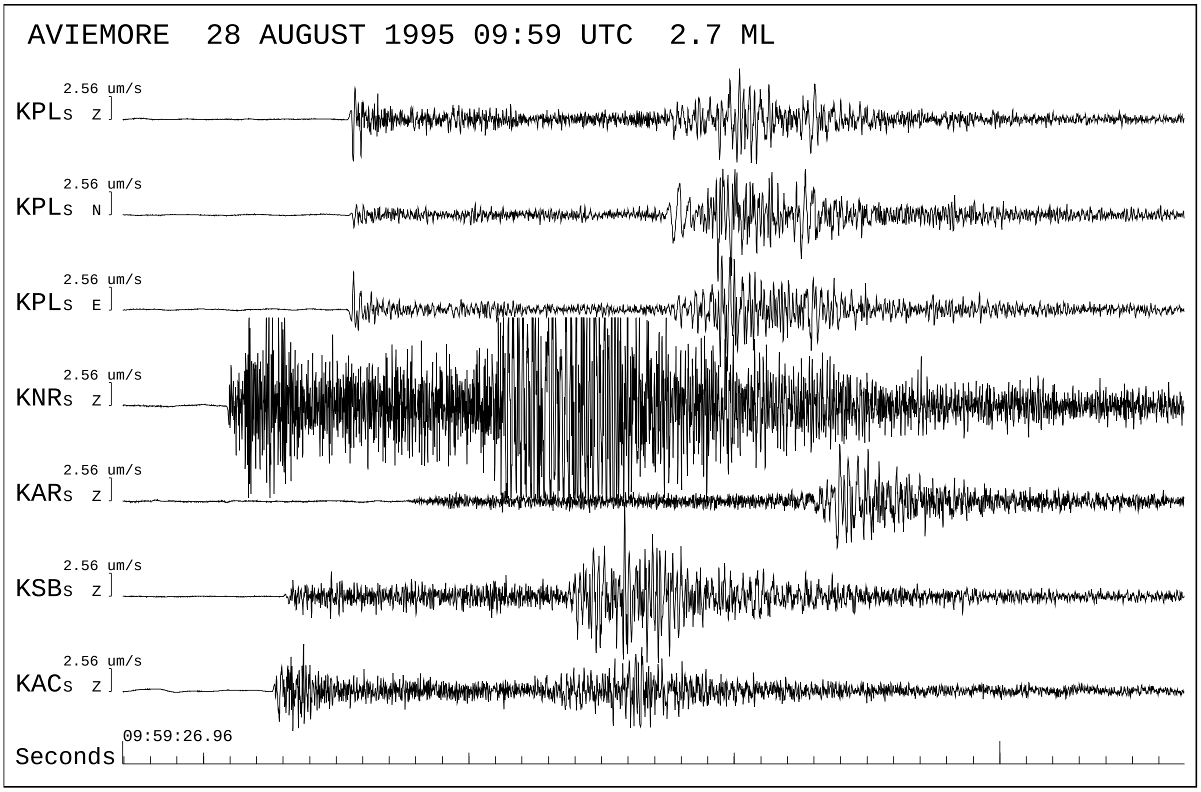

Figure 9. Seismograms recorded on the Kyle network from a magnitude 2.7 ML earthquake felt in the Aviemore area on 28 August 1995 09:59 UTC. Three letter codes refer to stations in Annex E.

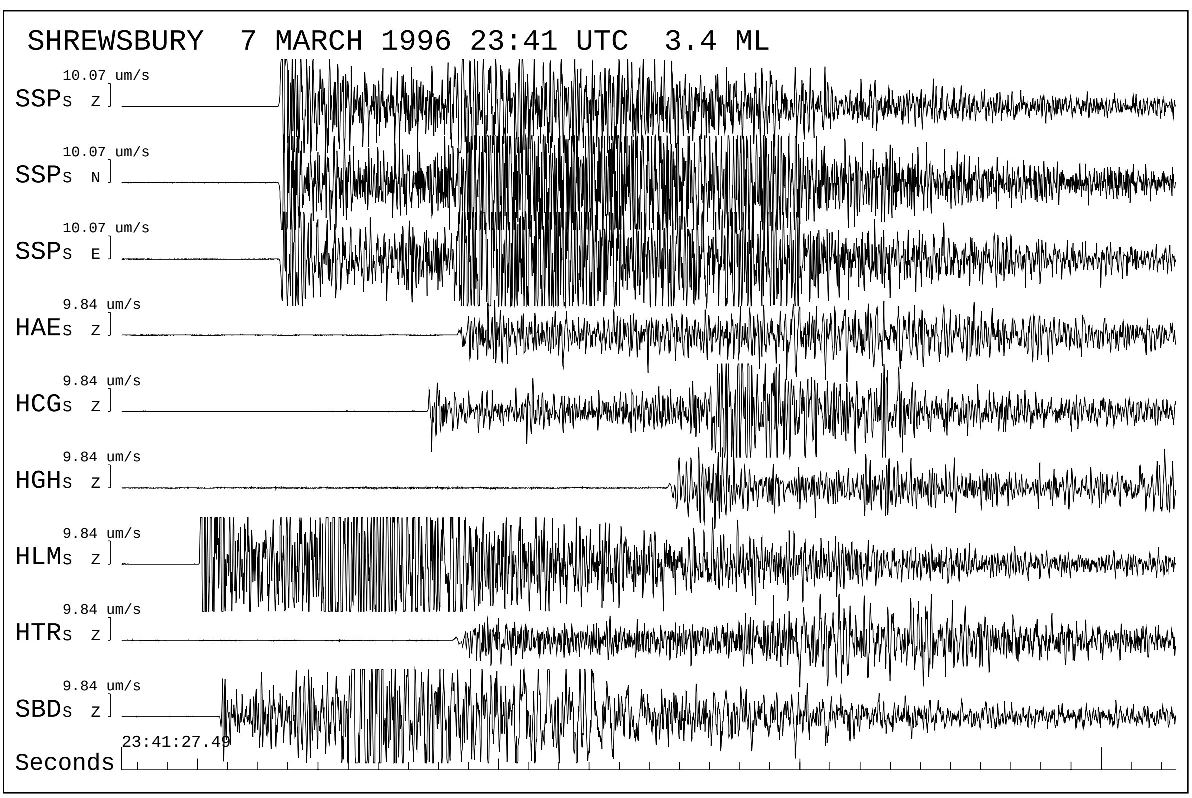

Figure 10. Seismograms recorded on the Hereford network from a magnitude 3.4 ML earthquake felt in the Shrewsbury area on 7 March 1996 23:41 UTC. Three letter codes refer to stations in Annex E.

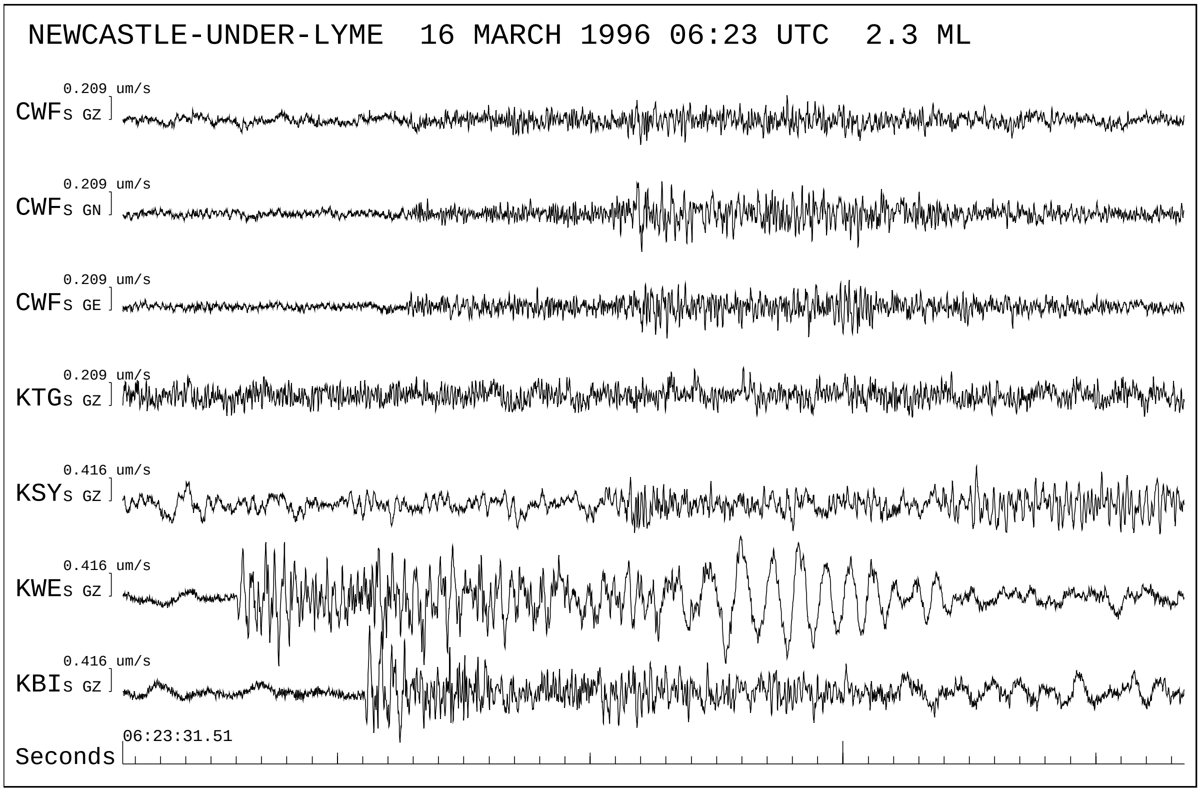

Figure 11. Seismograms recorded on the Keyworth network from a magnitude 2.3 ML coalfield event felt in the Newcastle-Under-Lyme area on 16 March 1996 06:23 UTC. Three letter codes refer to stations in Annex E.

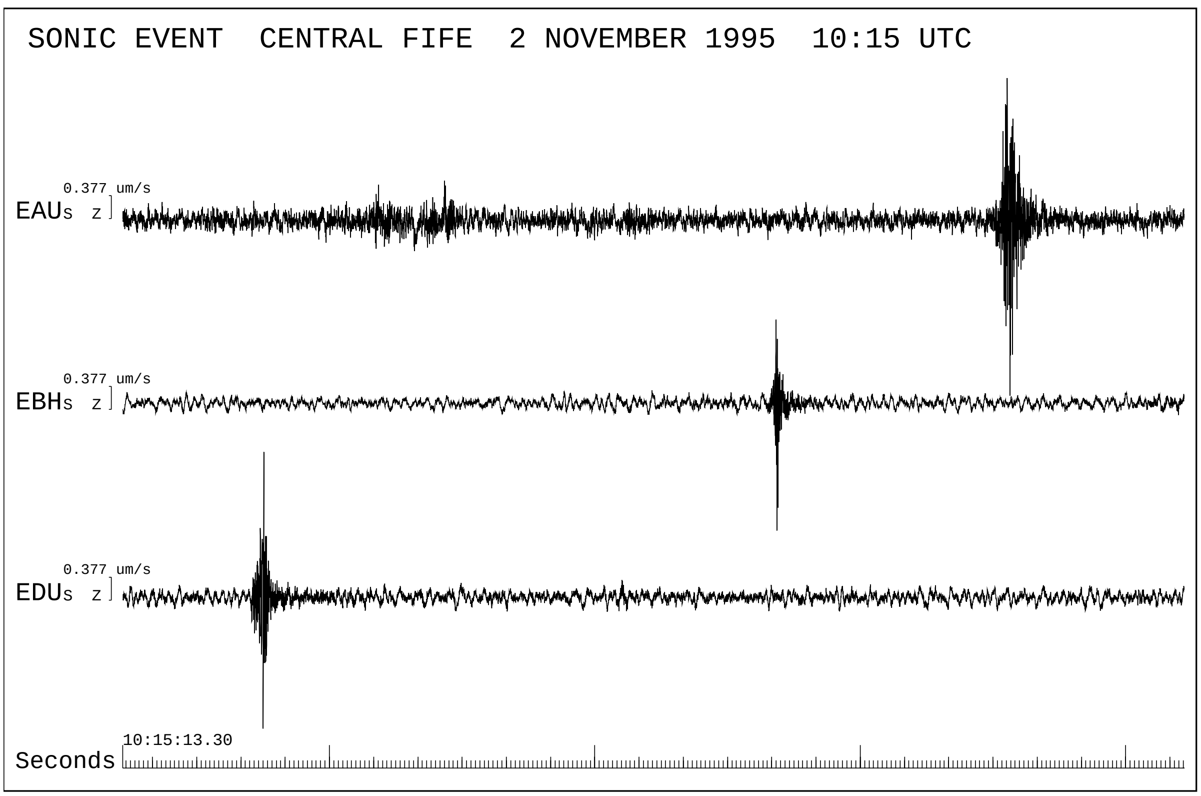

Figure 12. Seismograms recorded on the Lowlands network around Edinburgh from a sonic event felt in the central Fife area on 2 November 1995 10:15 UTC. Three letter codes refer to stations in Annex E.

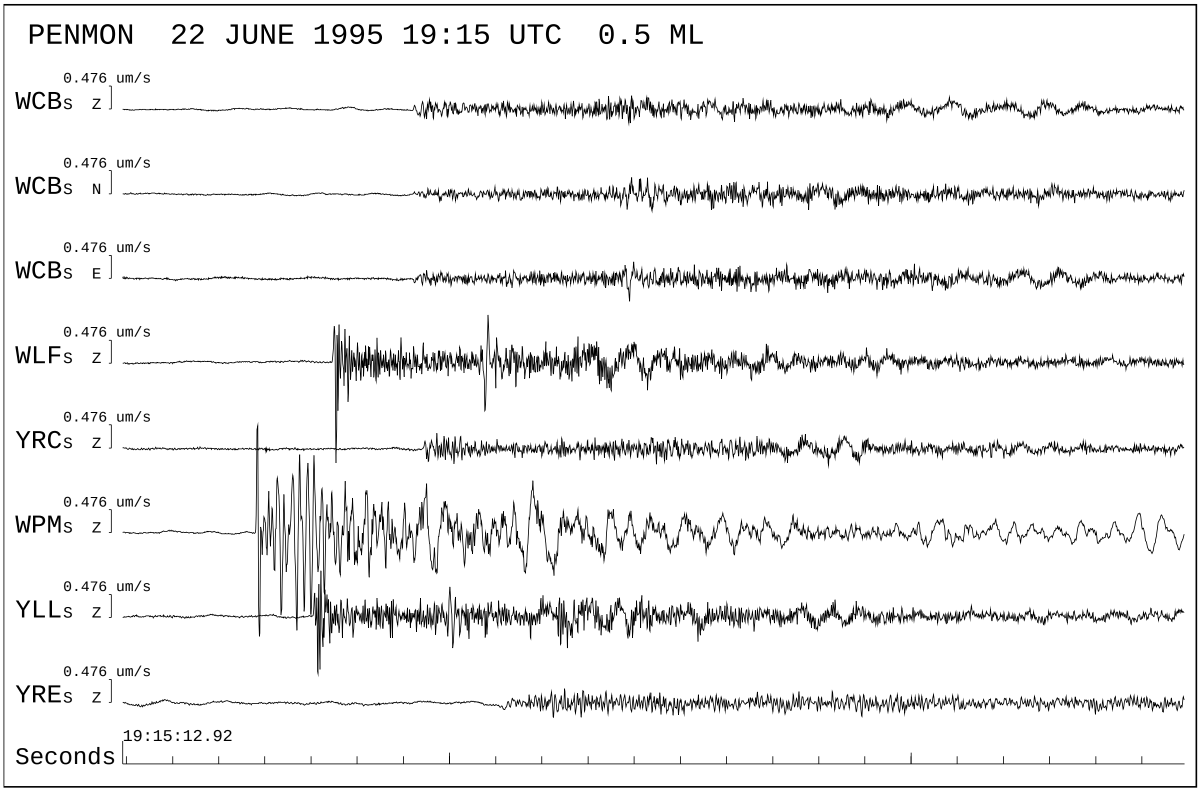

Figure 13. Seismograms recorded on the North Wales network from a magnitude 0.5 ML Penmon explosion on 22 June 1995 19:15 UTC. Three letter codes refer to stations in Annex E.

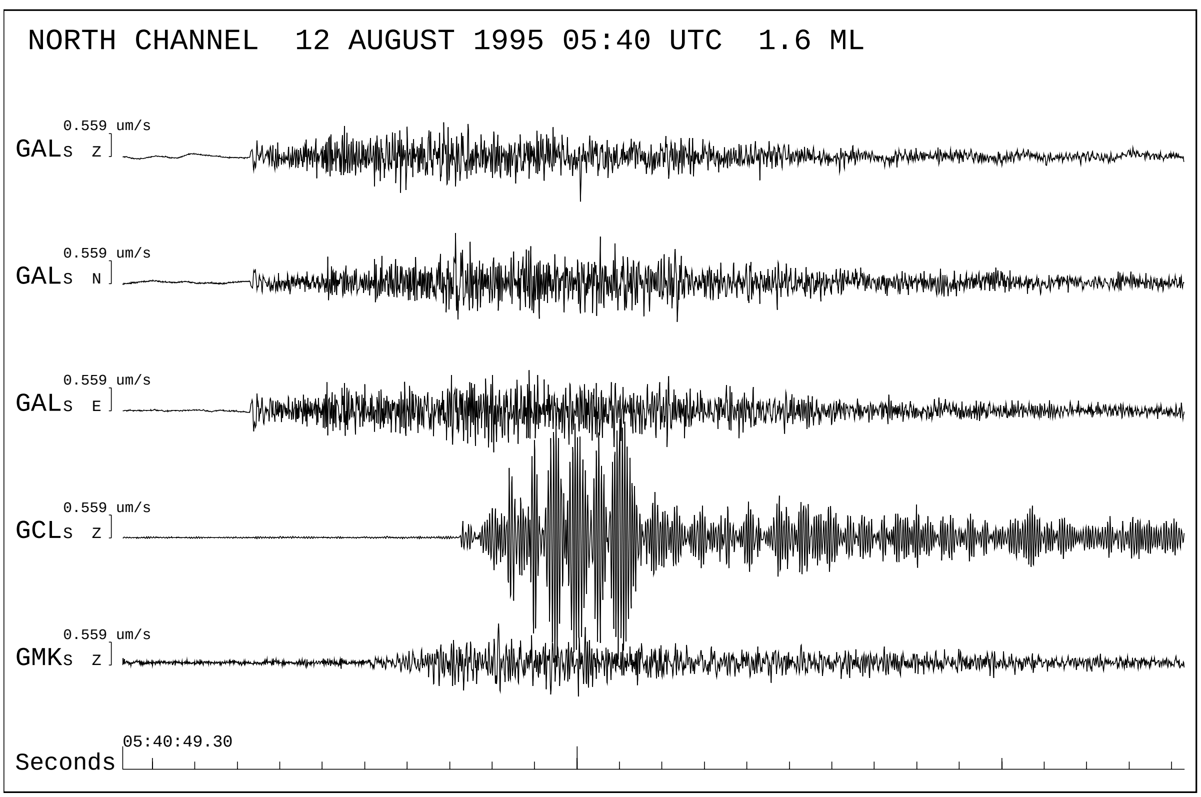

Figure 14. Seismograms recorded on the Galloway network from a magnitude 1.6 ML North Channel explosion on 12 August 1995 05:40 UTC. Three letter codes refer to stations in Annex E.

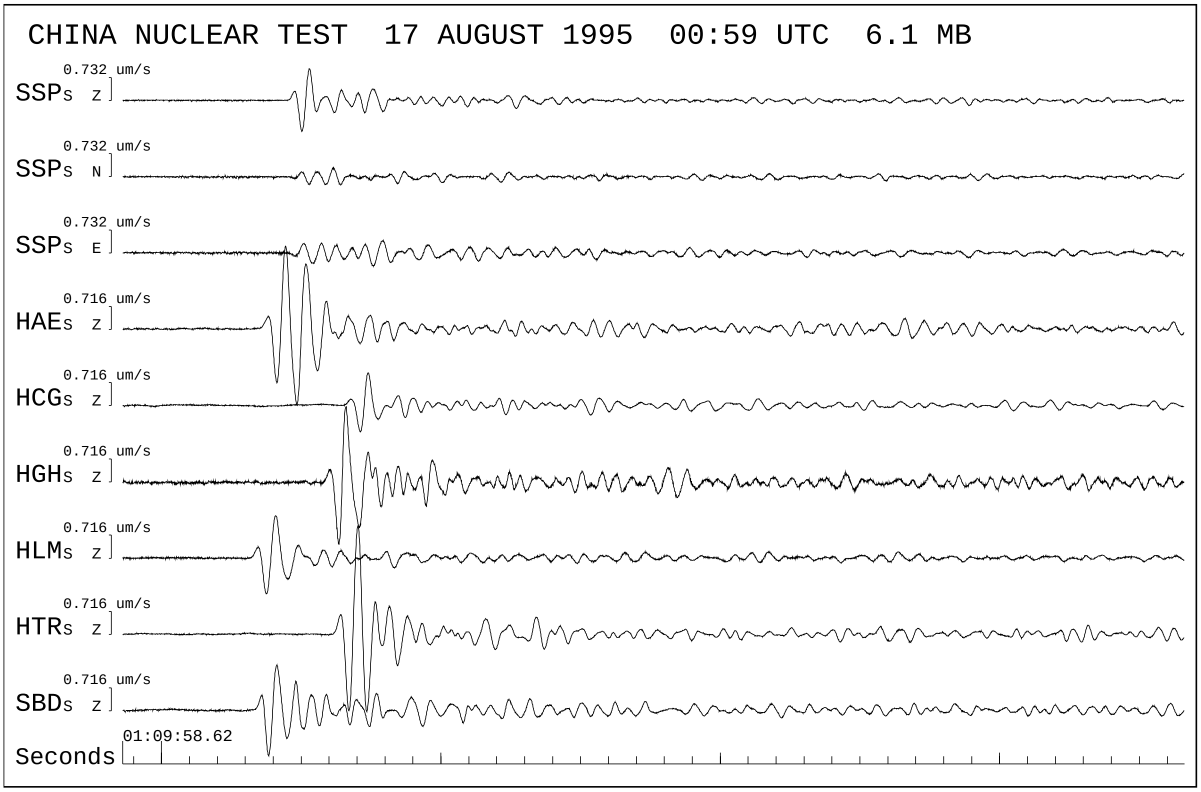

Figure 15. Seismograms recorded on the Hereford network from a magnitude 6.1 MB China nuclear test on 17 August 1995 00:59 UTC. Three letter codes refer to stations in Annex E.

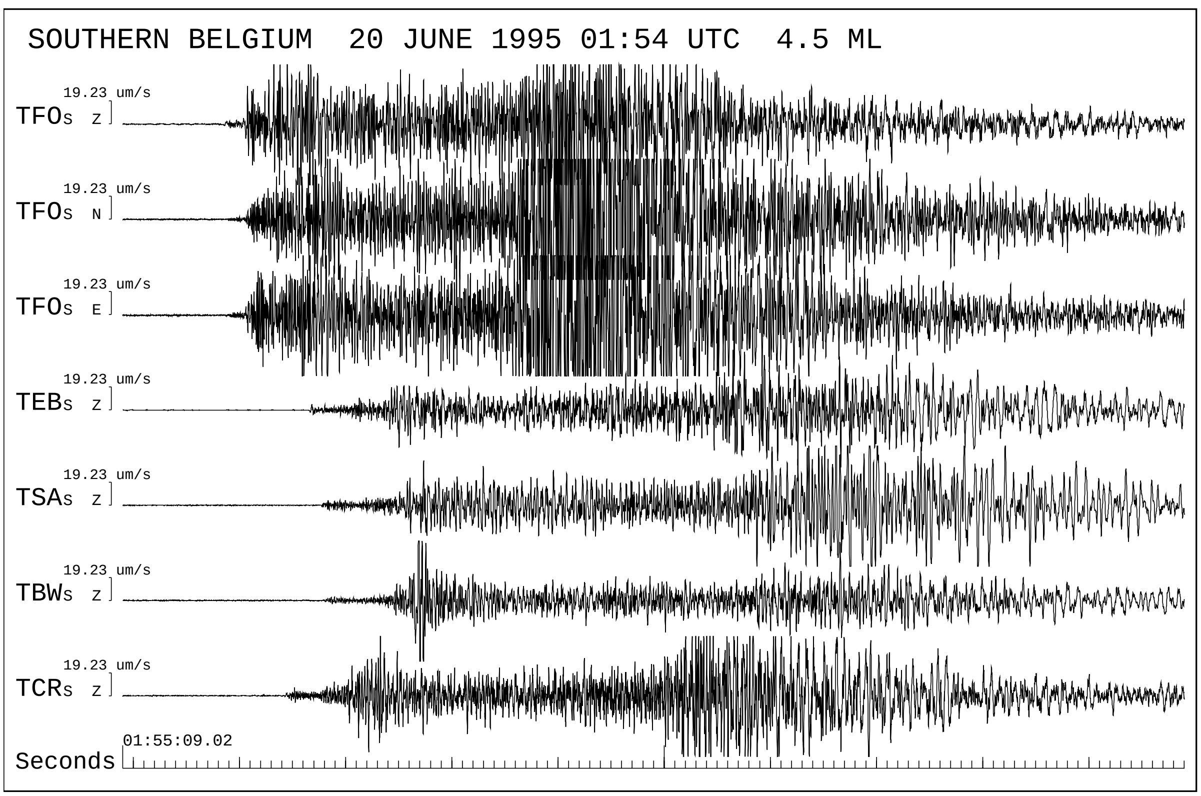

Figure 16. Seismograms recorded on the south east England network from a magnitude 4.5 ML earthquake in southern Belgium on 20 June 1995 01:54 UTC. Three letter codes refer to stations in Annex E.

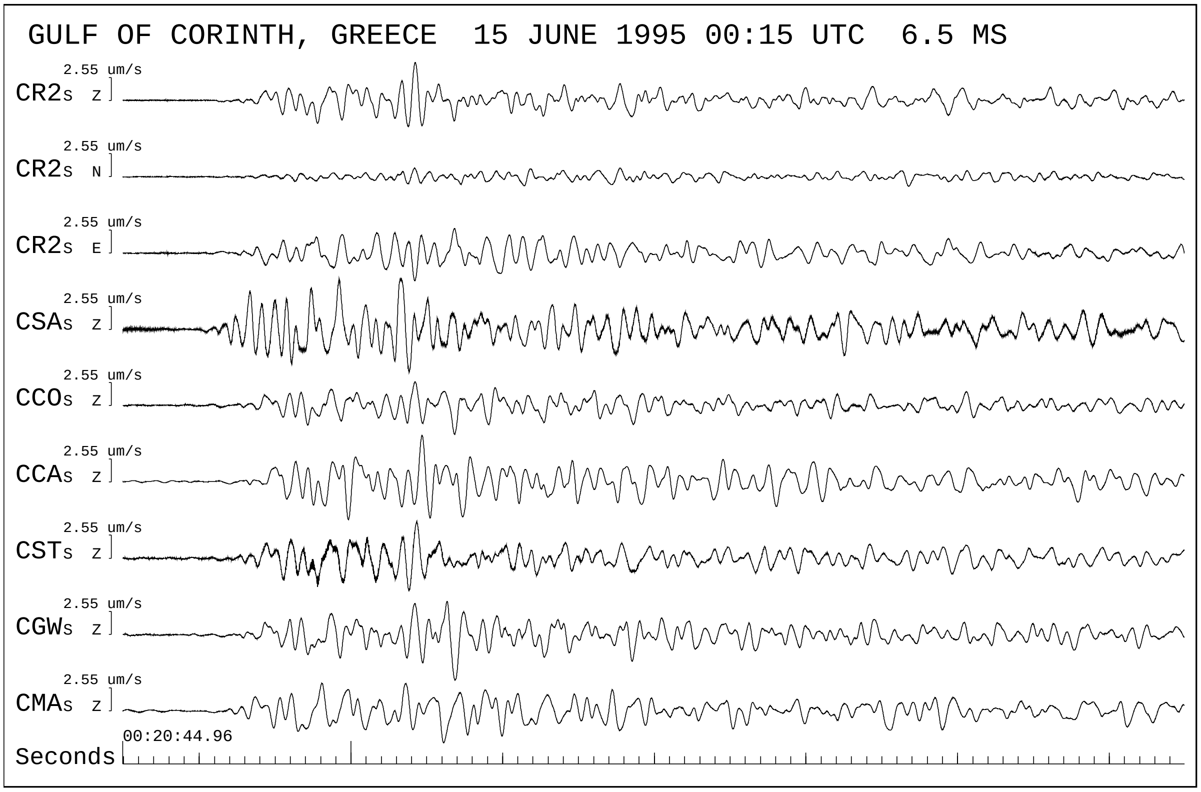

Figure 17. Seismograms recorded on the Cornwall network from a magnitude 6.5 MS earthquake in the Gulf of Corinth, Greece on 15 June 1995 00:15 UTC. Three letter codes refer to stations in Annex E.

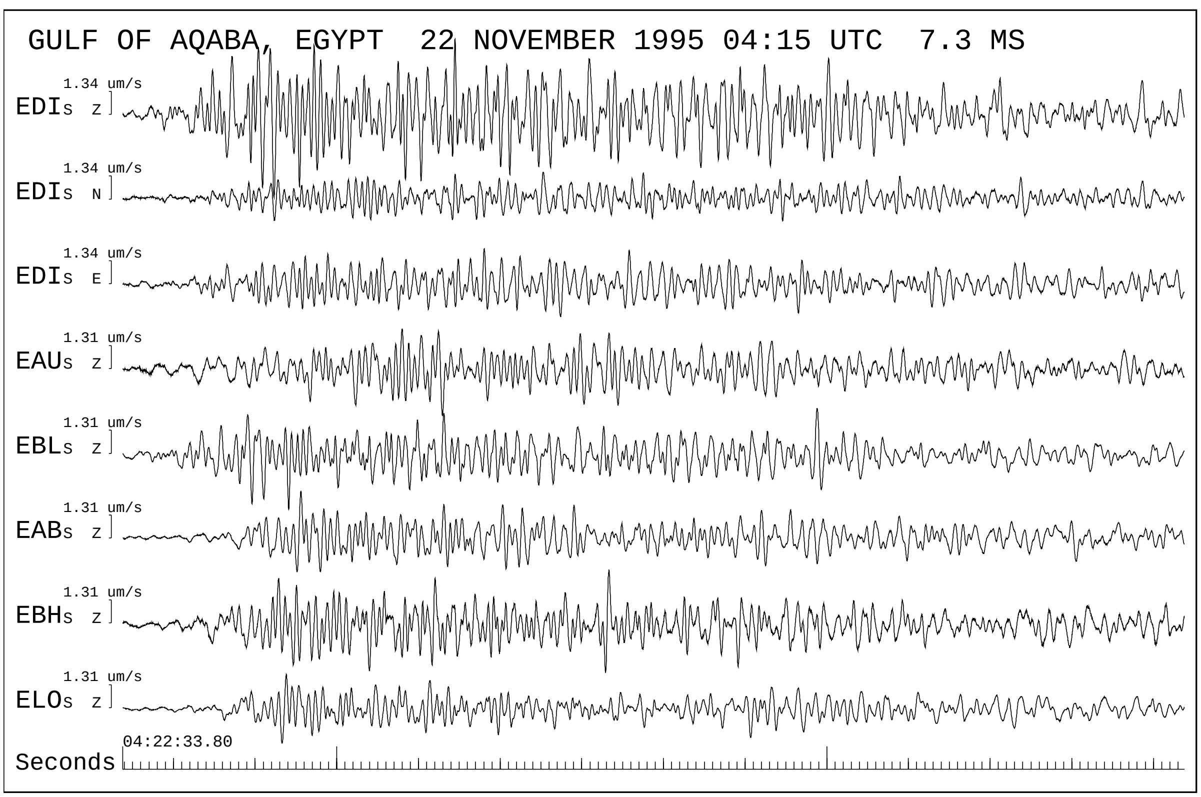

Figure 18. Seismograms recorded on the Lowlands network around Edinburgh from a magnitude 7.3 MS earthquake in the Gulf of Aqaba, Egypt on 22 November 1995 04:15 UTC. Three letter codes refer to stations in Annex E.

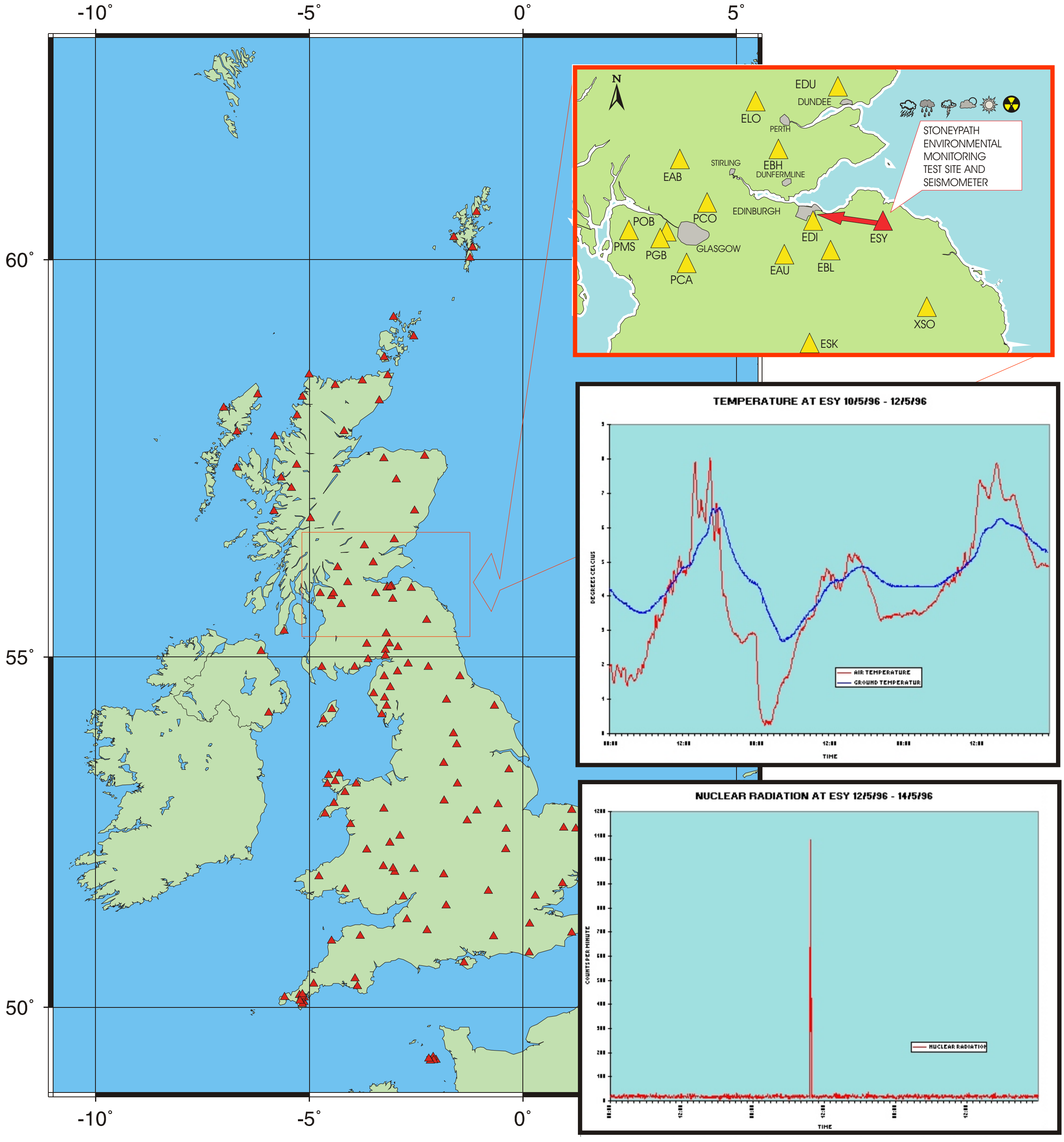

Figure 19. Environmental data from the experimental monitoring station 'ESY'. The charts show radiaactivity, ground and air temperature over a twelve hour period.

Plate 1. Damage caused by the magnitude 7.3 MS Gulf of Aqaba, Egypt earthquake of 22 November 1995 which caused the deaths of 8 people. (Photograph supplied by Amr Elnashi of Imperial College London)

Plate 2. Damage caused by the magnitude 6.5 MS Greece earthquake of 15 June 1995 which resulted in the deaths of some 26 people. (Photograph supplied by Kathimerini, newspaper, Athens)

ANNEX A

CONTRIBUTORS TO THE PROJECT

British Nuclear Fuels plc
Department of the Environment
Natural Environment Research Council
Nirex
Nuclear Electric plc
Nuclear Installations Inspectorate
Renfrew District Council
Scottish Hydro-Electric plc
Scottish Nuclear Ltd
Welsh Office
Western Frontiers Association

Atomic Weapons Establishment (Data only)

Customer Group Members (not contributing in Year Seven)

AEA Technology
British Gas
Health and Safety Executive
International Seismological Centre
Scottish Office

EARTHQUAKES WITH MAGNITUDE 2.0 AND ABOVE, RECORDED IN THE UK AND OFFSHORE WATERS : 1995

YearMoDy	HrMnSecs	Lat	Lon	kmE	kmN	Dep	Mag	Locality	Int	No	DM	Gap	RMS	ERH	ERZ	SQD	Comments
19950101	162010.5	52.57	1.56	641.0	303.4	6.0	2.7	REEDHAM,NORFOLK		15	22	205	0.22	1.1	1.2	B*D	
19950107	200424.9	59.33	-6.10	166.8	1056.8	17.6	2.1	NW LEWIS,OUTER HEBRIDES		10	193	323	0.53			D*D	POOR LOCATION
19950202	084321.7	59.56	2.23	638.9	1082.7	13.9	2.2	NORTHERN NORTH SEA		17	176	128	0.31	1.4	2.6	C*D	
19950202	212609.7	57.96	0.52	549.2	899.4	17.0	3.2	CENTRAL NORTH SEA		56	172	134	0.27	0.5	1.1	B*D	
19950220	015905.2	53.04	-2.20	386.7	348.8	3.0	2.5	STOKE-ON-TRENT,STAFFS	4+	14	6	139	0.13	0.7	1.6	A*C	FELT STOKE-ON-TRENT...
19950221	231524.8	53.02	-2.18	387.7	347.3	1.6	2.2	STOKE-ON-TRENT,STAFFS	3+	16	23	120	0.12	0.4	0.5	A*C	FELT STOKE-ON-TRENT...
19950222	075131.8	52.97	-2.26	382.2	341.5	2.3	2.3	NEWCASTLE-U-LYME,STAFFS	4+	20	29	95	0.13	0.5	0.7	A*C	C/F, FELT NEW-U-LYME...
19950222	103309.4	53.02	-2.19	387.3	346.8	1.7	2.0	STOKE-ON-TRENT,STAFFS		13	23	159	0.17	0.8	0.9	B*C	
19950222	211503.0	53.03	-2.19	387.0	348.1	1.7	2.3	STOKE-ON-TRENT,STAFFS	4+	15	24	98	0.13	0.6	0.7	A*C	FELT STOKE-ON-TRENT
19950224	103122.0	53.03	-2.19	387.2	348.0	1.3	2.2	STOKE-ON-TRENT,STAFFS	3+	17	23	99	0.15	0.5	0.6	B*C	FELT STOKE-ON-TRENT...
19950311	144414.6	54.30	-4.00	269.6	491.4	9.8	2.3	IRISH SEA		14	30	167	0.12	0.6	4.0	B*C	12KM EAST OF RAMSEY
19950313	224510.5	51.55	-3.13	321.9	184.3	11.0	2.2	CARDIFF,SOUTH GLAMORGAN		15	24	88	0.10	0.4	1.3	A*C	
19950318	234402.5	62.34	2.77	647.0	1393.6	15.0	2.4	NORTHERN NORTH SEA		5	325	354	0.11			D*D	
19950413	203412.6	58.81	0.51	544.8	994.1	8.0	2.2	NORTHERN NORTH SEA		13	167	248	0.11	2.0	1.9	B*D	
19950421	181618.3	62.31	1.20	565.7	1385.0	19.8	2.9	NORTHERN NORTH SEA		24	217	232	0.29	2.4	3.1	B*D	
19950501	233048.6	61.37	2.45	638.0	1284.6	7.1	2.5	NORTHERN NORTH SEA		22	129	179	0.47	1.6	2.0	C*D	
19950502	042334.0	61.97	2.23	621.8	1350.1	9.5	2.1	NORTHERN NORTH SEA		18	154	208	0.32	2.6	2.6	C*D	
19950502	231444.0	53.10	2.19	680.7	363.8	2.3	3.4	SOUTHERN NORTH SEA		9	58	316	0.11	5.2	3.8	D*D	65KM NE OF GT YARMOUTH
19950515	084254.2	62.29	2.33	624.6	1386.7	13.7	3.4	NORTHERN NORTH SEA		46	162	220	0.38	1.6	2.3	C*D	
19950620	212217.6	61.59	3.63	698.8	1313.4	17.3	3.2	NORTHERN NORTH SEA		23	149	263	0.22	4.5	4.7	C*D	
19950628	054831.1	59.06	1.50	600.4	1024.8	8.1	3.6	NORTHERN NORTH SEA		30	178	135	0.42	1.3	2.4	C*D	
19950706	103829.3	55.23	-3.51	304.2	593.8	8.4	2.1	JOHNSTONEBRIDGE,D & G		32	11	58	0.15	0.3	1.0	B*B	
19950813	095957.3	61.31	2.41	635.9	1277.7	15.0	3.0	NORTHERN NORTH SEA		10	236	333	0.13			D*D	
19950817	160123.3	49.88	-4.26	237.5	0.6	11.1	3.1	ENGLISH CHANNEL		20	56	172	0.14	0.9	1.5	A*D	55KM SOUTH OF PLYMOUTH
19950818	132635.1	61.57	4.21	729.5	1314.9	20.8	3.2	NORTHERN NORTH SEA		11	334	335	0.12			D*D	
19950828	095917.5	57.25	-3.86	287.9	818.8	7.6	2.7	AVIEMORE,HIGHLAND	4	21	37	41	0.19	0.6	4.5	B*C	FELT AVIEMORE....
19950908	094918.2	61.83	4.38	735.6	1343.8	17.3	2.6	NORTHERN NORTH SEA		6	355	355	0.02			D*D	
19950908	195722.4	61.75	4.05	719.0	1334.1	5.1	3.1	NORTHERN NORTH SEA		18	56	182	0.25	1.1	1.2	B*D	
19950909	135036.3	61.77	4.03	717.8	1335.9	2.4	3.4	NORTHERN NORTH SEA		20	57	183	0.30	1.3	1.4	B*D	
19950909	182024.2	50.91	-0.87	479.5	112.4	9.3	2.5	HORNDEAN,HAMPSHIRE		11	21	136	0.09	0.5	2.4	B*C	
19950917	165000.9	61.38	2.68	649.9	1286.7	15.0	2.8	NORTHERN NORTH SEA		12	252	332	0.16			D*D	
19950926	153245.0	53.32	-1.84	410.8	379.8	0.4	2.1	PEAK FOREST,DERBYSHIRE		23	22	97	0.28	0.6	0.9	B*C	COLLAPSE TYPE EVENT
19951003	004251.3	57.07	-5.62	180.4	803.8	4.3	2.1	KNOYDART,HIGHLAND		22	20	88	0.23	0.7	1.4	B*C	
19951011	182039.4	53.06	-1.28	448.5	351.3	6.8	2.4	MANSFIELD,NOTTS	3+	14	24	95	0.28	1.2	2.1	B*C	FELT SOUTH NORMANTON
19951011	212332.7	53.41	-1.16	455.9	390.8	1.0	2.0	MALTBY,S YORKSHIRE	2+	10	30	163	0.36	2.7	5.9	C*C	C/F,FELT STAINTON
19951101	005521.9	53.85	-1.09	459.6	440.0	0.5	2.1	STILLINGFLEET,N YORKS	2+	10	37	145	0.36	2.3	4.0	C*C	C/F,FELT STILLINGFLEET
19951113	080921.2	61.47	3.94	716.0	1302.2	1.5	3.6	NORTHERN NORTH SEA		19	61	171	0.43	1.1	1.4	C*D	
19951129	205140.3	52.96	-2.26	382.3	340.5	1.0	2.0	NEWCASTLE-U-LYME,STAFFS	2+	15	29	94	0.15	0.6	0.9	A*C	C/F,FELT NEW-U-LYME

BRITISH GEOLOGICAL SURVEY
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P A MERRIMAN	- BNFL	J P McFARLANE	- SCOTTISH NUCLEAR
H TUR	- BNFL CAPEN	P W WINTER	- AEA
U M MICHIE	- NIREX	P J BUCKLEY	- HSE
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 PRESS OFFICE
C BEAK	- HYDRO ELEC	DIRECTOR	- BGS
P M BRADFORD	- NII, BOOTLE	M RAINES	- BGS KEYWORTH
J E INKESTER	- NII, BOOTLE	A WHITTAKER	- BGS KEYWORTH
A GONSALVES	- BRITISH GAS	S BRACKELL	- BGS, LONDON INFO OFF
W RICHARDSON	- ISC		

FROM: Glenn Ford/Alice Walker
DATE: 6 November 1995
TIME: 09:30 UTC
PAGES TO FOLLOW: 0

SEISMIC ALERT: WEST LONDON EVENTS OF 4 AND 5 NOVEMBER 1995

Reports of seismic events on Saturday and Sunday 4 and 5 November have been received from Scotland Yard and the Kensington, Chelsea and Fulham Police. They received several calls from concerned residents who reported buildings shaking, candlesticks rocking and a chandelier swinging. On the Saturday, events occurred apparently at about 21:00, 21:30 and 22:13 UTC; on the Sunday, just after 21:00 UTC. The Oasis rock group were playing in a concert at Earls Court Exhibition Centre at the time and BGS attributes these effects to that event. One report was about 1 km from Earls Court and, on the Sunday, there were 15 calls from an area of 1 sq mile. There were no earthquakes nor explosions detected on the BGS seismograph network.

There are similarities between these events and those of 8 and 9 August 1992, when buildings were evacuated around Finsbury Park, north London, at the time of a Madness concert, and on two occasions during the 1980s when U2 were playing in Brussels.

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C BUMPUS	- NIREX	P J BUCKLEY	- HSE
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 PRESS OFFICE
C BEAK	- HYDRO ELEC	DIRECTOR	- BGS
P M BRADFORD	- NII, BOOTLE	M RAINES	- BGS KEYWORTH
J E INKESTER	- NII, BOOTLE	A WHITTAKER	- BGS KEYWORTH
A GONSALVES	- BRITISH GAS	S BRACKELL	- BGS, LONDON INFO OFF
W RICHARDSON	- ISC		

FROM: Bennett Simpsion
DATE: 8 March 1996
TIME: 03:30 UTC
PAGES TO FOLLOW: 2

SEISMIC ALERT: SHREWSBURY, SHROPSHIRE, 7 MARCH 1996 23:41 UTC 3.4ML

A magnitude of 3.4 ML earthquake has been detected by BGS networks in Shropshire on 7 March 1996 at 23:41 UTC with an epicentre 9 km north of Shrewsbury. Reports have been received of it being felt throughout Shrewsbury, Telford and Oswestry. Felt reports describe "a rumble and shuddering" and "felt the settee move sideways".

The following preliminary information is available for this earthquake:

DATE	:	7 March 1996
ORIGIN TIME	:	23:41 24.4s UTC
LAT/LONG	:	52.780 North / 2.740 West
GRID REF	:	349.81 kmE / 321.58 kmN
DEPTH	:	11.6 km
MAGNITUDE	:	3.4 ML
INTENSITY	:	5+
LOCALITY	:	Shrewsbury, Shropshire

Previous events in the area include the Bishop's Castle earthquake of 2 April 1990 (magnitude 5.1 ML) with an epicentre 30 km SW of today's event, the 10 July 1990 Shrewsbury event (magnitude 2.2 ML) 10 km south of today's event and the Newtown event on 17 March 1994 (magnitude 3.1 ML) 30 km SW of today's event.

A seismograph of the event, as recorded on the Hereford n[illegible]ing the seismicity within 50 km of the epicentre are attached.

ANNEX D

BGS STAFF WITH INPUT TO THE PROJECT

Ms R A R Aitken
Mr B J Baptie
Mr J A Bolton
Dr D C Booth
Dr C W A Browitt
Mr R Carsley
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 J H Lovell
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
Mrs 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 G J Webster
Dr P W Wild
Mrs F Wright
Mr R M Young

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1996

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
ORKNEY									
ORE	REAY	58.5480	-3.7622	297.45	963.52	100	95-	4Rm	BGS
OTO	TONGUE	58.4953	-4.3940	260.49	958.79	338	95-	1R	BGS
OHO	HOY	58.8321	-3.2464	328.05	994.48	172	95-	1R	BGS
OWE	WESTRAY	59.3180	-3.0289	341.44	1048.36	87	95-	1R	BGS
OST	STRONSAY	59.0860	-2.5516	368.39	1022.04	15	95-	1R	BGS
OBR	BRABSTER	58.6142	-3.1623	332.47	970.13	89	95-	1R	BGS
MINCH									
RRR	RUBHA REIDH	57.8577	-5.8067	174.19	891.68	61	95-	4Rm	BGS
RSC	SCOURIE	58.3485	-5.1684	214.61	944.33	60	95-	1R	BGS
RRH	RHENIGIDALE	57.9197	-6.6882	122.43	901.86	103	95-	1R	BGS
RFO	FORSNAVAL	58.2133	-7.0052	106.10	935.83	197	95-	1R	BGS
RTO	TOLSTA	58.3778	-6.2092	153.95	950.93	74	95-	1R	BGS
RCR	CAPE WRATH	58.6240	-4.9986	225.90	974.53	100	95-	1R	BGS
REB	EISG-BRACHAIDH	58.1188	-5.2822	206.70	919.10	100	95-	1R	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

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1996

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (M)	Yrs Open	Comp	Agency
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
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

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1996

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (M)	Yrs Open	Comp	Agency
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
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

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1996

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (M)	Yrs Open	Comp	Agency
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
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/95/07	Walker, A.B. and van Barneveld, S.J. HDR Seismic Monitoring Annual Report: 1994 - 1995. April 1995.
WL/95/14	Walker, A.B. and Browitt, C.W.A. UK Earthquake monitoring 1994/95, BGS Seismic Monitoring and Information Service, Sixth Annual Report. June 1995.
WL/95/19	Redmayne, D.W. Ambient Seismic noise at BGS seismometer sites in the UK. June 1995.
WL/95/20	Musson, R.M.W. Report on the relics of West Bromwich Observatory. June 1995.
WL/95/28	Walker, A.B. Transfrontier Research in Low Seismicity Areas. October 1995.
WL/95/30	Galloway, D.D., Redmayne, D.W., Wright F. Guidelines for producing BNFL style reports. March 1996.
WL/95/32	Laughlin, J. User Manual for interfacing the VME Seislog and the 9690 Digital Data Acquisition System. September 1995.
WL/95/34	Wright, F. and Richards, J.A. The Coniston Earthquake of 18 July 1994 (2.2 ML). December 1995.
WL/95/35	Ritchie, M.E.A., Ford, G.D., and Musson, R.M.W. The Newtown earthquake of 17 March 1994 (3.1 ML). December 1995.
WL/96/03	Musson, R.M.W., 1996. Roots and references for the UK earthquake catalogue. January 1996.
WL/96/04	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. and Wright, F. Bulletin of British Earthquakes, 1995. March 1996.
WL/96/12	Musson, R.M.W. On the quality of intensity assignments from historical earthquake data. March 1996.
WL/96/14	Redmayne, D.W., Richards, J.A. and Wild, P.W. Seismic monitoring of mining-induced earthquakes during the closing stages of production at Bilston Glen Colliery, Midlothian, 1987-1990. March 1996.
WL/96/16	Simpson, B.A. The Bristol Channel earthquake of 1 January 1994 (2.8 ML). March 1996.

In addition, two 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

Haak, H.W., van Bodegraven, J.A., Sleeman, R., Verbeiren, R., Ahorner, L., Meidow, H., Grünthal, G., Hoang-Trong, P., Musson, R.M.W., Henni, P., Schenková, Z. and Zimová, R., 1995. The macroseismic map of the 1992 Roermond earthquake, the Netherlands. Geologie en Mijnbouw, 73, 265-270.

Musson, R.M.W., Grünthal, G. and Stucchi, M., 1995. Comment on "The 17 August 1991 Honeydew Earthquake: a Case for Revising the Modified Mercalli Scale in Sparsely Populated Areas" by Dengler and McPherson. Bull. Seism. Soc. Am., 85:4, 1266-1267.

Ritchie, M.E.A., 1996. Seismicity of the Montgomery sheet and the Shelve area to the north. In: Cave, R. and Hains, B.A., The geology of the country around Montgomery. Memoir for 1:50,000 geological sheet 165 (England and Wales). Memoir of the British Geological Survey.

PUBLICATION SUMMARIES ANNEX G

HDR SEISMIC MONITORING ANNUAL REPORT: 1994 - 1995

A B Walker and S J van Barneveld

The potential for earthquakes to be triggered by fluid injected into boreholes has been recognised for over 30 years and natural earthquakes in Cornwall have been reported for over 250 years. As a result, the Geothermal Steering Committee which advised the Hot Dry Rock 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 1995. 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 this year, 75 natural earthquakes with magnitudes ranging from -0.6 to 2.2 ML have been located in SW England. Sixty-eight located near Constantine, some 6 km from the HDR site, with magnitudes ranging between -0.6 and 2.2 ML. The largest of the events was felt by local residents in Constantine, Four Lanes, Penryn and Helston with an intensity of at least 4 MSK on 11 June 1994. Another smaller event (1.6 ML), was also felt two hours later. They form part of the continuing series of natural earthquakes located in that area since 1981, now including seven felt events. No hydrofracture or peripheral events, which might have been associated with the HDR experiments, were detected in the monitoring period.

Since 1981, Cornwall has proved to be an area of moderate seismicity within the UK with seven events felt by people from epicentres near the village of Constantine, 6 km south of the HDR site, and one felt around Liskeard near the Cornwall-Devon border. The Richter magnitudes (ML) of these events ranged from 1.9 to 3.5 ML. Some 700 smaller, natural earthquakes, which were imperceptible to people, have been located in the region, including many aftershocks of the larger Constantine events.

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

A B Walker and C W A Browitt

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).

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.

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.

AMBIENT SEISMIC NOISE AT BGS SEISMOMETER SITES IN THE UK

D W Redmayne

Ambient noise, from mainly natural sources, was sampled at all the BGS normal-gain seismometer sites in the UK in conditions of 'low', 'normal' and 'high' background noise as judged by a BGS seismic analyst. Values of noise were measured as ground displacements in nanometres and tabulated in this report. Generally, background noise is lowest on the hard rock sites of north-west Britain and highest on the softer rocks of the south and east. On hard rock sites peak ambient noise at seismic frequencies is typically around 10 Hz whereas resonance effects in areas of softer sediments result in peak noise at frequencies as low as 1 Hz. Comparison of noise levels at sites where surface seismometers have been replaced by borehole instruments suggests that significant reductions in background noise can be achieved with boreholes a few tens of metres deep.

Typically, most seismometer sites experience around 1 nm of noise in low noise conditions. Normal noise conditions vary from around 2 nm to 6 nm. High noise conditions vary much more widely but are typically in the range 8 nm to 20 nm, although some sites can be as low as 1 nm for high noise and others exceed 90 nm. Although in general agreement with earlier assumptions about background noise in the UK, the values in this report will help to tailor earthquake detection estimations more accurately to specific areas.

REPORT ON THE RELICS OF WEST BROMWICH OBSERVATORY

R M W Musson

The West Bromwich Observatory was not a formally-instated observatory but rather a convenience term for the seismic monitoring carried out by JJ Shaw (who was actually a pawnbroker by trade). Shaw is best known as the man who developed John Milne's original design into the much improved Milne-Shaw instrument. After his death his work was carried on fitfully by his son, HV Shaw. The surviving papers of the two Shaws have been traced to the Lapworth Museum, Birmingham. This report presents a preliminary calendar of the materials in the collection.

TRANSFRONTIER RESEARCH IN LOW SEISMICITY AREAS

A B Walker

It has become widely recognised in recent years that areas of low to medium seismicity contain a definite risk for industrialised countries which engage in 'high consequence' activities (eg nuclear power and reprocessing, offshore and onshore hydrocarbon exploitation, chemical works and large engineered structures such as bridges and tunnels). Understanding the earthquake hazard and identifying the causative faults in such areas is difficult because of the infrequency of the larger earthquakes and the relatively short period of instrumental monitoring. Recognising that 10 of the northern and western Member States of the European Union fall into the category outlined above, the Commission contracted research under the Second Framework Agreement for these States to improve, enhance and harmonise their capabilities in this area. Emphasis was to be placed on tackling the problems of free and rapid data exchange, particularly in transfrontier areas.

Methods of rapid access to earthquake information in one Member State by any other participant have been pursued, using the latest computer-to-computer data exchange techniques (AutoDRM), which also open up the prospect of more wide-ranging interaction elsewhere. Fax machines, computer bulletin boards, 'dial-up' seismograph stations and real-time transmission of data across borders by radio and land-line will become secondary methods with the expansion of AutoDRM within the project and the convergence towards such techniques among the wider community.

GUIDELINES FOR PRODUCING BNFL STYLE REPORTS

D D Galloway, D W Redmayne and F Wright

These guidelines give the procedures and patterns for producing British Nuclear Fuels Limited (BNFL) style annual reports for the microseismic monitoring of a specified area. Command files are specified along with the details of their use. Standard WordPerfect files giving outline text are also included. Much of each report will follow the standard pattern, however, in most cases individual variations on this will be required. Event and focal mechanism descriptions, although standard in style, will be different for each report.

The standard format for BNFL reports was initially developed for CEGB and later for Nuclear Electric reports. A number of improvements have been made to the initial format and more will be made in the future as new techniques become available.These guidelines are a guide to their present production on the Murchison House computer and on WordPerfect.

USER MANUAL FOR INTERFACING THE SEISLOG COMPUTER AND THE 9690 SP DIGITAL DATA ACQUISITION SYSTEM

J Laughlin

This document contains the description, installation procedures and operating guide for the system which records digital data from a seismic network using the Earth Data 9690 digital telemetry system and Interpolating Line Interface (ILI). This equipment is interfaced to the SEISLOG computer via a BGS designed FIFO (First In First Out) buffer and driver software.

The manual is limited to the Seislog ILI driver, the ILI unit and the FIFO buffer. It does not cover the 9690 Digital Modulators or the Seislog system in general. It describes installation, operation, and fault finding procedures.

The three separate functional blocks, the FIFO Buffer and the Software Driver in combination provide the Seislog system with the facility to access remote seismic digital data. The data are digitised local to the transducer with a dynamic range of 96db and bandwidth of 30Hz, which is defined by digital brick-wall filtering within the ILI. There is no further degradation of the seismic information after digitisation because the system is completely digital throughout the data transmission path. The system can digitise up to 16 seismic sites each with a three component set.

THE CONISTON EARTHQUAKE OF 18 JULY 1994 (2.2 ML)

F Wright and J A Richards

On 18 July 1994 at 12:29 UTC, a magnitude 2.2 ML earthquake occurred in the Wrynose Pass area of the Lake District, 6 km NNW of Coniston, Cumbria. The computed focal depth was 12.5 km. A macroseismic survey was not undertaken but felt reports indicated a maximum intensity of at least 3 EMS. Past seismicity includes a number of events located a few kilometres to the east, in the Grasmere/Ambleside area, notably the magnitude 3.0 ML Ambleside earthquake of 12 September 1988.

The fault plane solution for the Coniston event suggests reverse faulting with a small strike-slip component. Movement took place either on a plane striking N-S and dipping westwards at about 60°, or on a plane striking NE-SW and dipping at 45° to the SE. The mechanism is consistent with a generally NW-SE regional compressive stress direction determined for most of Britain and NW Europe. The causative fault cannot be identified with any degree of certainty because the geology and structure at depth are unknown, but the evidence obtained appears to be consistent with a possible origin on the Coniston Fault.

PUBLICATION SUMMARIES ANNEX G

THE NEWTOWN EARTHQUAKE OF 17 MARCH 1994 (3.1 ML)

M E A Ritchie, G D Ford and R M W Musson

A magnitude 3.1 ML earthquake occurred on 17 March 1994 near Newtown, Mid Wales at a depth of 21.6 ± 4.4 km in the lower crust. It was followed by two small aftershocks suggesting incomplete release of strain energy following the mainshock. Detailed analysis of the event using spectral analysis, focal mechanism study and the results of a macroseismic survey yielded detailed hypocentral parameters. The event was felt over an area of 6,500 km^2 (2 EMS) and had a seismic moment of around 3.1×10^{20} dyne cm, a moment magnitude of 3.0 and an estimated fault radius of 155 m. Preliminary examination of heat-flow maps for the Newtown area suggest a lower than average heat-flow and may be an indication of a depressed seismogenic zone, as reflected by the anomalously deep seismicity.

The focal mechanism obtained for the mainshock shows dominant reverse faulting, with a strike-slip component, about either a NNE- or ENE-striking fault plane. The direction of the principal compressive stress axis is NW-SE and agrees with that usually observed for the UK. The orientation of both the intermediate and minimum compressive stress axes, however, suggests a relative rotation, possibly in response to local geology.

ROOTS AND REFERENCES FOR THE UK EARTHQUAKE CATALOGUE

R M W Musson

The Basic European Earthquake Catalogue project (BEECD), which is an EC Environment project (contract EV5V-CT94-0497), will in due course prepare an earthquake catalogue for the whole of the European area to a common standard. The preliminary work to be done involves evaluating the entries in existing national earthquakes catalogues. This is to be done in the first instance by classifying the roots of each catalogue entry as a means of establishing its quality - does it relate closely to original source materials or is it a set of parameters that has been passed down from one parametric catalogue to another without any checking?

This report takes the UK earthquake catalogue of Musson (1994) and classifies the roots of each pre-1970 event according to a standard system, and also introduces a prime reference code for each event. The results show high quality codes throughout the catalogue with very few exceptions, a reflection of the high standard of historical earthquake research practised in the UK in the various studies conducted in the last twenty years by various authors on whose work the UK earthquake catalogue draws.

BULLETIN OF BRITISH EARTHQUAKES 1995

A B Walker (editor)

There have been 225 earthquakes located by the monitoring network in the year, with 38 of them having magnitudes of 2.0 ML or greater. Of these, nine are known to have been felt, together with a further twelve smaller ones, bringing the total to twenty one felt earthquakes in 1995.

The two largest onshore earthquakes during 1995 had magnitudes of 2.7 ML. The first occurred at Reedham in Norfolk on 1 January. No felt reports were received and it is thought that this may be due to the depth of occurrence (6 km) or time of year. The other, occurred near Aviemore, Highlands, on 28 August and was felt in Boat of Garten, Aviemore, Grantown-on-Spey, Carrbridge and many of the surrounding villages. Felt reports described "a bang, a rumble, the building shaking" and one person reported that "ornaments moved and glasses shook"; a few reports of minor damage were also received. The earthquake was felt over 1300 km^2 (Isoseismal 3) and located in an area where no previous seismicity had been recorded. A macroseismic survey throughout the region showed that it was felt in the epicentral area with a maximum intensity of 4 EMS. The two largest offshore earthquakes, with magnitudes of 3.6 ML, were located in the northern North Sea on 28 June and 13 November.

Several events of interest have been recorded throughout the year, in Stoke-on-Trent, in the Irish Sea, near Cardiff, in the English Channel, near Horndean and in Mansfield.

Some 56 coalfield events with magnitudes ranging between 0.5 and 2.3 ML have been detected in 1995, thirteen of which were felt. Thirty-one of them located in the Clackmannan area in the central region of Scotland, where the magnitudes ranged from 0.5 to 1.8 ML; five of these were felt by local residents.

ON THE QUALITY OF INTENSITY ASSIGNMENTS FROM HISTORICAL EARTHQUAKE DATA

R M W Musson

It is well understood that expression of the epicentral parameters of an earthquake should be accompanied with a measure of the uncertainty in these parameters. An epicentral position determined ± 30 km will be treated differently in subsequent analyses from one determined ± 5 km. The same is true with regard to intensity values, although this is less frequently done. In this paper the causes and expression of uncertainty in intensity values will be considered with special reference to those derived for historical earthquakes, although the same considerations (to a lesser extent) may still be applicable to modern macroseismic data.

SEISMIC MONITORING OF MINING-INDUCED EARTHQUAKES DURING THE CLOSING STAGES OF PRODUCTION AT BILSTON GLEN COLLIERY, MIDLOTHIAN, 1987-1990.

D W Redmayne, J A Richards and P W Wild

Early in November 1987, the British Geological Survey installed a seismometer network in and around Rosslyn Chapel, in the Midlothian Coalfield, to monitor earthquakes which were causing damage. The network was in operation until January 1990, during which time 247 locatable earthquakes were detected. Accurate locations were obtained for these events and epicentres and depths proved to be closely associated, in space and time, with concurrent mining around the villages of Roslin and Rosewell. This, along with evidence that the level of seismicity followed a pattern related to mining production, indicates that the earthquakes were mining-induced. Earthquake activity in the area died out shortly after the closure of Bilston Glen Mine, the local colliery, in June 1989 and apart from a minor swarm in the summer and autumn of 1990 there has been minimal seismicity until at least March 1996.

A large proportion of the earthquakes had foci close to the depth of past mining in the area, suggesting that residual stresses were an important factor in generating seismicity and, in particular, the larger events. A frequency-magnitude analysis indicates a relatively high abundance of small events in this coalfield area and that the maximum credible magnitude for mining-induced events in this area was around 3.0 ML. Seismograms recorded at Rosslyn Chapel, on a foundation of sand, indicate significant amplification of seismic signals when compared with a nearby bedrock site. This resulted in the high seismic intensities experienced at the chapel and could be an important factor elsewhere on similar sites.

THE BRISTOL CHANNEL EARTHQUAKE 1 JANUARY 1994 (2.8 ML)

B A Simpson

On 1 January 1994 at 03:17 UTC a magnitude 2.8 ML earthquake occurred with an epicentre in the Bristol Channel approximately 30 km SW of Cardiff, South Glamorgan. The computed focal depth was 14.7 km, within the 'basement' crust underlying the Bristol Channel sedimentary basin. Felt reports were received from North Devon and Somerset and indicated a maximum intensity of at least 3 EMS. The location parameters of the event were determined using the BGS seismograph networks in Hartland, Hereford, Swindon, North Wales and Devon and from the Nuclear Electric (formally CEGB) Hinkley Point network.

An interpretation of the focal mechanism of the event shows two possible mechanism types, one showing strike-slip faulting and the other representing normal faulting. The P-axes are horizontal for the strike-slip mechanisms and trend NW-SE, in agreement with the regional compressive stress direction observed generally in Britain. The normal faulting mechanism, however, shows the P-axes to be vertical, which indicates a rotation of the regional stress tensor. The causative fault cannot be identified with any degree of certainty because the geology and structure at depth are unknown.

This earthquake occurred in a region where previous seismic activity has been detected, with a number of previous events some 30 kilometres to the east, in the Bristol Channel/Bridgwater Bay area. The largest of these recorded in recent times was the magnitude 2.8 ML Bridgwater Bay earthquake of 23 October 1988.

THE MACROSEISMIC MAP OF THE 1992 ROERMOND EARTHQUAKE, THE NETHERLANDS

H W Haak, J A van Bodegraven, R Sleeman, R Verbeiren, L Ahorner, H Meidow, G Grünthal, P Hoang-Trong, R M W Musson, P Henni, Z Schenková and R Zimová

The effects of the 13 April 1992 Roermond earthquake were felt in the Netherlands, Germany, Belgium, Luxembourg, France, the UK, the Czech Republic, Switzerland and Austria. Macroseismic data was gathered by seismologists in six of these countries, and combined in a single coherent intensity data file. The maximum intensity was 7 EMS and the earthquake was felt over 600,000 km^2. This international effort has allowed the construction of a good quality isoseismal map of the earthquake. Macroseismic parameters derived from this study agree well with the instrumentally derived ones.

COMMENT ON "THE 17 AUGUST 1991 HONEYDEW EARTHQUAKE: A CASE FOR REVISING THE MODIFIED MERCALLI SCALE IN SPARSELY POPULATED AREAS" BY DENGLER AND McPHERSON

R M W Musson, G Grünthal and M Stucchi

The paper commented on, proposes a new version of the Modified Mercalli Scale, which will add further to the confusion surrounding the large number of scales bearing this name. The proposed new version contains a number of features which are unreliable or misleading. These problems are pointed out, and the solutions found for the European Macroseismic Scale are recommended.

SEISMICITY OF THE MONTGOMERY SHEET AND THE SHELVE AREA TO THE NORTH

M E A Ritchie

The BGS earthquake database was searched for the period 1 January 1970 to 1 September 1995 for the area including the Montgomery sheet and the Shelve area immediately to the North. Eleven earthquakes, ranging in magnitude from 0.0 to 5.1 ML were detected within the area; the Bishop's Castle mainshock, seven aftershocks and three small events representing background seismicity. The largest of these was the magnitude 5.1 ML Bishop's Castle earthquake of 2 April 1990. The initial hypocentral parameters were published in Ritchie et al, 1990, however, the location, magnitude and focal mechanism have all been revised using more detailed analysis of the digital data. The event occurred in the mid-crust at a depth of 14.1 ± 3.8 km and results from the preliminary macroseismic study indicate a felt area of 245, 000 km^2 at intensity 2 EMS.

The revised focal mechanism is almost identical to the original and shows dominant strike-slip faulting, with a component of either reverse or normal faulting, on either a NS or ENE-striking fault plane which dips W and SSE, respectively. The axis of maximum compression is orientated NW-SE, in agreement with that generally observed for the UK. The revised mechanism for the magnitude 0.5 ML aftershock of 17 April is similar to that of the mainshock, with either a NS or EW-striking fault plane dipping E or almost vertical, respectively.

Although contemporary seismicity was dominated by the Bishop's Castle event and its limited aftershock sequence, the area was also affected by the magnitude 5.4 ML Lleyn event of 19 July 1984; these events representing the two largest onshore events this century. Several significant historical events have also occurred in the general area, at Hereford in 1863 and 1896 and near Ludlow in 1926, suggesting this is an area which generally suffers larger and more frequent seismicity than the majority of the UK.

ANNEX H

SYNOPSIS OF THE EUROPEAN MACROSEISMIC SCALE - EMS 92

1 - Not felt
Not felt, even under the most favourable circumstances.

2 - Scarcely felt
Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.

3 - Weak
The vibration is weak and is felt indoors by a few people. People at rest feel a swaying or light trembling.

4 - Largely observed
The earthquake is felt indoors by many people, outdoors by very few. A few people are awakened. The level of vibration is not frightening. Windows, doors and dishes rattle. Hanging objects swing.

5 - Strong
The earthquake is felt indoors by most, outdoors by few. Many sleeping people awake. A few run outdoors. Buildings tremble throughout. Hanging objects swing considerably. China and glasses clatter together. The vibration is strong. Top heavy objects topple over. Doors and windows swing open or shut.

6 - Slightly damaging
Felt by most indoors and by many outdoors. Many people in buildings are frightened and run outdoors. Small objects fall. Slight damage to many ordinary buildings eg; fine cracks in plaster and small pieces of plaster fall.

7 - Damaging
Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many ordinary buildings suffer moderate damage: small cracks in walls; partial collapse of chimneys.

8 - Heavily damaging
Furniture may be overturned. Many ordinary buildings suffer damage: chimneys fall; large cracks appear in walls and a few buildings may partially collapse.

9 - Destructive
Monuments and columns fall or are twisted. Many ordinary buildings partially collapse and a few collapse completely.

10 - Very destructive
Many ordinary buildings collapse.

11 - Devastating
Most ordinary buildings collapse.

12 - Completely devastating
Practically all structures above and below ground are heavily damaged or destroyed.

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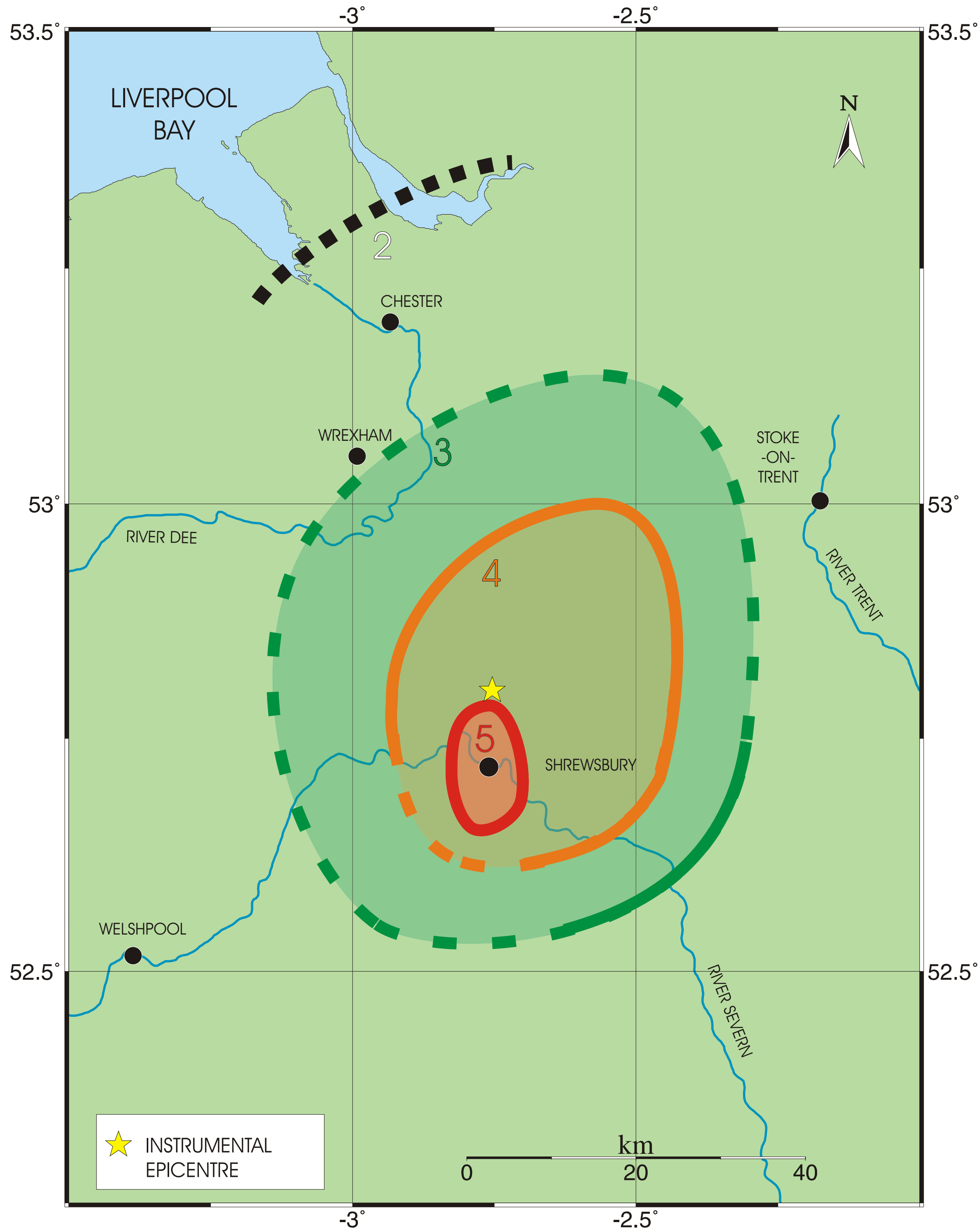
A complete description of the EMS-92 scale is given in: Grunthal, G., (Ed) 1993. European Macroseismic scale 1992 (up-dated MSK-scale). Cahiers du Centre European de Geodynamique et de Seismologie. Vol 7.

Natural Environment Research Council



Shrewsbury Earthquake 7th March 1996, 23:41 UTC (3.4 ML) - EMS Intensities