UK EARTHQUAKE MONITORING 1996/97

BGS Seismic Monitoring and Information Service

Eighth Annual Report

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BRITISH GEOLOGICAL SURVEY

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UK Earthquake Monitoring 1996/97

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Eighth Annual Report

A B Walker

June 1997

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

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

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UK EARTHQUAKE MONITORING 1996/97

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 28 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 eighth year of the project (April 1996 to March 1997), the upgrading of the UK network to the new digital standard, has been completed. One low sensitivity and three 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 204 earthquakes have been located by the monitoring network in 1996, with 27 of them having magnitudes of 2.0 or greater, of which nine are known to have been felt. The largest felt earthquake in the reporting year (April 1996 to March 1997), with a magnitude of 3.8 ML, occurred 12 km offshore, Penzance, Cornwall, on 10 November 1996. The earthquake was felt over an area of 14,000 km^2 and the maximum intensity in the epicentral region was 5 EMS (European Macroseismic Scale, Annex H). The two largest offshore events were in the northern North Sea, with magnitudes of 3.9 ML. 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 Musselburgh, near Edinburgh). During the reporting period, data on four controlled explosions and 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 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 completion of a joint EU project with neighbouring countries (10 member states led by BGS) to promote rapid data exchange across borders has led to a significant advance in the free flow of information. This 'Transfrontier Group' has adopted an e-mail based protocol for data exchange which operates in an automatic way, thereby avoiding time consuming person-to-person interactions and the problems of earthquakes which occur outwith working hours.

The potential of the network's data links and computing capabilities to provide an environmental monitoring capacity has been explored further using additional sensors. They now include radioactivity, ozone, sulphur dioxide and NOx gases. Proposal have been submitted to SEPA and the EU to help expand this environmental capability.

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 otherwise could prove hazardous to the population. 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 earthquakes.

This Year 8 report to the Customer Group follows the format of the first seven annual reports in reiterating the programme objectives and highlighting some of the significant seismic events in the period April 1996 to March 1997. The catalogue of earthquakes for the whole of 1996 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. Such events are normally felt by people.

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 added to it. 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. Three new strong motion systems have been established, during the year, at Lerwick, Keyworth and near Edinburgh, together with one low-gain instrument in south Devon. 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.

Filling the few remaining gaps in the high sensitivity network, which is intended to have effective station spacing of 70 km, continues to be a project objective although no progress has been possible during the year.

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 they were installed. Strong motion coverage is shown in Figure 6.

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. 5) 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.

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

3.3 Summary of achievements since 1989

Improvements in network coverage, event detection, delivery of information, databasing and archiving have been made during the course of the project. Highlights are outlined below.

- The installation of seismograph stations to fill in the gaps for the 70 km spacing objective; from 84 stations in 1988 to 141 in 1997. Large areas have been filled in southern England, Irish Sea and northern Scotland.

- The detection capabilities of the network have gradually improved with increasing station coverage and Figures 3 and 4 illustrate the change over the 8-year project period. Almost all magnitude 2.5 earthquakes are felt together with many in the 2.0-2.5 range, and, in 1988, there was poor coverage of such events in many parts of the country.

- In 1988, all stations were recording onto magnetic tapes, which were posted to Edinburgh for analysis. Access to data was generally achieved within two working days of a felt earthquake. In 1997, all stations are recording onto a computer and digital data is transferred automatically four times a day and at any other times if an earthquake occurs. Response time with objective data has been reduced to below one hour which can generally, be achieved outwith working hours also.

- All UK stations have been resurveyed using GPS techniques, with significant variations in positions (> 500m) incorporated into the master list of stations.

- Faster modem links have been installed at all computer nodes (23 in total).

- Following upgrading of digital rapid access systems, the potential problem of losing a continuous data record has been addressed by installing large capacity disks to provide a 3-days ring buffer at 18 nodes and 10-days at the other five. Developments are in progress to provide a cost-effective, continuous digital archive.

- In order to improve the study of seismicity in the border regions of the North and Irish Seas and the English Channel and SW Approaches, strong data exchange links have been established with European neighbours and with the international agencies, EMSC and ISC (the European Mediterranean Seismological Centre, Paris, and the International Seismological Centre, Newbury). In the North, collaboration with Bergen University has provided direct access, on-line, to digital seismograph stations in western Norway. Elsewhere, BGS has coordinated a 10-nation data exchange network (the Transfrontier Group) from Denmark to Portugal under the EU natural hazards programme.

- A 3-component strong motion network has been installed from Shetland to Jersey including 4 stations specifically commissioned by Scottish Nuclear, MOD and the Jersey New Waterworks Company.

- A computer bulletin board has been established which provides access to the catalogued seismic events for the previous 12 months, their phase data and details of seismic alerts issued. The Global Seismology Web site provides access through the Internet to the past month's catalogue of events.

- Historical material from former UK seismic stations has been brought together and housed in a National Seismological Archive (NSA) at the BGS laboratories in Edinburgh, with the collection computer-indexed. A watching brief has been kept on other archives, held elsewhere, with a view to increasing knowledge of the content and preventing their dispersal or destruction. Some of those collections have been transferred to Edinburgh as a result of these interactions.

- UK earthquake data held on ½" FM magnetic tapes, have been extracted and digitised for events with magnitudes ≥ 2.0 since 1977. There remains some data on the Edinburgh network for the period 1970-1976 which was recorded on a 1" tape format.

- The instrumental-recordings, digital database is held in a readily-accessible format (both for parameter and waveform data) and is updated continuously. Back-up copies are held outside the building in a commercial facility.

- An improved catalogue of historical UK earthquake information has been combined with the modern instrumental data to provide the input for 2 seismic hazard studies. The assessment for the offshore region was published in 1997 as a Health and Safety Division Offshore Technology Report and the onshore study which has been peer reviewed and is now with DTI for publication.

- The potential for using the seismic network for multifunctional environmental monitoring has been explored and tested at an experimental site near Edinburgh. A sample of environmental sensors has been interfaced with the seismic data transmission systems and data files to demonstrate the network's capability to provide baseline information, long term trends, climate change parameters and long-range impact of industrial plumes. An MOU with the Met Office has laid the basis of collaboration and meteorological quality control.

4. Development of the monitoring network

4.1 Station distribution

The network developed to March 1997, with rapid-access upgrades, is shown in Figure 1 with its detection capability in Figure 3. The scheduled programme for 1996/97 had as its aims:

(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 10 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 bulletin material held in the NSA will be published.

The upgrading of the network to rapid access has been completed (i) with the installation of rapid access systems in south Devon and Paisley but resources have not become available for the installation of stations in Northern Ireland (ii). An Automatic Data Request Manager has been installed (iii) and has been operating routinely. The multi-functional environmental potential of the network has been enhanced (iv) with the purchase and testing of a NOx sensor and the development of new software to graphically present the data. A study of strong ground motion attenuation in the UK has been completed using the random vibration (stochastic ω^2) method (v). The results of this study are presented as a series of graphs showing attenuation for spectral and peak acceleration values. The limited observed data available show an excellent fit to this theoretically derived model. The digitisation of events recorded on the 1" analogue magnetic tapes (vi) has been started following problems with old hardware and the upgrading and development of software. The installation of additional 4 gigabyte disks (vii) has been fulfilled; with five 4 gigabyte disks installed in Cumbria, East Anglia, Jersey, Keyworth and Moray. The strong motion network (viii) has been enhanced with the installation of three strong motion stations, in Keyworth, Shetland and east of Edinburgh (Musselburgh); all are recorded onto the rapid-access systems. This brings the total number to fifteen. Contact with archives outside BGS has been maintained (ix). The final catalogue of seismological bulletins (x) has been compiled.

4.2 Strong motion network

Obtaining records of strong ground motion for hazard assessments and engineering applications is difficult in areas of low to medium seismicity owing to the infrequency of larger earthquakes. The "importation" of such records from plate margin zones, however, may detract from the realism of analyses conducted in intraplate areas such as the UK. In recognition of the importance of measured strong ground motions, therefore, the project has focused on developing a distribution of 3-component instruments which would remain on-scale for the larger British earthquakes when the high sensitivity network saturates.

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 6. Twelve of the 15 strong motion stations generate open-file data; the other three are operated by, or on behalf of, Scottish Nuclear and MOD.

The impact of this growing network can be seen in Figures 7-10, which show the minimum and maximum magnitudes of earthquakes which can be detected and stay on-scale, as contour maps. Comparisons are drawn between the early phase of development (Figs. 7 and 8) and that prevailing at present (Figs. 9 and 10). Over most of Britain, a magnitude 4.0 earthquake will produce an on-scale trace on at least one strong motion instrument and only rarely will a magnitude 6.0 event cause saturation. The largest known earthquake in the several hundred year historical record, occurred near the Dogger Bank in 1931 with an estimated magnitude of 6.1 ML.

The Penzance earthquake, on 10 November 1996, with a magnitude of 3.8, has written the first of these rare strong motion records at a distance of 34 km from the epicentre (a peak acceleration of 62 mms^{-2}). It is described in more detail below (5.2 (v)). At Musselburgh, east of Edinburgh, a second record was made 1km from the epicentre of a mining-induced earthquake, on 9 January 1997, which had a magnitude of 1.7 ML. The peak acceleration was 92 mms^{-2}.

4.3 Related site specific monitoring

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

(i) Nirex continued to support the enhanced Cumbria network and detailed seismicity studies throughout the year. In view of the decision of the former Secretary of State for the Environment on 17 March 1997 not to approve Nirex's Planning Application for a Rock Characterisation Facility near Sellafield, Nirex has withdrawn funding to the Customer Group after 31 March 1997.

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

(iii) The free-field strong motion system for Scottish Nuclear at Torness has continued to operate.

(iv) The 13 stations in northern Scotland and the Orkney Islands supported by an oil company consortium and HSE has continued with funding assured until March 1998.

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.

4.4 Progress with instrumentation

The 16-bit systems on the Borders and Cumbria networks have continued to provide the increased dynamic range of 92 dB and 24-bit technology has been developed on the back of a contract to operate a 140 dB, dynamic range, system for volcanic monitoring on Montserrat. It has been proved over a period of 9 months and is, therefore, available for appropriate upgrades to the UK network when resources permit. The wide dynamic range removes the distinction between high sensitivity and strong motion systems but the cost of upgrades to 24-bits is considerably more than to 16-bits.

For the exchange of data with neighbouring countries and the European Mediterranean Seismological Centre (EMSC), a software protocol originally developed at ETH, Zurich has been adopted and interfaced with the BGS system. This so-called Automatic Data Request Manager (AutoDRM) is based on electronic mail (e-mail). It parses incoming e-mail for requests of data, processes the requests and returns the requested data by e-mail to the user. Its implementation as a standard is spreading and has been promoted in the EU by the Transfrontier Group of 10 Member States within a rapid data exchange project funded by the EC and coordinated by BGS.

All the networks in the UK now have fast Motorola modems. They permit fast transfer of data from the rapid-access networks to Edinburgh (up to three times faster).

Fifteen of the networks in the UK have one gigabyte disk storage, with only three remaining 400 Mb disks. The 1G disks give a three-day window of continuous data together with extra storage for event files which would be needed during sequences such as that experienced during the Musselburgh series in October/November 1996. Five 4 gigabyte disk have been successfully installed in the reporting period, allowing up to 10 days of continuous data to be recorded in a ring buffer. This 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).

A new operating system (QNX) has been purchased and has been installed on a PC, which is running in parallel with the Lowlands SEISLOG system. It has several advantages over the traditional SEISLOG recording systems (i) increased processing power, (ii) larger memory capacity from 4 Mb to upwards of 32 Mb, (iii) improved communication links using ethernet cards and ISDN links (digital telephone lines), and (iv) is more portable and cost effective.

New software recording data using multi-parameter files has been installed and operated on the Lowlands network. It is designed to trigger on different types of events using the frequency content of the signal, thereby providing the potential for more automated discrimination between local earthquakes, teleseisms, quarries, sonic booms etc.

4.5 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, radioactivity, sulphur dioxide, UVB and humidity data are being transmitted to a base station (Fig. 25). The station has the capacity to transmit data from 16 environmental sensors simultaneously. Hardware and software have been upgraded during the 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. A high sensitivity NOx sensor, capable of monitoring gas concentrations in the parts per billion range has recently been acquired. It has been interfaced to the standard data logging system and is currently undergoing evaluation within Murchison House prior to its deployment at a site near Edinburgh. Selected potential users of the system, including the Scottish Environmental Protection Agency and the Scottish Water Authorities, have been given demonstrations of the monitoring capabilities 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 8

5.1 Earthquakes located for 1996

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 1996 published and distributed in April 1997 (Walker, 1997). A map of the 204 events located in 1996 is reproduced here as Figure 11 and a catalogue of those with magnitudes of 2.0 or greater is given in Annex B. Nine in that magnitude category, together with 25 smaller ones, are known to have been felt. In the period since BGS extended its modern seismic monitoring in the UK (1979 to March 1997), almost all of the earthquakes with magnitudes ≥ 2.5 ML are believed to have been detected. The distribution of such events for that period (Fig. 12) 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 1996 to March 1997) are given below:

(i) On 6 May, an earthquake, with a magnitude of 2.8 ML, was felt in the Stoke-on-Trent area. The reports described a "rumble and bang". A macroseismic survey in the region revealed that it was felt over 900 km^2, with a maximum intensity of 4 EMS in the epicentral area. A further six events occurred in the area, with magnitudes ranging between 1.2 and 1.9 ML. Swarms of activity were detected in this same area in the mid 1970s, early 1980s, early 1990s and more recently in February 1995, where 6 events were felt in four days.

(ii) On 18 May, an earthquake, with a magnitude of 2.9 ML, occurred some 2 km north of the village of Furnace, on the banks of Loch Fyne, Strathclyde. It was felt in Furnace, Strachur and Inveraray with intensities of at least 3 EMS. Felt reports described "a large bang, followed by the whole house shaking" and " a light rattling of crockery on a display cabinet". An event, with a magnitude of 1.5 ML, occurred two days later in the same area, but was not reported felt.

(iii) An earthquake, with a magnitude of 3.0 ML, occurred on 20 September near Llanddewi Ystradenni, approximately 9 km NNE of Llandrindod Wells. A seismogram of the event recorded on the Hereford network is shown in Figure 13. The event was felt by local residents in Llandrindod Wells, Knighton, Rhayader, Builth Wells and in the village of Llanbister. Felt reports described "a shudder" and "the whole house shook and windows rattled" indicating an intensity of at least 4 EMS. No macroseismic survey was carried out, owing to the few reports received from each of the villages.

(iv) In Comrie, Tayside, a small earthquake with a magnitude of 1.4 ML, was felt by local residents on 20 October. A seismogram recorded on the Lowlands network is shown in Figure 14. Felt reports described a "big bang and a rumble" indicating a maximum intensity of at least 3 EMS. There have been occasional events over the past few years in the region which was famous for the frequency of its earthquakes in the 1790's, 1830s and 1840s. In 1875, following a number of small events, Victorian naturalists built an observatory with crude earthquake detection instruments in an attempt to learn more about the earthquakes. The observatory, which is called 'Earthquake House', has been restored and opened to the public by the Perth and Kinross Council with some help from BGS (Plate 1).

(v) The largest earthquake to affect the onshore area, 12 km south of Penzance, Cornwall occurred on 10 November. It had a magnitude of 3.8 ML and was felt over an area of 14,000 km^2 throughout the south west of England. Seismograms of the event recorded on the north Devon network are shown in Figure 15 and records from the strong motion instruments near Falmouth, some 34 km from the epicentre, are shown in Figure 16. The maximum ground acceleration measured at this site was 62 mms^{-2} on the vertical accelerometer, which is equivalent to 0.006g and it was felt, at this distance, with an intensity of 4 EMS (below damaging level). This is higher than the signal recorded on the horizontal components (52 mms^{-2} (NS component) and 27 mms^{-2} (EW component), respectively) and could be related to the focal mechanism of the event, which indicated normal faulting. A macroseismic survey was carried out and over 900 replies were received. A maximum intensity of 5 EMS was assessed close to the epicentre where minor damage (cracked plaster) occurred. Three aftershocks were detected, on the same day, but none were felt. This is the largest event to have affected mainland UK since the 15 February 1994 Norwich earthquake (magnitude 4.0 ML), which was felt with an intensity of 5 EMS in the epicentral area, and the largest in the region since the magnitude 4.4 ML Penzance earthquake on 15 July 1757, which was felt with intensities of between 5 and 6. Comparison between the 1996 and 1757 Penzance earthquakes is particularly interesting. The epicentres appear to be similar, and the intensity distributions also have much in common, allowing for the fact that the data for the recent event are far superior in quality and distribution. The macroseismic magnitude for the 1996 event overestimates the instrumental magnitude, and this may indicate that the macroseismic magnitude of the 1757 earthquake (4.4 ML) may also be an overestimate. It would therefore be a worthwhile exercise to investigate regional intensity attenuation in Cornwall with a view to revising seismic hazard estimates for this area. This is an excellent example of the way in which modern earthquakes can throw light on, and prompt reinterpretation of, historical data.

(vi) The two largest offshore earthquakes during the reporting year, with magnitudes of 3.9 ML, were located in the northern North Sea region on 25 June and 31 October; neither was reported felt. A further ten events occurred in the northern North Sea during the year, with magnitudes ranging between 1.8 and 3.8 ML, and were located using both the BGS and

Norwegian networks. Only one earthquake in the northern North Sea was reported felt during the year. It occurred on 16 December, with a magnitude of 3.3 ML, and was felt in Norway at the Fedje Fyr lighthouse and the village of Vaksdal.

(vii) A swarm of fourteen earthquakes was detected approximately 10 km south of the Isle of Arran, Strathclyde, during the year. The largest, with a magnitude of 2.2 ML, occurred on 26 June and was not reported felt. Similar swarms in the area were detected in the early 1990s.

(viii) Three events were located in the southern North Sea region, with magnitudes of 1.7, 1.8 and 2.1 ML; none were reported felt. These events are in the same area as the event on 2 May 1995, which had a magnitude of 3.4 ML.

(ix) In North Wales, three events with magnitudes of 0.1, 0.6 and 1.2 ML were located on the Lleyn Peninsula, in the same area and at similar depths, as the magnitude 5.4 ML Lleyn Peninsula earthquake of 19 July 1984, which was felt over an area of 250,000 km^2.

(x) An earthquake, with a magnitude of 1.9 ML, occurred near Maidenhead in Berkshire, on 8 December. This event, together with two others (Reading, 27 July 1985, 2.1 ML and Fleet, 2 December 1985, 2.7 ML), both some 30 km distant, represents the only seismicity detected in the area over the past 27 years.

(xi) On Rannoch Moor, Tayside, Scotland, an earthquake, with a magnitude of 2.6 ML, was felt by local residents in Appin and Bridge of Orchy on 4 February 1997. They described "the whole house shook" and "heard a loud bang". It occurred in a remote area where few earthquakes have been located previously.

(xii) On 10 February 1997, an earthquake, with a magnitude of 2.8 ML, was felt in Ashgate, South Wingfield and Matlock, Derbyshire. Felt reports described "the whole bed shook" and "the house trembled" indicating an intensity of at least 3 EMS.

(xiii) Near Mansfield, Nottinghamshire four events with magnitudes ranging from 0.7 to 2.1 ML have been located, one of which was felt by local residents in the Wellow region of Mansfield. At shallow depths, they are believed to be of coal mining origin.

(xiv) The coalfield areas of central Scotland, Yorkshire, Staffordshire and Nottinghamshire continued to experience earthquake activity of a shallow nature which is believed to be mining induced. Some 84 coalfield events, with magnitudes ranging between -0.6 and 2.1 ML, have been located in the year. Twenty-nine of these were felt by local residents; 26 from the series east of Edinburgh. Eighteen events, with magnitudes ranging between 0.7 and 1.5 ML, were located near Clackmannan in the central region of Scotland, an area which has experienced many such mining induced events in the past.

(xv) On 2 October 1996, an earth tremor was felt strongly by residents in the Newcraighall/Musselburgh area to the east of Edinburgh. Eight other events, which were not felt, were detected in the period 8 to 11 October before another felt one occurred. Thereafter, the tremors, both felt and not felt, increased in frequency until mid-November. After a few weeks of minimal activity, felt events resumed on 7 January and the total number recorded by BGS up to the end of March 1997 is 139 (54 were located a further 85 were detected on one station near the epicentre). The largest event, with a magnitude of 2.0 ML, occurred on 25 October and was felt with intensities of up to 5 EMS. Information directly from local residents and through the completion of macroseismic questionnaires, distributed by BGS and published in local newspapers, have shown that the events were generally felt up to 2 km from the epicentre and in some cases up to 3 km. Macroseismic maps of the four events studied in detail are shown on the back cover of this report. Twenty-six events in the series were felt by local residents. The shocks were frequently compared to a nearby explosion or a lorry shaking the house, and in some cases residents were frightened and ran outside. However, few effects on objects were observed. Macroseismic effects were consistent with small, shallow events producing relatively high frequency vibration. Additional instruments were installed in the area and the results showed that the pattern (most events occurring in the working week, Figure 17) and location of the activity was a consequence of mining at Monktonhall colliery. A seismogram from the nearby strong motion instrument (within 1 km of the epicentre) of the event on 9 January 1997 (magnitude 1.7 ML), is shown in Figure 18. The maximum horizontal ground acceleration was 92 mms^{-2} and the felt intensity near the site was 4 EMS (below damaging level). The two most likely causes of these events are: the undermining and subsidence of old workings with void and pillar collapses and shearing in strained rock layers; the bridging, and subsequent breaking during subsidence, of a strong rock layer between the mine and the surface (in this case, 900 metres above).

(xvi) In other coalfield areas, small events were located near Worksop, Nottinghamshire (1.3 ML, 11 April and 1.1 ML, 12 April 1996; none were reported felt), Ollerton, Nottinghamshire (two events with magnitudes of 1.0 ML and 2.0 ML on 10 September 1996 and 4 October 1996, respectively), Ranskill, Nottinghamshire (1.5 ML, 6 February 1997, felt by a number of people in Ranskill), Maltby, South Yorkshire (1.6 ML, 7 February 1997) and Blyth, Nottinghamshire (2.0 ML, 23 March 1997, felt by one person in Blyth). These events are presumed to be related to present-day coal mining activity.

(xvii) 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 (Figure 19). Specific examples are: mid Wales (30 April 1996), Isle of Man (21 May 1996), Lothian (19 November 1996), North Wales (12 March 1997) and South Yorkshire (24 March 1997).

(xviii) Reports have been received of man-made events which were the focus of media attention. Offshore the town of Felixstowe, East Anglia on 23 July 1996, a controlled explosion to detonate ordnance dragged in by a fishing trawler's net, was conducted. On 27 August 1996, blasting at a quarry in Cowieslinn, Lothian, was felt by local residents. Two WWII mines were detonated; offshore Amble, Northumberland, on 5 March 1997, and on 9 March 1997, offshore Port Seton, near Edinburgh. The former was felt by local residents who described "glasses on the dressing table shook" and the explosion off Port Seton, was reported in local newspapers. A seismogram of the explosion offshore Amble is shown in Figure 20.

(xix) On 8 June 1996, a nuclear explosion (magnitude 6.0 MB) from the Lop Nur test site in China, was recorded throughout the UK network. 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 21.

5.3 Annecy, France earthquake

The earthquake that occurred at Annecy (Haute Savoie, France) on 15 July 1996 at 00:13 UTC, with a magnitude of 5.3 ML, is the largest event in the French Alps since the magnitude 5.3 Corrençon earthquake of 25 April 1962. Heavy damage was observed at Epagny, Metz-Tessy (Plate 2), Meythet, Poisy and NW of Annecy; in particular, two churches were closed to the public due to numerous cracks on the vault; a 4-storey building was evacuated. The maximum intensity was evaluated to be 7-8 EMS and it is thought that the heavy damage was a result of site effects and shallow depth.

The mainshock was recorded by French and all European seismic networks, which provided good digital signals from more than 200 stations. The well-constrained hypocentral determination indicates an epicentre a few kilometres NW of Annecy and a shallow focal depth of 4 km. A reliable focal mechanism was obtained, indicating strike-slip faulting with near-vertical nodal planes. The Vuache fault, striking NW-SE, is compatible with the nodal plane which dips to the NE and the 1000 aftershocks which were recorded, elongate in a NW-SE direction and also coincides with the strike of the Vuache fault. The largest aftershock had a magnitude of 4.3 ML.

The Annecy earthquake is similar in size to the Lleyn Peninsula earthquake, which occurred in 1984, with a magnitude of 5.4 ML. In that case, however, it was located at a depth of around 20 km with lower intensities (6 EMS) reported in the epicentral area. A seismogram of the Annecy earthquake recorded on the south east England network is shown in Figure 22.

5.4 Global earthquakes

The monitoring network detects large earthquakes elsewhere in the world. During the year there was a fortunate absence of major earthquake disasters, however, the two earthquakes which received most media attention were:

(i) An earthquake in Pakistan, on 27 February 1997 at 21:08 UTC, with a magnitude of 7.3 Ms, which resulted in the deaths of at least 57 people, injured many others and left thousands homeless. Extensive damage occurred throughout the Sibi and Quetta areas; it was confirmed that 29 people were killed when a mud house on a mountain caved in. The mainshock was followed 22 minutes later by an aftershock with a magnitude of 6.3 MS. A seismogram of the event recorded on the North Wales network is shown in Figure 23.

(ii) An earthquake in NW Iran, on 28 February 1997 at 12:57 UTC, with a magnitude of 6.1 Ms, killed at least 965 people and injured some 2,600. Approximately 36,000 people were left homeless after the destruction of many houses in the region. Damage was reported in the Ardabil and Meshkinshahr areas and also in many neighbouring villages. The epicentre of this earthquake is in the same general area as the 1990 Manjil earthquake, with a magnitude of 7.7 Ms, which caused 50,000 fatalities. A seismogram of the event recorded on the Cornwall network is shown in Figure 24.

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. An update on the status of major known seismological archival materials is given below:

Aberdeen: All material from the original Parkhill Observatory, Dyce (1914-1932) is presumed lost (one small photo of a 1924 seismogram is held). Seismograms and seismological bulletins from the Aberdeen Observatory, Kings College, Aberdeen University (1936-1967), are maintained by the University of Aberdeen, with a duplicate set of bulletins held in the NSA. Arrangements for seismogram microfilming and possible transfer of this material to the NSA remain in hand.

Bidston: Material from the Bidston Observatory, Liverpool (1898-1957) held in the archive, consists of seismograms (1938-1956) and station bulletins (1901-1919, 1925-1940). The seismograms have been copied onto film and microfilmed.

Cambridge: Material held from the Crombie Seismological Laboratory, Cambridge consists of annual bulletins (1954-1968).

Coats Observatory, Paisley: Material held from this observatory (1898-1919) consists of seismograms (1900-1919) and a seismographic register (1902-1909).

Durham: Material held from the Durham University Seismological Observatory (1930-1975) consists of seismograms (1938-1975) and bulletins (1930-1975).

Edinburgh: Material held from the Royal Observatory, Edinburgh, consists of seismograms (1902-1908) and bulletins (1922-1965). The archive holds a wider range of microfilmed seismograms (1896-1962) than originals, which were destroyed in the late 1960s.

Eskdalemuir: Material from the Eskdalemuir Observatory (1908-1925) is varied, and consists of Seismograms (1910-1920) and bulletins and day files (1913-1925). The seismograms have been microfilmed. Some material is still held at Eskdalemuir.

Eskdalemuir WWSSN: The Eskdalemuir Worldwide Standard Seismograph Network seismograms (1964-present) continue to be stored at Eskdalemuir, with microfilm copies available for inspection in the NSA.

Guildford: Material held from the Seismograph Station at Woodbridge Hill, Guildford, consists of bulletins (1910-1914).

Jersey: Material held from the Maison Saint Louis Observatory (1935-1994) consists of seismograms (1936-1985) and bulletins (1946-1948). The seismograms have been copied to film and microfilmed.

Kew: Material held from the Kew Observatory (1898-1969) consists of seismograms (1904-1969) and bulletins (1899-1969), together with a wide range of related material. The seismograms have been microfilmed.

Oxford: Material from the Oxford Observatory (1918-1947) are presumed lost, bar one seismogram held in the NSA.

Rathfarnham: Material from the Rathfarnham Castle Observatory, Dublin (1916-1964) is held by the Dublin Institute for Advanced Studies (DIAS).

Shide: Material from the Shide Observatory, Isle of Wight (1895-1913) is presumed destroyed except for some material at the Isle of Wight County Record Office, which includes tracings of a few seismograms.

Stonyhurst: Material from the Stonyhurst College Observatory, Blackburn (1908-1947) is also presumed destroyed, except for bulletins held in the NSA (1909-1933).

Valentia WWSSN: All records from this station are held at the Valentia Observatory, Ireland, by the Irish Meteorological Service.

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 being curated well by the Lapworth Museum, Birmingham University, although the number of actual seismograms is very small.

6.2 Storage and Inspection facilities

The National Seismological Archive has been visited this year by five scientists and many data requests have been answered from scientists and researchers worldwide, including a large number by e-mail via the Internet Web pages.

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

The World Seismological Bulletin collection is now catalogued, comprising around 18,000 records, and is currently undergoing quality checking before publication. A reference copy is held in the archive for the use of staff and researchers. Cataloguing of seismological reports and publications, seismograms, microfilm, newspaper references and other material progresses, subject to staff availability.

Completion of the major renovation of Murchison House will allow for the refit of the main archive inspection room to provide improved facilities; a PC workstation for staff and users, a larger inspection area and easier access to reference materials.

6.3 Digital records

The programme of digitising old 1" analogue tapes has started following the upgrade of computer digitising software.

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 38 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. 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/). Questionnaires and updated information on the Penzance earthquake and Musselburgh series were also made available on the home page. Feedback suggests that the GSRG web site is being used extensively for the wide variety of seismological information it offers.

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

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 1996, it was issued within 4 months.

8. Programme for 1997/98

During the year, the project team (Annex D) will continue to detect, locate and understand natural seismicity and man-made events in and around the UK and to supply timely information to the Customer Group. Further progress will be made in the provision of a 'user-friendly' database and archive of UK seismicity and in extending the background, 70 km-spacing, seismograph coverage of the country. Specific advances anticipated for 1997/98, subject to the continuation of funding, at least at the current level and without any unexpected closures of site specific networks, are:

(i) Further development of the QNX operating system and deployment, for a full trial, alongside an existing SEISLOG unit.

(ii) Installation of additional 4 gigabyte disks to increase the continuous recording capability at all sites where such capacity can be utilised.

(iii) Introduction of two or three new strong motion systems at sub-network digital acquisition centres (priorities being North Wales, Leeds and Moray).

(iv) Continuation of modest enhancements to the multifunctional environmental potential of the network while seeking external support for this initiative.

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

(vi) Publication of archive holdings in an 'updateable' form and inclusion in the Global Seismology web page.

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

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).

10. References

Walker, A.B., (editor), 1997. Bulletin of British earthquakes 1996, *Brit.Geol.Surv.* Tech. Rep. No. WL/97/03.

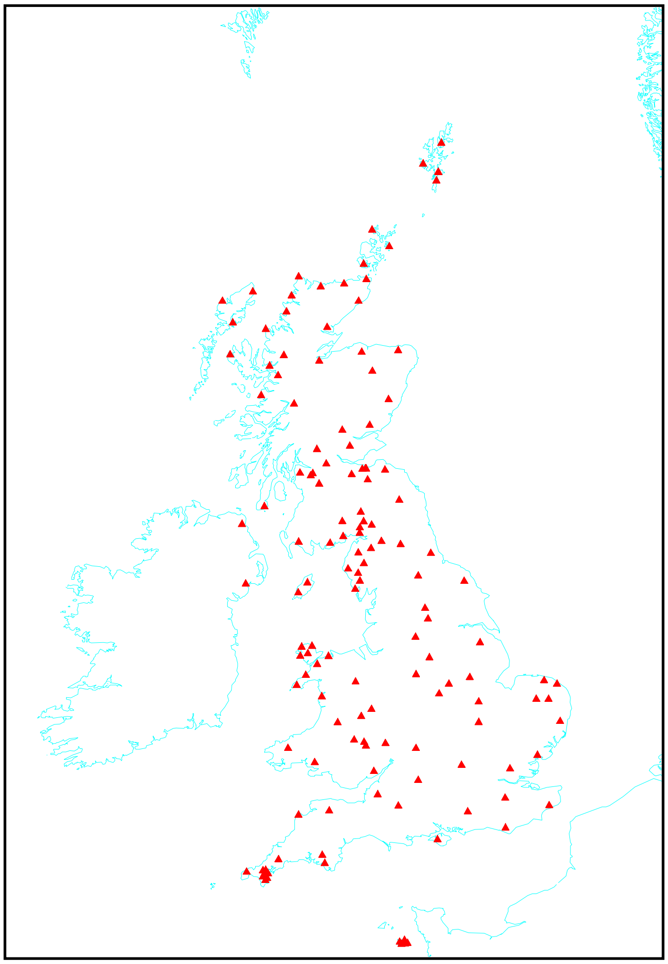

Figure 1. **BGS rapid access seismograph network operational in March 1997.**

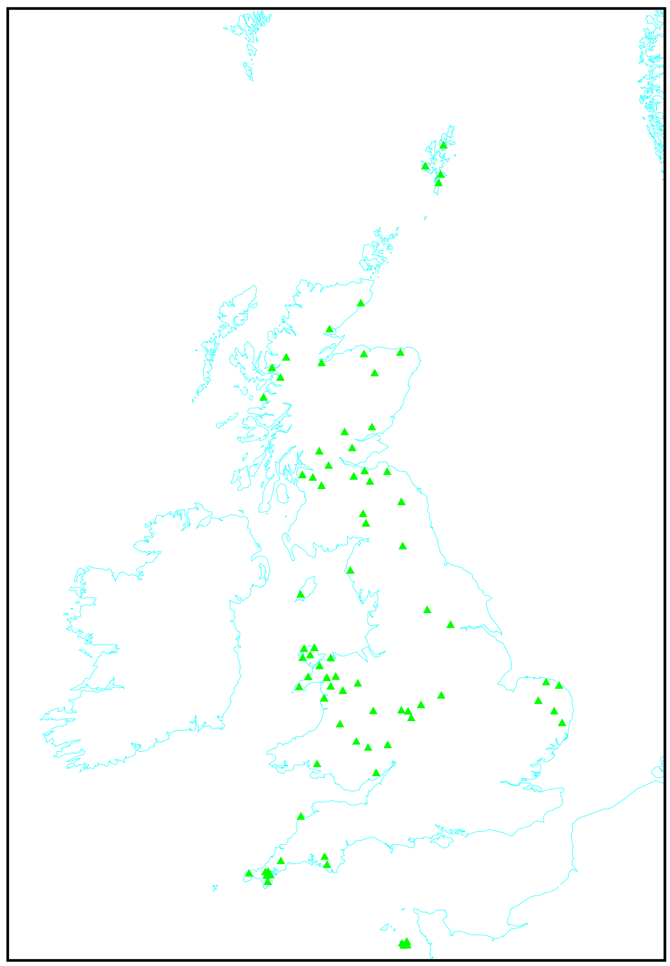

Figure 2. **BGS seismograph network in 1988 prior to the commencement of the UK monitoring enhancement project.**

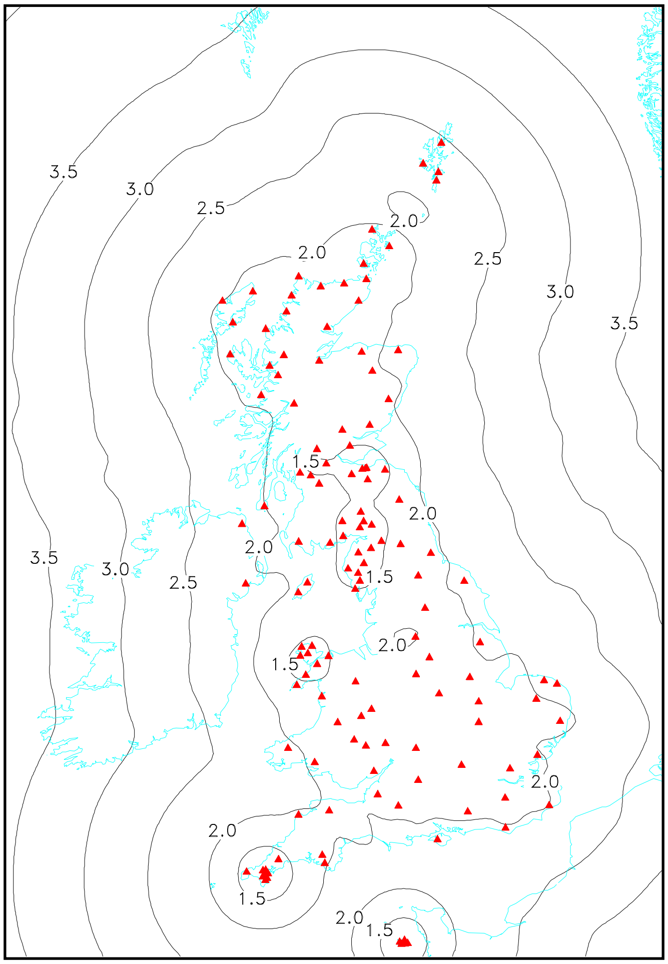

Figure 3. **Detection capability of seismograph network, March 1997. contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.**

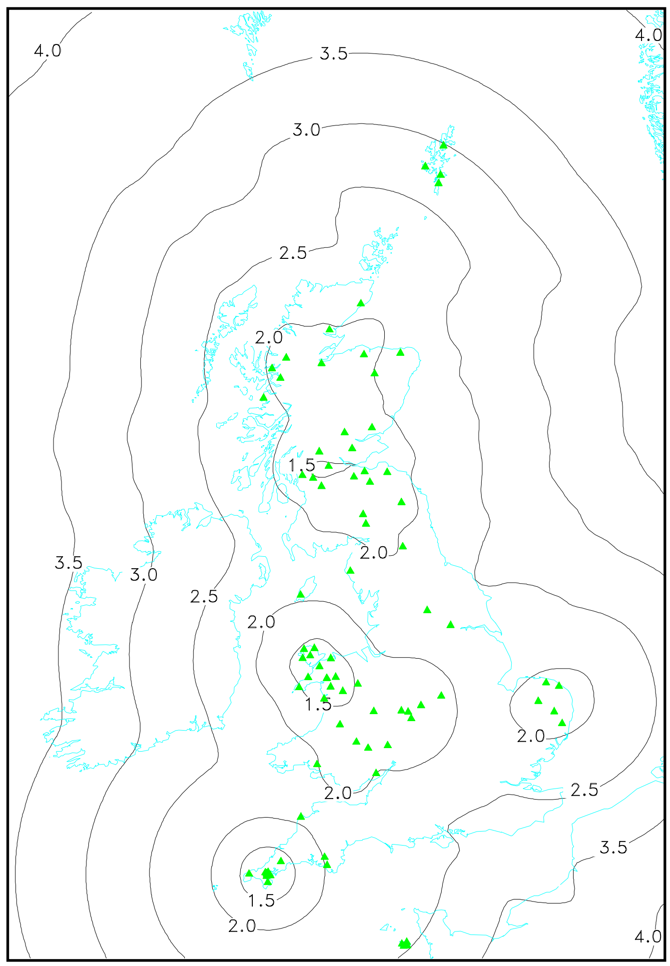

Figure 4. **Detection capability of seismograph network, 1988. contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.**

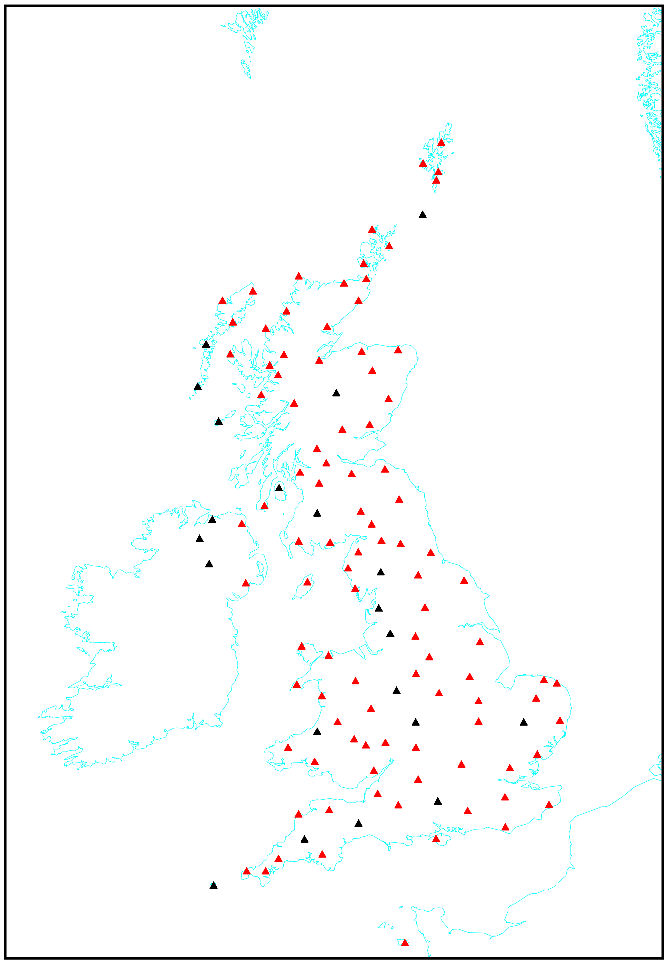

Figure 5. Proposed long-term background seismic monitoring network with an average station spacing of 70 km. Colour coding shows existing coverage (red) and proposed stations (black).

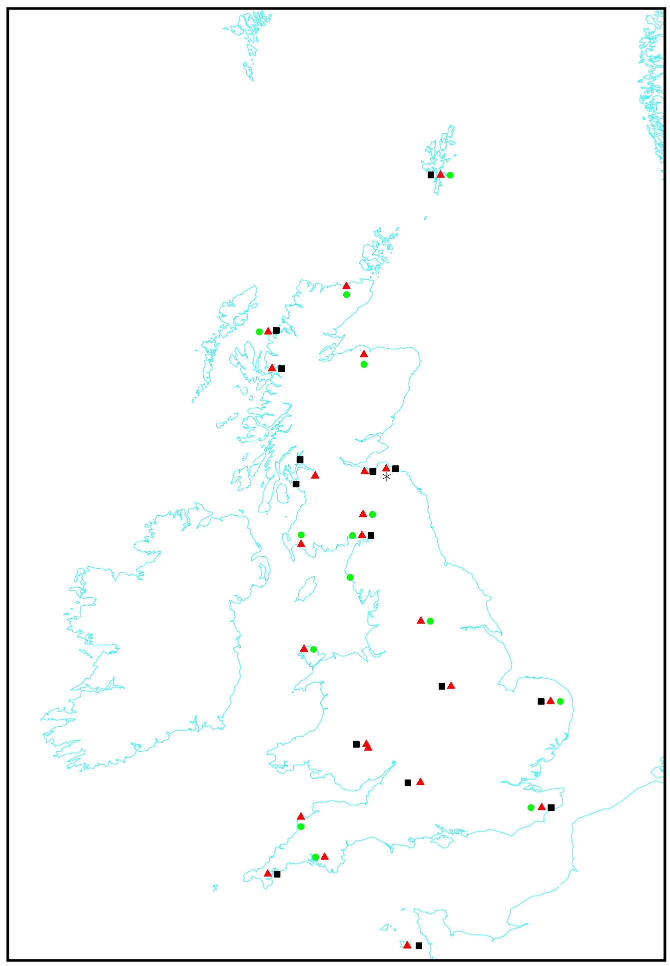

Figure 6. BGS network of strong-motion instruments (black), low sensitivity (red), microphones (green) and environmental station (star) in March 1997.

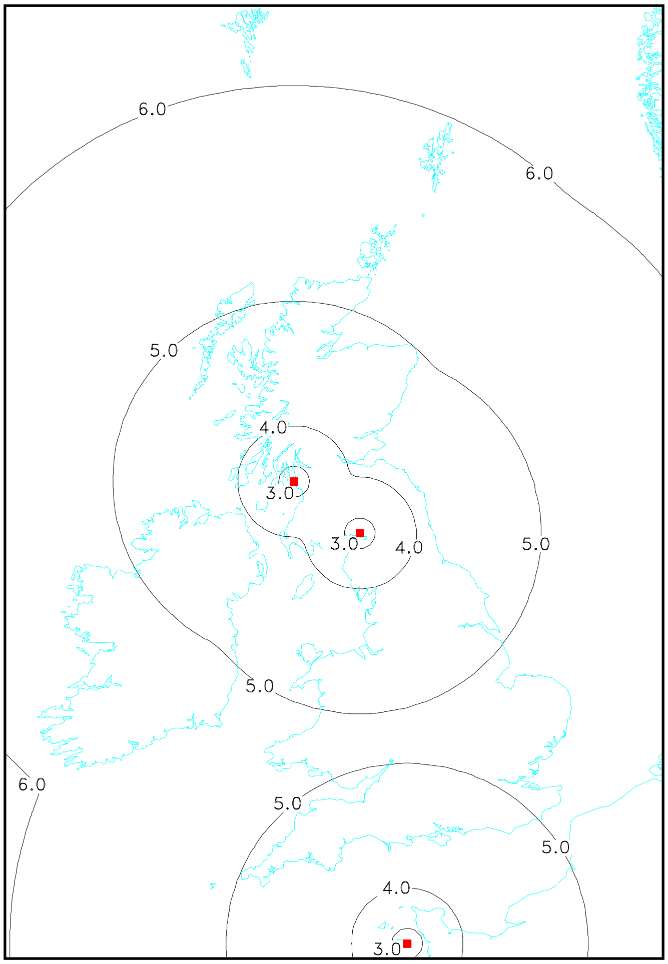

Figure 7. Minimum Richter local magnitude (ML) detectable by the strong motion network operational December 1992.

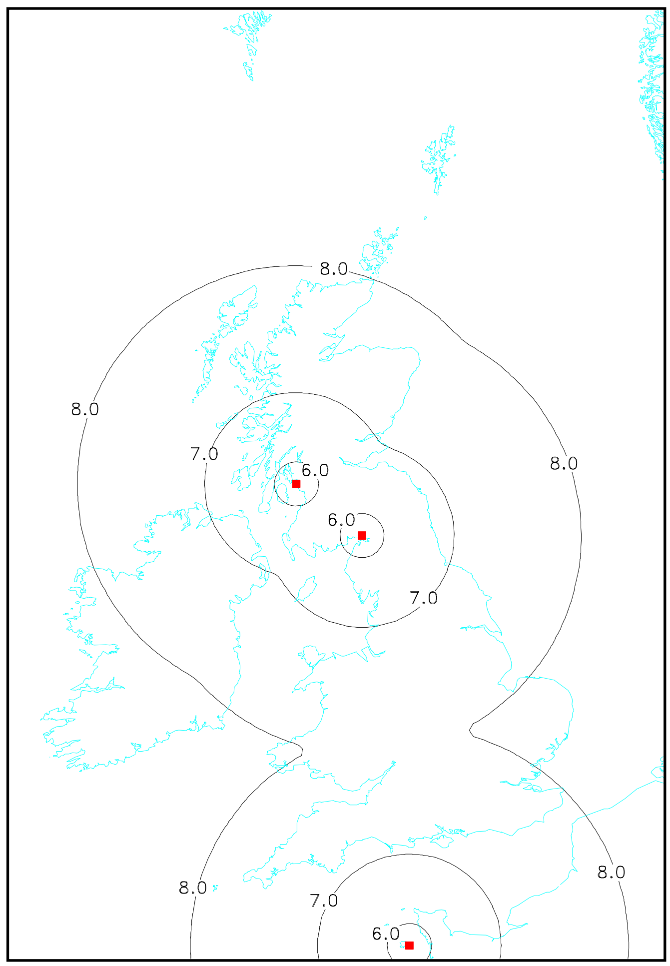

Figure 8. Maximum Richter local magnitude (ML) which will not saturate the strong motion network operational December 1992.

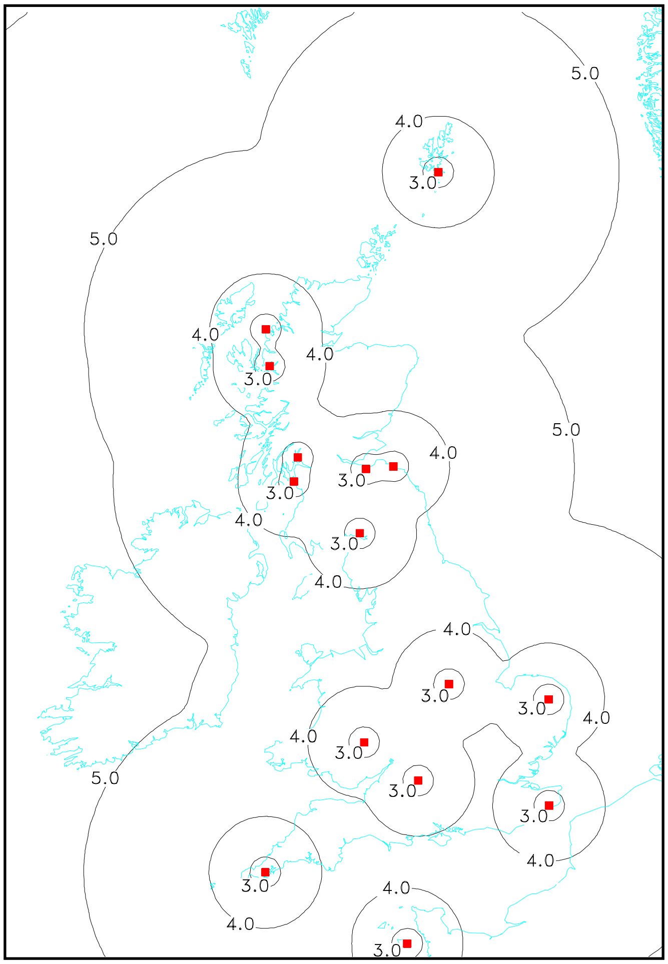

Figure 9. Minimum Richter local magnitude (ML) detectable by the strong motion network operational March 1997.

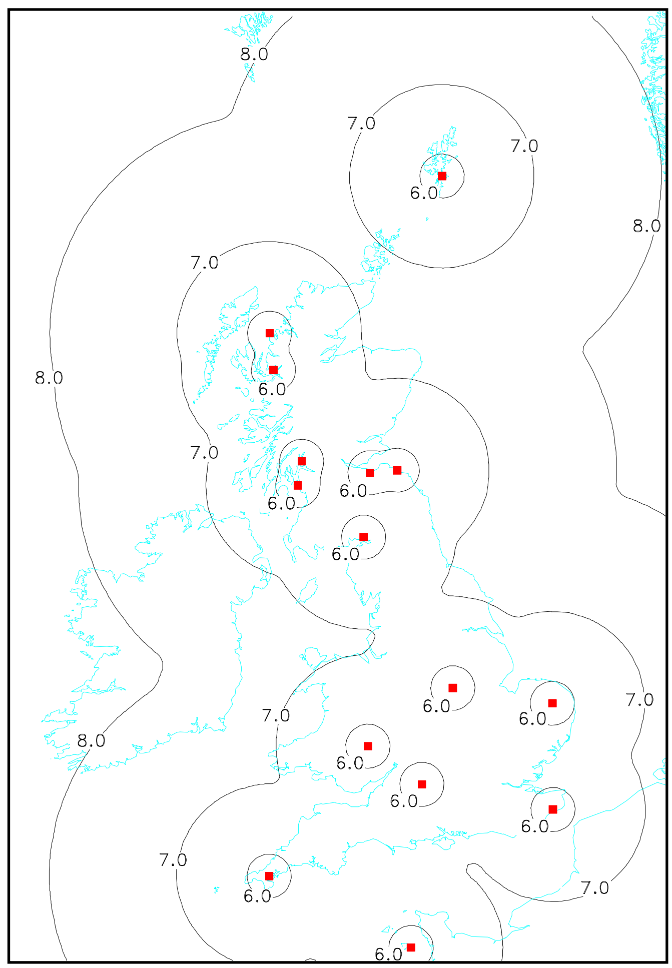

Figure 10. Maximum Richter local magnitude (ML) which will not saturate the strong motion network operational March 1997.

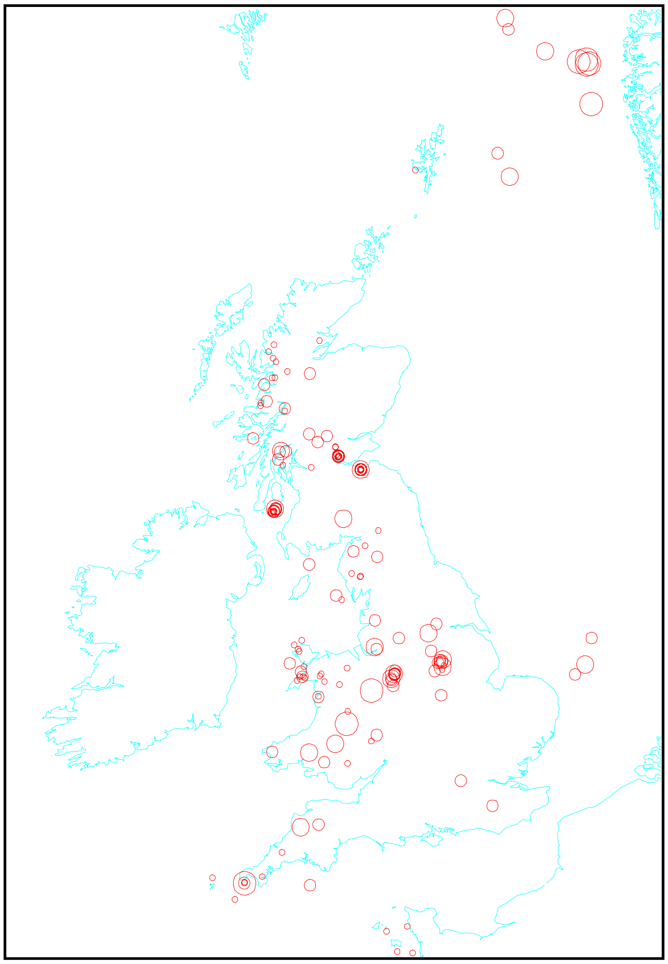

Figure 11. **Epicentres of all UK earthquakes located in 1996.**

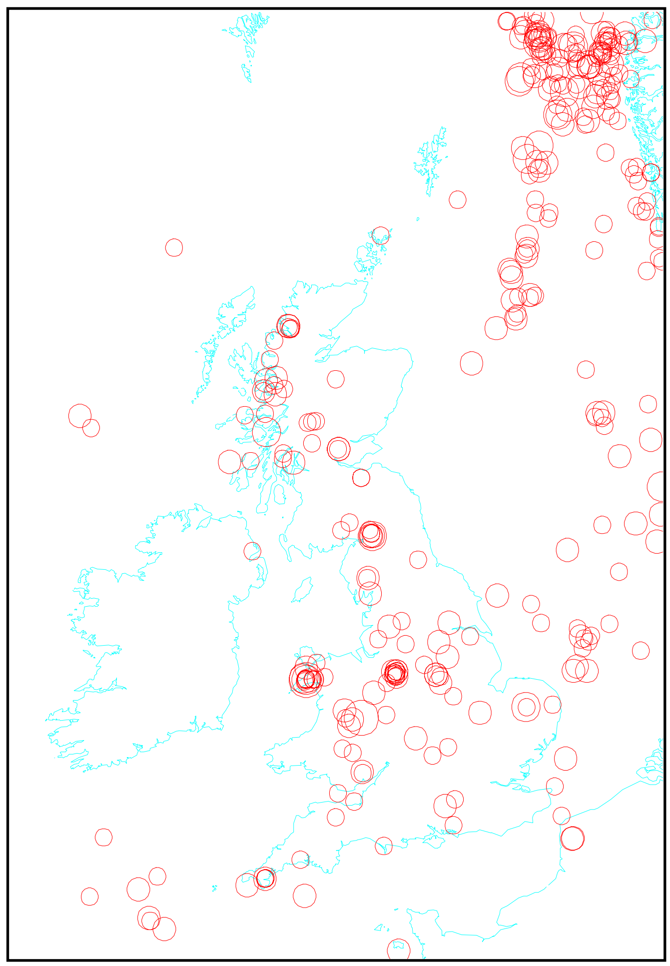

Figure 12. **Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 1997.**

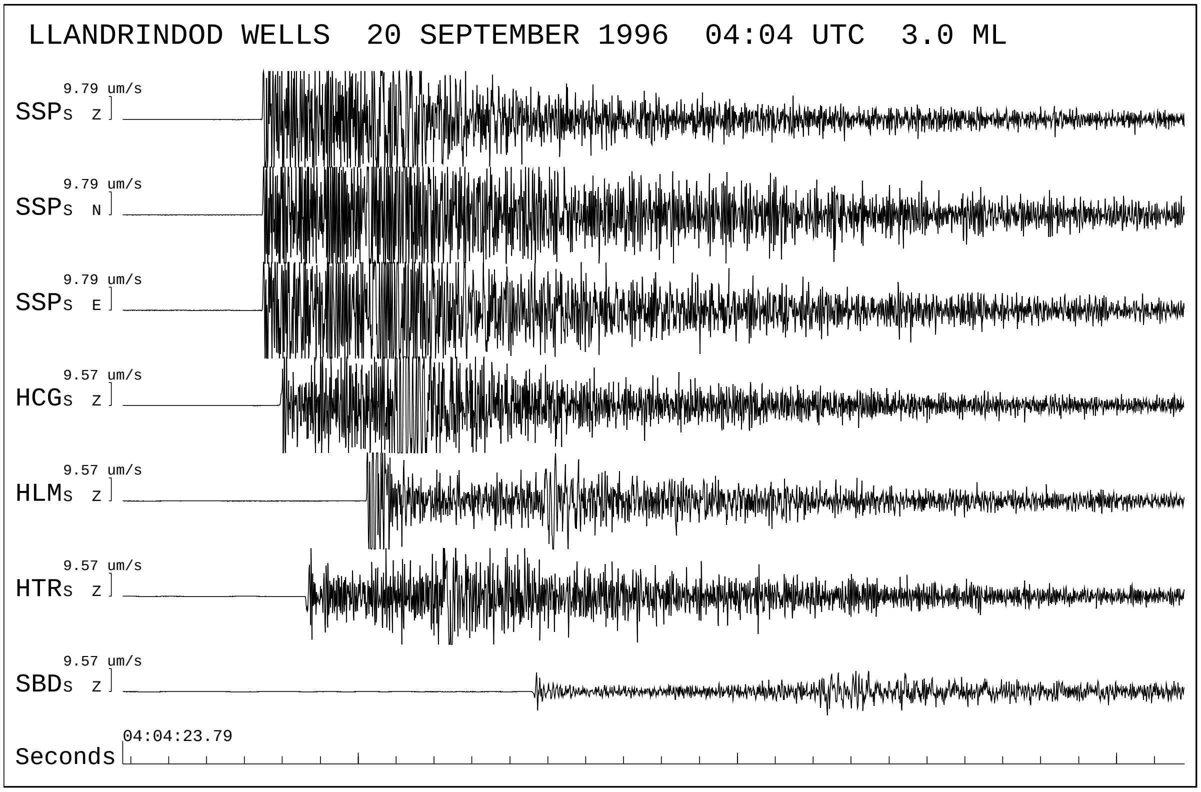

Figure 13. Seismograms recorded on the Hereford network from a magnitude 3.0 ML earthquake felt in the Llandrindod Wells area on 20 September 1996 04:04 UTC. Three letter codes refer to stations in Annex E.

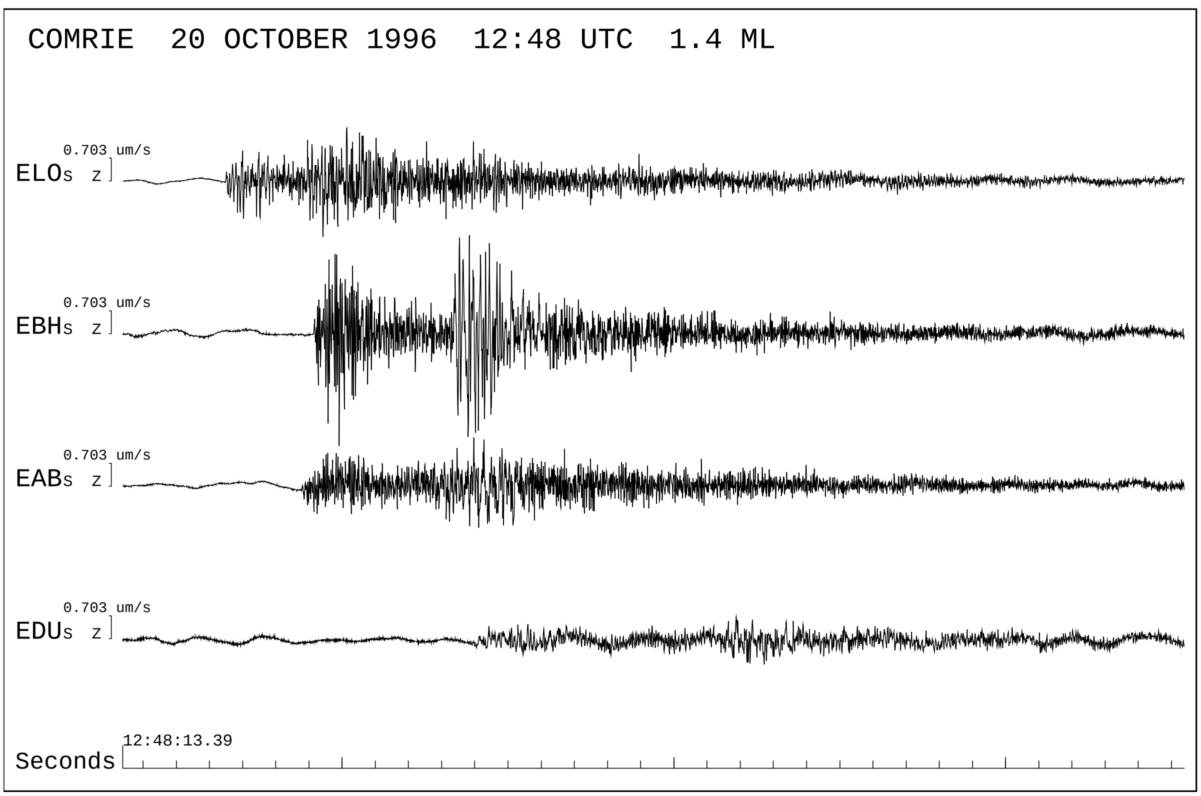

Figure 14. Seismograms recorded on the Lowlands network around Edinburgh from a magnitude 1.4 ML earthquake felt in the Comrie area on 20 October 1996 12:48 UTC. Three letter codes refer to stations in Annex E.

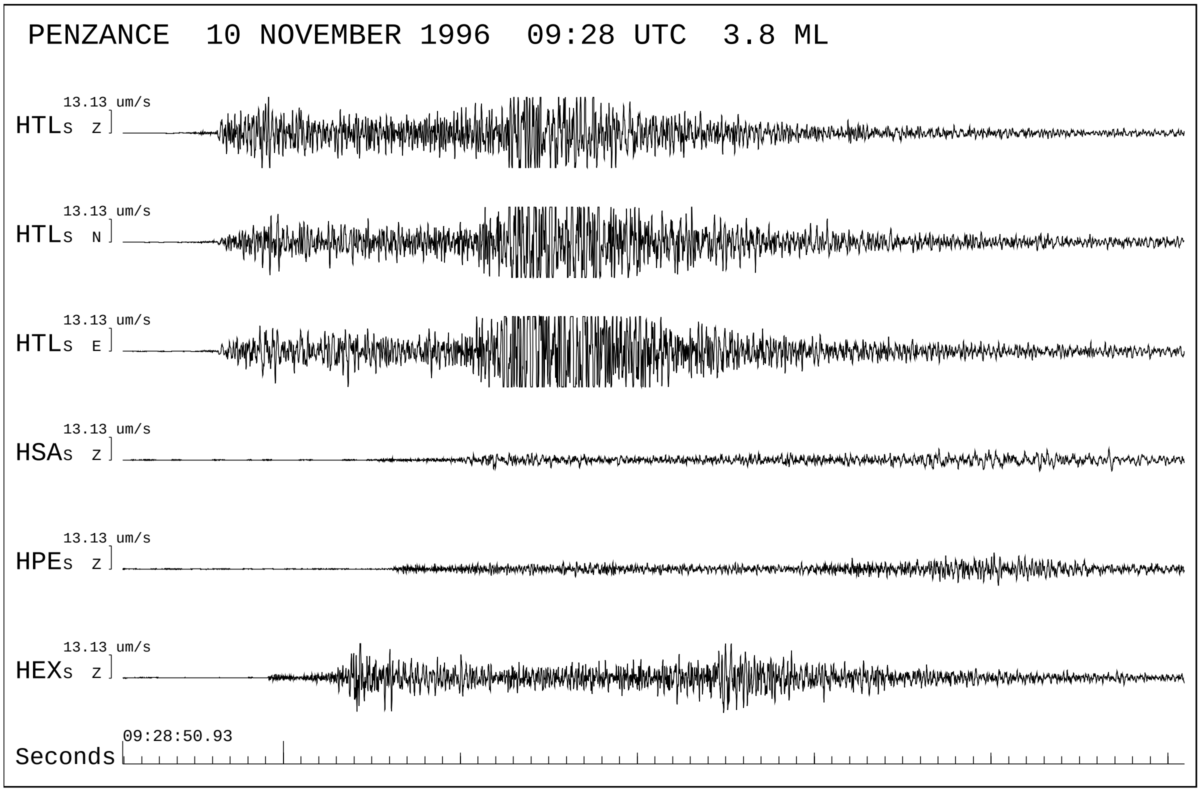

Figure 15. Seismograms recorded on the Hartland network from a magnitude 3.8 ML earthquake felt in the Cornwall area on 10 November 1996 09:28 UTC. Three letter codes refer to stations in Annex E.

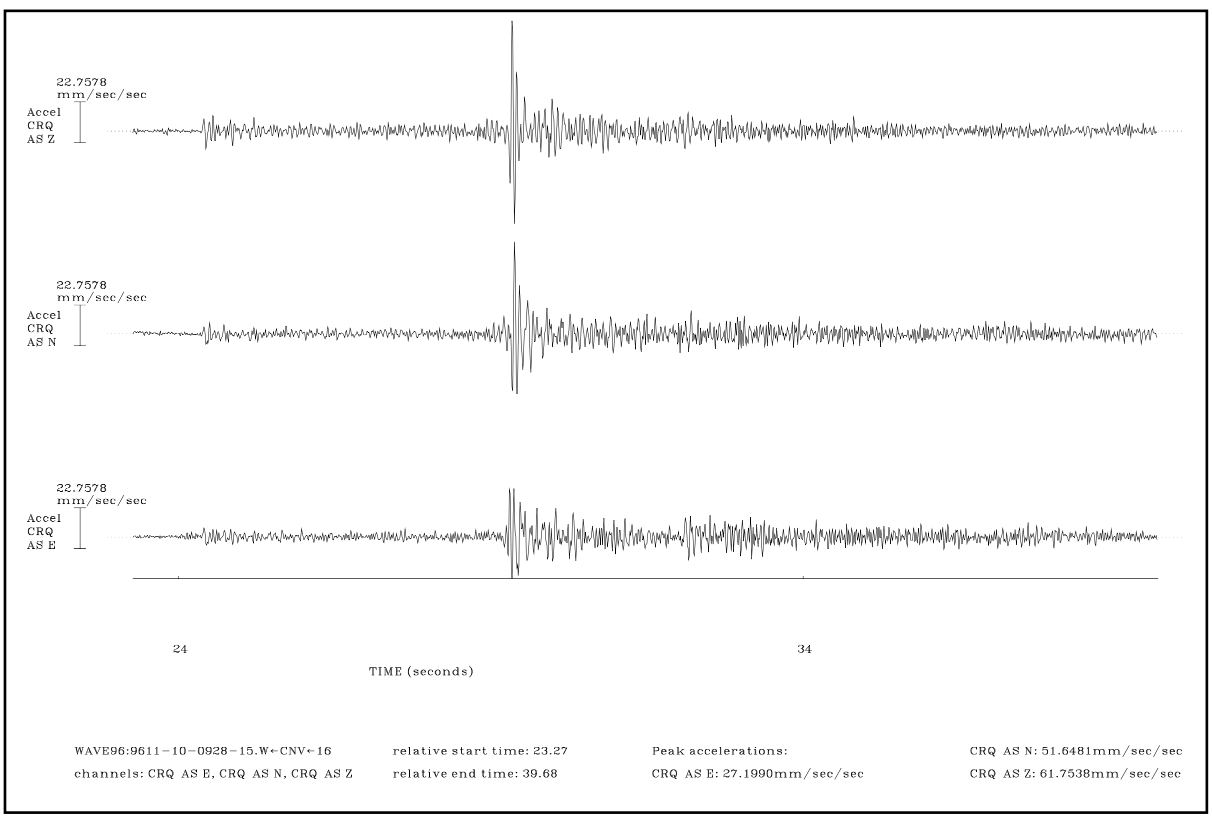

Figure 16. Seismograms recorded on the strong motion instruments near Falmouth, Cornwall from the Penzance earthquake with a magnitude of 3.8 ML on 10 November 1996 09:28 UTC. Three letter codes refer to stations in Annex E.

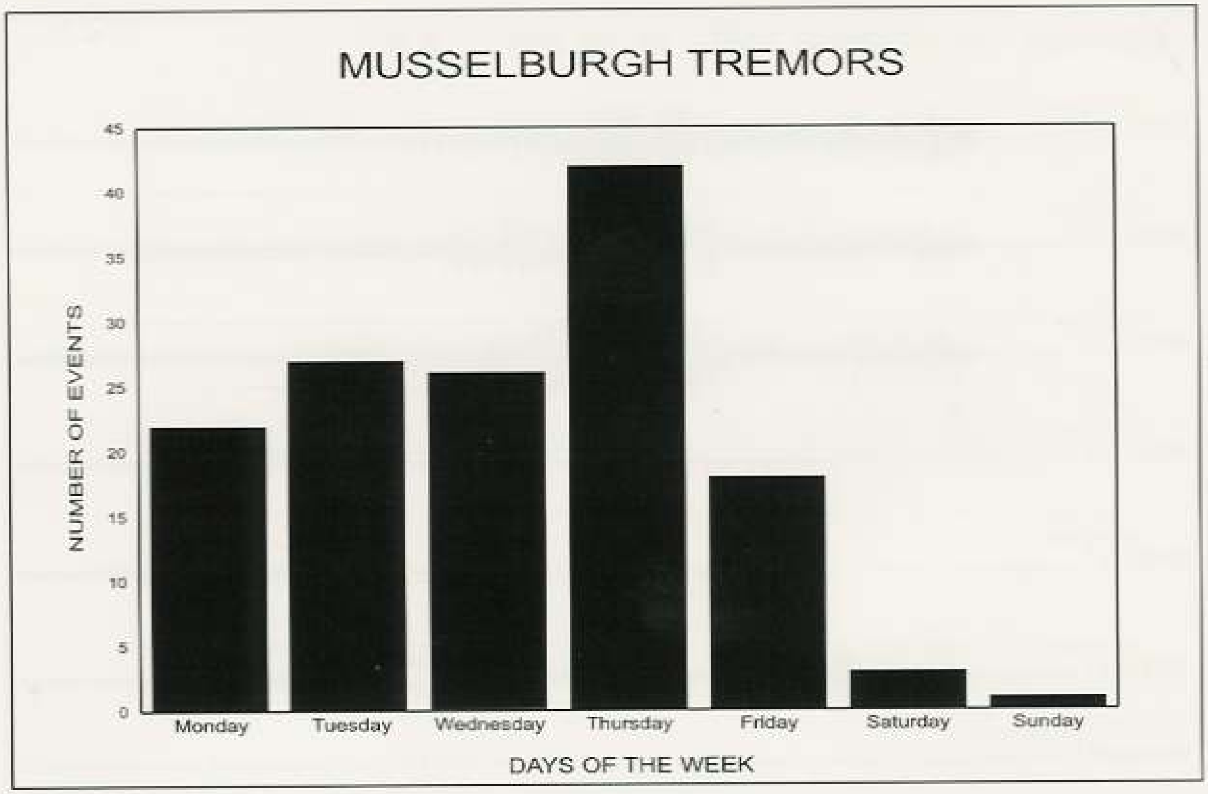

Figure 17. Histogram of cumulative number of Musselburgh events (139) against day of the week (October 1996 - March 1997).

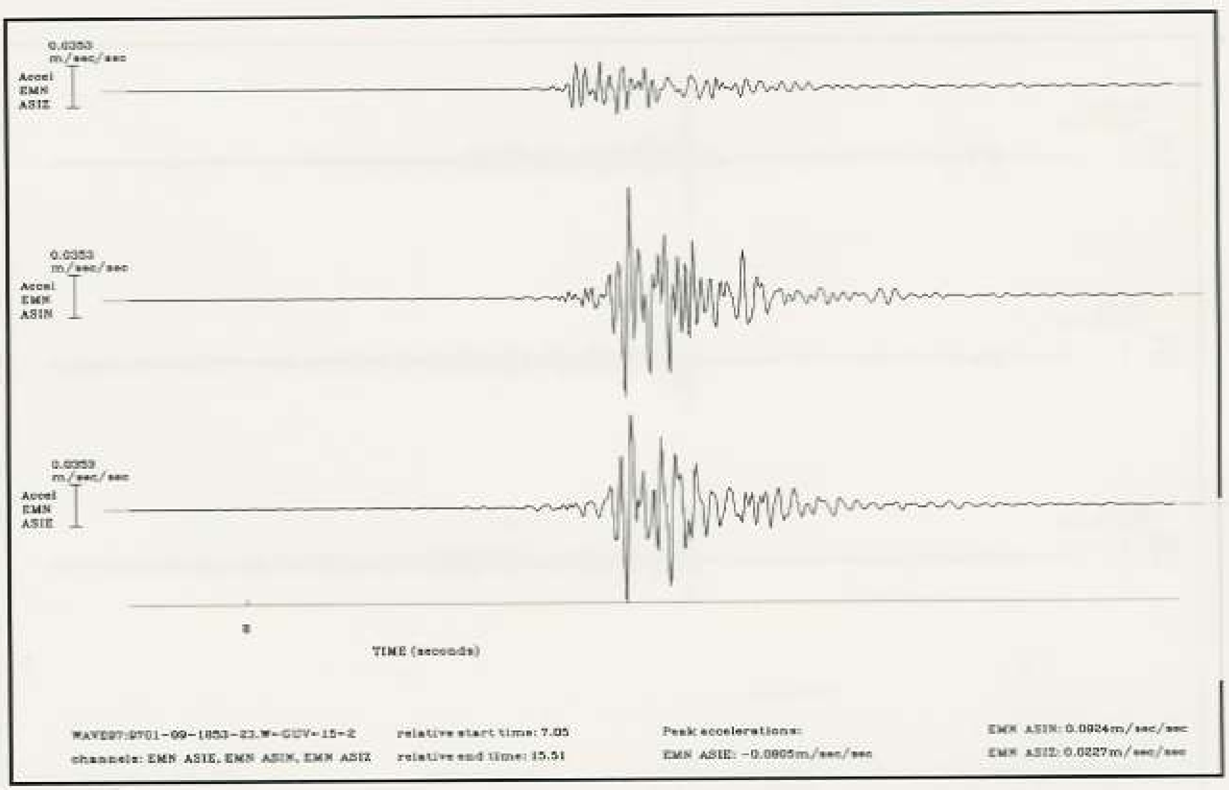

Figure 18. Seismograms recorded on the strong motion instruments near Edinburgh from an earthquake felt in Musselburgh with a magnitude of 1.7 ML on 9 January 1997 18:53 UTC. Three letter codes refer to stations in Annex E.

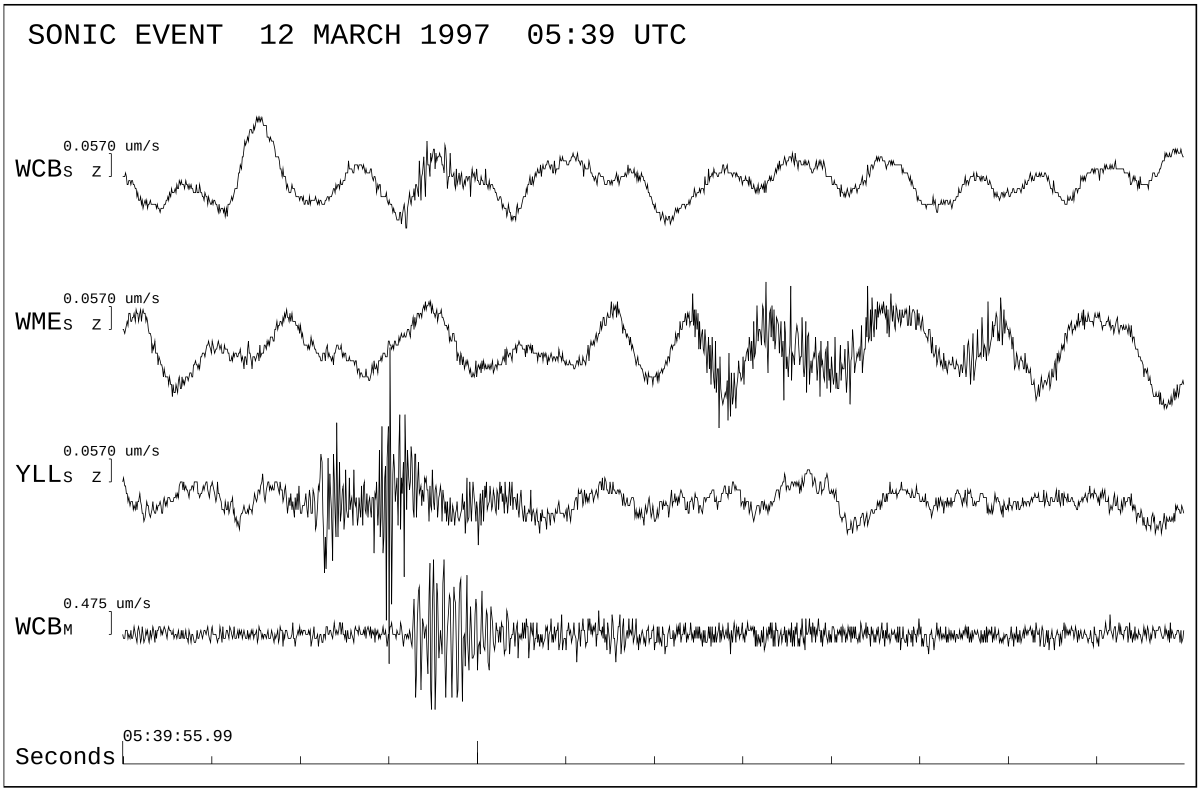

Figure 19. Seismograms recorded on the North Wales network from a sonic event felt in North Wales on 12 March 1997 05:39 UTC. Three letter codes refer to stations in Annex E.

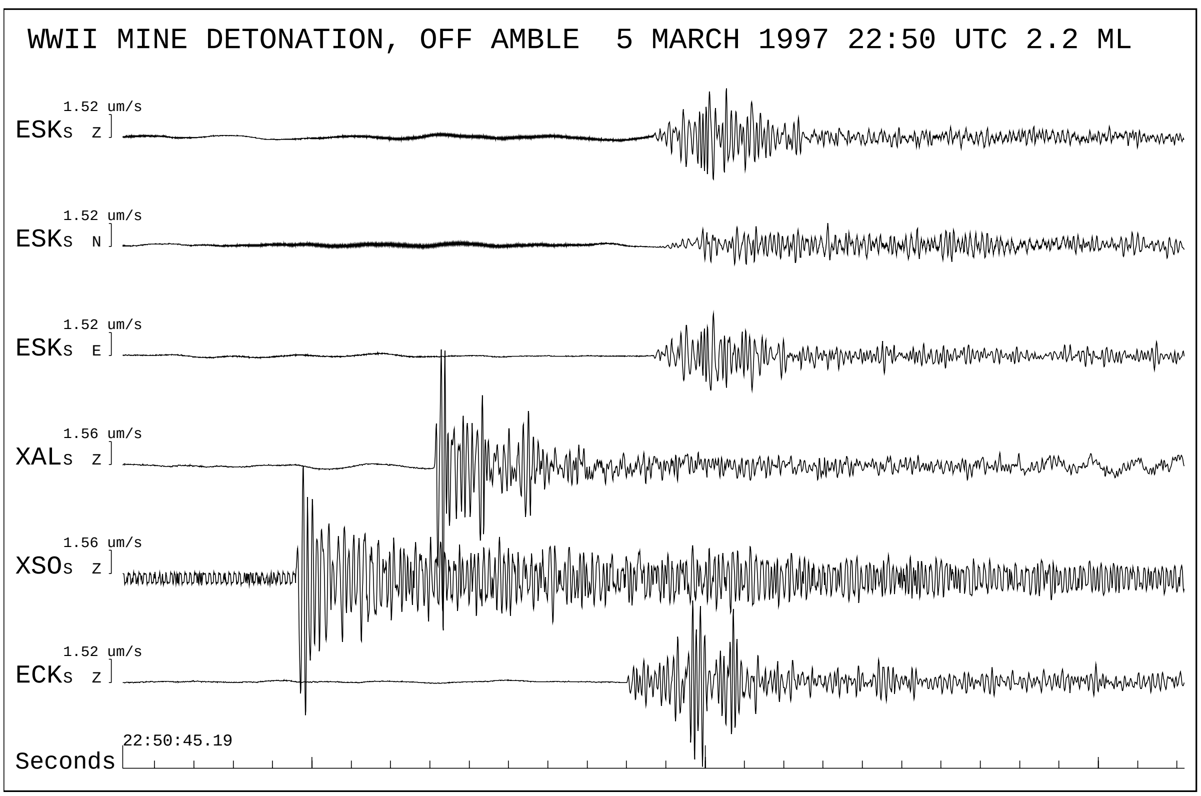

Figure 20. Seismograms recorded on the Eskdalemuir network from a magnitude 2.2 ML WWII mine detonation off Amble on 5 March 1997 22:50 UTC. Three letter codes refer to stations in Annex E.

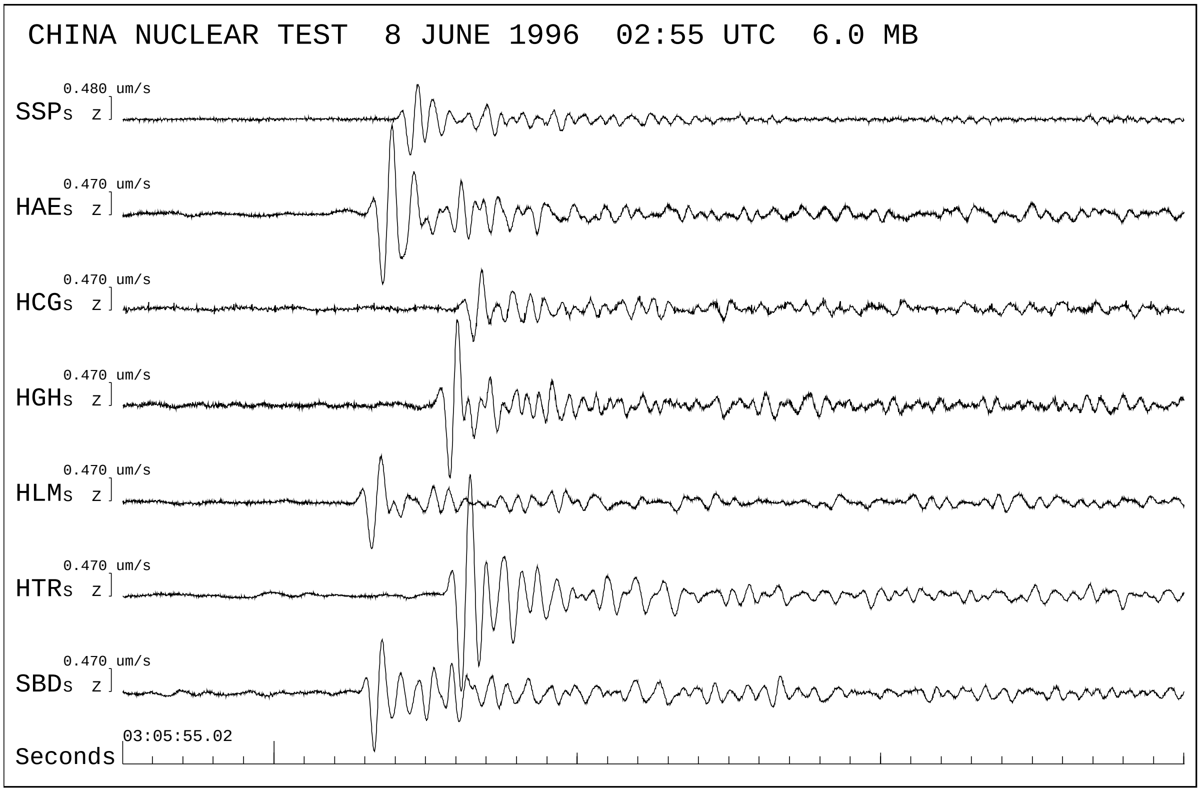

Figure 21. Seismograms recorded on the Hereford network from a magnitude 6.0 MB China nuclear test on 8 June 1996 02:55 UTC. Three letter codes refer to stations in Annex E.

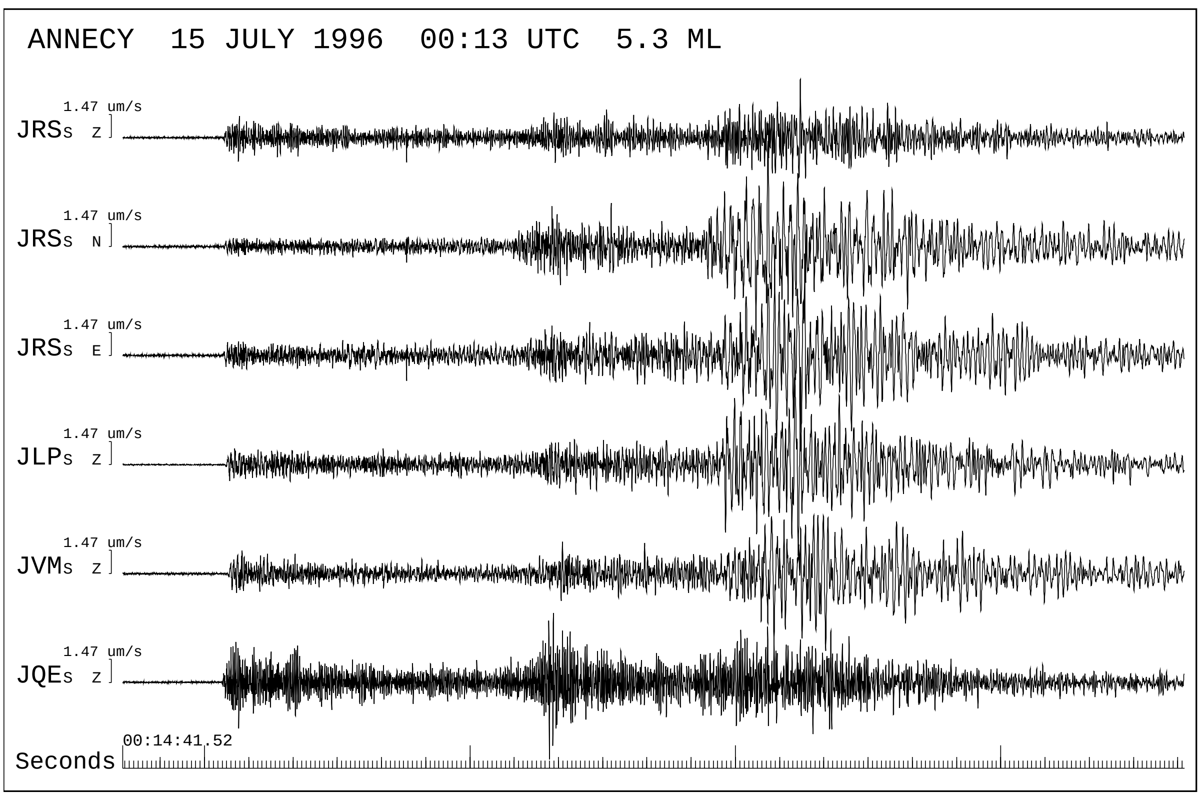

Figure 22. Seismograms recorded on the Jersey network from a magnitude 5.3 ML earthquake in Annecy on 15 July 1996 00:13 UTC. Three letter codes refer to stations in Annex E.

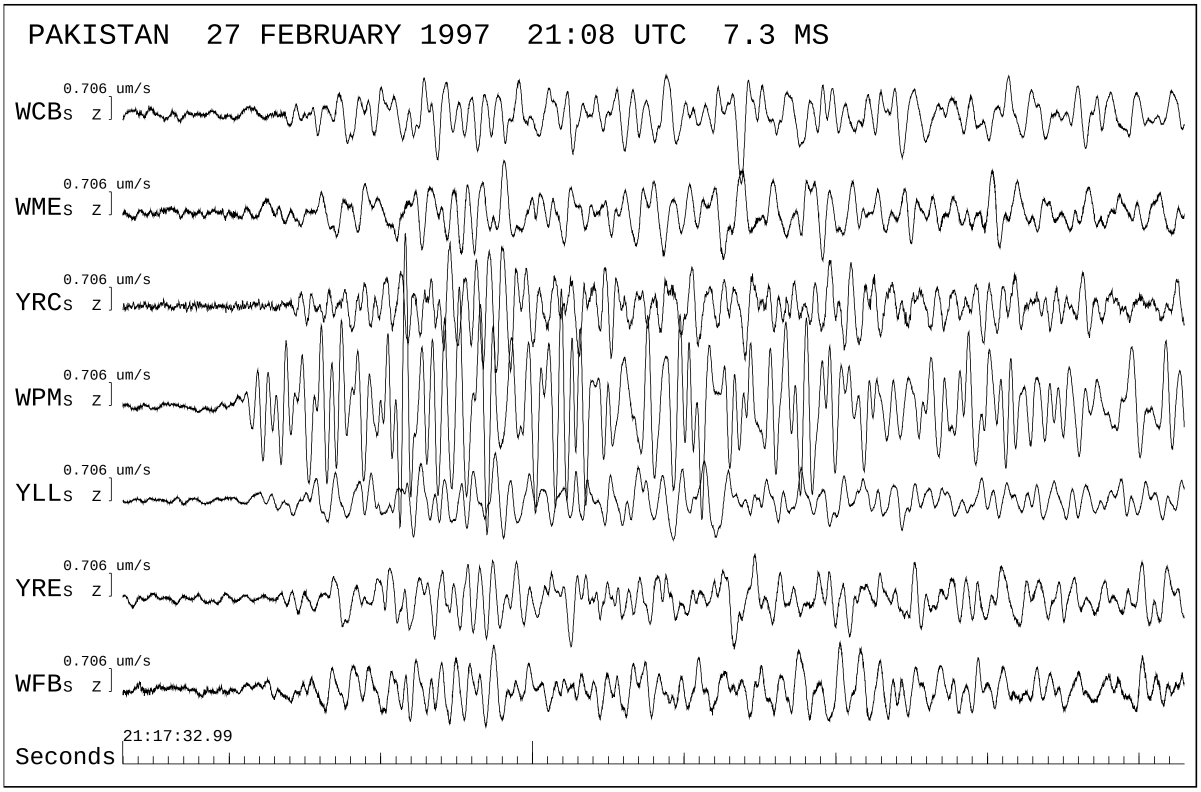

Figure 23. Seismograms recorded on the North Wales network from a magnitude 7.3 MS earthquake in Pakistan on 27 February 1997 21:08 UTC. Three letter codes refer to stations in Annex E.

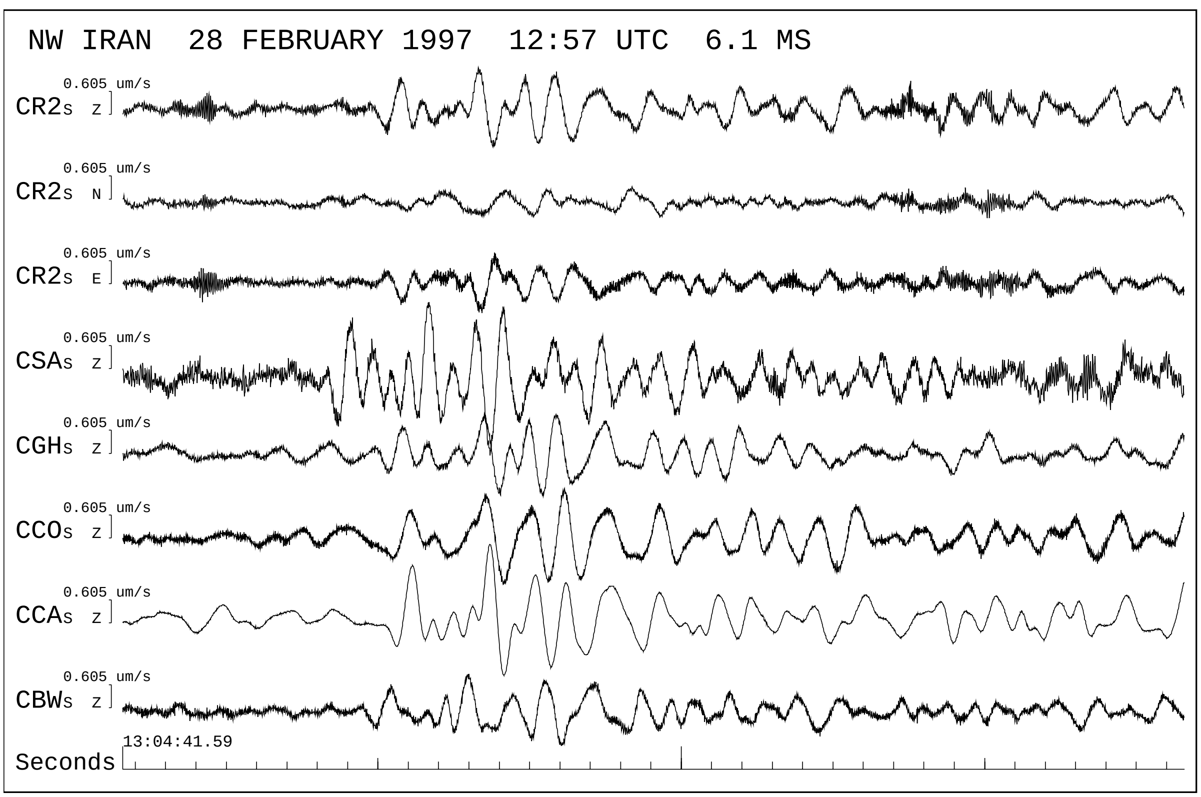

Figure 24. Seismograms recorded on the Cornwall network from a magnitude 6.1 MS earthquake in NW Iran on 28 February 1997 12:57 UTC. Three letter codes refer to stations in Annex E.

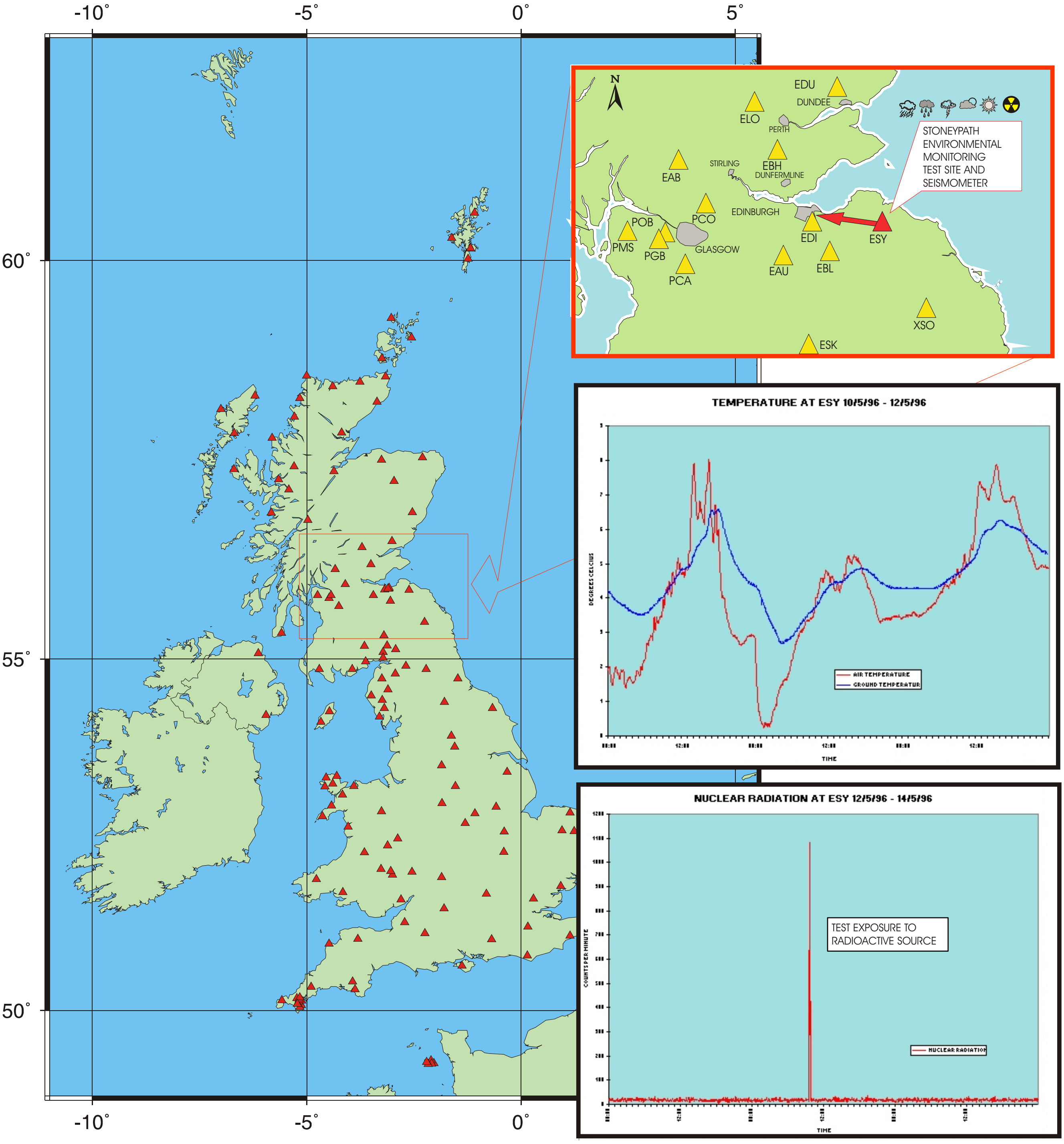

Figure 25. Environmental data from the experimental monitoring station 'ESY'. The charts show ground and air temperature and radioactivity over a twelve hour period.

Plate 1. Earthquake House, Comrie, restored and opened to the public by Perth and Kinross Council.

Plate 2. Earthquake damage in Metz-Tessy from the Annecy earthquake 15 July 1996 00:13 UTC, magnitude 5.3 ML. (Photograph supplied by Francois Thouvenot, LGIT - Observatoire de Grenoble, Grenoble)

ANNEX A

CONTRIBUTORS TO THE PROJECT

British Nuclear Fuels plc
Department of the Environment
Magnox Electric plc
Natural Environment Research Council
Nuclear Electric plc
Nuclear Installations Inspectorate
Renfrewshire Council
Scottish Hydro-Electric plc
Scottish Nuclear Ltd
United Kingdom Nirex Limited
University of Exeter
Welsh Office
Western Frontiers Association

Atomic Weapons Establishment (Data only)

Customer Group Members (not contributing in Year Eight)

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 : 1996

YearMoDy	HrMnSecs	Lat	Lon	kmE	kmN	Dep	Mag	Locality	Int	No DM	Gap	RMS	ERH	ERZ	SQD	Comments
19960111	014046.8	55.23	-3.51	304.3	594.3	7.3	2.0	JOHNSTONEBRIDGE,D & G		26 11	121	0.20	0.6	1.9	B*B	6KM W OF JOHNSTONEBRIDGE
19960307	234124.2	52.80	-2.74	349.9	322.3	10.6	3.4	SHREWSBURY,SHROPSHIRE	5	11 32	138	0.09	0.6	1.1	A*C	FELT SHREWSBURY...
19960316	062330.6	52.97	-2.27	381.9	341.2	1.8	2.3	NEW-U-LYME,STAFFS	3+	24 4	79	0.24	0.7	1.0	B*A	C/F,FELT NEW-U-LYME...
19960420	094213.0	62.60	1.06	556.9	1417.1	15.0	2.2	NORTHERN NORTH SEA		6297	354	0.03	2.5	1.6	B*D	
19960421	022719.8	53.61	-1.36	442.4	413.0	4.2	2.3	BARNSLEY,S YORKSHIRE		7 25	129	0.04	0.4	0.9	A*C	8KM NE OF BARNSLEY
19960421	182850.4	51.90	-4.20	248.5	224.4	8.6	2.2	CARMARTHEN,DYFED		14 17	85	0.14	0.5	0.9	A*B	7KM NE OF CARMARTHEN
19960506	034929.1	53.04	-2.20	386.6	348.8	2.6	2.8	STOKE-ON-TRENT,STAFFS	4	23 24	95	0.11	0.3	1.0	A*C	FELT STOKE-ON-TRENT...
19960518	210154.5	56.16	-5.17	202.9	701.3	7.9	2.9	LOCH FYNE,STRATHCLYDE	3+	17 44	128	0.11	0.5	1.7	A*C	FELT FURNACE,INVERARAY..
19960527	222119.3	50.83	-4.35	234.7	106.4	6.7	2.2	HOLSWORTHY,DEVON		18 20	102	0.11	0.6	1.4	A*C	
19960625	033732.2	61.63	3.41	686.5	1316.8	15.0	3.9	NORTHERN NORTH SEA		33 87	188	0.36	1.2	1.4	C*D	
19960626	015242.1	55.34	-5.26	193.0	609.7	13.9	2.2	ARRAN,STRATHCLYDE		10 21	117	0.04	0.2	0.4	A*B	SOUTH OF ARRAN
19960718	094647.1	60.06	1.13	574.4	1134.9	11.3	2.3	NORTHERN NORTH SEA		13129	282	0.10	3.5	4.5	C*D	
19960726	074211.6	61.81	2.40	632.0	1333.2	12.7	2.6	NORTHERN NORTH SEA		5234	352	0.12			D*D	
19960801	205506.8	55.09	4.74	829.7	598.3	26.1	3.4	CENTRAL NORTH SEA		40340	203	0.26	1.3	2.7	B*D	
19960826	111652.9	52.03	-3.59	290.9	238.2	18.0	2.1	SENNYBRIDGE,POWYS		12 23	102	0.07	0.4	1.5	A*B	8KM NORTH OF SENNYBRIDGE
19960906	002851.8	62.31	1.23	567.4	1385.5	15.8	2.6	NORTHERN NORTH SEA		14215	231	0.19	3.5	4.6	C*D	
19960920	040423.4	52.32	-3.33	309.4	269.7	14.4	3.0	LLANDRINDOD WELLS	4+	13 18	74	0.06	0.3	0.3	A*B	FELT LLANDRO'D WELLS...
19961004	031744.4	53.24	-1.02	465.7	371.5	1.0	2.0	OLLERTON,NOTTS		9 34	89	0.16	0.8	1.5	B*C	C/F,3KM N OF OLLERTON
19961018	210911.1	53.13	-1.02	465.4	360.1	2.0	2.1	MANSFIELD,NOTTS	3+	10 29	146	0.35	1.8	2.8	C*C	C/F,FELT WELLOW...
19961025	123718.1	55.93	-3.08	332.3	671.7	1.5	2.0	MUSSELBURGH,LOTHIAN	5	7 1	194	0.02	0.3	0.1	A*D	C/F,FELT MUSSELBURGH...
19961031	125212.1	61.58	3.65	699.6	1312.3	20.8	3.8	NORTHERN NORTH SEA		19280	331	0.10			D*D	
19961031	125743.4	61.59	3.73	704.1	1313.9	15.0	3.9	NORTHERN NORTH SEA		17284	332	0.11			D*D	
19961031	234739.1	61.65	3.65	699.2	1320.3	15.0	3.7	NORTHERN NORTH SEA		9283	342	0.09			D*D	
19961110	092833.8	50.00	-5.58	143.8	17.8	9.6	3.8	PENZANCE,CORNWALL	5	11 17	278	0.04	0.9	2.0	B*D	FELT CORNWALL & DEVON
19961117	030627.5	53.42	-2.68	354.9	391.4	9.7	2.0	ST HELENS,MERSEYSIDE		20 56	74	0.13	0.4	1.4	A*D	
19961125	013242.7	53.09	2.44	697.0	363.5	10.2	2.1	SOUTHERN NORTH SEA		6 72	330	0.06	1.3	1.3	B*D	
19961216	040903.5	61.01	3.68	706.8	1250.0	13.7	3.3	NORTHERN NORTH SEA	2+	21 59	150	0.25	1.3	1.8	B*D	FELT FEDJE FYR & VAKSDAL

BRITISH GEOLOGICAL SURVEY PRIVATE
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TO: M JOHNSTON	- DOE	H PAYNE	- WELSH OFFICE
M WILSON	- SCOT H & H	H GULVANESSIAN	- BRE
P A MERRIMAN	- BNFL	J P McFARLANE	- SCOTTISH NUCLEAR
H TUR	- BNFL CAPEN	P W WINTER	- AEA
C BUMPUS	- NIREX	P J BUCKLEY	- HSE
T C CHIVERS	- NUCLEAR ELEC	V KATHIGAYAN	- HSE OFFSHORE
C F ALLEN	- MAGNOX ELEC	A W B JACOB	- DIAS
W P ASPINALL	- AA	G DUDDRIDGE	- EXETER UNIVERSITY
C BEAK	- HYDRO ELEC	P McCORMACK	- PAISLEY OBSERVATORY
P M BRADFORD	- NII, BOOTLE	DIRECTOR	- BGS, KEYWORTH
J E INKESTER	- NII, BOOTLE	M RAINES	- BGS, KEYWORTH
D J MALLARD	- CONSULTANT	S BRACKELL	- BGS, LONDON INFO OFF
A HUGHES	- ISC	D W HOLLIDAY	- BGS, KEYWORTH
H J HEASON	- BGS PRESS OFFICE		

FROM: Bennett Simpson
DATE: 25 October 1996
TIME: 14:15 UTC
PAGES TO FOLLOW: One

SEISMIC ALERT: MUSSELBURGH, LOTHIAN 25 OCTOBER 1996 12:37 UTC 2.0 ML

The following preliminary information is available for this earthquake:

DATE	:	25 October 1996
ORIGIN TIME	:	12:37 18.1s UTC
LAT/LONG	:	55.93° North / 3.08° West
GRID REF	:	332.23 kmE / 671.43 kmN
DEPTH	:	1.5 km
MAGNITUDE	:	2.0 ML
INTENSITY	:	4+
LOCALITY	:	Musselburgh, Lothian

Reports have been received of the earthquake being felt in the Musselburgh, Joppa and Newcraighall areas of Lothian. Felt reports describe "the whole house shook and the settee moved", "like an underground explosion" and "people ran out into the street frightened".

Today's event, the largest since the tremors began on 2 October 1996, locates in the same general area as all the previous events during October.

A seismogram of the event, as recorded on instruments in Edinburgh, is attached.

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TO: M JOHNSTON	- DOE	H PAYNE	- WELSH OFFICE
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P A MERRIMAN	- BNFL	J P McFARLANE	- SCOTTISH NUCLEAR
H TUR	- BNFL CAPEN	P W WINTER	- AEA
C BUMPUS	- NIREX	P J BUCKLEY	- HSE
T C CHIVERS	- NUCLEAR ELEC	V KATHIGAYAN	- HSE OFFSHORE
C F ALLEN	- MAGNOX ELEC	A W B JACOB	- DIAS
W P ASPINALL	- AA	G DUDDRIDGE	- EXETER UNIVERSITY
C BEAK	- HYDRO ELEC	P McCORMACK	- PAISLEY OBSERVATORY
P M BRADFORD	- NII, BOOTLE	DIRECTOR	- BGS, KEYWORTH
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A GONSALVES	- BRITISH GAS	S BRACKELL	- BGS, LONDON INFO OFF
A HUGHES	- ISC	D W HOLLIDAY	- BGS, KEYWORTH
D J MALLARD	- CONSULTANT	H J HEASON	- BGS PRESS OFFICE

FROM: Davie Galloway
DATE: 10 November 1996
TIME: 12:00 UTC
PAGES TO FOLLOW: TWO

SEISMIC ALERT: PENZANCE EARTHQUAKE 10 NOVEMBER 1996 09:28 UTC 3.8 ML

BGS have received many calls from the local authorities, media and general public reporting an earthquake in Cornwall early this morning. Reports have been received of it being felt throughout the SW Cornwall area. Felt reports describe "a loud bang and rumble" and "the whole house shook for about 5 or 6 seconds" . The following preliminary information is available for this earthquake:

DATE	:	10 November 1996
ORIGIN TIME	:	09:28 33.9s UTC
LAT/LONG	:	50.00° North / 5.57° West
GRID REF	:	143.97 kmE / 17.53 kmN
DEPTH	:	9.1 km
MAGNITUDE	:	3.8 ML
INTENSITY	:	4+
LOCALITY	:	Penzance, Cornwall

Previous events in the area include the Penzance earthquake of 15 July 1757 (magnitude 4.4 ML) with an epicentre 19 km NE of today's event, the 23 July 1966 Helston earthquake (magnitude 4.1 ML) 28 km ENE of today's event and the Constantine earthquake on the 25 February 1981 (magnitude 3.5 ML) 30 km ENE of today's event.

A seismogram of the event, as recorded on instruments in Hereford, and a map showing the instrumental seismicity, since 1970, within 50 km of the epicentre are attached.

BGS STAFF WITH INPUT TO THE PROJECT

Ms R A R Aitken
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
Ms M E A Ritchie
Mr B A Simpson
Mr D A Stewart
Mr T Turbitt
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 1997

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 1997

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 1997

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 1997

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/96/06	Walker, A.B. and Browitt, C.W.A. UK Earthquake monitoring 1995/96, BGS Seismic Monitoring and Information Service, Seventh Annual Report. June 1996.
WL/96/21	Musson, R.M.W., 1996. The Barrow-in-Furness earthquake of 15 February 1865: liquefaction from a very small magnitude event. June 1996.
WL/96/22	Musson, R.M.W., 1996. On the evaluation of macroseismic scales. June 1996.
WL/96/29	Walker, A.B. Rapid Transfrontier Seismic Data Exchange Network (Transfrontier Group); Second Annual Report. November 1996.
WL/96/32	Richards, J.A. Site response and mining-induced earthquakes in the Midlothian coalfields. October 1996.
WL/96/33	Browitt, C.W.A. and Walker A.B. Musselburgh Earth Tremors. November 1996.
WL/97/04	Walker, A.B. (ed), Ford, G D., Galloway, D D., Simpson, B.A., and Wright, F. Bulletin of British Earthquakes, 1996. March 1997.

In addition, 3 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

Ceci_, I., Musson, R.M.W., and Stucchi, M., 1996. Do seismologists agree upon epicentre determination from macroseismic data? A survey of ESC WG "Macroseismology", Annali di Geofisica, vol 39, no 5, pp 1013-1029.

Galloway, D.D. and Walker, A.B., 1997. A summary of earthquakes in 1996. The Society for Earthquake and Civil Engineering dynamics (SECED) Newsletter. Vol 11 No 1., January 1997.

Grünthal, G., Bosse, C., Musson, R.M.W., Gariel, J.-C., de Crook, T., Verbeiren, R., Camelbeeck, T., Mayer-Rosa, D. and Lenhardt, W., 1996. Joint seismic hazard assessment for the central and western part of GSHAP Region 3 (Central and Northwest Europe), in Thorkelsson, B., (ed) Seismology in Europe, Icelandic Met. Office, Reykjavik, pp 339-342.

Musson, R.M.W., 1996. The seismicity of the British Isles, Annali di Geofisica, vol 39, no 3, pp 463-469.

Musson, R.M.W., 1996. On the quality of intensity assignments from historical earthquake data, in Thorkelsson, B., (ed) Seismology in Europe, Icelandic Met. Office, Reykjavik, pp 607-612.

Musson, R.M.W., 1996. Determination of parameters for historical British earthquakes, Annali di Geofisica, vol 39, no 5, pp 1041-1048.

Musson, R.M.W., Pappin, J., Lubkowski, Z, Booth, E. and Long, D., 1997. UK Continental Shelf seismic hazard, Health and Safety Division Offshore Technology Report OTH 93 416.

Musson, R.M.W., 1997. Fake quakes in Britain, UKGA-21 Abstracts, JAG Newsletter, p8.

Ritchie, M.E.A. and Walker, A.B., 1996. UK seismicity and its relationship to heat flow and the regional stress tensor [ABST.] JAG Newsletter UKGA-20. Issue 7., April 1996.

Sleeman, R., and Walker, A.B., 1996. Rapid Transfrontier Seismic Data Exchange Network. Abstract, ESC XXV General Assembly.

UK EARTHQUAKE MONITORING 1995/96 BGS SEISMIC MONITORING AND INFORMATION SERVICE: SEVENTH 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 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 km² 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.

THE BARROW-IN-FURNESS EARTHQUAKE OF 15 FEBRUARY 1865: LIQUEFACTION FROM A VERY SMALL MAGNITUDE EVENT

R M W Musson

The earthquake of 15 February 1865 affected only a very small area around Barrow-in-Furness, yet had a very high epicentral intensity (8 EMS). Considerable damage was caused at the village of Rampside. On the sands near Rampside, liquefaction effects such as sand fountaining and quicksand were observed. Conventional wisdom states that liquefaction only occurs with large earthquakes; this event shows that very vulnerable sediments can liquefy even with a small earthquake if the intensity is high enough.

ON THE EVALUATION OF MACROSEISMIC SCALES

R M W Musson

The introduction and testing of the new European Macroseismic Scale has raised questions about how intensity scales can be evaluated or compared. Some weaknesses in intensity scales can be observed as problems encountered in practice, such as inconsistency, lack or resolving power, irregularity, etc. Comparing one scale against another is difficult when scales are roughly similar (e.g. the various twelve degree scales), as there are usually more significant differences between investigators than there are between scales.

RAPID TRANSFRONTIER SEISMIC DATA EXCHANGE NETWORK (TRANSFRONTIER GROUP); SECOND ANNUAL REPORT.

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, Annex F), 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.

This second year report reiterates the overall rationale, objectives and methodologies that have been applied in the project together with an outline of progress throughout the reporting period. There has been considerable interchange and mutual assistance between participants in order to develop a more even level of exchange techniques.

Progress has been facilitated by five meetings of the participants: in February 1994 (Edinburgh, UK) for pre-project planning, in April 1995 (Madrid, Spain), October 1995 (De Bilt, the Netherlands), April 1996 (Dublin, Ireland) and October 1996 (Strasbourg, France). They proved to be positive, engendering a strong spirit of cooperation and an essential vehicle for problem solving and planning.

SITE RESPONSE AND MINING-INDUCED EARTHQUAKES IN THE MIDLOTHIAN COALFIELD

J A Richards

A series of mining-induced tremors in the Midlothian coalfield, Scotland, during the late 1980's resulted in minor damage to a 15th Century listed building, despite its protection from subsidence by a 300 m radius mining prevention zone. The event magnitudes were relatively small (maximum 2.3 ML) to have produced damaging intensities, and it was suspected that localised superficial deposits, approximately 33 m in depth, were causing amplification of ground motions in the affected area.

Comparisons of seismic records from the superficial site with those from a nearby bedrock site over a period of more than 2 years confirmed the amplification effect. Analysis of Fourier spectra and spectral ratios demonstrated that the ground response at the superficial site was frequency dependent, with maximum amplifications seen at frequencies of around 2 to 4 Hz on the horizontal components and 6 to 8 Hz on the vertical component. Provisional results for levels of amplification at the superficial site suggested that ground velocities were often 10 to 20 times greater than at the bedrock site, particularly in the horizontal direction. Preliminary analysis of the largest (2.2 ML) event recorded during the monitoring period indicated maximum ground accelerations of up to 5% g at the affected site.

The amplification effect at soft sites should clearly be taken into account when considering the protection of structures in mining areas, even when those structures are outside the zone normally considered to be at risk from subsidence.

MUSSELBURGH EARTH TREMORS, 1996

C W A Browitt and A B Walker

On 2 October 1996, an earth tremor was felt strongly by residents in the Newcraighall/Musselburgh area to the east of Edinburgh. Eight other events, which were not felt, were detected by the British Geological Survey's national seismic monitoring network in the period 8 to 11 October before another felt one occurred. Thereafter, the tremors, both felt and not felt, had an increased frequency to the present date. The total number recorded by BGS is 80 with 20 of them reported to be felt.

The UK national monitoring network is designed to have an effective uniform station coverage at a density of one monitoring station every 70 km although in some areas it is better than this (Fig 1). Its purpose is to detect and locate all earthquakes on land above magnitude 2.0, in average to difficult noise conditions, and to discriminate, as far as possible, natural earthquakes from man-made seismic vibrations including quarry blasts, underwater explosions, sonic booms etc. The ultimate goal is an improved, quantified assessment of seismic hazard for Government, Local Authorities, planners and industry. Figure 2 shows the earthquakes located by the network since 1979 for a magnitude threshold of 2.5 on the Richter scale. The record is thought to be complete for such events despite the poorer station coverage in the early years. Almost all magnitude 2.5 earthquakes are capable of being felt by people.

BULLETIN OF BRITISH EARTHQUAKES 1996

A B Walker (editor)

There have been 204 earthquakes located by the monitoring network during the year, with 27 of them having magnitudes 2.0 ML or greater. Of these, nine are known to have been felt, together with a further 25 smaller ones, bringing the total to 34 felt earthquakes in 1996.

The largest earthquake occurred offshore, 12 km south of Penzance, Cornwall, on 10 November. It had a magnitude of 3.8 ML and was felt over an area of 14,000 km² throughout Cornwall, the Scilly Isles and in parts of Devon. Felt reports included "bottles on a shelf shook and fell off" and that people "ran outside to see if an explosion had demolished a house". A macroseismic survey, with 900 replies showed a maximum intensity of 5 EMS close to the epicentre where minor damage (cracked plaster) occurred. Three aftershocks were detected, on the same day, but none were felt. This is the largest event to have affected mainland UK since the 15 February 1994 Norwich earthquake (magnitude 4.0 ML), which was felt with an epicentral intensity of 5 EMS. It occurs in the same area as the magnitude 4.4 ML Penzance earthquake on 15 July 1757, which was felt with intensities of between 5 and 6 EMS. A poorly constrained fault plane solution shows normal faulting, with varying components of strike-slip motion, on planes striking either NS and dipping to the east or striking NW-SE and dipping to the SW.

Two of the largest offshore earthquakes during 1996, with magnitudes of 3.9 ML, were located in the northern North Sea region on 25 June and 31 October; neither was reported to be felt. A further eight events occurred in the area during the year, with magnitudes ranging between 1.8 and 3.8 ML, and were located using both the BGS and Norwegian networks. Earthquake activity in the offshore areas during 1996 was higher than the long-term average, with five events exceeding magnitude 3.0 ML, against an average annual occurrence of four per annum. Only one earthquake in the northern North Sea was reported felt during the year. It occurred on 16 December, with a magnitude of 3.3 ML, and was felt at the Fedje Fyr lighthouse and in the village of Vaksdal, Norway.

On 7 March, an earthquake, with a magnitude of 3.4 ML, was located approximately 9 km north of Shrewsbury in Shropshire. It was felt throughout Shrewsbury, Telford, Oswestry and in many surrounding villages. The reports described "vibrations like a heavy vehicle had crashed into the house" and "a violent shuddering"; a few reports of minor damage (cracked plaster) were also received. The earthquake was felt over an area of 3000 km². A macroseismic survey throughout the region indicated a maximum intensity of 5 EMS in the epicentral area. The fault plane solution of the event shows dominant normal faulting on planes striking NW-SE and dipping NE or SW.

On 6 May, an earthquake, with a magnitude of 2.8 ML, was felt in the Stoke-on-Trent area. The reports described a "rumble and bang". A macroseismic survey in the region revealed that it was felt over 900 km^2, with a maximum intensity of 4 EMS in the epicentral area. A further six events occurred, with magnitudes ranging between 1.2 and 1.9 ML. Swarms of activity were detected in this same area in the mid 1970s, early 1980s, early 1990s and more recently in 1995, where 6 events were felt in four days.

On 18 May, an earthquake, with a magnitude of 2.9 ML, occurred some 2 km north of the village of Furnace, on the banks of Loch Fyne, Strathclyde. It was felt in Furnace, Strachur and Inveraray with intensities of at least 3 EMS. Felt reports describe "a large bang, followed by the whole house shaking" and " a light rattling of crockery on a display cabinet". An event, with a magnitude of 1.5 ML, occurred two days later in the same area, but was not reported felt.

An earthquake, with a magnitude of 3.0 ML, occurred on 20 September at Llanddewi Ystradenni, approximately 9 km NNE of Llandrindod Wells. The event was felt by local residents in Llandrindod Wells, Knighton, Rhayader, Builth Wells and in the village of Llanbister. Felt reports described "a shudder" and "the whole house shook and windows rattled" indicating an intensity of at least 4 EMS. No macroseismic survey was carried out owing to the few reports received from each of the villages. A poorly constrained fault plane solution was obtained.

In Comrie, Tayside, a small earthquake with a magnitude of 1.4 ML, was felt by local residents on 20 October. Felt reports described a "big bang and a rumble" indicating a maximum intensity of at least 3 EMS. There have been occasional events over the past few years in the region which was famous for the frequency of its earthquakes in the 1790s, 1830s and 1840s. In 1875, following a number of small events, Victorian scientists built an observatory with crude earthquake detection instruments in an attempt to learn more about the earthquakes. The observatory, which is called 'Earthquake House', has been restored and opened to the public by Perth and Kinross District Council with some help from BGS.

A swarm of fourteen earthquakes was detected approximately 10 km south of the Isle of Arran, Strathclyde, during 1996. The largest, with a magnitude of 2.2 ML, occurred on 26 June and was not reported felt. Similar swarms in the area were detected in the early 1990s.

Throughout the southern North Sea region, three events have been located, with magnitudes of 1.7, 1.8 and 2.1 ML; none were reported felt. These events are in the same area as the event on 2 May 1995, with a magnitude of 3.4 ML.

In North Wales, three events with magnitudes of -0.2, 0.6 and 1.2 ML were located on the Lleyn Peninsula, in the same area and at similar depths, as the magnitude 5.4 ML Lleyn Peninsula earthquake of 19 July 1984, which was felt over an area of 250,000 km^2.

Near Maidenhead in Berkshire, an earthquake, with a magnitude of 1.9 ML, occurred on 8 December. This event, together with 2 others, both some 30 km distant, represents the only seismicity in the area over the past 27 years.

The coalfield areas of central Scotland, Yorkshire, Staffordshire and Nottinghamshire continued to experience earthquake activity of a shallow nature which is believed to be mining induced. The area east of Edinburgh became active as a result of mining this year. Some 71 coalfield events, with magnitudes ranging between -0.4 and 2.3 ML, have been detected in the year. Twenty six of these were felt by local residents; 22 from the series around Edinburgh.

During October and early November, a series of events (37 were located a further 73 were recorded on one station near the epicentre) occurred in the Musselburgh/Newcraighall area, to the east of Edinburgh. The largest event, with a magnitude of 2.0 ML, occurred on 25 October and was felt with intensities of at least 5 EMS. Information directly from local residents and through the completion of macroseismic questionnaires, distributed by BGS and published in local newspapers, have shown that the events were felt, generally, up to 2 km from the epicentre and in some cases up to 3 km. Twenty-two events in the series were felt by local residents who described the effects as being like "a heavy lorry passing outside" or "similar to an explosion". Additional instruments were installed in the area and the results showed that the pattern (most events occurring in the working week) and location of the activity was a consequence of mining at Monktonhall colliery. The two most likely causes of these events are: the undermining and subsidence of old workings with void and pillar collapses and shearing in strained rock layers; or the bridging, and subsequent breaking during subsidence, of a strong rock layer between the mine and the surface (in this case, 900 metres above).

Near Newcastle-under-Lyme, Staffordshire, three shallow events, with magnitudes of 1.9, 1.9 and 2.3 ML occurred on 20 February, 7 March and 16 March, respectively. All three events were felt by local residents in the Newcastle-under-Lyme and Keele areas with intensities of at least 3 EMS. The signals recorded by the BGS seismic network in the area indicated a shallow source (presence of surface waves) and they are thought to be related to nearby mines.

Near Mansfield, Nottinghamshire, five events with magnitudes ranging from 0.7 to 2.1 ML have been located, one of which was felt by local residents in the Wellow region of Mansfield. At shallow depths, they are believed to be of coal mining origin.

Twenty events, with magnitudes ranging between 0.7 and 1.6 ML, were located near Clackmannan in the Central region of Scotland. None were reported felt. This is an area which has experienced many such mining induced events in the past.

DO SEISMOLOGISTS AGREE UPON EPICENTRE DETERMINATION FROM MACROSEISMIC DATA? A SURVEY OF ESC WORKING GROUP "MACROSEISMOLOGY"

I Ceci_, R M W Musson and M Stucchi

The goal of the ESC Working Group "Macroseismology" is to review the current procedures for assessing macroseismic parameters. It has been considered that the best way to start was to survey current seismologists' practice. Fifteen cases of intensity maps of historical earthquakes were distributed to a number of experts, asking the seismologists to give their solutions and explain their reasons. It was shown that clear differences exist between those who sought to treat the macroseismic epicentre as the same point as the instrumental epicentre, and those who sought to find a point from which the intensity field could be remodelled, irrespective of whether this point had any tectonic significance.

SUMMARY OF 1996 EARTHQUAKES

D D Galloway and A B Walker

The year 1996 was not exceptional in terms of the earthquakes which occurred world-wide. There was one 'great' earthquake with a magnitude over 8.0, ten 'major' earthquakes (magnitudes between 7.0 and 7.9) and 88 'strong' earthquakes (magnitudes between 6.0 and 6.9). These figures are in general below the long term averages which are one, 18 and 120, respectively. The number of people reported killed by earthquakes during 1996 was 500 against a long term average of 8,700 per annum. This was because most of the major earthquakes occurred in remote, sparsely populated areas.

Without doubt, the Yunnan, China earthquake was the most disastrous of 1996, accounting for about half of the fatalities. It occurred on 3 February and caused the deaths of some 250 people, injured over 4,000, destroyed 329,000 homes and left over 1,000,000 homeless. Several rockslides were also reported in the Lijiang area. The earthquake was not, however, exceptionally large, with a magnitude of 6.5 Ms, and such events can be expected once or twice a week on average, worldwide. It was the second large earthquake within a few months, in this area of the Yunnan Province, on the eastern edge of the Himalayas, following a magnitude 6.4 event on 23 October 1995 which killed 40 people in the Wuding area.

The one great earthquake of the year, with a magnitude of 8.1 Ms, occurred on 17 February, in Irian Jaya, Indonesia. It resulted in the deaths of 108 people and caused injury to over 400. Some 5,000 houses were destroyed in the epicentral area and extensive damage on the islands of Biak and Supiori was reported due to the earthquake and resultant tsunami, which reached heights of 7 metres in many areas. Hundreds of aftershocks, with magnitudes greater than 4, were detected in the first few days following the mainshock; the largest with a magnitude of 6.7 Ms.

Most of the severely damaging earthquakes in 1996 were in the ‘major’ or ‘strong’ categories. There were, however, a number of notable exceptions proving once again that a relatively small magnitude earthquake, with a shallow depth of focus in a highly populated area, can be disastrous. The magnitude 5.8 Mb Ecuador event of 28 March was the most notable of these, killing some nineteen people, causing injury to 58 others and leaving several thousand homeless. It caused considerable damage to houses, bridges and water and gas pipes in the Cotopaxi, Pastaza and Tungurahua Provinces. The smallest earthquake of 1996 to cause injury, with a magnitude of 4.5 Ms, occurred on 15 July in the Annecy region of France. One person was slightly injured and minor damage was reported at Cruseilles. The earthquake was felt strongly at Annecy and Lyon and was also widely felt in the Alps and southern Switzerland.

The year started off with a destructive earthquake on the Minahassa Peninsula, Sulawesi on 1 January. It had a magnitude of 7.7 Ms and killed eight people and damaged over 200 buildings in the Tolitoli area. A local tsunami contributed to much of the damage in the epicentral area.

Two damaging earthquakes occurred in Peru. The first, on 21 February with a magnitude of 6.6 Ms, killed four people, injured several others and left three missing. The deaths and injuries were all attributed to a tsunami which devastated some low lying coastal areas. This local tsunami destroyed about 150 huts (homes) along the coast near Chimbote. The second event, occurred on 12 November, with a magnitude of 7.3 Ms. It killed at least 15 people, injured 700 others and left over 12,000 homeless from Chincha Alta to Acari. Extensive damage occurred at Nazca, where over 4,000 houses were damaged or destroyed, and some occurred in the Marcona region. The earthquake was felt strongly in the Marcona region, at Ica, Palpa, Arequipa and Camana and was also felt by people in high-rise buildings at Guayaquil, Ecuador, and La Paz, Bolivia. This thrust earthquake is associated with the subduction of the Nazca Ridge (a major feature of the Nazca plate) beneath the South American plate. It originated near the southern end of a seismic gap between the large Peruvian earthquakes of 24 August 1942 and 3 October 1974, with the aftershock sequence progressing southward into the zone of the 1942 event.

A further two earthquakes occurred in China during 1996; the first, with a magnitude of 6.0 Ms on 19 March, in southern Xinjiang killed 24 people, injured 128 and destroyed and damaged over 15,000 houses in the Artux-Jiashi area; the second, on 3 May with a magnitude of 6.0 Ms struck Western Nei Mongol killing at least 18 people and injuring 300 others. Extensive damage occurred in the Baotou region and it was felt at Beijing, Hohhot, Taiyuan, Xian and Yinchuan.

In the Solomon Islands, on 29 April, an earthquake with a magnitude of 7.5 Ms killed one person, collapsed numerous houses in western Bougainville and was felt throughout the island of Bougainville.

A damaging earthquake in the Cyprus region on 9 October, with a magnitude of 6.8 Ms, resulted in two deaths in Cyprus and Egypt. Twenty others were injured on Cyprus. The earthquake was felt strongly on Cyprus and was also felt in Egypt, Israel, Jordan, Lebanon and Syria.

Other notable world earthquakes during 1996 included; Washington State, on 3 May with a magnitude of 5.2 Mb which injured two people and caused slight damage in the epicentral area; Eastern Honshu, Japan, on 10 August (magnitude 6.0 Mb) which injured ten people and damaged some 15 houses; Adriatic Sea, on 5 September (magnitude 6.0 Ms) which injured several people, left 2,000 homeless and caused extensive damage in the Ston-Slano region, Croatia.

The UK summary of earthquakes is covered in the summary for the 1996 bulletin of British earthquakes above.

JOINT SEISMIC HAZARD ASSESSMENT FOR THE CENTRAL AND WESTERN PART OF GSHAP REGION 3 (CENTRAL AND NORTHWEST EUROPE)

G Grünthal, C Bosse, R M W Musson, J-C Gariel, T de Crook, R Verbeiren,T Camelbeeck, D Mayer-Rosa and W Lenhardt

A unified seismic hazard assessment for the whole of NW and Central Europe was carried out as part of the Global Seismic Hazard Assessment Programme, giving hazard maps free from discontinuities at national boundaries, which were a prominent feature of previous maps. In the case of the UK, very similar results were obtained from those in the national hazard maps, despite significant differences in the methodological approach.

ON THE QUALITY OF INTENSITY ASSIGNMENTS FROM HISTORICAL EARTHQUAKE DATA

R M W Musson

Historical earthquake data that have survived to the present day have undergone a series of non-random filters and distortions as a result of processes of document creation, survival and retrieval. Not all accounts yield intensity assessments of equal value. One can distinguish between certainty and quality – the certainty of an intensity assessment is the extent to which it can be expressed as a single value; the quality is the extent to which the recorded data reliably expresses what actually happened. A system is presented for classifying the latter.

THE SEISMICITY OF THE BRITISH ISLES

R M W Musson

The publication of the BGS catalogue of British earthquakes allows an improved look at the pattern of British seismicity. There are clear regional variations, which are hard to explain from geological data. Values for the recurrence rate of British earthquakes are presented.

DETERMINATION OF PARAMETERS FOR HISTORICAL BRITISH EARTHQUAKES

R M W Musson

The construction of a parametric catalogue of historical earthquakes in the UK required the determination of means for converting intensity data into estimates of those parameters normally determined from instrumental observations. Epicentral parameters were derived from the location of highest intensities plus other information including location of accessory shocks. Magnitude was determined from a good correlation between magnitude and felt area. Depth was determined by a variation of the Sponheuer method.

UK CONTINENTAL SHELF SEISMIC HAZARD

R M W Musson, J Pappin, Z Lubkowski, E Booth and D Long

Seismic hazard maps were compiled for the whole of the UK territorial waters, using the USGS hazard mapping program SEISRISK III. The results are presented in the form of maps showing peak ground acceleration values with different return periods. Sample hazard curves and unified hazard spectra are also given for points with different seismic hazard characteristics.

FAKE QUAKES IN BRITAIN

RMW Musson

In compiling a catalogue of historical earthquakes for any region, it is important to pay particular care to the identification and removal of spurious events that may appear in previous compilations. Many early British earthquake cataloguers paid little attention to matters of historical accuracy, and as a result numerous errors have been repeated time and time again. An analysis of fake quakes in British catalogues reveals nine possible sources of error: (1) errors of date resulting from the confused state of medieval calendars; (2) errors of date resulting from misidentification of relative dates (eg "last Tuesday"); (3) confusion of places in Britain with places overseas; (4) confusion of places in Britain that have similar names; (5) misidentification of gunfire, explosions, etc as earthquakes; (6) confusion of landslips with earthquakes, often as a result of loose terminology; (7) obvious hoaxes; (8) probable hoaxes; (9) events for which no good evidence can be found, but which cannot with certainty be classified in any of the previous categories.

PUBLICATION SUMMARIES ANNEX G

UK SEISMICITY AND ITS RELATIONSHIP TO HEAT FLOW AND THE REGIONAL STRESS TENSOR

M E A Ritchie and A B Walker

UK seismicity tends to be concentrated in the upper crust, however, occasionally earthquakes are located at depths of between 20 and 24 km in the lower crust. Heat-flow maps may act as an indicator of the deepest seismicity for a given area. For example, the 1994 Newtown earthquake occurred at a focal depth of 21.6 km and observations suggest a lower than average heat-flow in that area. In contrast, the high heat-flow of the Cornubian batholiths relates to some of the shallowest seismicity in the UK. Evidence suggests that the largest earthquakes will nucleate at the base of the seismogenic zone where shear resistance peaks. Mapping the depth to the brittle-ductile transition for the UK may, therefore, identify those areas at most risk.

Focal mechanisms obtained for single earthquakes provide only limited information on the nature of the ambient stress regime but add to the database of UK fault plane solutions and regional stress directions. In general, there is a dominance of strike-slip mechanisms, highlighting the extreme horizontal forces acting on Britain as a result of the spreading at the Mid-Atlantic Ridge and the compression of Africa. The orientation of the principal compressive stress axis, generally observed for the UK, acts in a NW-SE direction. Deviations of the regional stress tensor may, however, be a function of local geology.

RAPID TRANSFRONTIER SEISMIC DATA EXCHANGE NETWORK (TRANSFRONTIER GROUP)

R Sleeman and 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, 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. Ordinary dwellings and industries can be at risk from earthquakes in the magnitude range of 5 to 5.5, when they occur close to vulnerable cities. For example, the 1992 Roermond earthquake in the Netherlands, with a magnitude of 5.8 ML caused damage in the epicentral region and losses estimated in excess of 100 MECUs. Ten EU Member States in the low to medium seismicity region, Ireland, United Kingdom, the Netherlands, Denmark, Belgium, Luxembourg, France, Germany, Portugal and Spain are collaborating to establish and maintain a network of seismological institutions with the capability of exchanging raw data within, at most, one working day of the occurrence of a significant earthquake. The extension of networks and harmonisation of methods have been features of the project with the differing levels of available resources leading to cross-institution technology transfers. The introduction of a standard automated data exchange system (AutoDRM) has put the project on a convergent path with the European data centres EMSC and ORFEUS and with GSETT. Success in this endeavour will benefit social, scientific and engineering communities. This project is supported by the European Commission DG XII for Science, Research and Development under the Environment programme 1991-1994: Climatology and Natural Hazards.

ANNEX H

SYNOPSIS OF EMS-92 INTENSITY SCALE

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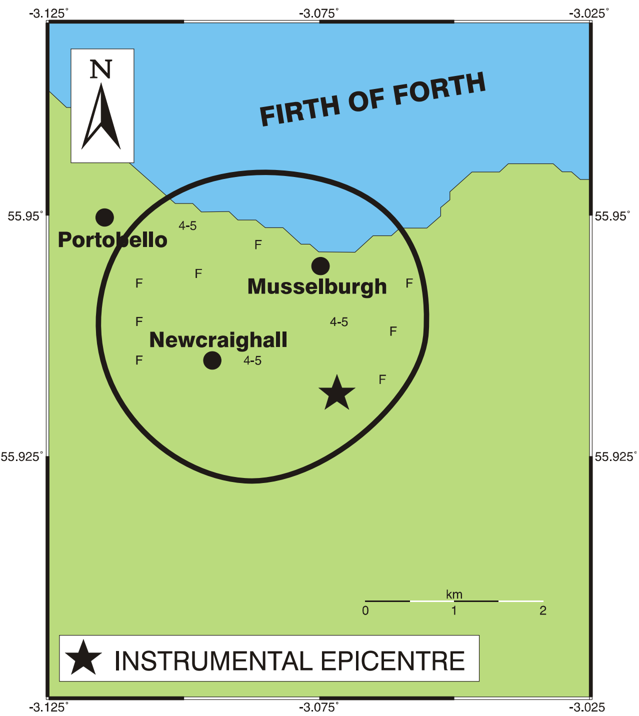
A complete description of the EMS-92 scale is given in: Grunthal, G., (Ed) 1993. European Macroseismic scale 1992 (up-dated MSK-scale). Cahiers du Centre European de Geodynamique et de Seismologie. Vol 7.



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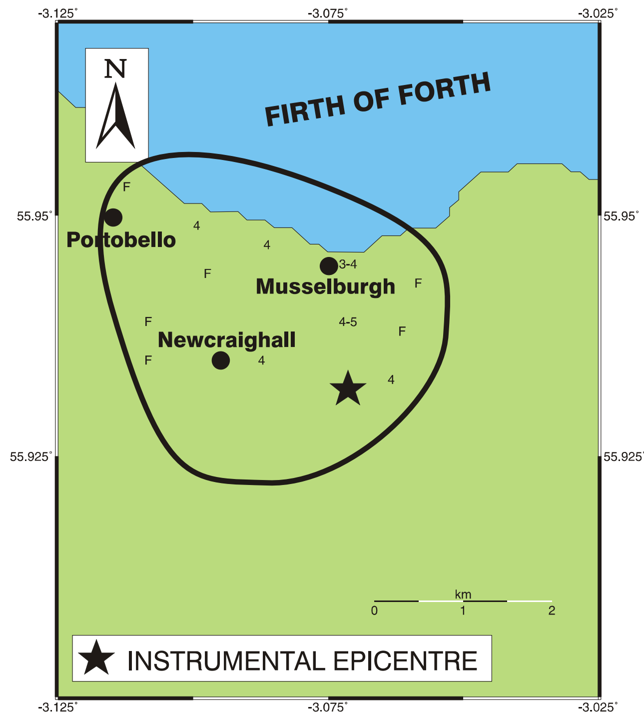

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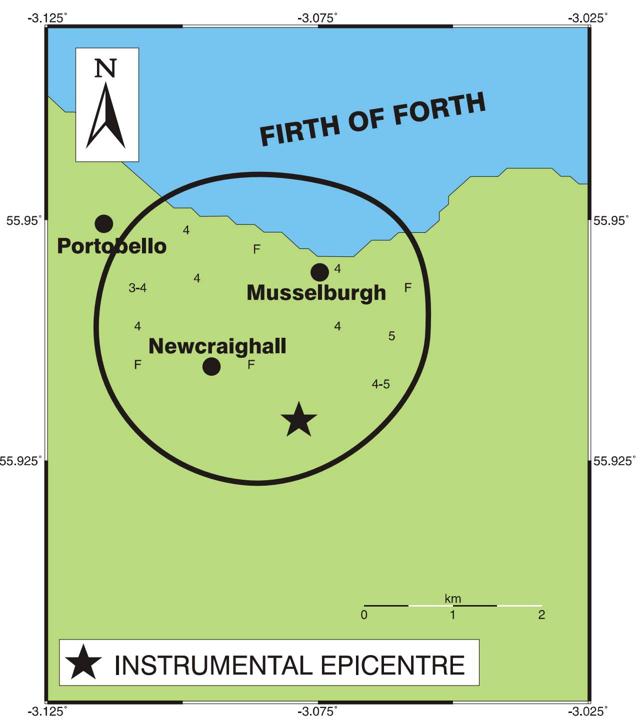
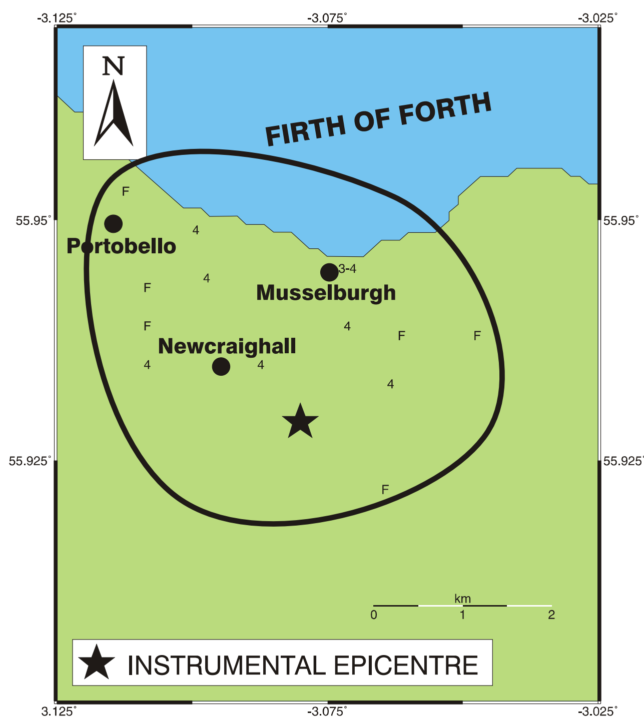


25th October 1996, 12:37 UTC (2.0ML)



28th October 1996, 20:36 UTC (1.9ML)

Felt areas of Musselburgh earthquakes, October 1996.