UK EARTHQUAKE MONITORING 2001/2002

BGS Seismic Monitoring and Information Service

Thirteenth Annual Report

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

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

BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT IR/02/053

Global Seismology and Geomagnetism

UK Earthquake Monitoring 2001/2002

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Thirteenth Annual Report

Alice B Walker

June 2002

UK Seismic Monitoring and Information Service Year Thirteen Report to Customer Group: June 2002

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

Bibliographic reference
Walker, A. B., 2002.
BGS Seismic Monitoring and Information Service Thirteenth Annual Report.
British Geological Survey Technical Report IR/02/053

Edinburgh British Geological Survey 2002

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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.

The British Geological Survey is a component body of the Natural Environment Research Council

Keyworth, Nottingham NG12 5GG
☎ 0115 936 3100
FAX 0115 936 3200

Murchison House, West Mains Road
Edinburgh EH9 3LA
☎ 0131 667 1000
FAX 0131 668 2683

London Information Office at the Natural History Museum, Earth Galleries, Exhibition Road, South Kensington, London SW7 2DE
☎ 0171 589 4090
☎ 0171 938 9056/57
FAX 0171 584 8270

Forde House
Park Five Business Centre
Harrier Way, Sowton
Exeter, EX2 7HU
☎ 01392 445271
FAX 01392 445371

Geological Survey of Northern Ireland,
20 College Gardens,
Belfast BT9 6BS
☎ 01232 666595
FAX 01232 662835

Maclean Building, Crowmarsh Gifford,
Wallingford,
Oxfordshire OX10 8BB
☎ 01491 838800
FAX 01491 825338

Parent Body
Natural Environment Research Council
Polaris House, North Star Avenue, Swindon
Wiltshire SN2 1EU
☎ 01793 411500
FAX 01793 411501

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UK EARTHQUAKE MONITORING 2001/2002

1. Executive Summary

The aims of the Seismic Monitoring and Information 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. The British Geological Survey (BGS) has been charged with the task of operating and further developing a uniform network of seismograph stations throughout the UK in order to acquire standardised data on a long-term basis. The project is supported by a group of organisations under the chairmanship of the Department of Transport Local Government and the Regions (DTLR) with major financial input from the Natural Environment Research Council (NERC). This Customer Group is listed in Annex A.

In the 13th year of the project (April 2001 to March 2002), nine networks were upgraded with the installation of QNX operating systems and a strong motion instrument was installed at Hartland in North Devon. Some gaps still remain in station coverage; notably in Northern Ireland. Other areas with site-specific networks, in Jersey, northern Scotland, the Outer Hebrides and the Orkney Islands, remain vulnerable to closure owing to their dependency on funds from the commissioning bodies.

Some 135 earthquakes were located by the monitoring network in 2001, with 37 of them having magnitudes of 2.0 ML or greater and 16 reported as felt. Six strong-motion records were captured from five of the eighteen sites now equipped with strong motion instruments. The largest earthquake in the reporting year on 28 October was widely felt in central England, had a magnitude of 4.1 ML, with an epicentre near Melton Mowbray. A macroseismic survey was conducted and around 6,500 replies were received, giving a maximum intensity of 5 on the European Macroseismic Scale (EMS, Annex H). The earthquake was felt up to 140 km away and over an area of 25,000 km^2 (Isoseismal 3). The nearest 3-component strong motion instrument to record the earthquake was 15 km from the epicentre and accelerations of 121, 190 and 212 mms^{-2} were recorded for the vertical, NS and EW components, respectively. The focal mechanism indicates oblique normal faulting along either a near N-S fault plane dipping at 51° or along a near E-W fault plane dipping at 58°. The largest offshore earthquake occurred in the central North Sea on 7 May 2001 with a magnitude of 5.0 Mw, approximately 410 km east of Edinburgh. It was felt on three nearby oil platforms in the Ekofisk field. The Ekofisk Hotel Platform control tower described “a swaying lasting 2 minutes which left us feeling dizzy”, they also confirmed that the Albuskjell platform, some 15 km to the north and the Eldfisk platform, some 26 km to the south, reported similar felt effects. The focal mechanism obtained for the earthquake shows normal faulting with north-south trending nodal planes. In addition to earthquakes, BGS frequently receives 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. During the reporting period, data from four sonic events were processed and reported upon following public concern or media attention.

All significant felt events and some others were reported rapidly to the Customer Group through seismic alerts sent by e-mail. The initial alert was followed by a more detailed information release. The alerts were also published on the Internet

(http://www.gsrg.nmh.ac.uk). Monthly seismic bulletins were issued 6 weeks in arrears and, following revision, were compiled into an annual bulletin (Simpson, 2002). In all these reporting areas, scheduled targets have been met or surpassed.

The environmental monitoring stations at Eskdalemuir and Hartland observatories recorded a variety of parameters throughout the year and the data are now accessible on-line through an Internet connection.

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 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 with respect to potentially hazardous installations and sensitive structures. This work 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. For nuclear sites, objective information is also provided to verify the nature of seismic events or to confirm false alarms, which might result from locally generated instrument triggers. 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 ones in order to allay any unnecessary worries. Most seismic events occur naturally, but some are triggered by human activities such as mining, and other tremors (eg. sonic booms and explosions) are often mistaken for earthquakes.

This Year 13 report to the Customer Group follows the format of the first twelve annual reports in reiterating the programme objectives and highlighting some of the significant seismic events in the reporting period April 2001 to March 2002. The catalogue of earthquakes for the whole of 2001 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, Nineteen strong motion instruments have been integrated with the UK network. They record ground acceleration for the larger felt earthquakes, remaining on-scale up to 0.1g. Traditionally, strong motion and high sensitivity networks have been treated separately for technical reasons but the digital technology now employed permits both to be integrated with benefits in cost and reliability. Most importantly, this approach ensures that there is a pool of analysts familiar with extracting and processing data despite the infrequency of strong motion earthquakes. Now that 24-bit technology can capture data with accelerations up to 0.25g, the strong motion instruments are being upgraded as funds permit.

The permanent BGS broadband station in Edinburgh has been successfully running throughout the year and has continued to provide data through a French satellite system to the European-Mediterranean Seismological Centre (EMSC). Together with rapidly linked short-period data from three subnetworks of the UK system, it contributes to the wider European capability of providing alerts within two hours for earthquakes with magnitudes greater than 5.0.

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 in Jersey, northern Scotland, Outer Hebrides and the Orkney Islands. These are vulnerable to closure when the commissioning organisations have completed the work for which they were installed. For the next twelve months, however, there is no threat. The developing strong motion coverage is shown in Figure 6.

3. Programme objectives

The overall objectives of the service established in 1988 were:

- 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.

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

- To establish and maintain a database and archive of seismicity and seismic records.

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. Further improvement can be achieved by upgrading the network to 24-bits, therefore increasing the dynamic range of individual stations and reducing the number of saturated records. 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. Advantage was taken of existing site-specific monitoring networks so that, in places, the overall network density is greater than 70 km spacing.

As the programme developed under the guidance of the Customer Group, further objectives were added:

- To develop a strong motion capability within the network to permit the maximum ground accelerations to be captured on-scale from nearby small earthquakes and widely from the rare larger ones.

- To guarantee a 24-hour on-call service by experienced seismic analysts.

- To upgrade the capability of the network following advances in technology, as funding permits.

- To extend the environmental parameters monitored in order to broaden customer support.

3.1 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 146 in 2002. Large areas have been filled in to give coverage of southern England, the Irish Sea, northern Scotland and, recently, in the Faroe islands to cover offshore 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 13-year project period. Almost all magnitude 2.5 earthquakes are felt together with many in the 2.0-2.5 range. In 1988, however, these events may have been poorly located owing to the poor station distribution in 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. Since 1997, stations record digitally with data transferred automatically four times a day and on demand when an earthquake occurs. Response time with objective data has been reduced to below one hour, which can generally also be achieved outside working hours.

- All UK station positions have been resurveyed using GPS techniques.

- Faster modem links have been installed at all computer recording nodes (24 in total).

- Following the upgrade of digital rapid access systems, the potential problem of losing a continuous data record has been addressed by installing large capacity disks (60Gb), allowing up to 100 days ring buffer.

- 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 (European Mediterranean Seismological Centre, Paris), the ORFEUS data centre (De Bilt, , Netherlands) and ISC (International Seismological Centre, Newbury). In the North, collaboration with Bergen University has provided direct access, 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 of nineteen stations has been installed from Shetland to Jersey including four stations specifically commissioned by British Energy, MOD and the Jersey New Waterworks Company.

- The Global Seismology Web site (http://www.gsrg.nmh.ac.uk) provides access to data through the Internet to the past month's catalogue of events and to UK and world seismic alerts.

- 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. A watching brief has been kept on archives held elsewhere to prevent their dispersal or destruction and some have been transferred to Edinburgh as a result. A series of eight reports has been made available on-line.

- The World Seismological Bulletin collection database has been published and is available on the Internet. A UK historical seismological observatories report has been compiled and is also available on the Internet.

- 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 potential data on the Edinburgh network for the period 1970-1976, recorded on a 1" tape format, which has proved difficult to extract owing to the condition of the tapes and old replay equipment.

- The seismicity 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 BGS 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 two seismic hazard mapping studies. The assessment for the offshore region was published in 1997 as a Health and Safety Division Offshore Technology Report and the onshore study has been peer reviewed and published in scientific journals (Musson and Winter, 1997 and Musson, 1997).

- The potential for using the seismic network for multifunctional environmental monitoring has been proved and a full demonstration system has been established at the BGS Eskdalemuir Observatory. Twenty environmental parameters have 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. A Memorandum of Understanding (MOU) with the Meteorological Office has laid the basis of collaboration and meteorological quality control.

3.2 Uses of the seismic database

In addition to the specific needs of the Customer Group members, the seismic database is used by a variety of organisations both in the UK and worldwide. A summary of the use made of this 32-year catalogue and digital archive of earthquakes, during the past year, follows:

3.2.1 University collaboration

Bristol University; Mapping seismic discontinuities

A study at Bristol University, under the leadership of George Helffrich, has been looking at reflectors under the Scottish Highlands with the deployment of broadband sensors.

The broadband deployment in the Scottish Highlands (RUSH, Reflectors Under the Scottish Highlands) ended in November, 2000. This network of nine broadband instruments was deployed to gather evidence for whether the offshore mantle reflectors reported by BIRPS (British Institutions Reflection Profiling Syndicate) off the north coast of Scotland extends under the Highlands. The wide frequency capabilities of these instruments are ideal for the two analysis techniques being used: teleseismic shear-wave splitting and teleseismic receiver function analysis. The October 1999 Hector Mines earthquake in southern California occurred during the deployment, which readily confirmed the reflector's presence under the Orkneys and the northern Scottish coast. These had been seen previously in short-period receiver function analysis of BGS network data from the seismograph station at Reay (ORE). The next phase will be to complete the teleseismic shear-wave splitting analysis of the data. This will provide key information to test two hypotheses of what the reflectors represent: large-scale shear zones in the crust, or a relic lithospheric slab left under Scotland after the end of Caledonian age subduction.

Brunel University; Glaciotec project

Glacio-isostatic rebound following the decay of the main British ice sheet has long been considered a trigger for palaeoseismic activity in northern Britain, but it is widely seen as a vestigial influence on contemporary seismic strain release. Brunel University's **Glaciotec** project, led by Dr Iain Stewart, is critical re-evaluating these views, in the context of a wider resurgence of interest in the effects of former ice sheets on ongoing crustal deformation and seismicity (Stewart *et al*. 2001). As new research from eastern North America and Fennoscandia highlights the subtle role that residual postglacial rebound plays in promoting ongoing crustal instability in deglaciated regions, seismologists are even concluding that rebound may be responsible for large historical earthquakes, such as the great 1811-1812 New Madrid, eastern USA. In the UK domain, recent studies conclude that, albeit on a more modest scale to that evident in Fennoscandia, the marked variations in the levels of seismicity around the former British rebound dome may reflect a glacio-isostatic component.

Ironically, the recognition that postglacial rebound may still exert a small but not insignificant influence on present-day UK seismicity patterns emerges as **Glaciotec** re-evaluates the evidence for significant 'endglacial' fault activity and seismicity. The **Glaciotec** project has undertaken a systematic appraisal of reported postglacial faults in the Scottish

Highlands, and concludes that published accounts of large postglacial fault displacements are spurious, and instead are limited to metre-scale vertical movements (Firth & Stewart 2000- abstract listed in Annex G, Stewart *et al.* in press). With all the documented postglacial faults in the NW Highlands being considered as 'unproven', the Scottish case for a burst of major seismotectonic activity during deglaciation appears unconvincing. Rejection of major strike-slip postglacial movements, which are kinematically incongruous with the present-day crustal stress regime, also resolves the need to invoke large regional rotations of the Scottish stress field during the last few thousand years, as recently proposed by researchers at Edinburgh University.

To convincingly demonstrate significant past seismotectonic activity in the Scottish Highlands, future **Glaciotec** research aims to exploit an array of multi-disciplinary investigative practices. These practices, such as subsurface geophysical imaging, fault trenching, and palaeoenvironmental studies, are now routinely applied elsewhere in the low-seismicity intraplate domain of northern Europe. At the same time, however, resolving the subtle influence of glacial unloading on seimotectonic activity in the UK will also require improved focal mechanisms and *in situ* stress data, and detailed measurements of contemporary horizontal and vertical crustal motions. Without these integrating these approaches, the UK's glacio-seismotectonic heritage will remain ambiguous.

Leicester University; UK velocity model

In the last decade, teleseismic receiver function analysis has become a powerful tool for investigating lithospheric structure. Conventionally, the method uses broadband seismic recorders, and models the derived receiver functions in terms of 1-D shear wave velocity models beneath the receiving stations. Recently, various authors (e.g. Yuan et al 1997) have shown that deconvolution of the instrument response from short period waveforms can provide stable crustal models able to resolve velocities and thicknesses of the major crustal layers.

The resulting seismic model of UK crustal structure will be used to constrain the long-wavelength modelling of the BGS UK gravity data base. Gross seismic velocity and density changes across boundaries will be interpreted in terms of crustal structure and composition and analysed in relation to the tectonic processes resulting in the present UK geological architecture. Residual pressure differences at depth derived from the density model will be examined in relation to present UK seismic activity.

Leeds University

Leeds and Bristol Universities' broadband stations, which were co-located throughout the UK, with BGS short period instruments in July 1998, continued to operate until September 2000. The objective of the array is two-fold:

- An investigation of the Earth's core-mantle boundary region and the inner-core/outer core boundary.

- A prototype for a 3-component broadband seismic network in Britain.

Teleseismic events from around the world are used to image the lowermost mantle and inner core. South Pacific events are used to map the lower mantle scatterers and the inner core boundary. North-west Pacific events and Central American events are used to investigate D" reflections from discontinuities at the core-mantle boundary.

The data, along with that from other European arrays, has been used to map detailed variations in the morphology of the D" region beneath northern Asia using migration techniques. Data was also made available to BGS for analysis of significant UK earthquakes.

Stephen Arrowsmith (co-supervised by Leeds University and BGS), has been collecting P- and S-wave arrival data for 100 teleseismic events from Leeds broadband stations and the BGS short period seismograph stations, and testing tomographic inversion software provided by J VanDecar. The overall aim of the project is to create a 3D model of the structure beneath Britain at crustal and upper mantle depths.

A long standing question in Geophysics is to what degree are the crust and mantle coupled during orogenic deformation? Do surface expressions of structural geology reflect the structural geology of the mantle? Such issues are important for understanding the driving forces of plate tectonics and the shaping of continents. Tomographic images provide a picture of the underlying crustal and mantle structure, in much the same way as ultrasonic imaging is used to view the interior of the human body.

Cambridge University- Atlantic Margins Project

The Atlantic Margins Project (AMP) is investigating the deep structure of the Faroe-Shetland, Rockall-Hatton and Porcupine troughs and surrounding regions using deep seismic reflection and refraction profiling, integrated with potential field studies. The research provides constraints on the thickness and nature of basement, depth to Moho, and the distribution and thickness of basaltic lavas and underplated igneous rock, on a regional scale. A primary scientific objective is to test the theory that magmatic underplating is directly responsible for the early Tertiary epeirogenic uplift observed on the continental shelf of the eastern North Atlantic. The data will also provide new constraints for basin modelling and analysis.

The AMP acquired three deep seismic reflection/refraction lines over the Shetland Platform and Faroe-Shetland Trough, and the airgun shots along these were recorded on four BGS seismograph stations on the Shetland Islands. The landstations recorded clear refracted arrivals from the crust and upper mantle. Over 11,000 first arrival travel-times were picked from the data and input to a 3-D tomographic P-wave velocity inversion code (FAST - First Arrival Seismic Tomography, Zelt and Barton (1998)). Although the spatial distribution of sources and receivers was sub-optimal, the resulting velocity model shows variations in the Moho depth under the platform and trough and also includes basin structures that were not previously resolved by the 2-D AMP models as they lay off-line. Provided that the marine data are acquired with a sufficiently large, low frequency source, timed to an accuracy of 1 ms, recording the shots on nearby landstations provides an extremely useful, low cost additional dataset.

The AMP research team comprises Richard Hobbs, Rose Edwards and Frauke Klingelhoefer at the University of Cambridge and Richard England at the University of Leicester. Further details and data examples can be found on the project's web-site, at http://bullard.esc.cam.ac.uk/~amp.

3.2.2 European collaboration

For a number of years data exchange with neighbouring countries has been fostered and improved through an EU project led by BGS. This has led to more rapid information becoming available on larger transfrontier earthquakes and harmonisation of the catalogues of data used for hazard assessments. The strong Ekofisk earthquake of 7 May 2001 resulted in the pooling of data from some eight countries to better understand its mechanism, depth and cause. Under another EU project for disseminating rapid warnings on earthquakes with magnitudes ≥ 5.0, parts of the UK network have been linked automatically to the European Mediterranean Seismological Centre at Bruyeres-le-Chatel, south of Paris. Separately, French workers have been provided with data on English Channel earthquakes to constrain focal mechanisms.

SESAME, a successor project to the Global Seismic Hazard Assessment Programme (GSHAP) for the Mediterranean area, was completed in the past year with the co-operation of BGS in helping with the preparation of source zone models, and also running some of the hazard calculations, which required advanced features available in BGS software.

Joint developments to upgrade data acquisition and analysis software, with Bergen University, have continued.

As a result of a resolution passed at the last European Seismological Commission (ESC) General Assembly, a provisional committee has been established to investigate the formation of a European field investigation team for making specifically seismological (as opposed to engineering) surveys of the effects of major European earthquakes; BGS is actively involved in this project. The present emphasis is on establishing the initial key personnel for the project and agreeing procedures.

BGS is also a participant in the PEGASOS project. This is the most ambitious seismic hazard study ever conducted in Europe, using the methodology developed for the Yucca Mountain study in the USA to examine seismic hazard at three nuclear sites in Switzerland. Teams of experts have been assembled from all over Europe and the USA. BGS is involved both in supplying staff to one of the expert teams, and in developing software to support the project.

Collaboration with the Faroese Geological Survey, has continued and data from the Faroe Islands network has considerably improved the monitoring of seismic events offshore northern and western Scotland. This collaboration has also produced the first ever study of the historical seismicity of the Faroe Islands which demonstrated a low level of activity in the past 400 years.

3.2.3 Hazard studies and database enquiries

The BGS database continues to play an important role in studies of UK seismic hazard. There are two principal applications: safety case preparation for hazardous facilities and more general hazard assessments. Advice is also given on seismic hazard for specific sites for a variety of engineering projects. Overseas, significant hazard studies were completed for sites in Taiwan and Angola, and several studies were completed for UK sites. The PEGASOS hazard project in Switzerland has already been mentioned in the previous section. This project will run until 2003.

BGS uses its own in-house software for seismic hazard calculations, and this has undergone continual development as new features have been identified for useful inclusion. Supporting analysis software is also in a state of general development; a recent innovation is the creation of a tool for determining the possible values of the magnitude-frequency distribution for a seismic zone, and the uncertainty weightings, without recourse to subjective decision making.

Strong motion records

With the expansion of the strong motion network in the past few years, strong ground accelerations, which would previously have saturated the network, are being recorded from British earthquakes. To-date, twenty-eight three-component acceleration records (Table 1) have been recorded for earthquakes with magnitudes between 1.1 and 4.2 ML at distances of between 3 and 166 km. Six of these records were recorded in the reporting year. The values of acceleration measured from these instruments are less than those expected from the attenuation laws currently used for the UK (PML, 1988; Ambraseys and Bommer, 1995; Dahle et al. 1990). However, most of these relations are not appropriate for small magnitude earthquakes. Attenuation of small events tends to be higher than for larger events because they have a higher frequency content, and higher frequencies attenuate faster. Of necessity, these laws have been constructed using empirical data from more seismically active regions using earthquakes with larger magnitudes. The build-up of UK records by BGS will eventually permit more appropriate relationships to be established for use by engineers in this country.

Broadband Seismometry

Broadband seismometers record ground motion over a wider frequency range than conventional short period instruments. These instruments are typically used for analysis of large earthquakes at teleseismic distances, which generate longer period waves than the typical small to moderate earthquakes in the UK. Broadband data is also extremely valuable for analysing large earthquakes in the UK. As well as containing information on the nature of the seismic source, and the deep Earth through which the waves have passed, teleseismic data recorded on broadband seismometers may also be used to improve our understanding of crustal structure in the locality of the recording instrument. The analysis of surface waves from regional earthquakes can further help to improve the model of crustal structure. Improved models should lead to greater accuracy in the determination of UK earthquake epicentres, focal mechanisms and the crucial (for hazard assessment) depths of occurrence. The BGS broadband station at Edinburgh has been upgraded to provide high dynamic range, 24-bit continuous data. Continuous, near real-time data from this station are available from the BGS web pages in the form of 24-hour helicorder records and also from the AutoDRM (Automatic Data Request Manager). Data from a broadband sensor at the Eskdalemuir seismic array can also be viewed through the web pages. Additional broadband data are readily available from the United States IRIS station hosted by BGS at Eskdalemuir Observatory. A further four broadband instruments were purchased over the last year and were delivered in February 2002. Two of these instruments are currently being tested in Edinburgh and are intended for deployment at the Hartland and Lerwick observatories. The network of broadband sensors operated by AWE Blacknest, known as UKNET has ceased to operate due to funding constraints.

Parliamentary questions and advice to Public Authorities, Industry and media

Some 969 enquiries have been answered during the year, with intense interest following felt UK events and the devastating world earthquake in Afghanistan. Some 20 TV and 62 radio interviews were conducted. Of these 17 TV interviews and 53 radio interviews were prompted by UK earthquakes.

Data exchange and world reporting

BGS data is exchanged regularly with European and world agencies to help locate and improve focal mechanism parameters for earthquakes outside the UK. As a *quid pro quo*, BGS receives data for UK earthquakes and world events of relevance to the UK, recorded by many other agencies and institutions.

Test ban treaty verification

Data has been contributed to a programme for calibrating the international network of stations for monitoring the Comprehensive Test Ban Treaty (CTBT). Earthquakes and explosions with magnitudes ≥2.5 ML, within 1000 km of the UK are relevant, and data from such events have been processed and submitted to the International Data Centre in Vienna.

Earthquake statistics

The UK instrumental database covers the past 32 years, although in the early years, to 1978, it is probably only complete for magnitudes of 3.5 and greater. Since 1979, the completeness threshold is magnitude 2.5. The total statistics for earthquakes of magnitudes ≥ 2.0, shown in Figure 23, illustrates the recent history of UK seismicity. Some apparent cycles of activity are evident but no significance can be placed on them at this stage. Figure 24 shows the record of earthquakes reported to have been felt, separating out those in coalfield areas where the majority will have been caused by mining. The variable reporting of the latter set, often prevents any meaningful analysis although the increase in 1996 can be attributed to the Monktonhall series near Edinburgh and the miners strikes between 1983 and 1985 explains the low level at that time. For the natural earthquakes, peaks can be attributed to swarm activity in 1974 (Kintail), 1980 (Carlisle), 1981 and 1986 (Constantine) and in 1984 (North Wales). The seismogenic thickness of the earth's crust across the UK is demonstrated by the distribution of earthquakes with depth. The higher quality data available to date indicates significant geographic variations; for example, the majority of earthquakes in Scotland are relatively shallow (< 15 km), whereas in Wales, earthquakes occur at greater depths (10-25 km). Most earthquakes in Cornwall are shallow (<7 km) probably due to high heat flow associated with granite intrusions. Shallow coalfield events (< 2km) dominate the Midlands region and the eastern end of the Midland Valley of Scotland, but these are probably induced by mining.

Focal mechanisms

Earthquake focal mechanisms are generally determined to investigate both local and regional tectonics, providing information on the style of faulting that is occurring in the crust. In the past, focal mechanisms could only be obtained for the largest events. As a result of the expansion of the UK network over the years, an increasing number can be determined for smaller events, which are now recorded on many stations. In areas of North Wales, Cumbria, the Scottish Borders and Cornwall, events with magnitudes of less than 2.0 ML can be processed in this way.

Four focal mechanisms were obtained during the reporting period; for earthquakes at Ekofisk (Mw 5.0), Dumfries (ML 3.0), Bargoed (ML 3.1) and Melton Mowbray (ML 4.1). The mechanism obtained for the Ekofisk earthquake shows normal faulting with north-south trending nodal planes. At Dumfries the earthquake shows predominantly strike-slip faulting along near-vertical fault planes striking approximately NNW-SSE and ENE-WSW, respectively. The near horizontal, NW-SE orientation for the principal stress direction (P-axis) is in good agreement with the expected regional stress tensor. The Bargoed mechanism shows oblique normal faulting along either a NW-SE striking fault plane dipping at 38° or a NNE-SSW striking fault plane dipping at 63°. The average maximum compressive stress direction has an azimuth of 142°and a dip of 61°, and the minimum stress direction strikes at 258° and dips at 14°. The focal mechanism for the Melton Mowbray earthquake also shows oblique normal faulting along either a near N-S fault plane dipping at 51° or along a near E-W fault plane dipping at 58°. The average maximum compressive stress direction has an azimuth of 140°and dip of 55° and the minimum stress direction strikes at 44° and dips at 4°.

In collaboration with the Nuclear Installations Inspectorate (NII), a systematic program of revising the focal mechanism catalogue is continuing. As more focal mechanisms are obtained, we gain a better understanding of the stresses that cause earthquakes in the UK. The results are being compiled in a GIS database showing fault plane solutions and stress axes orientations. Overall, a variety of focal mechanisms are observed and the relationship between tectonics and local geology appears complex and there is no clearly defined relationship between either locality or depth and mechanism type. However, an estimate of the state of stress can be made using an inversion method to look for the best-fitting stress tensor that lies in the overlap between the families of stresses associated with a population of focal mechanisms for earthquakes in this database. This gives an estimate of both the orientations and relative magnitudes of the principle stress directions. The principal compression is found to be in north-northwest south-southeast direction. This result in consistent with expected stress associated with tectonic plate motion, mainly ridge-push from the Mid-Atlantic. The axes of maximum and minimum compression (P and T), though well constrained in azimuth are not so well constrained in dip.

Public Understanding of Science

A number of lectures and presentations have been given to school and university students and other interested parties. Some 282 media interviews have been conducted, including 20 for TV broadcasts and 62 for radio (Fig. 25), following significant earthquakes. The BGS also participated in the Giant Jump Experiment, in which groups of school children across the country attempted to simulate earthquakes by jumping up and down simultaneously. The object of the exercise was to raise awareness of the earth sciences. The Internet home page has been a source of information for the public, media and other organisations, with over 300,000 visitors in the year and over 65,000 in the days following the Melton Mowbray earthquake in October 2001. BGS, in collaboration with UKAEA, produced another updated earthquake information booklet to include the Melton Mowbray earthquake. This was distributed to the Customer Group and is being used in school educational packs, at workshops for schools, at various science festival events throughout the country and for general enquiries. So far this year over 1,500 copies have been distributed.

4. Development of the monitoring network

4.1 Station distribution

The network developed to March 2002, with rapid-access upgrades, is shown in Figure 1 with its detection capability in Figure 3. The scheduled programme for 2001/2002 had as its aims:

(i) Further installation of the QNX operating system.

(ii) Upgrade of four stations to the broadband standard with high dynamic range 24-bit digitizers and Internet connections to Edinburgh.

(iii) Upgrade of three-component short period stations by installation of 24-bit digitizers to provide high dynamic range digital data. The number of sites will be determined by funding constraints and opportunities.

(iv) Capture of more strong motion data in collaboration with the nuclear industry.

(v) Collaboration with Universities to secure further broadband data.

(vi) 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.

(vii) Continue collaboration with the IASPEI international effort to make archives available electronically.

Nine networks have been upgraded to use QNX SEISLOG data acquisition (i). Two broadband instruments (ii) are currently being tested in the seismic vault at the Royal Observatory Edinburgh prior to deployment at stations at Hartland and Lerwick. High speed internet links have been installed at Hartland and Lerwick which will allow the transfer of continuous data. Three component sensors with 24-bit digital data acquisition (iii) have been installed at Eskdalemuir, Hartland and Paisley. During the year, a further six strong motion records (iv) have been obtained from the following five earthquakes: Dumfries, Hartland Point, Sedbergh, Bargoed and Melton Mowbray (Table 1). Collaboration with the universities of Bristol, Leicester, Leeds and Cambridge has continued and a new initiative has started with Imperial College. Contact with archives outside BGS has been maintained (vi). Data has been supplied to IASPEI and work is progressing with the international effort to make archives available electronically (vii).

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. 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 stations, is shown in Figure 6. Sixteen of the 19 strong motion stations generate open-file data; the other three are operated by, or on behalf of, British Energy and MOD. Strong motion records have been written for the following earthquakes this year; the Dumfries, Hartland Point, Sedbergh, Bargoed and Melton Mowbray earthquakes.

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 a magnitude 6.0 event will not cause saturation at all strong motion stations. 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. As noted in 4.1, the anticipated upgrade of the network to 24-bits will extend the strong motion capability further and increase the rate of capture of strong ground motion records.

4.3 Related site specific monitoring

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

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

(ii) The free-field strong motion system for British Energy at Torness has continued to operate and a proposal to upgrade the Hunterston equipment has been submitted.

(iii) The 13 stations in northern Scotland and the Orkney Islands, supported by an oil company consortium and the Health and Safety Executive (HSE), has continued with funding assured until March 2002.

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 QNX SEISLOG data acquisition equipment has now been installed at eighteen sites across the UK network, with nine sites being upgraded over the past year. The upgrades are at Cornwall, East Anglia, Hartland, Jersey, Keyworth, Minch, Paisley, Shetland and Swindon. This leaves seven remaining networks still using the VME SEISLOG data acquisition: Borders, Cumbria, Devon, Galloway, Moray, North Wales and Torness. QNX gives a number of advantages over the VME system; increased processing power, larger memory capacity (from 8 Gbyte to upwards of 60 Gbyte), improved communication links using Ethernet cards and ISDN links (digital telephone lines), together with greater portability. Eleven of the QNX SEISLOG systems have 60 Gbyte storage capacities that give a hundred day ring buffer of continuous data. These large capacity disks help prevent potential losses if the event-triggered systems miss spurious events, very small earthquakes and sonic booms.

Four broadband instruments were ordered over the last year, two of which were delivered in February 2002. They are currently being tested in the seismic vault at the Royal Observatory in Edinburgh. Broadband seismometers record ground motion over a wider frequency range than conventional short period instruments and will provide valuable data for analysing large earthquakes in the UK. In addition, teleseismic data recorded on broadband seismometers may also be used to improve our understanding of crustal structure in the locality of the recording instrument leading to improved epicentre locations.

The installation of 24-bit data acquisition systems has begun, though at a slower pace than anticipated. This equipment will give a higher dynamic range (140dB) than previously (72dB) and will provide high quality on-scale data for larger earthquakes at closer epicentral distances.

A strong motion instrument was installed at Hartland in North Devon bringing the total to nineteen.

4.5 Environmental monitoring

Environmental monitoring is becoming increasingly important in modern life. Many cities now have air pollution monitoring equipment but national background levels 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. Using the existing infrastructure of the UK seismograph monitoring network, with its remote stations giving continuous on-line data stretching from the Faroe Islands in the north, to Jersey in the south, a cost-effective environmental monitoring network can be provided. Environmental data collected from sensors interfaced to this network allows users to inspect the data in real-time or transfer it at intervals via modem or the Internet. In principle, any environmental sensor can be interfaced to this network and be sampled every minute.

Currently, there are five environmental stations in operation in the UK: two on the outskirts of Edinburgh, at Loanhead and Stoneypath; two in Eskdalemuir, at the geophysical observatory and at the seismological array station (EKA); and, in 2001, a further station, monitoring meteorological parameters, was installed at Hartland Observatory, Devon. The environmental monitoring concept was first developed using a limited suite of sensors at the near-Edinburgh sites, and a more comprehensive system was installed at Eskdalemuir Observatory during 1999. In 2000, the meteorological monitoring site at EKA was installed and radio-linked to the observatory. The sensors deployed at the Eskdalemuir sites monitor a variety of pollution and meteorological parameters: concentrations of ozone, sulphur dioxide, and nitrogen oxides; and wind speed and direction, air temperature, soil temperature, rainfall, humidity, surface wetness, ultra-violet (UVB), nuclear radiation and sunshine. The Eskdalemuir data are recorded using a Campbell Scientific logger and a BGS-designed logger, both of which are interfaced to a networked computer. Eskdalemuir Observatory has the advantage of being a Meteorological Office site and so direct comparisons can be made between the standard Meteorological Office data and the BGS-recorded measurements. At Hartland Observatory, a Campbell Scientific logger records a range of meteorological parameters including temperature, wind speed and direction, rainfall and solar radiation. Temperature and humidity are monitored at Loanhead and, at Stoneypath, measurements of UVB, air temperature, ground temperature, humidity and nuclear radiation are made. Data from all the environmental stations can be provided to users by e-mail, and software to enable data to be viewed and downloaded on-line using a Web-browser has been developed.

Potential users of the system, including the Scottish Environmental Protection Agency (SEPA), Environment Agency (EA) and the Scottish Water Authorities, have been kept informed of the monitoring capabilities with a view to seeking further support for its development. A Memorandum of Understanding with the Meteorological Office is designed to explore possible avenues of collaboration.

5. Seismic activity in Year 13

5.1 Earthquakes located for 2001

The 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 2001 published and distributed in April 2002 (Simpson, 2002). A map of the 135 events located in 2001 is reproduced here as Figure 11 and a catalogue of the 37 with magnitudes of 2.0 or greater is given in Annex B. Ten events in that magnitude category, together with 6 smaller ones, are known to have been felt.

Spatially, the distribution of seismicity in 2001 was similar to that of previous years with the majority of earthquakes occurring in and around Wales, the Midlands, Cumbria, the Borders, and in central and western Scotland. Some activity occurred around the Channel Islands and in the northern North Sea. In 2001, no events were recorded in south-eastern England, Ireland, north-eastern Scotland and the Outer Hebrides. Historically, south-eastern England has been active but Ireland and north-eastern Scotland have rarely experienced events in the past. Earthquake occurrence during 2001 was fairly uniform throughout the year, except for

June which was slightly more active than the other months. The high activity in June resulted from a total of 15 earthquakes recorded near Constantine, Cornwall which has been the site of swarms of events in the past, up to magnitude 3.5 ML. On this occasion, the magnitude ranged between 0.0 to 1.1 ML. Similarly, five events in the magnitude range 0.5 to 3.0 ML occurred near Dumfries on 13 May. Other clusters of events during the year (of 4 or more) occurred near Blackford and Bargoed. The largest event onshore in 2001 was the Melton Mowbray earthquake, with a magnitude of 4.1 ML. The largest event offshore was the Ekofisk event, with a moment magnitude of 5.0 Mw.

In the period since BGS extended its modern seismic monitoring in the UK (1979 to March 2002), 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 and with time.

5.2 Significant events

Highlights of the seismic activity during the thirteenth year of this collaborative project (April 2001 to March 2002) are given below:

(i) The largest offshore earthquake occurred in the Central North Sea on 7 May. It had a magnitude of 5.0 Mw and was located approximately 410 km east of Edinburgh. It was felt on three nearby oil platforms in the Ekofisk area. The Ekofisk Hotel platform control tower described "a swaying lasting 2 minutes which left us feeling dizzy", and they also confirmed that the Albuskjell platform, 15 km to the north and the Eldfisk platform, 26 km to the south, reported similar felt effects. A seismogram of the Ekofisk event recorded on the Edinburgh broadband station is shown in Figure 13. Its focal mechanism shows normal faulting with north-south trending nodal planes. A further 22 events occurred in the North Sea and surrounding waters during the year, with magnitudes ranging between 1.2 and 3.9 ML. They were located using both the BGS and Norwegian networks.

(ii) An earthquake with a magnitude of 3.0 ML occurred on 13 May, near Dumfries (Fig. 14). BGS received many felt reports, from the Police, the media, Dumfries Council and residents of the Dumfries area. Descriptions included, "the entire house shook", "the neighbours felt a shaking and ran into their back gardens", "the floor moved" and "felt like an explosion". A macroseismic survey was conducted and over 590 replies were received, indicating a maximum intensity of 5 EMS. This event was followed by four aftershocks on the same day with magnitudes ranging between 0.5 and 1.3 ML, the largest was felt with intensities of at least 3 EMS. A map of the felt area is shown in Figure 26. The focal mechanism shows predominantly strike-slip faulting along near vertical fault planes striking approximately NNW-SSE and ENE-WSW, respectively. This is an area which has experienced many small earthquakes in the past and was the largest earthquake in the area since the 1888 when a magnitude 3.4 event was widely felt in the area between Annan and Galashiels.

(iii) An earthquake, with a magnitude of 3.6 ML occurred off Hartland Point, Devon, on 31 May. BGS received many felt reports from residents of Cornwall and Devon, who described, "I ran outside alarmed", " I thought a nuclear explosion had gone off" and "the whole house shook". A macroseismic survey was conducted and over 520 replies were received, indicating a maximum intensity of 5 EMS. A seismogram of the earthquake recorded on the North Wales network is shown in Figure 15 and a map of the felt area in Figure 26.

(iv) Near Mallaig, Highland, an earthquake with a magnitude of 1.7 ML occurred on 20 June. Felt reports were received from the village of Mallaig, where intensities reached 3 EMS. Descriptions included, "I felt a shudder through my feet" and "sounded like a large explosion".

(v) Fifteen events occurred near Constantine, Cornwall, throughout June, with magnitudes ranging between 0.0 and 1.1 ML; none were felt. This is an area that has experienced similar swarm activity in the past with magnitudes up to 3.5 ML.

(vi) An earthquake with a magnitude of 2.2 ML occurred on 27 June, with a location near Sedbergh, Cumbria. A single felt report was received from a resident in Cowgill**,** some 9 km to the west of the epicentre, who described "the whole house shook, I was woken from sleep and I heard a bang", indicating an intensity of at least 4 EMS. This is the largest earthquake in the area since 1976, where a magnitude 2.8 ML earthquake was felt with intensities of at least 3 EMS.

(vii) On 21 July, an earthquake with a magnitude of 1.9 ML occurred at the northern end of the Isle of Mull, western Scotland. BGS received one felt report from a resident in Salen, approximately 15 km southeast of the epicentre, who gave the following description "like a strong gust of wind" and "quite a weak rumble", indicating an intensity of 2 EMS.

(viii) On 1 September, an earthquake with a magnitude of 1.8 ML occurred near Blackford, Tayside. BGS received felt reports from residents of Glendevon, stating that "the whole house shook". A further two earthquakes with magnitudes of 2.1 and 1.3 ML occurred in the Blackford area, with intensities of 3 EMS, on 19 December. Felt reports were received from the Blackford and Glendevon areas of Tayside, including, "we heard a loud rumble", "the house shook" and "the radiators rattled". This is an area that has continued to be active in recent years; 49 events occurred in 1997, of which five were felt by local residents; 10 events occurred in 1998, of which 2 were felt by local residents, 3 events occurred in 1999 and 4 events occurred in 2000, of which 3 were felt**.** In the same general area in 1979, a magnitude 3.2 ML Ochil Hills earthquake was felt with a maximum intensity of 5 EMS.

(ix) Ten earthquakes have occurred near Bargoed, Mid-Glamorgan, since October, with magnitudes ranging between 1.4 and 3.1 ML. The largest earthquake occurred on 10 October and was widely felt by residents in the Bargoed area. Felt reports described "the bed was shaking", "the entire house shook" and "I was woken from sleep". A macroseismic survey was conducted and over 125 replies were received, indicating a maximum intensity of 4 EMS (Fig. 26). The focal mechanism shows oblique normal faulting along either a NW-SE striking fault plane dipping at 38° or a NNE-SSW striking fault plane dipping at 63°. In February, an earthquake with a magnitude of 3.0, was felt strongly in Bargoed (Fig. 17).

(x) The largest onshore earthquake, with a magnitude of 4.1 ML, occurred near Melton Mowbray, Leicestershire on 28 October. BGS conducted a macroseismic survey and earthquake questionnaires were distributed through local and national newspapers. Approximately 1,900 e-mailed responses were received, the most received for any UK earthquake so far, together with an estimated 4,600 paper questionnaires, giving a total of 6,500 responses in all. Many media interviews were conducted and a large number of enquiries were received. The seismology home page received over 65,000 visitors in the days following the earthquake. It was felt up to 140 km from the epicentre and throughout Lincolnshire, Leicestershire, Warwickshire, Yorkshire, Shropshire and Nottinghamshire; an area of 25,000km^2 (Isoseismal 3). The most distant reports were from the following places: in the west, the earthquake was felt near Chester; in the east, it was reported felt in King's Lynn, Norfolk; in the north, the limit of observation was marked by Knaresborough. In the south, the shock was felt as far as Oxford, with a single very distant observation from Salisbury. There were reports of damage to chimneys in the Melton Mowbray area, indicating an intensity of 6 EMS. Felt reports described "we ran into the streets", "the whole house shook", "the table moved" and "we were very frightened". A maximum acceleration of 0.02g was measured at the strong motion station at Keyworth, some 15 km from the earthquake (Fig. 16). The focal mechanism shows oblique normal faulting along either a near N-S fault plane dipping at 51° or along a near E-W fault plane dipping at 58°.

(xi) Near Chester, Cheshire, three events occurred on 17 October, with magnitudes of 2.4, 2.1 and 1.5 ML. BGS received no felt reports for these earthquakes.

(xii) An earthquake with a magnitude of 2.3 ML, occurred near Anglesey, Gwynedd on 5 November. BGS received a single felt report for this earthquake which described "a bang, then a rumbling" indicating an intensity of at least 2 EMS.

(xiii) An earthquake with a magnitude of 1.5 ML occurred on 1 December, with a location near Ballachulish, Highland. BGS received a number of felt reports from residents of Glenachulish, Ballachulish and Onich. Felt reports described "we heard a loud rumble", "we felt a vibration" and "we ran outside", indicating an intensity of 4 EMS.

(xiv) On 16 December, an earthquake with a magnitude of 2.6 ML occurred approximately 6 km southwest of Halifax, West Yorkshire. BGS received felt reports from residents of Halifax and Todmorden which described "we heard a loud rumble", the "whole house shook" and "we ran outside", indicating an intensity of 4 EMS. This event had a location approximately 3 km southeast of the magnitude 4.0 ML Todmorden earthquake, on 7 March 1972, that was felt with intensities of 5 EMS.

(xv) In North Wales, two events with magnitudes of 0.7 and 1.2 were located on the Lleyn Peninsula, in the same area and at similar depths (20 km) as the magnitude 5.4 ML Lleyn earthquake of 19 July 1984, which was felt throughout England and Wales and into Scotland and Ireland.

(xvi) The coalfield areas of Yorkshire, Staffordshire, Nottinghamshire and Derbyshire continued to experience shallow earthquake activity that is believed to be mining induced. Coalfield events were located near Rotherham, South Yorkshire (1.6 ML, 31

May 2001), Ashbourne, Derbyshire (0.8 ML, 26 July 2001), Worksop, Nottinghamshire (1.8 ML, 10 December 2001), Ollerton, Nottinghamshire (1.6 ML, 6 January 2002), and Newcastle-Under-Lyme, Staffordshire (1.2 ML, 15 March 2001). These events are probably related to present-day coal mining activity. A seismogram of the Rotherham event is shown in Figure 18.

(xvii) Elsewhere in the country, seismic events have been reported felt or heard like small earthquakes but, on analysis, have been proved to be sonic booms (Fig. 19). On 13 November, residents of Eyemouth and Ayton in the Berwickshire coastal area described "a loud bang" and "the house shook". On 16 November, BGS received numerous reports that residents in Northumberland, Durham, Tyne and Wear and Cleveland, felt an event. Descriptions included "the windows rattled", "a loud bang" and "the whole building shook". On 10 January, BGS received calls via BBC Radio Devon, from residents of Plymouth who described " the building shook", "heard a loud bang" and "felt like an explosion". On this occasion, Concorde was responsible for the disturbance. On 15 January 2002, BGS received a call from a resident of North Devon who described, "sounded like a series of loud bangs".

No felt explosions were detected in the reporting period. A seismogram from explosions near the Sound of Bute is shown in Figure 20.

5.3 Global earthquakes

The monitoring network detects large earthquakes elsewhere in the world for which selected data are made available to European and International agencies. The past year has seen a number of significant and devastating earthquakes, details of which are given below, with over 21,000 deaths occurring in the year 2001. The most disastrous earthquake during 2001, with a magnitude of 7.7 Mw, occurred on 26 January in the state of Gujurat, India and caused the deaths of some 20,023 people constituting 94% of the fatalities in 2001 (see 12th Annual report).

(i) The largest earthquake during the reporting year, with a magnitude of 8.4 Mw, occurred on 23 June off the coast of Peru, approximately 190 km west of Arequipa and 600 km southeast of the Peruvian capital, Lima. It caused the deaths of over 81 people, (26 in the tsunami which followed), injured 2,734 more and left over 220,000 homeless. An estimated 36,769 homes suffered some damage and a further 24,972 were completely destroyed. The coastal towns of Camana, Chala and La Punta in the Arequipa department suffered severe damage and some villages in the coastal area were completely destroyed as a result of the tsunami. Tsunami run-up heights of approximately 7 metres were observed at some locations and the tsunami inundation distance extended to more than 1 km inland. The earthquake occurred at the boundary between the Nazca and South American tectonic plates, which are converging towards each other at a rate of about 8cm per year. An aftershock, with a magnitude of 7.6 Mw, occurred on 7 July and killed 1 further person, injured 26 more and destroyed hundreds of buildings, which had been weakened by the mainshock.

(ii) On 3 February, an earthquake with a magnitude of 6.5 Mw, occurred in Afyon Province, Western Turkey, approximately 200 km southwest of Ankara and about 300 km southeast of Istanbul. It killed 54 people and injured 318 in the epicentral area.

Over 4,000 houses and buildings were destroyed or heavily damaged. Over 550 aftershocks were detected within 72 hours of the mainshock. The earthquake was felt throughout west-central Turkey and also in the Dodecanese Islands, Greece. Preliminary reports indicated 30 km of surface faulting with near vertical offset in the Cay-Sultandagi region. A seismogram of the event recorded on the broadband station in Edinburgh is shown in Figure 21 and some pictures of damage in Figures 27 and 28.

(iii) In March 2002, two fatal and damaging earthquakes occurred in the mountainous region of Hindu Kush, Afghanistan. The first, on 3 March, with a magnitude of 7.4 Mw, killed at least 150 people, injured others and destroyed or damaged over 400 houses when a landslide dammed and flooded Surkundara Valley in the Samanghan Province. A 45 metre wide fissure was reported to have opened in the Xiker Reservoir in Xinjiang Province, China. The second event occurred on 25 March, with a magnitude of 6.1 Mw, and killed upwards of 1,500 people, injured 4,000 others, destroyed or damaged over 1,500 houses and left approximately 20,000 homeless in Nahrin and other areas of Baghlan Province, northern Afghanistan. Twenty-five percent of the houses in the Nahrin area collapsed and 90 percent had some structural damage. Several landslides blocked many roads in the epicentral area. The earthquake was felt strongly in much of northern Afghanistan and was also felt in the Islamabad-Peshawar area, Pakistan and at Dushanbe, Tajikistan. A seismogram of the event recorded on the broadband station in Edinburgh is shown in Figure 22.

6. The National Seismological Archive (NSA)

6.1 Identification, curation and cataloguing

Routine maintenance of the archive has been continued over the past year, and a number of enquiries and data requests were answered. There are no major developments to report.

The following section, reproduced from last year's report, describes the status of the material from known major seismological observatories, i.e. excluding a few small amateur-run stations. All extant seismograms and bulletins from these observatories have been catalogued and the seismograms have all been microfilmed, with a backup copy set stored off site from the NSA, at BGS Keyworth.

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 held in the NSA.

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).

Cambridge: Material from the Crombie Seismological Laboratory, Cambridge consists of annual reports (1954-1968) and one bulletin (1958).

Coats Observatory, Paisley: Material held from this observatory (1898-1919) consists of seismograms (1900-1919 and 1931-1935) 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 from the Royal Observatory, Edinburgh (1894-1962) consists of seismograms (1902-1908) and bulletins (1922-1962). 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, Scotland Observatory (1908-1925) is varied, and consists of seismograms (1910-1920) and bulletins (1913-1916, 1920-1925).

Eskdalemuir WWSSN: The Eskdalemuir Worldwide Standard Seismograph Network seismograms (1964-1995) are stored at Eskdalemuir, with microfilm copies available for inspection in the NSA. More information on ESK WWSSN can be found in report WL/99/18.

Guildford: Material held from the Seismograph Station at Woodbridge Hill, Guildford consists of bulletins (1910-1915).

Jersey: Material from the Jersey Observatory (1935-1994) consists of seismograms (1936-1985) and bulletins (1946-1965).

Kew: Material from the Kew Observatory (1898-1969) consists of seismograms (1904-1965) and a range of bulletins (1899-1969), together with a wide range of related material.

Oxford: Material from the Oxford Observatory (1918-1947) are presumed lost, bar one seismogram held in the NSA; this record was borrowed by ATJ Dollar and never returned, which is how it escaped the fate of the bulk of the records. Two seismograms have been discovered on the Isle of Wight, amongst Milne material.

Rathfarnham: Material from the Rathfarnham Castle Observatory, Dublin (1916-1964), is held by the Dublin Institute for Advanced Science (DIAS). The NSA holds some bulletins (1950-1960).

Shide: Although most material from the Shide Observatory, Isle of Wight (1895-1917) was presumed destroyed, items remaining in the Isle of Wight County Record Office, Carisbrooke Castle Museum and in private hands have been examined and catalogued.

Stonyhurst: Material from the Stonyhurst College Observatory, Blackburn (1908-1947) is also presumed destroyed, except for some bulletins held in the NSA (1909-1933), and a single seismogram (for 7-8 March 1931) which exists as a photographic copy supplied to Bidston observatory at some point.

Valentia WWSSN: All records from this station are presumed to be held at Valentia, Ireland.

West Bromwich: The surviving papers and records from West Bromwich Observatory (JJ Shaw) are held at the Lapworth Museum, Birmingham University. The seismograms, bulletins and selected other material have now been microfilmed. One seismogram is held by the NSA; this record was discovered to have been used as a bookmark in a book purchased from a Midlands second-hand bookshop.

In addition to the above, mention can be made of the seismological activity at Fort Augustus. In 1947 ATJ Dollar installed a Jagger shock recorder at Fort Augustus Abbey; this instrument was formerly deployed at Dunira, near Comrie, and before that was used in Montserrat during the previous volcanic crisis to the recent one (in the 1930s). This instrument was poorly located in the Abbey (next to the back door) and never worked (except for recording the closing of the back door). Shortly before the Abbey closed last year, the instrument was donated to the NSA. Attempts are presently underway to restore the clock mechanism. So far as can be determined, this is the last Jagger shock recorder in existence. There are none surviving at Hawaii Volcano Observatory where the instruments were invented and manufactured.

6.2 Storage and Inspection facilities

Data requests and general enquiries were answered from scientists and researchers around the world. Seismograms and related bulletins for the requested earthquakes were converted to electronic format and placed on the NSA Internet Web pages to allow both the original enquirer and others to access them freely. Updated information is also at the same place (address http://www.gsrg.nmh.ac.uk/hazard/nsa_reports.htm)

The NSA Internet Web database and related search pages were hacked last year and it was necessary to withdraw them from use. The database is in the process of being converted to Access2000 and updated to account for more recent bulletin acquisitions.

The full report series summarising the principal NSA contents remains available for reading online or for download, together with descriptions of the main collections (address http://www.gsrg.nmh.ac.uk/hazard/nsahome.htm), providing an easily accessible first point of information for researchers requiring access to NSA material.

Archive material has been supplied to and received from Dr WHK Lee of IASPEI as a part of an international collaborative effort to publish electronically historical seismograms, bulletins, catalogues and other related data for use by the scientific community. This is being done to mark the centenary of IASPEI, and is being undertaken in the frame of the publication of the International Handbook of Earthquake and Engineering Seismology, this book being accompanied by much supplementary material on CD-ROM. BGS has also contributed two chapters to the Handbook itself, on historical earthquake in the UK and on macroseismology (Lee et. al., 2002).

6.3 Digital records

The digitisation of seismograms from old 1" analogue tapes has been halted owing to the degradation of the tapes which date from the early 1970’s. No further data can be usefully extracted. Information from ½" tapes, which were introduced in 1975, has been completed with digital files of all significant events now held and protected in digital form.

7. Dissemination of results

7.1 Near-immediate response

Customer Group members have received seismic alerts by e-mail (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 29 alerts have been issued to the Customer Group during the year.

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 Melton Mowbray earthquake were also made available on the home page. Feedback suggests that the Global Seismology web site is being used extensively for the wide variety of seismological information it offers. In the past year, over 300,000 visitors have been logged, an increase of over 75% on the previous year.

Remote telephone access to all the UK seismic stations is available and six of the principal BGS seismologists can obtain data directly from their homes. Two members of staff are on-call 24 hours-a-day to improve the response to earthquakes and seismic alerts outside working hours. 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 British Earthquakes within 6 months of the end of a calendar year. For 2001, it was issued within 4 months.

8. Programme for 2002/03

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. The database and archive of UK seismicity and related material will be maintained and extended, with information on holdings disseminated on the Internet. Modest improvements will be made to the station coverage and capabilities. Specific advances anticipated for 2002/03, subject to the continuation of funding at least at the current level and without any unexpected closures of site specific networks, are:

(i) Continue the upgrade of the remaining VME Seislog data acquisition systems to QNX Seislog.

(ii) Deployment of previously purchased broadband sensors at up to four stations with 24-bit data acquisition and high speed internet connections to Edinburgh.

(iii) Upgrade of three-component stations by installation of 24-bit digitizers to provide high dynamic range digital data. The number of sites will be determined by funding constraints and opportunities.

(iv) Capture of more strong motion data in collaboration with the nuclear industry.

(v) Collaboration with Universities.

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

(vii) Continue collaboration with the IASPEI international effort to make archives available electronically.

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 this report is published with the approval of the Executive Director of the British Geological Survey (NERC).

10. References

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Table 1
Measured Ground Accelerations Recorded on Strong Motion Instruments in the UK
1994 - March 2002

Date	ML	Depth	Event Location		Locality	Distance	Z	NS	EW	Station	Station Grid Ref	
YearMnDD		km	KmE	KmN		km	mm/s^2	mm/s^2	mm/s^2	Code	KmE	KmN
19940317	3.1	21.7	302.3	294.2	NEWTOWN	61	4.3	4.2	3.6	HBL2	328.8	239.7
19940611	2.2	7.4	172.7	27.9	CONSTANTINE	7	8.0	8.7	14.4	CRQ	173.5	34.6
19940817	3.1	3.0	174.5	816.7	ISLE OF SKYE	18	4.3	3.9	2.8	KPL	180.2	833.5
19961110	3.8	8.3	143.7	17.2	PENZANCE	34	62.0	52.7	26.9	CRQ	173.5	34.6
19980403	1.1	6.7	325.3	569.4	ANNAN	3	3.7	9.6	6.3	BCC	322.0	569.7
19980528	1.5	12.0	328.8	553.7	WIGTON	17	0.9	2.4	1.3	BCC	322.0	569.7
19980721	2.0	12.8	295.8	579.9	LOCHARBRIGGS	28	1.1	0.4	0.4	BCC	322.0	569.7
19990121	2.8	16.9	538.7	357.1	BOSTON	95	8.3	10.1	6.3	AEU	618.9	307.5
19990304	4.0	19.0	194.8	616.2	ARRAN	136	1.4	4	3.6	BCC	322.0	569.7
19990314	1.9	11.0	295.9	579.2	DUMFRIES	28	0.7	0.2	0.3	BCC	322.0	569.7
19990617	2.8	21.1	360.9	233	HEREFORD	33	8.1	20	12.1	HBL2	328.8	239.7
19990713	1.8	10.2	376.9	-76.1	JERSEY	20	3.7	5.7	6.8	JDG	396.6	-78.4
19990903	2.1	4.2	311.4	593.4	JOHNSTONEBRIDGE	26	1.1	0.5	0.8	BCC	322.0	569.7
19991025	3.6	14.1	292.2	230.8	SENNYBRIDGE	38	10.8	37.8	19.8	HBL2	328.8	239.7
20000107	1.8	10.3	295.8	579	DUMFRIES	28	0.5	0.2	0.3	BCC	322.0	569.7
20000212	2.7	8.8	193.1	673.5	LOCHGILPHEAD	166	0.2	0.2	0.2	BCC	322.0	569.7
20000424	2.6	13.8	347.6	541.5	CALTHWAITE	38	1.3	7.1	1.4	BCC	322.0	569.7
20000622	2.6	23.9	239.5	343.5	LLEYN PENINSULA	47	1.7	2.1	3.2	WCB	230.6	389.9
20000808	2.7	24.4	439.6	529.9	MIDDLESBROUGH	124	0.3	0.2	0.3	BCC	322.0	569.7
20000923	4.2	13.1	426.5	265	WARWICK	76	17.2	16.6	20.8	KEY2	462.1	331.7
20000923	4.2	13.1	426.5	265	WARWICK	87	7.1	5.5	6.6	SWN	413.9	179.4
20000923	4.2	13.1	426.5	265	WARWICK	101	5.0	6.7	5.9	HBL2	328.8	239.7
20010513	3.0	11.5	295.5	579.6	DUMFRIES	28	5.3	4.7	2.8	BCC	322.0	569.7
20010531	3.6	26.4	215.6	127.2	OFF HARTLAND POINT	98	8.0	7.5	7	CRQ	173.5	34.6
20010627	2.2	7.2	382.1	485.8	SEDBERGH	103	0.2	0.1	0.2	BCC	322.0	569.7
20011010	3.1	6.5	313.3	200.7	BARGOED	42	5.0	15.2	16	HBL2	328.8	239.7
20011028	4.1	11.6	477.1	328.3	MELTON MOWBRAY	15	121.0	190	212	KEY2	462.1	331.7
20011028	4.1	11.6	477.1	328.3	MELTON MOWBRAY	144	6.9	10.6	14.2	AEU	618.9	307.5

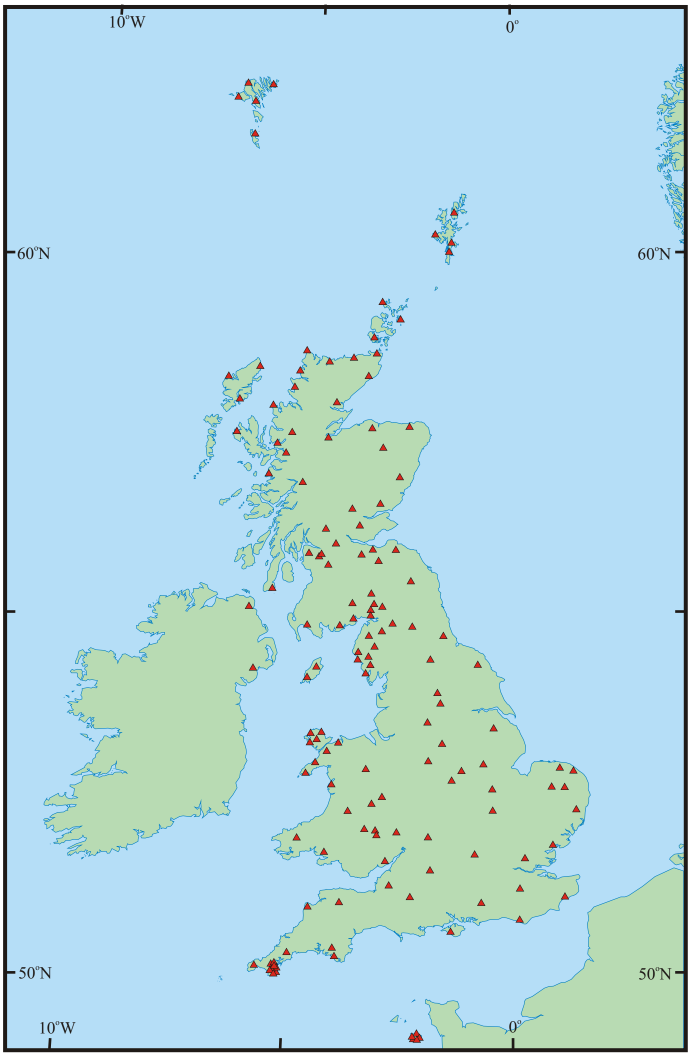


Figure 1. BGS rapid access seismograph network operational March 2002.

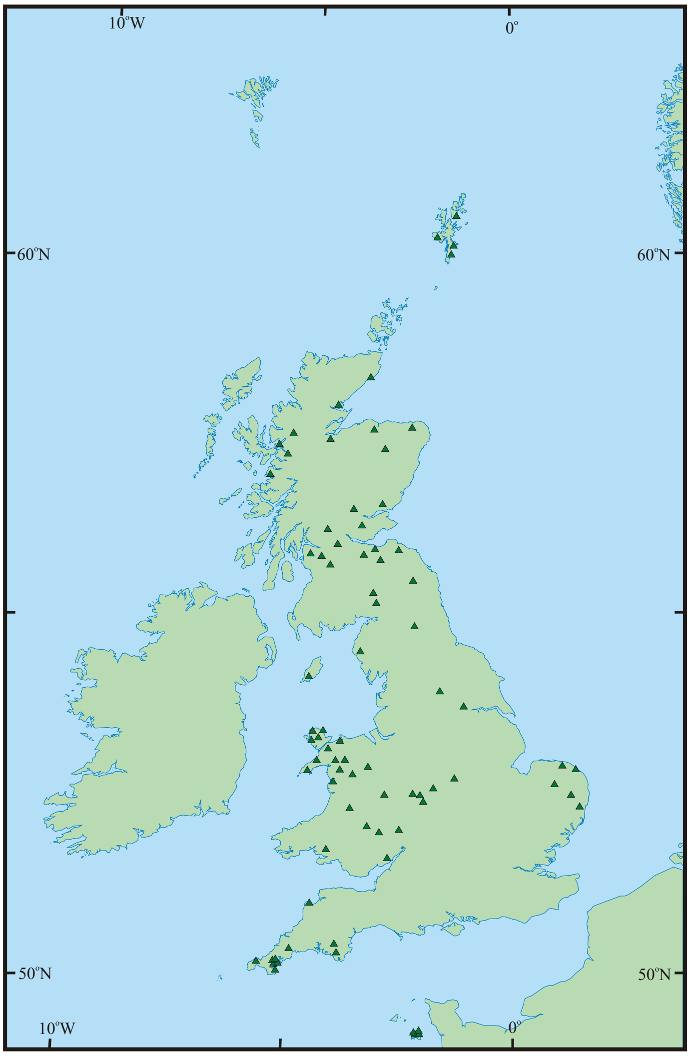
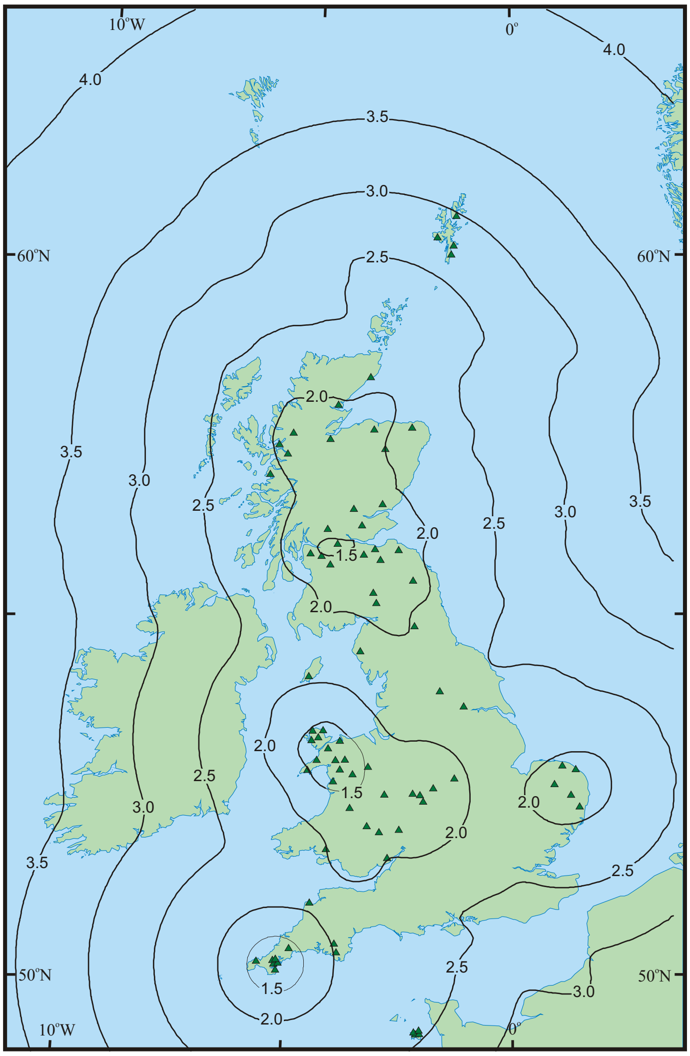


Figure 2. BGS seismograph network in 1988 prior to the commencement of the UK monitoring enhancement project.

Figure 3. Detection capability of network, March 2002. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.



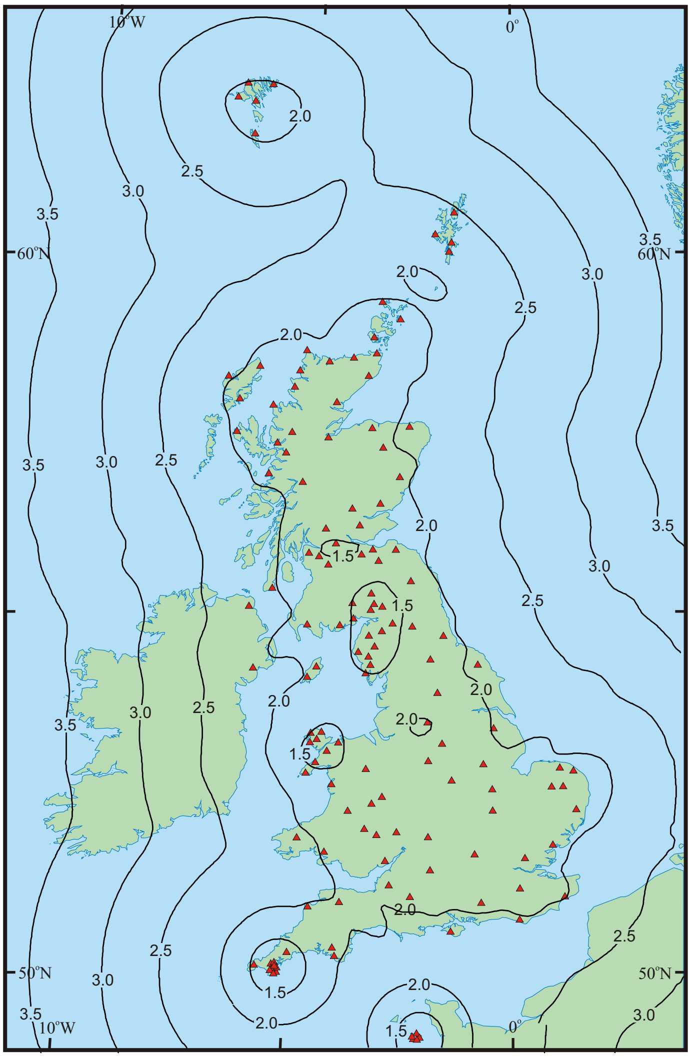


Figure 4. Detection capability of network, 1988. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.

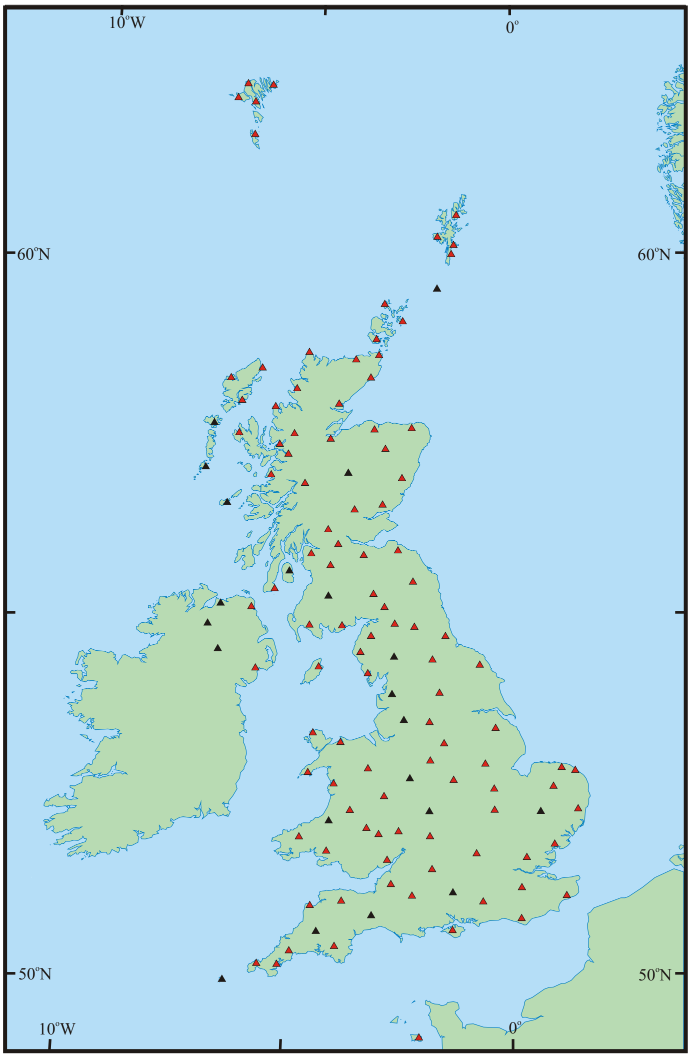


Figure 5. Proposed long-term background seismic monitoring network with an average station spacing of 70 km. Colour coding shows existing coverage (red) and proposed stations (black).

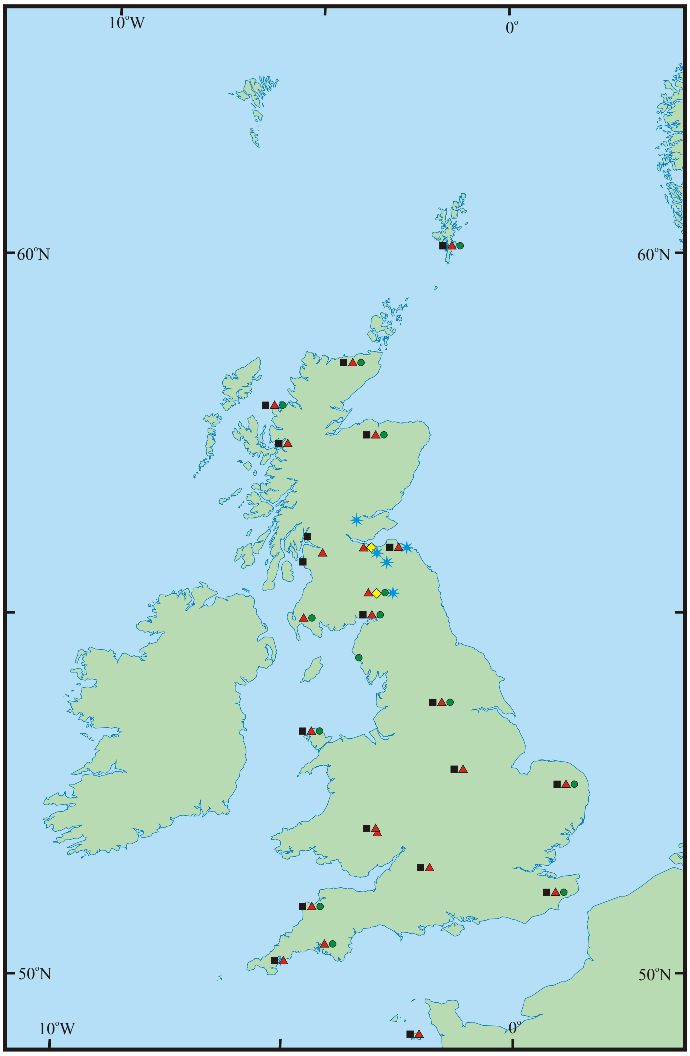


Figure 6. BGS network of strong motion instruments (black), low sensitivity (red), broadband (yellow), microphones (green) and environmental stations (blue) in March 2002.

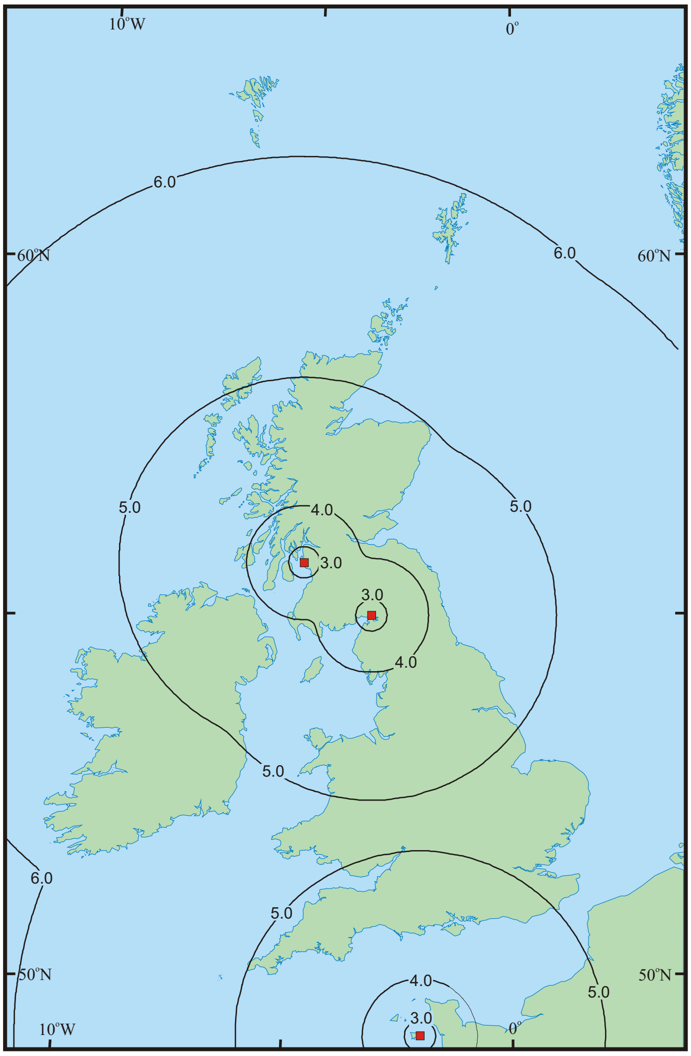


Figure 7. Minimum Richter local magnitude (ML) detectable by the strong motion network operational December 1992.

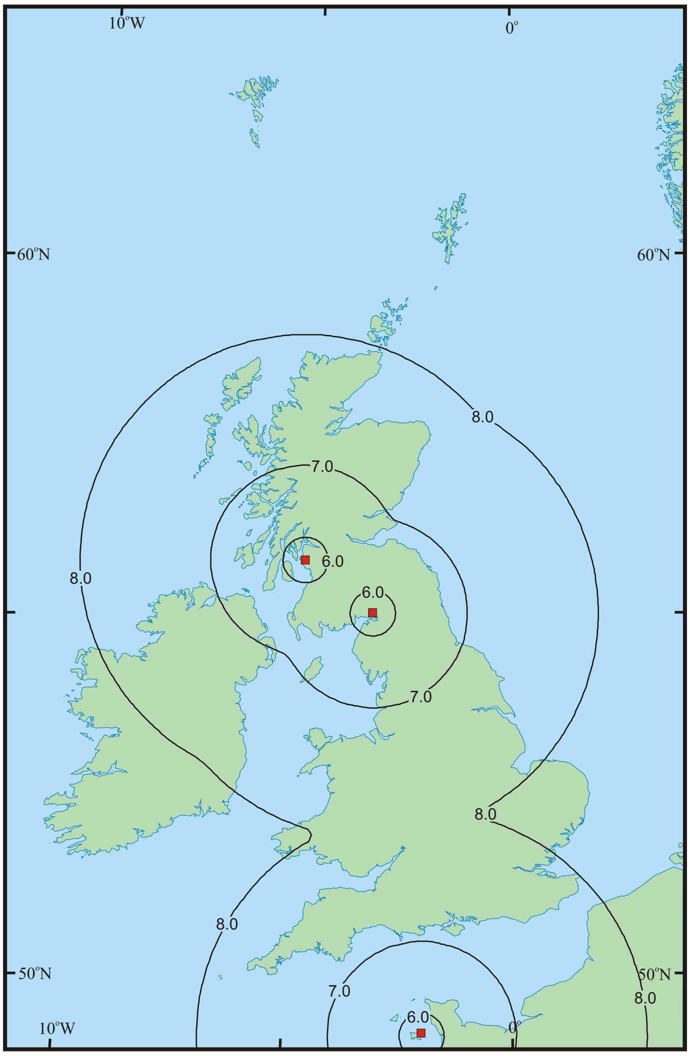


Figure 8. Maximum Richter local magnitude (ML) measurable by the strong motion network operational December 1992.

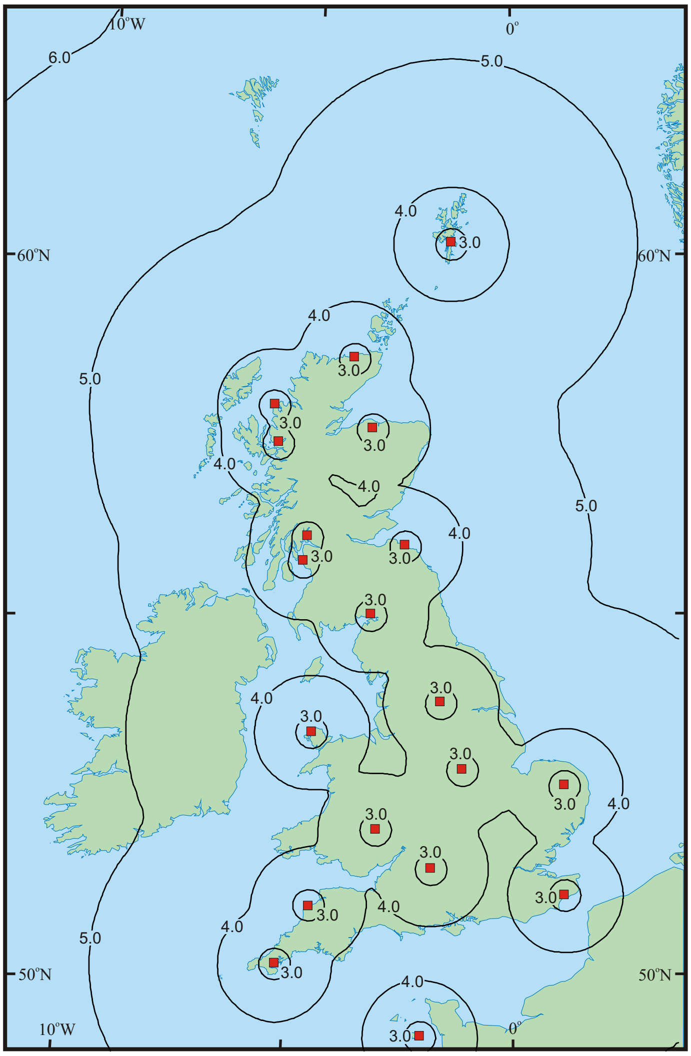


Figure 9. Minimum Richter local magnitude (ML) detectable by the strong motion network operational March 2002.

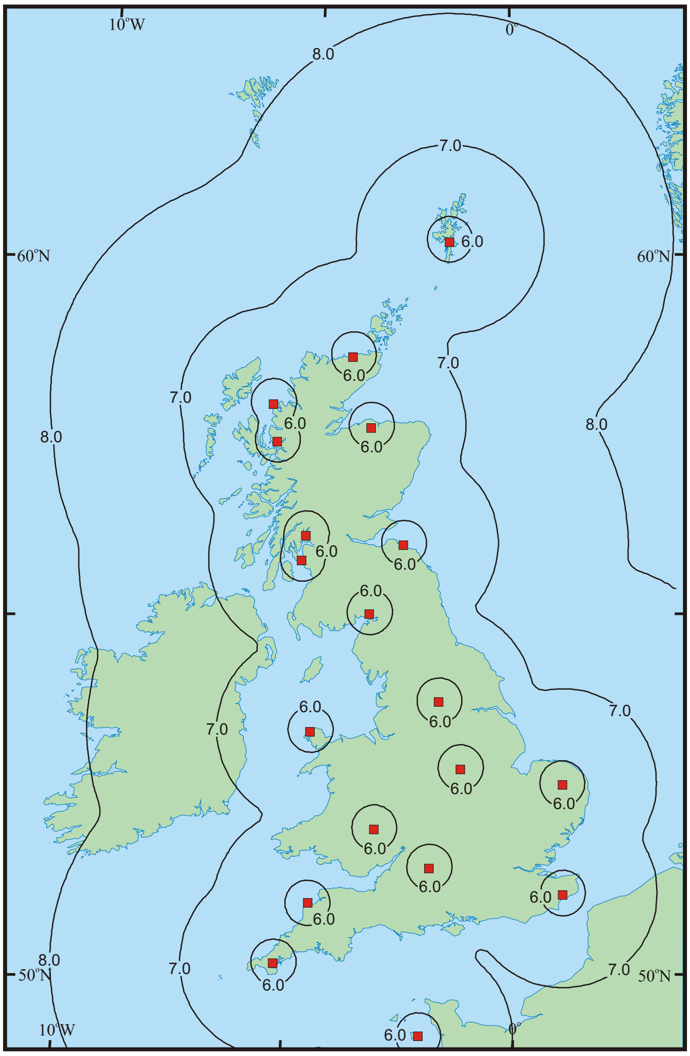


Figure 10. Maximum Richter local magnitude (ML) measurable by the strong motion network operational March 2002.

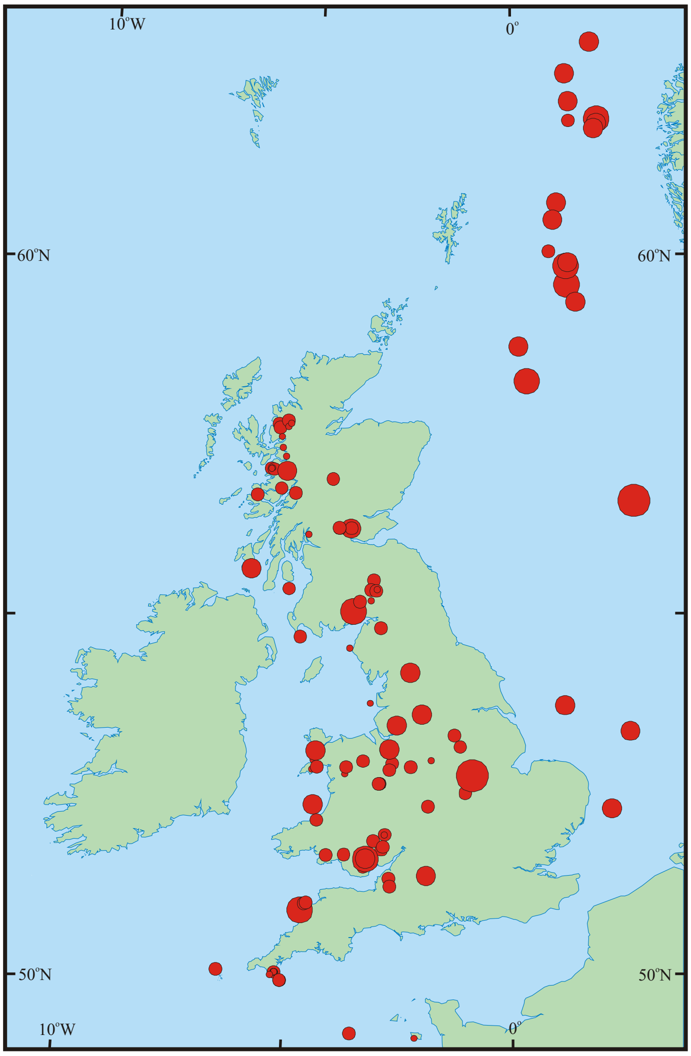


Figure 11. Epicentres of all UK earthquakes located in 2001.

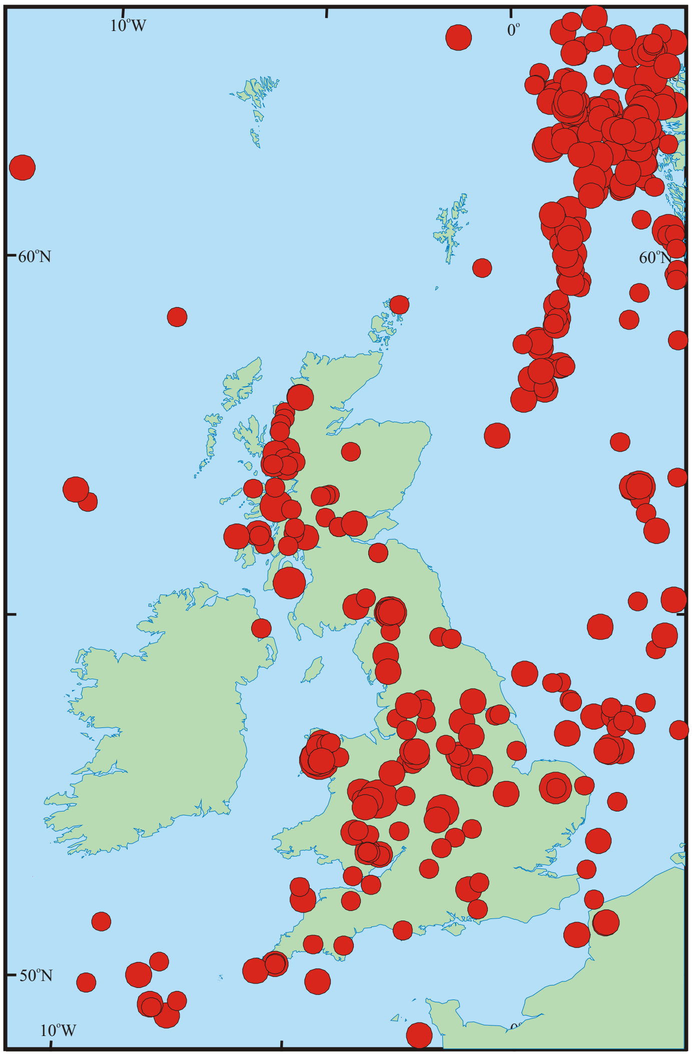


Figure 12. Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 2002.

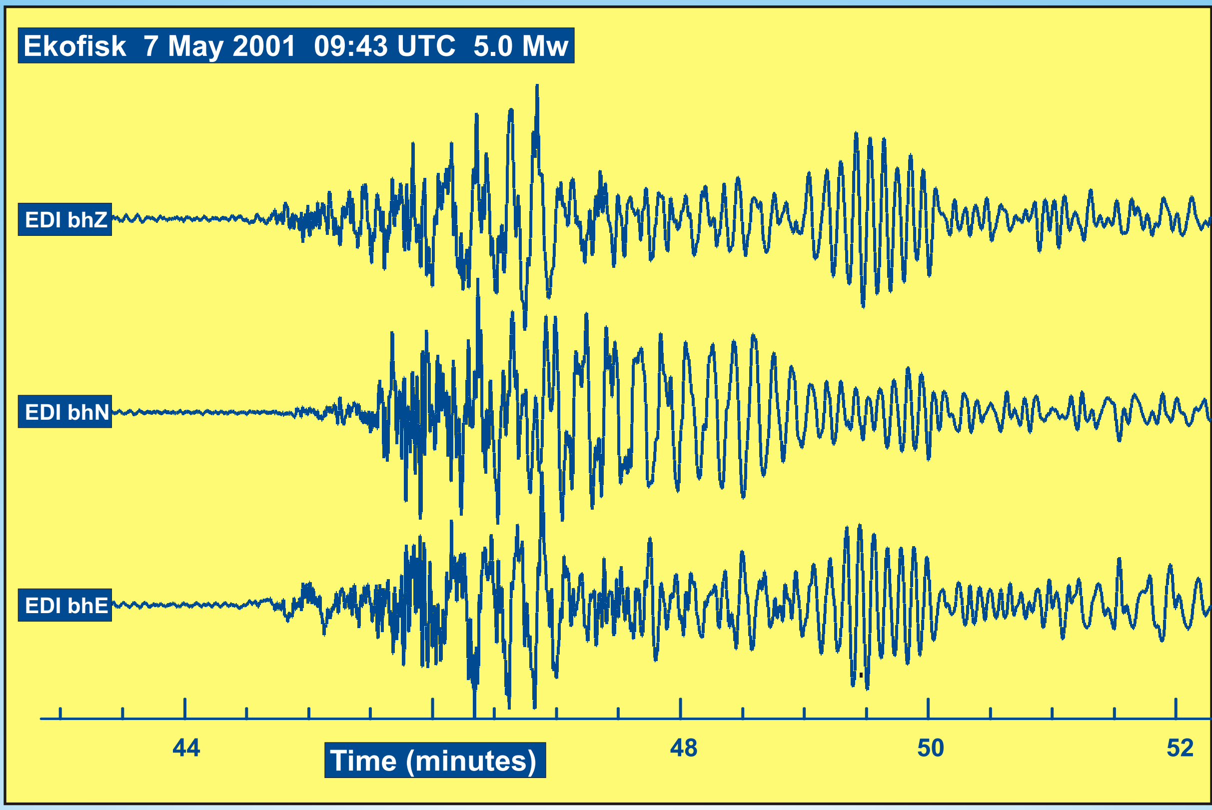


Figure 13. Seismograms recorded on the broadband instruments near Edinburgh from the magnitude 5.0 Mw earthquake felt in the Ekofisk field on 7 May 2001 09:43 UTC. Three letter codes refer to stations in Annex E.

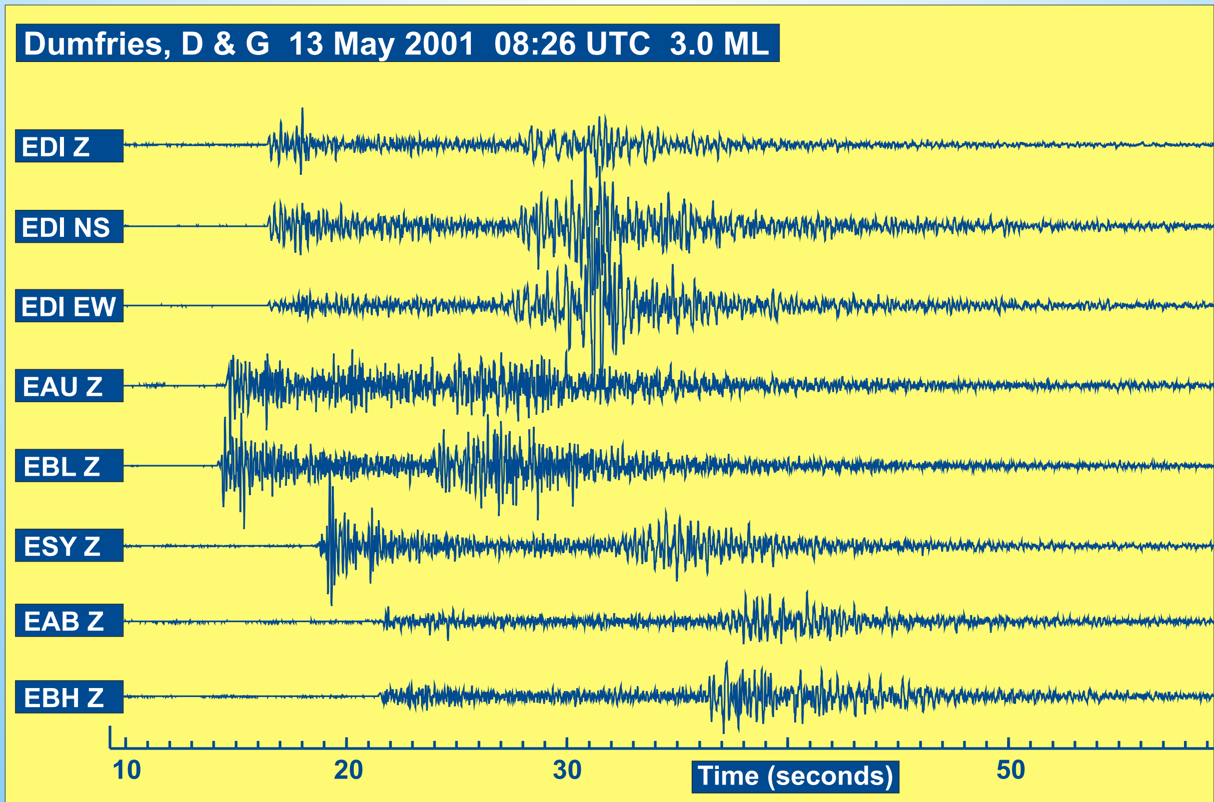


Figure 14. Seismograms recorded on the LOWNET (Edinburgh) network from the magnitude 3.0 ML earthquake felt in the Dumfries area on 13 May 2001 08:26 UTC. Three letter codes refer to stations in Annex E.

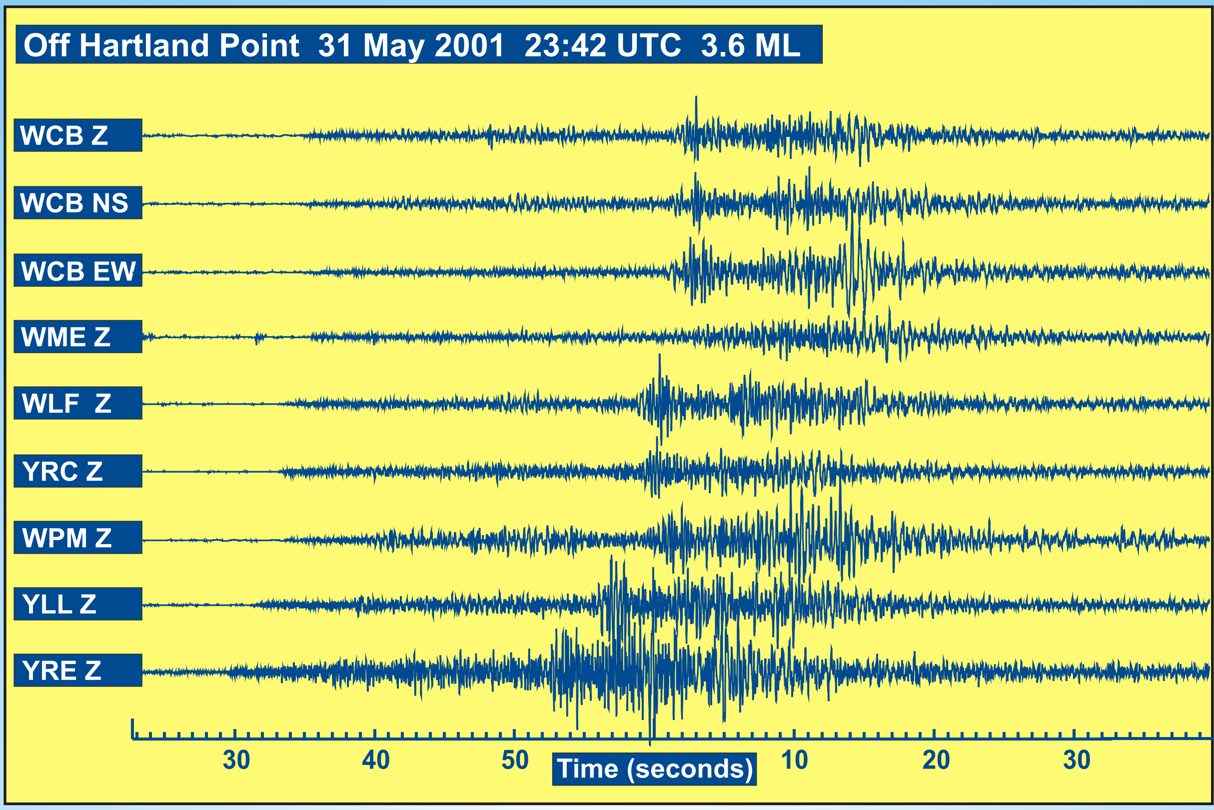


Figure 15. Seismograms recorded on the North Wales network from the magnitude 3.6 ML earthquake felt in the SW England area on 31 May 2001 23:42 UTC. Three letter codes refer to stations in Annex E.

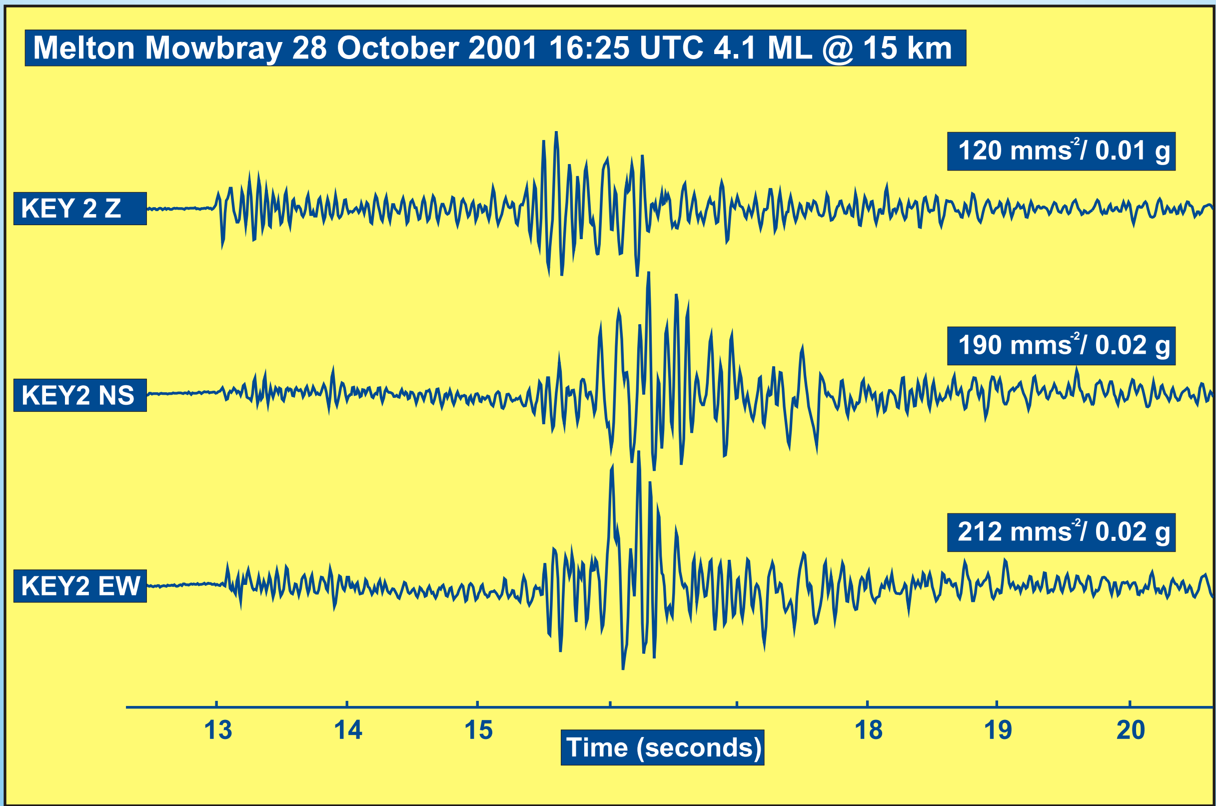


Figure 16. Seismograms recorded on the Keyworth network from the magnitude 4.1 ML earthquake felt in the Midlands area on 28 October 2001 16:25 UTC. Three letter codes refer to stations in Annex E.

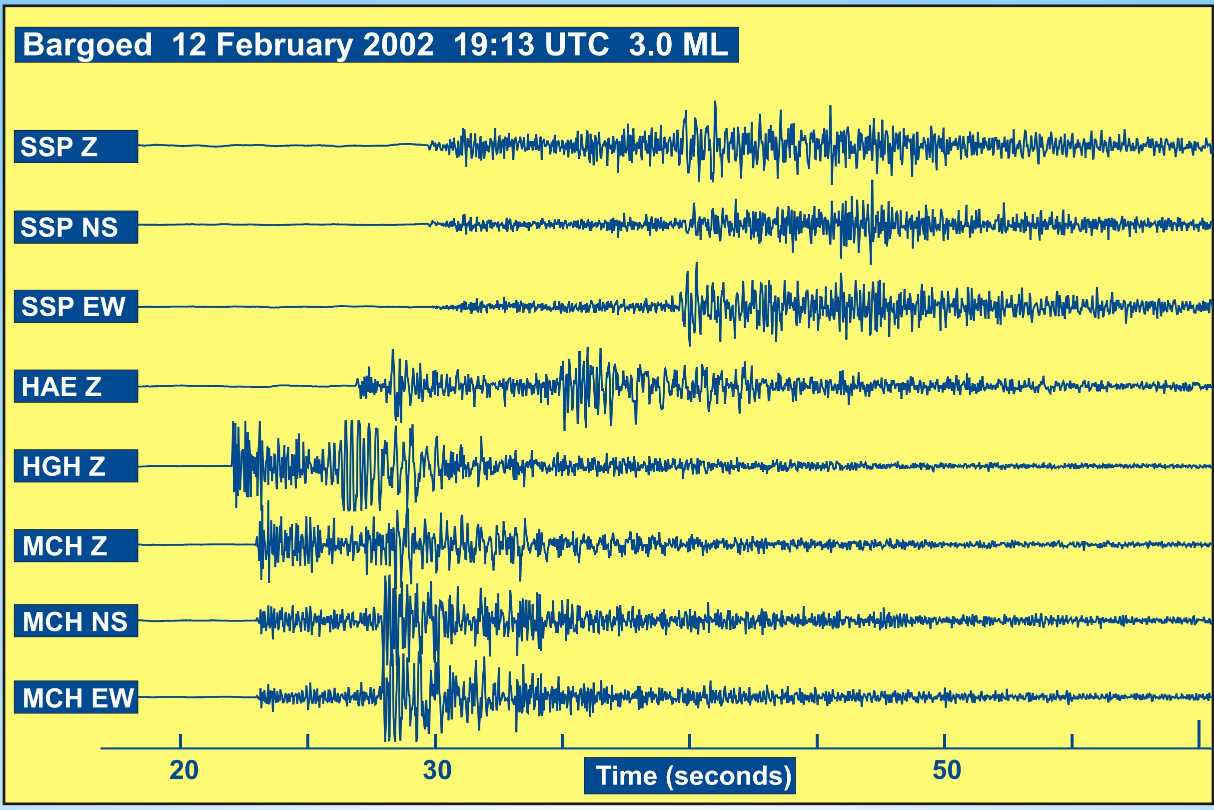


Figure 17. Seismograms recorded on the Hereford network from the magnitude 3.0 ML earthquake felt in the Bargoed area on 12 February 2002 19:13 UTC. Three letter codes refer to stations in Annex E.

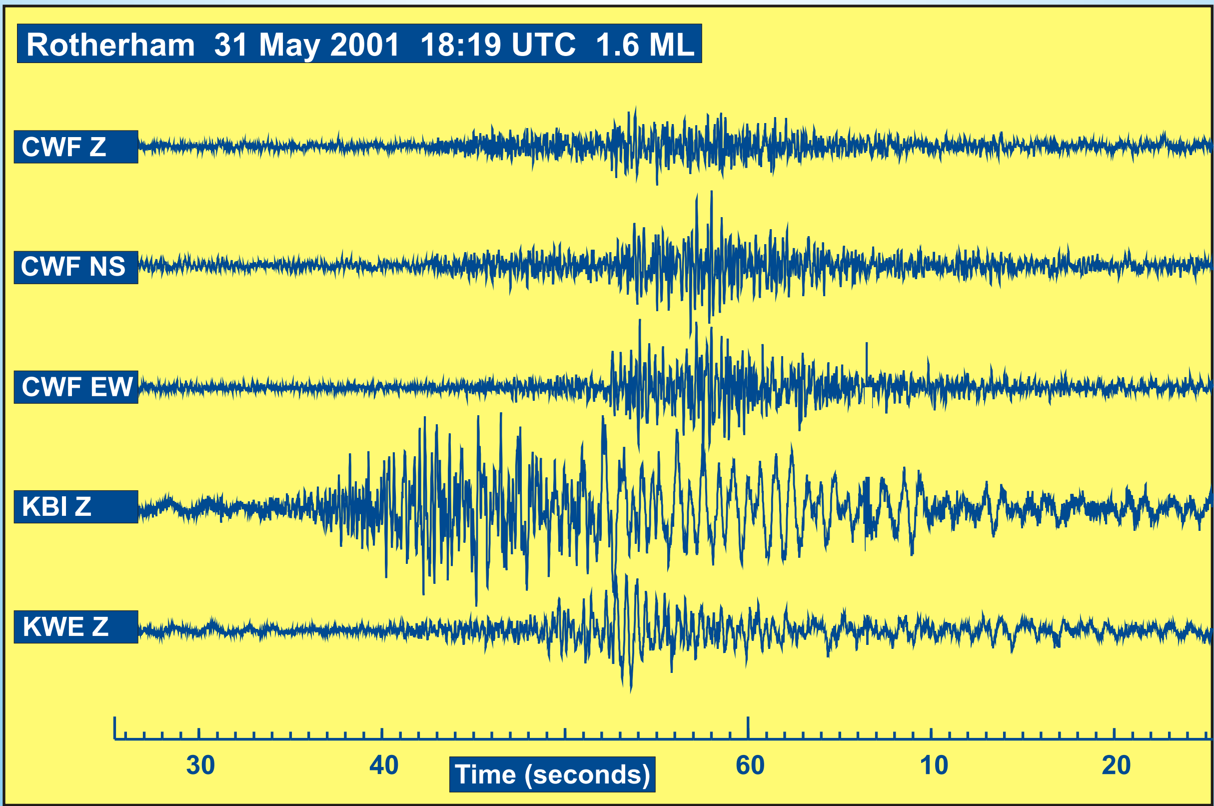


Figure 18. Seismograms recorded on the Keyworth network from the magnitude 1.6 ML event felt in the Rotherham area on 31 May 2001 18:19 UTC. Three letter codes refer to stations in Annex E.

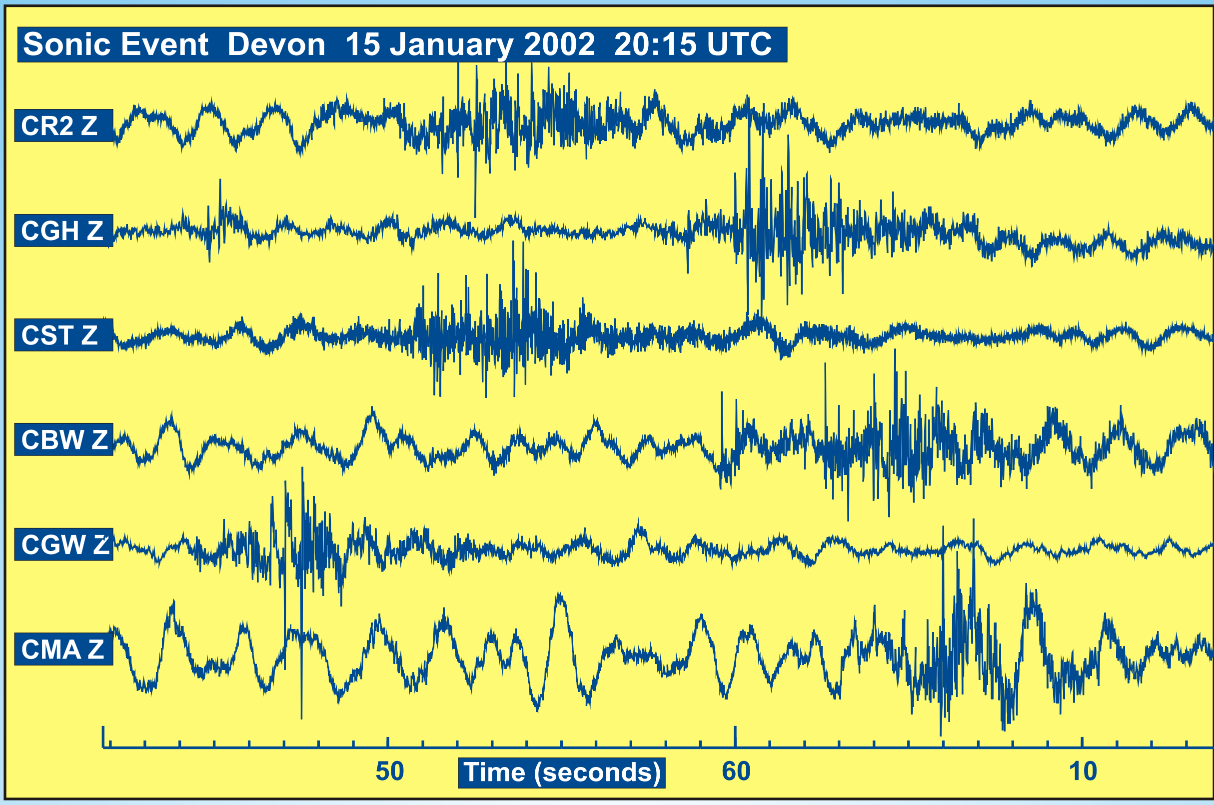


Figure 19. Seismograms recorded on the Cornwall network from the sonic event felt in the North Devon area on 15 January 2002 20:15 UTC. Three letter codes refer to stations in Annex E.

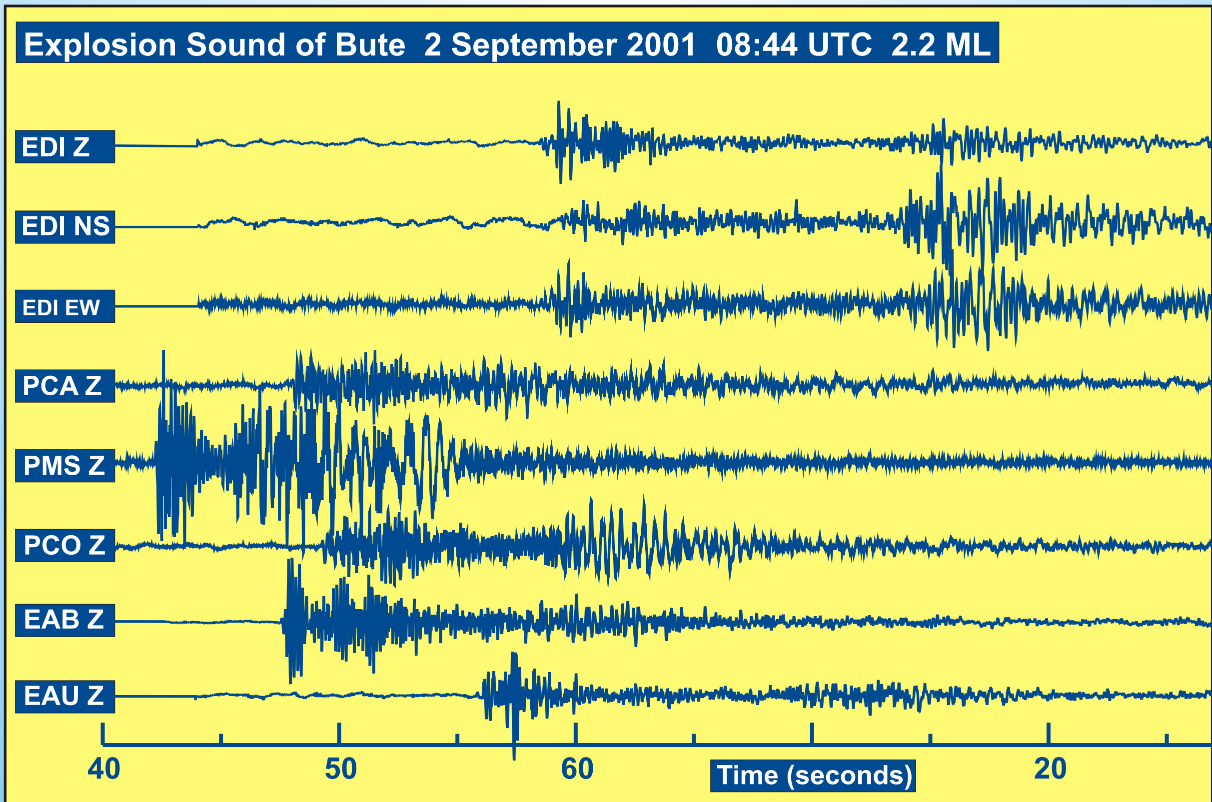


Figure 20. Seismograms recorded on the LOWNET (around Edinburgh) and Paisley networks from the magnitude 2.2 ML explosion on 2 September 2001 08:44 UTC. Three letter codes refer to stations in Annex E.

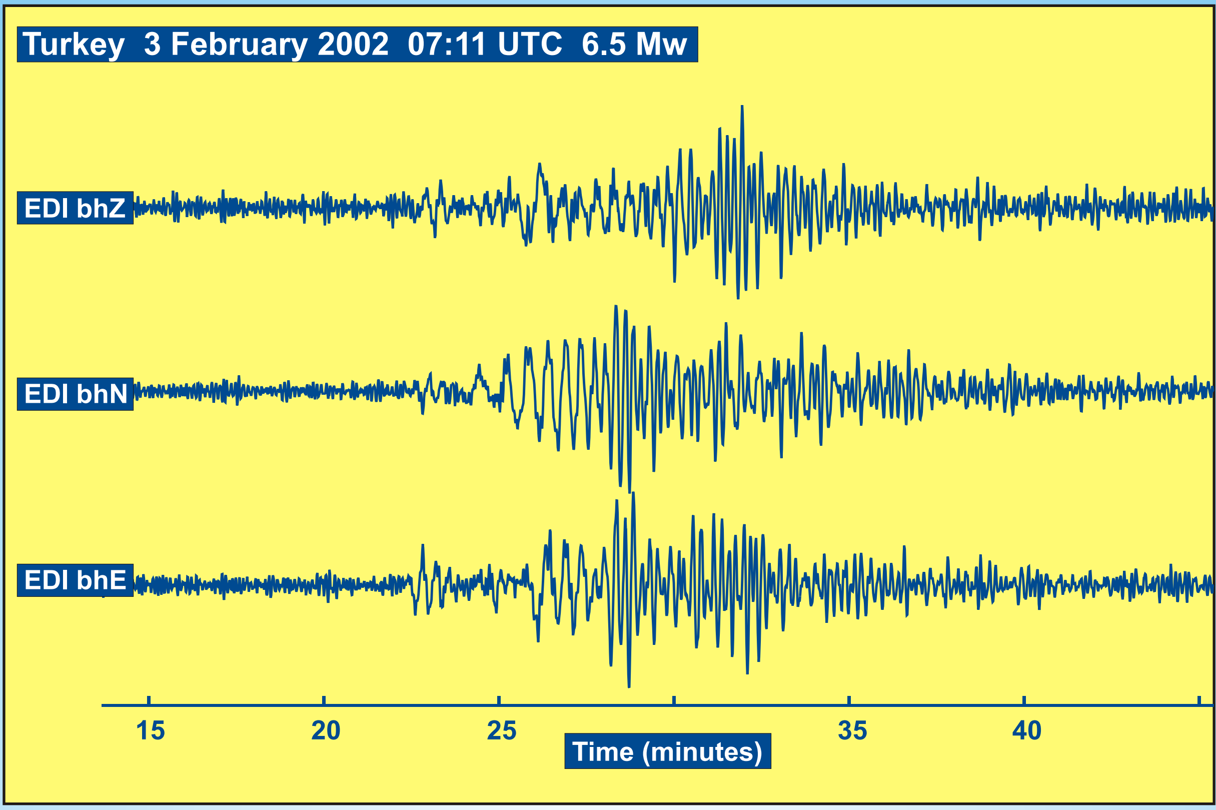


Figure 21. Seismograms recorded on the broadband instruments near Edinburgh from the Turkey earthquake with a magnitude of 6.5 Mw on 3 February 2002 07:11 UTC. Three letter codes refer to stations in Annex E.

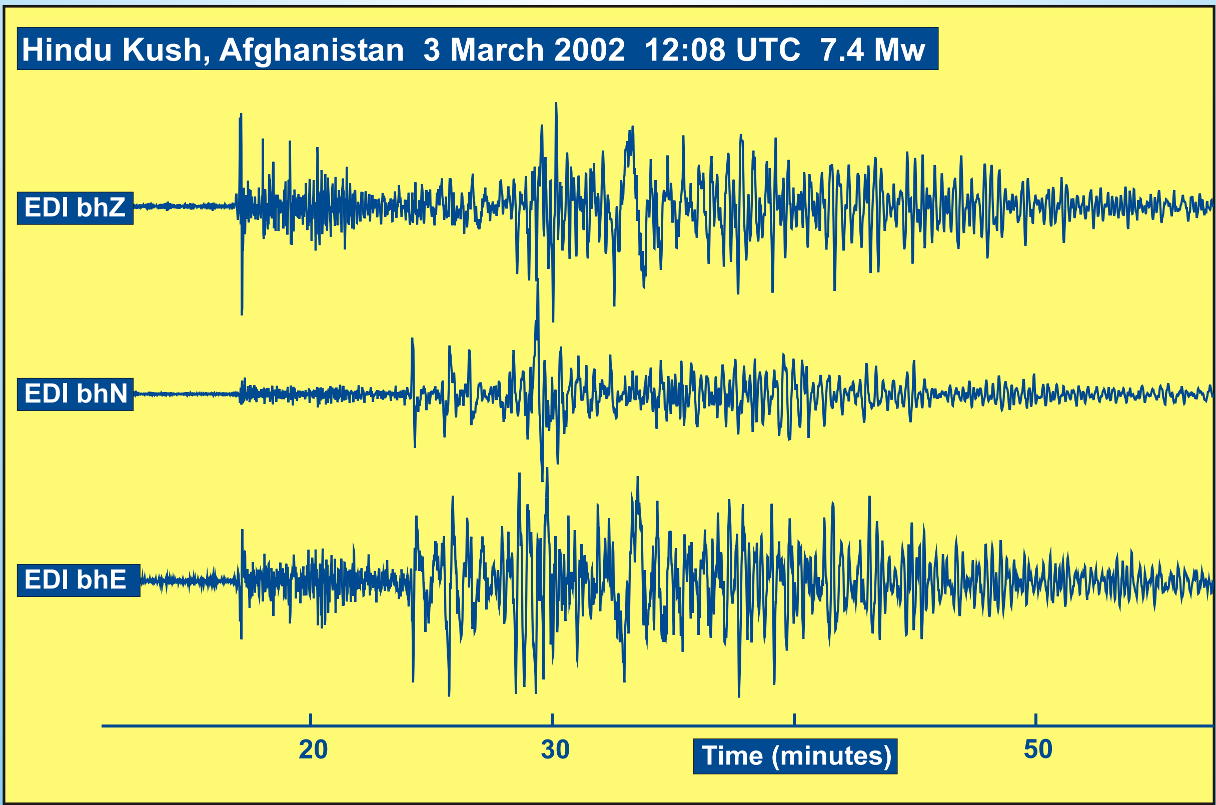


Figure 22. Seismograms recorded on the broadband instruments near Edinburgh from the Hindu Kush, Afghanistan earthquake with a magnitude of 7.4 Mw on 3 March 2002 12:08 UTC. Three letter codes refer to stations in Annex E.

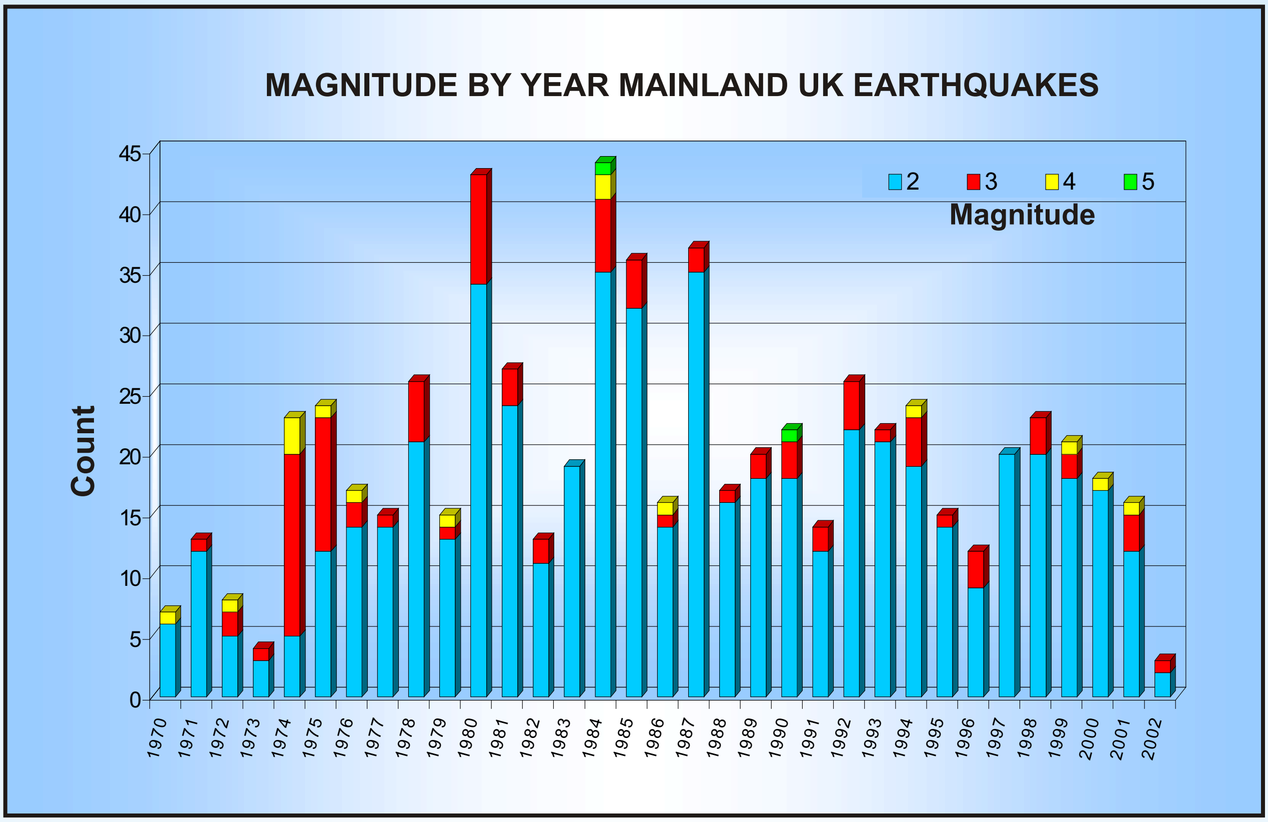


Figure 23. Histogram showing number of events magnitude 2.0 ML or above detected, 1970 - March 2002.

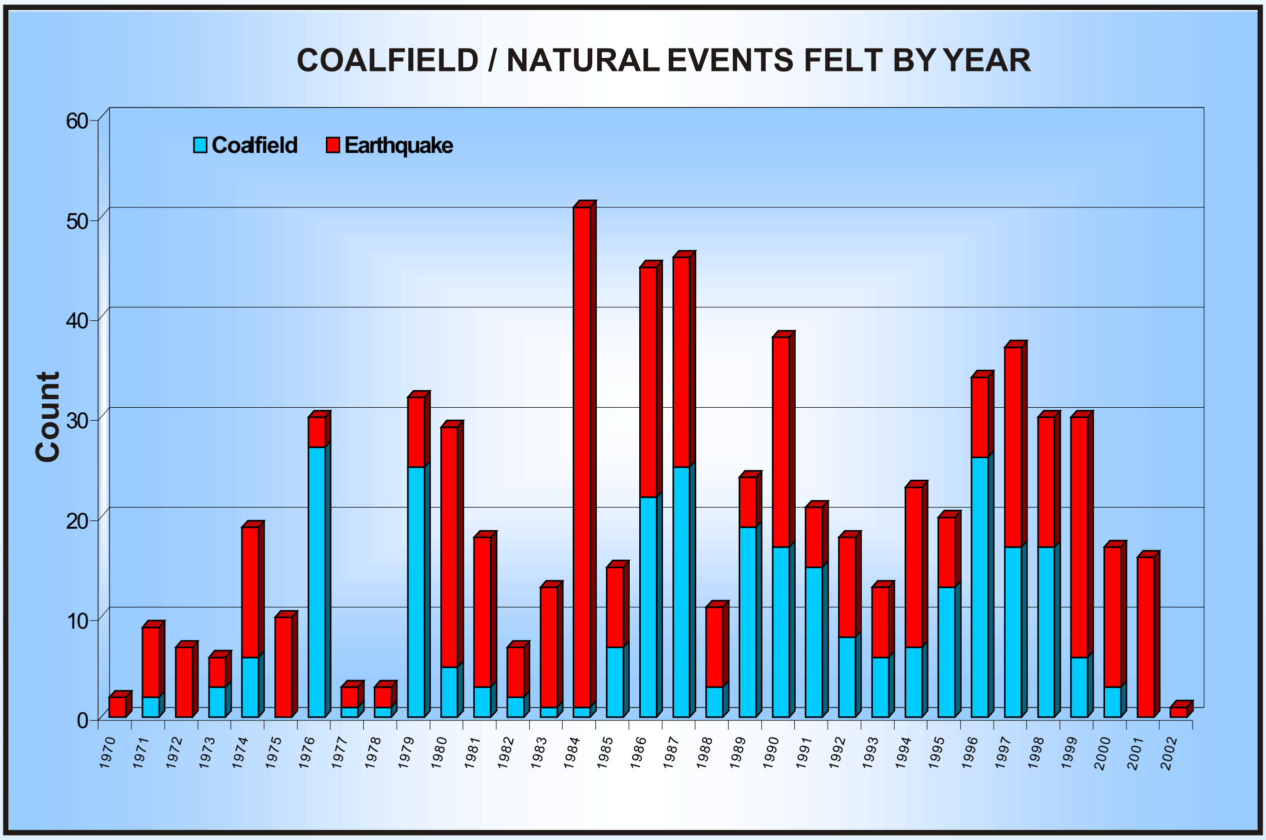


Figure 24. Histogram showing number of felt events 1970 - March 2002.

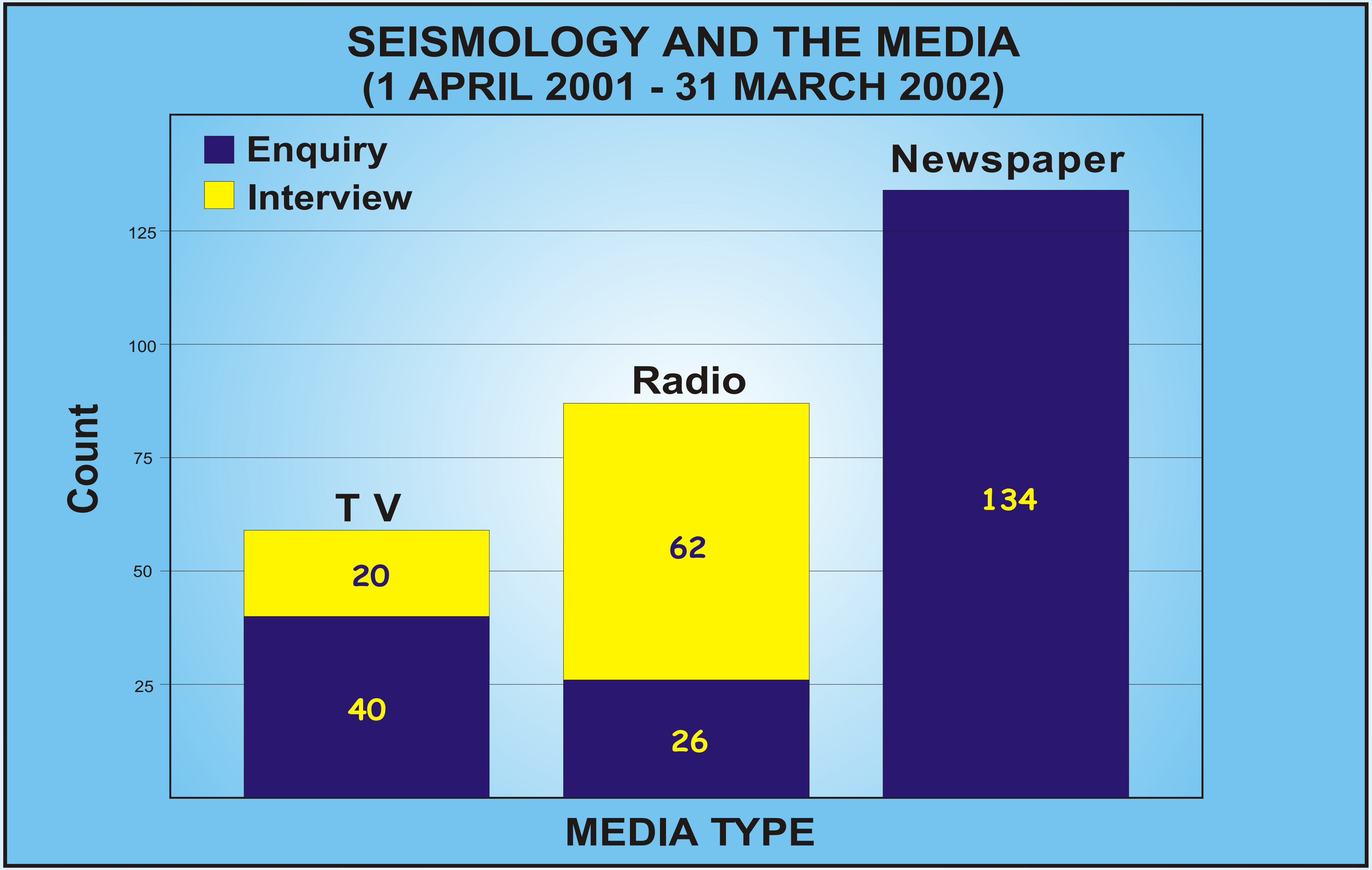


Figure 25. Histogram showing number of media enquiries answered for UK and world earthquakes between 1 April 2001 and 31 March 2002.

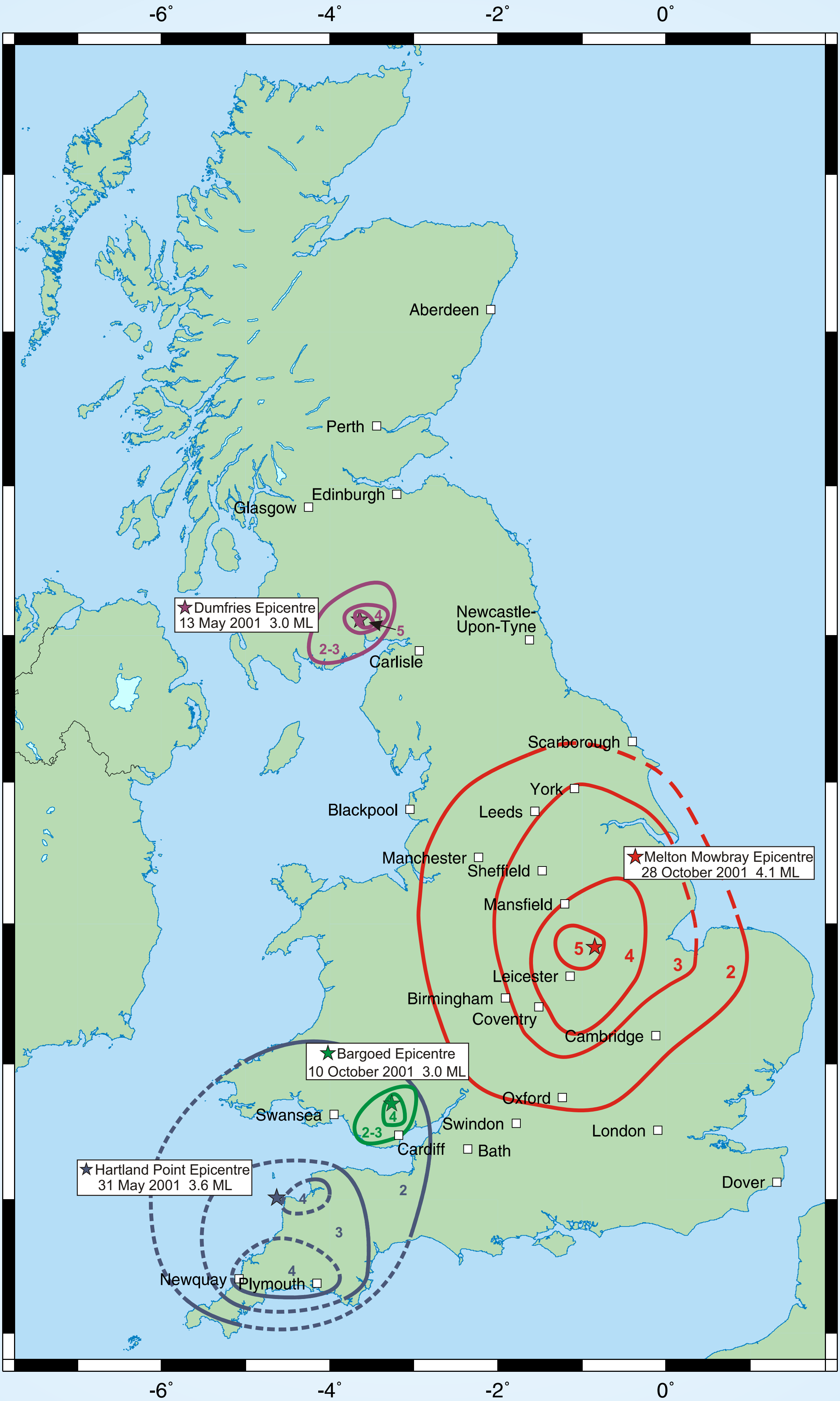


Figure 26. Felt areas of the Dumfries, Hartland Point, Bargoed and Melton Mowbray earthquakes.

Figure 27. Damage to 1-storey commercial buildings in Cay, Turkey from the Turkey earthquake 3 February 2002 07:11 UTC, magnitude 6.5 Mw. (Photograph supplied by Prof Feridun Cili, Istanbul Technical University, Turkey.

Figure 28. Damage to an 8-storey building in Cay, Turkey from the Turkey earthquake 3 February 2002 07:11 UTC, magnitude 6.5 Mw. (Photograph supplied by Dr Oguz Cem Celik, Dept. of Civil Eng., Buffalo, NY).

CONTRIBUTORS TO THE PROJECT

Alcan Smelting and Power UK
British Energy
British Nuclear Fuels plc
BNFL Magnox Generation
Department of Transport Local Government and the Regions
East of Scotland Water
Faroese Geological Survey
Health and Safety Executive
Natural Environment Research Council
Nuclear Installations Inspectorate
Renfrewshire Council
Scottish Coal
Scottish Power
Scottish and Southern Energy plc
United Kingdom Atomic Energy Authority
Welsh Assembly
Western Frontiers Association

Atomic Weapons Establishment (Data only)

Customer Group Members (not contributing in Year Thirteen)

British Gas/Transco
International Seismological Centre
Scottish Office
United Kingdom Nirex Limited
University of Exeter

EARTHQUAKES WITH MAGNITUDE 2.0 AND ABOVE, RECORDED IN THE UK AND OFFSHORE WATERS:2001

YearMoDy	HrMnSecs	Lat	Lon	kmE	kmN	Dep	Mag	Locality	Int	No DM	Gap	RMS	ERH	ERZ	SQD	Comments
20010101	182707.9	55.63	-6.14	139.3	645.6	9.0	2.1	ISLAY,INNER HEBRIDES		6 47	256	0.08	2.20	3.70	B*D	
20010103	065848.7	59.85	1.97	622.5	1114.1	15.0	2.6	NORTHERN NORTH SEA		9179	140	0.47	5.40	17.80	D*D	
20010104	213117.1	59.80	1.92	619.7	1108.3	19.2	3.1	NORTHERN NORTH SEA		9177	143	0.15	2.00	6.20	C*D	
20010117	161225.0	59.55	1.91	621.1	1079.8	10.0	3.0	NORTHERN NORTH SEA		10185	157	0.50	4.70	12.50	D*D	
20010209	214522.1	62.84	3.15	661.9	1450.3	15.0	2.9	NORWEGIAN SEA		6339	314	0.34			D*D	
20010212	111948.4	52.33	2.27	690.8	278.4	15.4	2.7	SOUTHERN NORTH SEA		6 54	312	0.08	2.30	2.20	B*D	
20010219	124521.5	59.39	6.08	858.0	1083.4	15.0	3.0	NORWEGIAN COAST		5416	352	0.29			D*D	
20010225	123938.4	53.54	-2.58	361.4	405.1	10.4	2.2	WIGAN,GTR MANCHESTER		15 77	126	0.09	0.50	1.20	A*D	
20010304	223630.9	52.43	-4.46	232.9	284.6	8.9	2.0	CARDIGAN BAY,WALES		12 40	190	0.08	0.50	0.70	A*D	25KM WEST OF ABERYSTWYTH
20010314	222043.3	58.25	0.69	558.1	932.4	19.5	3.4	CENTRAL NORTH SEA		28210	239	0.19	1.70	3.20	B*D	
20010318	014349.0	51.47	-1.91	406.0	175.1	8.5	2.7	SWINDON,WILTSHIRE		12 64	203	0.22	2.40	3.60	B*D	
20010507	094334.0	56.54	3.19	718.9	750.7	5.0	5.0	EKOFISK	4+	10297	231	0.84	14.80		D*D	FELT EKOFISK FIELD
20010509	163826.5	53.77	1.32	619.0	436.1	8.3	2.6	SOUTHERN NORTH SEA		13 99	238	0.50	6.40	5.70	D*D	
20010513	082659.4	55.10	-3.64	295.5	579.6	11.5	3.0	DUMFRIES,D & G	5	12 9	136	0.11	0.80	1.70	A*C	FELT DUMFRIES...
20010514	055039.4	62.44	2.21	617.0	1403.1	13.8	2.2	NORTHERN NORTH SEA		5274	354	0.10			D*D	
20010515	071933.0	59.30	2.12	634.7	1053.4	23.7	2.4	NORTHERN NORTH SEA		5205	345	0.28			D*D	
20010531	234259.1	50.98	-4.53	215.6	127.2	26.4	3.6	OFF HARTLAND PT,DEVON	5	10 10	180	0.07	0.90	0.30	A*D	FELT CORNWALL & DEVON
20010601	061807.0	61.79	3.06	666.4	1333.6	15.9	3.7	NORTHERN NORTH SEA		13107	223	0.13	5.80	3.70	D*D	
20010601	062251.4	61.66	2.94	661.6	1319.1	9.7	2.8	NORTHERN NORTH SEA		8182	227	0.20	4.80		C*D	
20010601	062620.2	61.73	3.04	666.0	1327.2	10.1	2.3	NORTHERN NORTH SEA		11107	219	0.30	3.70	4.80	C*D	
20010602	004457.2	56.81	6.80	936.4	803.3	15.0	3.9	NORWEGIAN-DANISH BASIN		15569	300	0.38	16.20		D*D	
20010617	235112.2	60.43	1.87	613.1	1177.9	15.0	3.0	NORTHERN NORTH SEA		6163	340	0.24			D*D	
20010627	030619.8	54.27	-2.27	382.1	485.8	7.2	2.2	SEDBERGH,CUMBRIA	4+	12 35	204	0.10	0.20	4.20	B*D	FELT COWGILL
20010813	095658.5	60.48	2.02	620.8	1184.0	15.0	2.0	NORTHERN NORTH SEA		5171	341	0.08			D*D	
20010918	055842.4	62.19	2.32	624.5	1375.1	15.0	2.9	NORTHERN NORTH SEA		5257	354	0.05			D*D	
20011010	025225.3	51.70	-3.25	313.3	200.7	6.5	3.1	BARGOED,MID GLAMORGAN	4	8 32	83	0.09	0.60	4.40	B*C	FELT BARGOED...
20011014	101732.6	53.37	2.79	718.8	397.0	15.0	2.7	SOUTHERN NORTH SEA		8108	324	0.45		18.70	D*D	
20011017	230311.1	53.21	-2.75	350.2	368.2	8.7	2.4	CHESTER,CHESHIRE		13 17	87	0.05	0.30	1.70	A*B	
20011017	232135.2	53.21	-2.75	349.8	368.0	6.9	2.1	CHESTER,CHESHIRE		11 17	86	0.05	0.50	0.80	A*C	
20011018	035013.6	51.70	-3.26	313.3	201.3	7.9	2.5	BARGOED,MID GLAMORGAN	4+	8 32	92	0.10	0.70		C*C	FELT BARGOED...
20011021	003129.0	56.89	7.43	973.5	817.3	15.0	3.7	NORWEGIAN-DANISH BASIN		19608	321	0.56			D*D	
20011028	162525.1	52.85	-0.86	477.0	328.3	11.6	4.1	MELTON MOWBRAY,LEICS	5	11 15	77	0.14	1.20	1.60	B*B	FELT MELTON MOWBRAY...
20011105	025218.9	53.17	-4.44	237.1	366.9	7.5	2.3	ANGLESEY,GWYNEDD	2+	13 63	86	0.18	0.80	2.50	B*D	FELT ANGLESEY
20011113	170202.0	57.00	-5.39	194.2	794.8	6.0	2.2	FORT WILLIAM,HIGHLAND		6 24	252	0.10	3.10	1.60	C*D	27KM NW OF FORT WILLIAM
20011216	132520.0	53.69	-2.00	399.9	421.8	9.8	2.6	HALIFAX,WEST YORKSHIRE	4+	17 19	81	0.12	0.60	1.50	A*B	FELT HALIFAX...
20011219	205845.1	56.24	-3.74	292.0	706.5	4.8	2.1	BLACKFORD,TAYSIDE	3+	10 15	129	0.06	0.40	0.70	A*C	FELT GLENDEVON...
20011221	093456.9	58.73	0.55	547.6	984.8	18.1	2.7	NORTHERN NORTH SEA		5176	349	0.12			D*D	

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

TEL: 0131 667 1000
FAX: 0131 667 1877
INTERNET: http://www.gsrg.nmh.ac.uk/.

TO: M THOMAS	- DTLR	P BATES	- UKAEA
D BROOK	- DTLR	P W WINTER	- AEA
P FORD	- NII, BOOTLE	T EVANS	- BP
J E INKESTER	- NII, BOOTLE	M WILSON	- SCOT H & H
J DONALD	- NII, BOOTLE	A W B JACOB	- DIAS
A H SMITH	- BRITISH ENERGY	R WILLEMANN	- ISC
J BETHELL	- BRITISH ENERGY	F LITTLE	- PAISLEY MUSEUM
J P McFARLANE	- BRITISH ENERGY	C FLAWS	- SCOTTISH COAL
P A MERRIMAN	- BNFL	K DEMPSTER	- S & S ENERGY
H TUR	- BNFL CAPEN	C McDONALD	- S & S ENERGY
C F ALLEN	- BNFL MAGNOX	S ROBERTS	- EAST OF SCOTLAND WATER
H GULVANESSIAN	- BRE	P LING	- WEST OF SCOTLAND WATER
A J HOLT	- HSE	A McDONALD	- SCOTTISH POWER
V KARTHIGEYAN	- HSE OFFSHORE	G MacKENZIE	- NORTH OD SCOTLAND WATER
K KEIRLE	- WELSH ASSEMBLY	R WALLIS	- ALCAN SMELTING & POWER UK
U MICHIE	- NIREX		

FROM: Bennett Simpson
DATE: 30 October 2001
TIME: 14:45 UTC
PAGES TO FOLLOW: 3

UPDATED MAGNITUDE INFORMATION

UPDATED SEISMIC ALERT: MELTON MOWBRAY 28 OCTOBER 2001 16:25 UTC 4.1 ML

After further analysis the magnitude of the earthquake on Sunday has been revised to 4.1 ML. So far, BGS have received approximately 900 e-mail reports about the earthquake and a large number of phone calls. Many media interviews have been given and macroseismic survey questionnaires will be published tomorrow in local and national newspapers. The earthquake has been felt up to 120 km away and throughout Lincolnshire, Leicestershire, Warwickshire, Shropshire and Nottinghamshire. There have also been reports of damage to chimneys in the Molten Mowbray area, indicating an intensity of 6 EMS. A maximum acceleration of 0.02g was measured at the strong motion station at Keyworth, some 15 km from the earthquake.

Revised parameters are as follows:

DATE	:	28 October 2001
ORIGIN TIME	:	16:25 25.1sUTC
LAT/LONG	:	52.84° North / 0.85° West
GRID REF	:	477.0 kmE / 328.3 kmN
DEPTH	:	11.6 km
MAGNITUDE	:	4.1 ML
INTENSITY	:	6+
LOCALITY	:	7 km north of Melton Mowbray, Leicestershire

A revised seismogram as recorded on the Hereford network, together with the strong motion record from Keyworth and a map of seismicity are attached.

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

TEL: 0131 667 1000
FAX: 0131 667 1877
INTERNET: http://www.gsrg.nmh.ac.uk/.

TO: M THOMAS	- DTLR	P BATES	- UKAEA
D BROOK	- DTLR	P W WINTER	- AEA
P FORD	- NII, BOOTLE	T EVANS	- BP
J E INKESTER	- NII, BOOTLE	M WILSON	- SCOT H & H
J DONALD	- NII, BOOTLE	A W B JACOB	- DIAS
A H SMITH	- BRITISH ENERGY	R WILLEMANN	- ISC
J BETHELL	- BRITISH ENERGY	F LITTLE	- PAISLEY MUSEUM
J P McFARLANE	- BRITISH ENERGY	C FLAWS	- SCOTTISH COAL
P A MERRIMAN	- BNFL	K DEMPSTER	- S & S ENERGY
H TUR	- BNFL CAPEN	C McDONALD	- S & S ENERGY
C F ALLEN	- BNFL MAGNOX	S ROBERTS	- EAST OF SCOTLAND WATER
H GULVANESSIAN	- BRE	P LING	- WEST OF SCOTLAND WATER
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V KARTHIGEYAN	- HSE OFFSHORE	G MacKENZIE	- NORTH OD SCOTLAND WATER
K KEIRLE	- WELSH ASSEMBLY	R WALLIS	- ALCAN SMELTING & POWER UK
U MICHIE	- NIREX		

FROM: Bennett Simpson
DATE: 16 November 2001
TIME: 11:30 UTC
PAGES TO FOLLOW: 1

BGS ALERT: SONIC EVENT NE COAST ENGLAND 16 NOVEMBER 2001 10:15 UTC

Police and Media have reported to BGS that numerous residents from Northumberland, Durham, Tyne and Wear and Cleveland, felt an event at approximately 10:13 – 10:15 today (16 November 2001). Felt reports described "a loud bang", "the windows rattled" and "the whole building shook". Data from the BGS rapid-access networks in the area were examined and signals consistent with a sonic origin were recorded at 10:15 UTC.

The RAF were contacted and confirmed that a military exercise was operational at the time.

A seismogram of the event, as recorded on the BGS Eskdalemuir network, is attached.

BGS STAFF WITH INPUT TO THE PROJECT

Mr Tom Alexander
Dr Brian Baptie
Ms Jacqueline Bott
Dr Chris W A Browitt
Mr Julian Bukits
Ms Freya Cromatry
Mr Daniel Dawes
Mr Simon Flower
Mr Glenn D Ford
Mr Charlie J Fyfe
Mr Davie D Galloway
Mr Paul H O Henni
Dr David J Kerridge
Mr John Laughlin
Ms Margaret Milne
Dr Roger M W Musson
Dr Lars Ottemöller
Mr Dave L Petrie
Mr David Scott
Mr Bennett A Simpson
Mr Ralph Southworth
Mr Dave A Stewart
Mr William A Velzian
Ms Alice B Walker
Ms Jennifer Williams

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS :MARCH 2002

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (m)	Yrs Open	Comp	Agency
FAROES									
FHV	HALDARSVIK	62.2597	-7.0984	135.46	1385.95	380	99-	1R	BGS
FSD	SUDUROY	61.5701	-6.7884	145.86	1308.06	480	99-	1R	BGS
FSV	SVINOY	62.2598	-6.3550	173.99	1383.14	430	99-	1R	BGS
FTO	TORSHAVN	62.0199	-6.8274	147.51	1358.21	325	99-	3R	BGS
FVA	VAGAR	62.0575	-7.3520	120.46	1364.55	430	99-	1R	BGS
SHETLAND									
LRW	LERWICK	60.1360	-1.1779	445.66	1139.27	98	78-	4R	BGS
LRWS	LERWICK (SM)	60.1397	-1.1831	445.37	1139.69	80	96-	3	BGS
SAN	SANDWICK	60.0179	-1.2392	442.41	1126.08	150	85-	1	BGS
WAL	WALLS	60.2564	-1.6173	421.18	1152.46	167	80-	1	BGS
YEL	YELL	60.5509	-1.0830	450.29	1185.55	203	79-	1	BGS
ORKNEY									
ORE	REAY	58.5480	-3.7622	297.45	963.52	100	95-	4Rm	BGS
OTO	TONGUE	58.4953	-4.3939	260.49	958.79	338	95-	1R	BGS
OHO	HOY	58.8322	-3.2465	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	1022.20	21	95-	1R	BGS
OBR	BRABSTER	58.6142	-3.1626	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	-5.1683	214.61	944.33	60	95-	1R	BGS
RRH	RHENIGIDALE	57.9197	-6.6881	122.43	901.86	103	95-	1R	BGS
RFO	FORSNAVAL	58.2133	-7.0052	106.10	935.83	195	95-	1R	BGS
RTO	TOLSTA	58.3778	-6.2092	153.95	950.93	74	95-	1R	BGS
RCR	CAPE WRATH	58.6245	-4.9987	225.90	974.58	100	95-	1R	BGS
REB	EISG-BRACHAIDH	58.1194	-5.2802	206.82	919.16	100	95-	1R	BGS
MORAY									
MCD	COLEBURN DISTIL	57.5828	-3.2541	325.02	855.42	293	81-	4Rm	BGS
MDO	DOCHFOUR	57.4409	-4.3633	258.17	841.39	415	81-	1R	BGS
MFI	FISHRIE	57.6119	-2.2956	382.34	858.00	232	88-	1R	BGS
MLA	LATHERON	58.3055	-3.3627	320.15	935.98	188	81-	1	BGS
MME	MEIKLE CAIRN	57.3149	-2.9647	341.90	825.32	475	81-	1	BGS
MVH	ACHVAICH	57.9250	-4.1825	270.75	894.90	185	84-	1	BGS
KYLE									
KAC	ACHNASHELLACH	57.4989	-5.2988	202.36	850.19	206	83-	1R	BGS
KAR	ARISAIG	56.9188	-5.8290	166.98	787.34	186	83-	1	BGS
KNR	NEVIS RANGE	56.8219	-4.9714	218.68	773.97	1147	91-	1	BGS
KPL	PLOCKTON	57.3391	-5.6527	180.21	833.50	13	86-	4R	BGS
KSB	SHIEL BRIDGE	57.2099	-5.4214	193.40	818.40	417	83-	1R	BGS
KSK	SCOVAL	57.4659	-6.7002	118.21	851.46	265	89-	1R	BGS
LOWNET									
EAB	ABERFOYLE	56.1887	-4.3373	254.97	702.02	279	69-	1R	BGS
EAU	AUCHINOON	55.8454	-3.4474	309.38	662.30	359	69-	1R	BGS
EBH	BLACK HILL	56.2476	-3.5084	306.54	707.13	375	69-	1R	BGS
EBL	BROAD LAW	55.7723	-3.0445	334.48	653.71	436	69-	1R	BGS
EDI	EDINBURGH	55.9233	-3.1875	325.80	670.66	125	69-	4R	BGS
EDR	DRUMTOCHTY	56.9190	-2.5393	367.17	780.97	401	89-	1R	BGS
EDU	DUNDEE	56.5477	-3.0110	337.85	739.97	421	69-	1R	BGS
ELO	LOGIEALMOND	56.4703	-3.7112	294.59	732.21	523	69-	1R	BGS
ESY	STONEYPATH	55.9175	-2.6141	361.62	669.55	337	81-	1R	BGS

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS :MARCH 2002

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (m)	Yrs Open	Comp	Agency
PAISLEY									
PCA	CARROT	55.7007	-4.2550	258.30	647.55	302	83-	1	BGS
PCO	CORRIE	55.9880	-4.1002	269.00	679.21	267	83-	1	BGS
PGB	GLENIFFERBRAES	55.8115	-4.4837	244.38	660.37	199	84-	3	BGS
PMS	MUIRSHIEL	55.8459	-4.7452	228.15	664.82	351	83-	1	BGS
POB	OBSERVATORY	55.8458	-4.4299	247.88	664.06	34	92-	1	BGS
ESKDALEMUIR									
ESK	ESKDALEMUIR	55.3165	-3.2052	323.52	603.16	261	65-	4R	BGS
ECK	CAULDKAINE HILL	55.1810	-3.1292	328.10	588.00	351	81-	1R	BGS
XAL	ALLENDALE	54.8617	-2.2147	386.22	551.91	458	83-	1R	BGS
XSO	SOURHOPE	55.4924	-2.2510	384.14	622.10	516	83-	1R	BGS
GALLOWAY AND N IRELAND									
GAL	GALLOWAY	54.8664	-4.7114	226.02	555.78	117	89-	4m	BGS
GCL	CUSHENDALL	55.0783	-6.1264	136.66	583.77	278	89-	1R	BGS
GMK	MULL OF KINTYRE	55.3458	-5.5934	172.19	611.64	164	89-	1R	BGS
GMM	MTNS OF MOURNE	54.2377	-5.9498	142.66	489.67	155	89-	1R	BGS
BORDERS									
BBH	BRUNTSHEIL	55.1333	-2.9299	340.72	582.50	216	92-	1	BGS
BNA	NEW ABBEY	54.9658	-3.6242	296.03	564.68	28	92-	1	BGS
BHH	HOWATS HILL	55.0931	-3.2181	322.27	578.31	216	92-	3	BGS
BTA	TALKIN	54.9057	-2.6844	356.12	557.00	279	92-	3	BGS
BDL	DOBCROSS HALL	54.8030	-2.9385	339.68	545.76	157	92-	1	BGS
BWH	WARDLAW	55.1758	-3.6549	294.62	588.09	269	92-	1	BGS
BBO	BOTHEL **	54.7367	-3.2464	319.76	538.69	209	92-	3	BGS
BCM	CHAPELCROSS	55.0151	-3.2212	321.92	569.64	78	92-	m	BGS
BCC	CHAPELCROSS	55.0153	-3.2201	321.99	569.66	138	92-	1	BGS
CUMBRIA									
CKE	KESWICK	54.5877	-3.1059	328.54	521.96	304	92-	1	BGS
CSF	SCAFELL	54.4478	-3.2430	319.41	506.55	540	92-	1	BGS
CDU	DUNNERDALE	54.3362	-3.1952	322.30	494.08	355	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	129	89-	3R	BGS
GIM	ISLE OF MAN(N)*	54.2923	-4.4672	239.44	491.35	346	89-	3R	BGS
GCD	CASTLE DOUGLAS*	54.8630	-3.9403	275.48	553.76	184	89-	1R	BGS
XDE	DENT *	54.5056	-3.4902	303.52	513.29	301	83-	1R	BGS
LEEDS									
HPK	HAVERAH PARK	53.9581	-1.6241	424.66	451.42	233	78-	3R	BGS
LCP	CASSOP	54.7370	-1.4744	433.84	538.14	185	91-	1	BGS
LWH	WHINNY NAB	54.3338	-0.6717	486.36	493.97	277	91-	1R	BGS
LRN	RICHMOND	54.4165	-1.8007	412.93	502.37	313	91-	1R	BGS
LMK	MARKET RASEN	53.4569	-0.3260	511.14	396.90	146	91-	1	BGS
LHO	HOLMFIRTH	53.5453	-1.8548	409.62	405.44	462	91-	1	BGS
LDU	LEEDS	53.8058	-1.5540	429.37	434.51	74	83-	2Rm	BGS

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS :MARCH 2002

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (m)	Yrs Open	Comp	Agency
NORTH WALES									
WCB	CHURCH BAY	53.3782	-4.5467	230.62	389.87	139	85-	4m	BGS
WFB	FAIRBOURNE	52.6831	-4.0383	262.23	311.48	316	85-	1R	BGS
WIM	ISLE OF MAN (S)	54.1475	-4.6738	225.39	475.73	386	85-	1R	BGS
WLF	LLYNFAES	53.2894	-4.3966	240.27	379.65	58	85-	1	BGS
WME	MYNDD EILIAN	53.3969	-4.3032	246.88	391.40	129	85-	1R	BGS
WPM	PENMAENMAWR	53.2581	-3.9048	272.95	375.18	353	85-	1	BGS
YRC	RHOSCOLYN	53.2508	-4.5753	228.21	375.77	22	84-	1R	BGS
YRE	YR EIFL	52.9811	-4.4254	237.19	345.43	193	84-	1R	BGS
YLL	LLANBERIS	53.1402	-4.1704	254.84	362.57	159	84-	1R	BGS
YRH	RHIW	52.8336	-4.6288	222.94	329.51	286	84-	1R	BGS
KEYWORTH									
CWF	CHARNWOODFST	52.7385	-1.3076	446.74	315.91	203	75-	3R	BGS
KBI	BIRLEY GRANGE	53.2543	-1.5279	431.49	373.17	272	88-	1	BGS
KEY	KEYWORTH	52.8779	-1.0757	462.20	331.59	59	88-	1	BGS
KEY2	KEYWORTH (SM)	52.8790	-1.0770	462.13	331.73	76	97-	3	BGS
KSY	SYSTON	52.9642	-0.5872	494.88	341.73	121	88-	1R	BGS
KTG	TILBROOK GRANGE	52.3264	-0.4019	508.90	271.06	83	88-	1	BGS
KUF	UFFORD	52.6170	-0.3907	508.94	303.39	38	88-	1R	BGS
KWE	WEAVER FARM	53.0164	-1.8412	410.65	346.61	328	88-	1R	BGS
EAST ANGLIA									
ABA	BACONSTHORPE	52.8884	1.1453	611.58	337.00	74	82-	1	BGS
AEA	E.ANGLIA UNIV.	52.6208	1.2403	619.30	307.53	45	84-	m	BGS
APA	PACKWAY	52.3006	1.4782	637.12	272.68	58	84-	1	BGS
AWH	WHINBURGH	52.6297	0.9507	599.67	307.68	64	80-	1R	BGS
AWI	WITTON	52.8319	1.4471	632.17	331.65	46	83-	1	BGS
AEU	E.ANGLIA	52.6202	1.2347	618.93	307.45	28	94-	4	BGS
HEREFORD									
SBD	BRYN DU	52.9055	-3.2585	315.37	335.01	489	80-	1	BGS
MCH	MICHAELCHURCH	51.9974	-2.9983	331.47	233.74	219	78-	4	BGS
HAE	ALDERS END	52.0368	-2.5434	362.73	237.79	260	82-	1R	BGS
HCG	CRAIG GOCH	52.3231	-3.6570	287.08	270.78	533	80-	1R	BGS
HGH	GRAY HILL	51.6379	-2.8057	344.25	193.59	223	80-	1R	BGS
HLM	LONG MYND	52.5184	-2.8807	340.25	291.57	429	84-	1	BGS
HTR	TREWERN HILL	52.0785	-3.2679	313.12	243.04	337	82-	1R	BGS
SSP	STONEY POUND	52.4177	-3.1119	324.39	280.59	428	90-	3	BGS
HBL2	BONNYLANDS	52.0508	-3.0384	328.80	239.71	437	91-	1R	BGS
SWINDON									
SWN	SWINDON	51.5131	-1.8004	413.85	179.42	192	93-	4	BGS
SMD	MENDIPS	51.3083	-2.7170	350.03	156.88	310	93-	1	BGS
SSW	STOW-ON-WOLD	51.9667	-1.8499	410.31	229.86	291	93-	1	BGS
SWK	WARMINSTER	51.1483	-2.2471	382.72	138.87	266	93-	1	BGS
SFH	HASELMERE	51.0604	-0.6912	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	51.7218	-0.8096	482.22	203.29	212	93-	1	BGS

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS :MARCH 2002

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (m)	Yrs Open	Comp	Agency
SOUTH EAST ENGLAND									
TFO	FOLKESTONE	51.1135	1.1409	619.81	139.66	202	89-	4m	BGS
TEB	EASTBOURNE	50.8187	0.1457	551.13	104.39	68	89-	1R	BGS
TSA	SEVENOAKS	51.2426	0.1561	550.48	151.53	177	89-	1	BGS
TBW	BRENTWOOD	51.6549	0.2913	558.48	197.66	89	89-	1R	BGS
TCR	COLCHESTER	51.8347	0.9212	601.24	219.20	45	89-	1R	BGS
CORNWALL									
CMA	MANACCAN	50.0821	-5.1274	176.29	24.98	42	93-	1	BGS
CCA	CARNMENELLIS	50.1866	-5.2277	169.62	36.90	210	81-	1	BGS
CBW	BUDOCK WATER	50.1482	-5.1144	177.53	32.29	94	81-	1	BGS
CCO	CONSTANTINE	50.1357	-5.1957	171.66	31.14	168	81-	1	BGS
CGH	GOONHILLY	50.0507	-5.1649	173.46	21.60	97	81-	1	BGS
CPZ	PENZANCE	50.1566	-5.5828	144.12	34.72	199	81-	1R	BGS
CR2	ROSEMANOWES 2	50.1667	-5.1687	173.74	34.51	143	81-	3	BGS
CRQ	ROSEMANOWES	50.1672	-5.1726	173.46	34.57	156	81-	4R	BGS
CSA	ST AUSTELL	50.3527	-4.8919	194.30	54.38	112	81-	1	BGS
CST	STITHIANS	50.1952	-5.1635	174.24	37.66	141	81-	1	BGS
CGW	GWEEK	50.1006	-5.2228	169.56	27.32	9	93-	1	BGS
DEVON									
DCO	COMBE FARM	50.3201	-3.8721	266.74	48.43	117	82-	1R	BGS
DYA	YADSWORTHY	50.4353	-3.9310	262.88	61.34	292	82-	3R	BGS
HTL	HARTLAND	50.9943	-4.4849	225.64	124.66	86	81-	4Rm	BGS
HSA	SWANSEA	51.7500	-4.1532	251.38	207.94	293	87-	1R	BGS
HPE	PEMBROKE	51.9372	-4.7746	209.29	230.21	349	90-	1R	BGS
HEX	EXMOOR	51.0664	-3.8026	273.71	131.28	230	91-	1R	BGS
JERSEY									
JQE	QUEENS EAST	49.2000	-2.0383			58	91-	1	BGS
JLP	LES PLATONS	49.2486	-2.1039			129	81-	1R	BGS
JRS	MAISON ST LOUIS	49.1922	-2.0922			56	81-	4R	BGS
JSA	ST AUBINS	49.1878	-2.1717			39	81-	1R	BGS
JVM	VALLE D.L.MARE	49.2169	-2.2067			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.

BGS Seismology reports

IR/01/46 Walker, A.B. UK Earthquake monitoring 2000/01, BGS Seismic Monitoring and Information Service, Twelfth Annual Report. June 2001.

IR/02/26 Simpson, B.A (ed), Ford, G.D., and Galloway, D.D. Bulletin of British Earthquakes 2001. February 2002

In addition, 12 confidential reports were prepared and bulletins of seismic activity were produced monthly, up to 6 weeks in arrears, for the Customer Group sponsoring the project.

External Publications

Braunmiller, J., L. Ottemöller, S.L. Jensen, A. Ojeda and K. Atakan, The May 7, 2001 Earthquake in the Ekofisk Area, North Sea, Orfeus Newsletter, Volume 3, no 2, 2001.

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Ottemöller, L. and V. Midzi, The crustal structure of Norway from inversion of teleseismic receiver functions, in press, Journal of Seismology, 2000.

Ottemöller, L., Lg wave Q tomography in Central America, in press, GJI, 2001.

UK EARTHQUAKE MONITORING 1999/00 BGS SEISMIC MONITORING AND INFORMATION SERVICE: TWELFTH ANNUAL REPORT

A B Walker

The aims of the Seismic Monitoring and Information 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. The British Geological Survey (BGS) has been charged with the task of operating and further developing a uniform network of seismograph stations throughout the UK in order to acquire standardised data on a long-term basis. The project is supported by a group of organisations under the chairmanship of the Department of the Environment, Transport and the Regions (DETR) with major financial input from the Natural Environment Research Council (NERC). This Customer Group is listed in Annex A.

In the 12th year of the project (April 2000 to March 2001), four networks were upgraded with the installation of QNX operating systems. Some gaps still remain in station coverage; notably in Northern Ireland. Other areas with site-specific networks, in Jersey, northern Scotland, the Outer Hebrides and the Orkney Islands, remain vulnerable to closure owing to their dependency on funds from the commissioning bodies.

Some 156 UK earthquakes were located by the monitoring network in 2000, with 35 of them having magnitudes of 2.0 ML or greater and 17 reported as felt. Six strong-motion records were captured from five of the eighteen sites now equipped with strong motion instruments. The largest felt earthquake in the reporting year, with a magnitude of 4.2 ML, occurred near Warwick on 23 September. A macroseismic survey was conducted and around 2,500 replies were received, giving a maximum intensity of 5 EMS (European Macroseismic Scale, Annex H). It was felt up to 150 km away and over an area of 14,900 km^2 (Isoseismal 3). The nearest 3-component strong motion instrument to record the earthquake was 76 km from the epicentre and accelerations of 17.2, 16.6 and 20.8 mms^{-2} were recorded for the vertical, NS and EW components, respectively. The focal mechanism indicates almost pure normal faulting on a NW-SE oriented plane, dipping either to the NE or to the SW. The largest offshore earthquake occurred in the northern North Sea on 8 December. It had a magnitude of 4.6 ML and was located approximately 175 km east of the Shetland Islands. It was felt on a nearby oil platform in the Bruce field, 20 km south west of the epicentre. In addition to earthquakes, BGS frequently receives 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. During the reporting period, data on one controlled explosion and four sonic events were processed and reported upon following public concern or media attention.

All significant felt events and some others were reported rapidly to the Customer Group through seismic alerts sent by fax and were subsequently followed up in more detail. The alerts were also available on the Internet (www.gsrg.nmh.ac.uk). Monthly seismic bulletins were issued 6 weeks in arrears and, following revision, were compiled into an annual bulletin (Simpson, 2001). In all these reporting areas, scheduled targets have been met or surpassed.

The environmental monitoring station at Eskdalemuir Observatory has been recording 20 parameters throughout the year and is now accessible on-line through an internet connection.

AN ILLUSTRATIVE SEISMIC HAZARD AND RISK CASE: NAGOYA, JAPAN

R M W Musson

This report gives an example of the use of probabilistic seismic risk assessment, based on Monte Carlo simulation and intensity distribution. It presents a simple study of seismic hazard and risk for the city of Nagoya, Japan. It is intended to show the sorts of calculations that can be made on the probability of earthquake damage using the concept of earthquake intensity. Earthquake risk studies are often based around the prediction of peak ground acceleration (pga) values as a function of earthquake magnitude and distance, and then the estimation of probable damage distribution as a function of pga and building vulnerability. The problem with this is that damage correlates very poorly with pga; this has been known for as long as pga values have been measured. The use of intensity as a measure of earthquake shaking avoids this problem. Intensity is measured directly from damage, and thus an intensity attenuation function effectively allows one to reconstruct damage distributions, with appropriate modifications for local factors such as soil conditions and directivity. The difficulty with this approach in the past has been the rigid nature of early intensity scales such as the so-called

Modified Mercalli scale (actually nothing to do with Mercalli). Modern scales such as the European Macroseismic Scale (EMS-98) apply a probabilistic approach to damage distributions and an adaptable scheme for handling building vulnerability, and are thus ideally suited for risk estimation applications. In this study, generic seismic risk curves are produced for the city of Nagoya that allow one to estimate the probability of different degrees of loss to buildings of different vulnerability classes. Thus if one were interested in a particular collection of (for example) reinforced concrete office buildings with a known total value, by consulting the appropriate curve one could estimate the probability of any actual loss figure to those buildings.

BULLETIN OF BRITISH EARTHQUAKES 2001

B Simpson (editor)

There have been 135 earthquakes located by the monitoring network during the year, with 37 of them having magnitudes of 2.0 ML or greater. Of these, 10 are known to have been felt, together with a further 6 smaller ones, bringing the total to 16 felt earthquakes in 2001.

The largest onshore earthquake, with a magnitude of 4.1 ML, occurred near Melton Mowbray, Leicestershire on 28 October (Appendix A5). BGS initiated a macroseismic survey and earthquake questionnaires were distributed through local and national newspapers. Approximately 1800 emailed responses were received, the most received for any UK earthquake so far, together with an estimated 4200 paper questionnaires, giving a total of 6000 responses in all. Many media interviews were conducted and a large number of enquiries were received. The earthquake was felt throughout Lincolnshire, Leicestershire, Warwickshire, Yorkshire, Shropshire and Nottinghamshire. The most distant reports were from the following places: in the west, the earthquake was felt near Chester. In the east, the earthquake was reported felt in King's Lynn, Norfolk. In the north, the limit of observation was marked by Knaresborough. In the south, the shock was felt as far as Oxford, with also a single very distant observation from Salisbury. There were reports of damage to chimneys in the Melton Mowbray area, indicating an intensity of 6 EMS. Felt reports described "we ran into the streets", "the whole house shook", "the table moved" and "we were very frightened". A maximum acceleration of 0.02g was measured at the strong motion station at Keyworth, some 15 km from the earthquake. The focal mechanism for the Melton Mowbray earthquake also shows oblique normal faulting along either a near N-S fault plane dipping at 51° or along a near E-W fault plane dipping at 58°. The average maximum compressive stress direction has an azimuth of 140°and dip of 55° and the minimum stress direction strikes at 44° and dips at 4°.

The largest offshore earthquake occurred in the Central North Sea on 7 May. It had a magnitude of 5.0 Mw (Appendix A1) and was located approximately 410 km east of Edinburgh. It was felt on three nearby oil platforms in the Ekofisk field, The Ekofisk Hotel platform control tower described "a swaying lasting 2 minutes which left us feeling dizzy", they also confirmed that the Albuskjell platform some 15 km to the north and the Eldfisk platform, some 26 km to the south reported similar felt effects. The focal mechanism obtained for the earthquake shows normal faulting with north-south trending nodal planes. A further 22 events occurred in the North Sea and surrounding waters during the year, with magnitudes ranging between 1.2 and 3.9 ML, and were located using both the BGS and Norwegian networks.

An earthquake with a magnitude 3.0 ML, occurred on 13 May (Appendix A2), with a location near Dumfries. BGS received many felt reports, from the Police, the media, Dumfries Council and residents of the Dumfries area. Felt reports described "the entire house shook", "the neighbours felt a shaking and ran into their back gardens", "the floor moved" and "felt like an explosion". A macroseismic survey was conducted and over 590 replies were received, indicating a maximum intensity of 5 EMS. This event was followed by four aftershocks on the same day with magnitudes ranging between 0.5 and 1.3 ML, the largest event was felt with intensities of at least 3 EMS. The focal mechanism obtained for the Dumfries earthquake shows predominantly strike-slip faulting along near vertical fault planes striking approximately NNW-SSE and ENE-WSW respectively. The near horizontal, NW-SE orientation for the principal stress direction (P-axis) is in ground agreement with the expected regional stress tensor.

An earthquake, with a magnitude of 3.6 ML, occurred off Hartland Point, Devon, on 31 May (Appendix A3). BGS received many felt reports from residents of Cornwall and Devon, who described "I ran outside alarmed", " I thought a nuclear explosion had gone off" and "the whole house shook". A macroseismic survey was conducted and over 520 replies were received, indicating a maximum intensity of 5 EMS.

Near Mallaig, Highland an earthquake with a magnitude of 1.7 ML, occurred on 20 June. Felt reports were received from the village of Mallaig, where intensities reached 3 EMS. Felt reports described "I felt a shudder through my feet" and "sounded like a large explosion".

Fifteen events occurred in Constantine, Cornwall throughout June, with magnitudes ranging between 0.0 and 1.1 ML. This is an area that has experienced similar swarm activity in the past.

An earthquake with a magnitude of 2.2 ML, occurred on 27 June, with a location near Sedbergh, Cumbria. A single felt report was received from a resident of Cowgill, some 9 km to the west of the epicentre, who described the following "the whole house shook, I was woken from sleep and I heard a bang", indicating an intensity of at least 4 EMS.

On 21 July, an earthquake with a magnitude of 1.9 ML occurred at the northern end of the Isle of Mull, western Scotland. BGS received one felt report from a resident of Salen, approximately 15 km southeast of the epicenter, who described "the whole house shook" and "quite a weak rumble", indicating an intensity of 3 EMS.

On 1 September, an earthquake with a magnitude of 1.8 ML occurred near Blackford, Tayside. BGS received felt reports from residents of Glendevon, which described "the whole house shook". A further two earthquakes with magnitudes of 2.1 and 1.3 ML, occurred in the Blackford area, with intensities of 3 EMS, respectively, on 19 December. Felt reports were received from the Blackford and Glendevon areas of Tayside and described "we heard a loud rumble", "the house shook" and "the radiators rattled". This is an area that has continued to be active in recent years; 49 events occurred in 1997, of which five were felt by local residents; 10 events occurred in 1998, of which 2 were felt by local residents, 3 events occurred in 1999 and 4 events occurred in 2000, of which 3 were felt. In the same general area in 1979, a magnitude 3.2 ML Ochil Hills earthquake was felt with a maximum intensity of 5 EMS.

An earthquake with a magnitude 3.1 ML, occurred on 10 October (Appendix A4), with a location near Bargoed, Mid-Glamorgan. BGS received felt reports from residents of the Bargoed area. Felt reports described "the bed was shaking", "the entire house shook" and "I was woken from sleep". A macroseismic survey was conducted and approximately 120 replies were received, indicating a maximum intensity of 4 EMS. This event was followed by three aftershocks with magnitudes of 1.6, 1.6 and 2.5 ML, the largest event (2.5 ML) on 18 October was felt with intensities of 4 EMS. The Bargoed focal mechanism shows oblique normal faulting along either a NW-SE striking fault plane dipping at 38° or a NNE-SSW striking fault plane dipping at 63°. The average maximum compressive stress direction has an azimuth of 142°and dip of 61° and the minimum stress direction strikes at 258° and dips at 14°.

Near Swindon, Wiltshire, an earthquake with a magnitude of 2.7 ML occurred on 18 March. Earthquakes of this size are usually felt when they occur onshore but enquiries to local Police stations and post offices revealed that no felt reports were received. This is an area that has experienced little seismicity in both the historical and instrumental periods, with only one event located since 1970 within a 20 km radius of this event.

Near Chester, Cheshire, three events occurred on 17 October, with magnitudes of 2.4, 2.1 and 1.5 ML, BGS received no felt reports for these earthquakes.

An earthquake with a magnitude of 2.3 ML, occurred near Anglesey, Gwynedd on 5 November. BGS received a single felt report for this earthquake which described "a bang, then a rumbling" indicating an intensity of at least 2 EMS.

An earthquake with a magnitude of 1.5 ML, occurred on 1 December with a location near Ballachulish, Highland. BGS received a number of felt reports from residents of Glenachulish, Ballachulish and Onich. Felt reports described "we heard a loud rumble", "we felt a vibration" and "we ran outside", indicating an intensity of 4 EMS.

On 16 December, an earthquake with a magnitude of 2.6 ML, occurred approximately 6 km southwest of Halifax, West Yorkshire. BGS received felt reports from residents of Halifax and Todmorden which described "we heard a loud rumble", the "whole house shook" and "we ran outside", indicating an intensity of 4 EMS. This event locates approximately 3 km southeast of the magnitude 4.0 ML Todmorden earthquake, on 7 March 1972, that was felt with intensities of 5 EMS.

In North Wales, two events on 6 and 11 December with magnitudes of 1.2 ML and 0.7 ML respectively, occurred on the Lleyn Peninsula, in the same area and at similar depths (20 km) as the magnitude 5.4 ML Lleyn earthquake of 19 July 1984, which was felt throughout England and Wales and into Scotland and Ireland.

The coalfield areas of Yorkshire, Staffordshire, Nottinghamshire and Derbyshire continued to experience shallow earthquake activity that is believed to be mining induced. Some 4 coalfield events, with magnitudes ranging between 0.8 and 1.8 ML, were detected during the year.

THE MAY 7, 2001 EARTHQUAKE IN THE EKOFISK AREA, NORTH SEA

J. Braunmiller, L. Ottemöller, S.L. Jensen, A. Ojeda and K. Atakan

A moderate seismic event ($m_b = 4.4$, $M_S = 4.6$, $M_w = 5.0$) occurred on May 7, 2001 within the Central Graben in the southern part of the Norwegian North Sea. The region is otherwise seismically quiet and the May 2001 event was the strongest in the area in more than 30 years. The event was strong enough to be well recorded at seismic stations more than 2500 km from the epicenter. Initial earthquake locations provided by several observatories placed the event near the Ekofisk oil field. Felt reports (intensity up to VI-VII EMS98-scale [Grünthal, 1998]) from the Ekofisk oil platforms did agree with the initial locations.

The coincidence of a seismic event occurring near ongoing hydrocarbon extraction immediately raised the question whether the event was natural or induced. Non-induced, purely tectonic earthquakes of magnitude 5 are possible in this region. To even discuss a possible relation between seismic event and oil extraction requires a high precision earthquake location and depth estimate. The event occurred far from any national network and routine locations provide only moderately accurate epicenter estimates while depth is essentially undetermined. Here, we report about our efforts to obtain an improved epicenter location and our ongoing efforts for constraining the hypocenter depth.

A SUMMARY OF EARTHQUAKES IN 2001

D D Galloway, D.D. and B Simpson, B

Overseas

This year was not exceptional in terms of the number of worldwide earthquakes (Figure 1). There was 1 'great' earthquake (magnitude over 8.0), 14 'major' earthquakes (magnitudes between 7.0 and 7.9) and 130 'strong' earthquakes (magnitudes between 6.0 and 6.9). These numbers are comparable with the long-term averages for these magnitude ranges, which are 1, 18 and 120, respectively. The number of people killed by earthquakes during 2001 was over 21,000 (Table 1), which is far greater than the long-term average of around 8,700.

The largest earthquake during the year, with a magnitude of 8.4 Mw, occurred on 23 June off the coast of Peru, approximately 190 km west of Arequipa and 600 km southeast of the Peruvian capital, Lima. It caused the deaths of over 81 people, including 26 killed by the subsequent tsunami, injured 2,734 more, left over 220,000 homeless and 64 are still reported as missing. An estimated 36,769 homes suffered some damage and a further 24,972 were completely destroyed. The coastal towns of Camana, Chala and La Punta in the Arequipa department suffered severe damage and some villages in the coastal area were completely destroyed as a result of the tsunami, which followed the earthquake. Tsunami runup heights are estimated at approximately 7 metres at some locations and at other locations the tsunami inundation distance extended to more than 1 km inland. The earthquake occurred at the boundary between the Nazca and South American tectonic plates, which are converging towards each other at a rate of about 8cm per year. The earthquake occurred as thrust faulting on the interface between the two plates, with the South American plate moving up and seaward over the Nazca plate. It occurred in the same region as an approximate magnitude 9.0 event on 13 August 1868, which produced a tsunami that killed thousands of people along the South American coast. An aftershock, with a magnitude of 7.6 Mw, occurred on 7 July and killed 1 further person, injured 26 more and destroyed hundreds of buildings, which had been weakened by the main shock, in the Arequipa department.

Two further fatal and damaging earthquakes occurred in the same region of Peru during 2001. One, on 9 August, with a magnitude of 5.8 Mw, killed 4 people, seriously injured 15 others and destroyed over 70% of homes in the Antabamba area of Peru. Another, on 4 December, again with a magnitude of 5.8 Mw, killed 2 people, injured 5 others in Chuquibamba and damaged 30 houses in the Condesuyos Province.

The most disastrous earthquake during the year, with a magnitude of 7.7 Mw, occurred on 26 January in the state of Gujurat, India. It caused the deaths of some 20,023 people (94% of the fatalities from earthquakes in 2001), injured over 166,800 more, left over 600,000 homeless and destroyed or damaged over 1,122,000 buildings affecting over 15 million people. The most affected areas were in the Gujurat districts of Bhuj, Kutch, Ahmadabad, Rajkot and Jamnagar area. There were significant effects on infrastructure with public facilities, including a number of schools and hospitals, power, water and telecommunication systems, bridges and roads being destroyed or damaged. Damage from the earthquake has been estimated at US$ 4.6 billion. The strain that caused this earthquake is due to the Indian plate pushing northward into the Eurasian plate. This northward crustal movement has also caused compression in the Gujarat area resulting in folds and thrust faults running approximately WNW-ESE. It was on one of these thrust faults that the earthquake occurred. This earthquake closely resembles the Rann of Kutch event of 16 June 1819 for which the exact death toll is not known but over 2,000 people were killed in Bhuj alone and some spectacular ground effects were caused including the 9 metre 'Wall of God' (the Allah Bund).

The year started off with a destructive earthquake (magnitude 7.7 Mw) in El Salvador, on 13 January. It killed 844 people, injured 4,723 more and completely or partially destroyed over 275,000 homes affecting over 1.3 million people (about one quarter of the population of El Salvador). The epicentre was in the Pacific Ocean, some 100 km southeast of the capital San Salvador. The earthquake caused major damage in the departments of San Miguel, Santa Ana, La Libertad, La Paz and San Salvador. The most affected area was Las Colinas where a landslide covered over 400 homes completely in mud. One month later, on February 13, an earthquake, with a magnitude of 6.6 Mw, occurred in the same general region with an epicentre approximately 30 km east of San Salvador. A further 315 people were killed, 3,399 more were injured and some 57,000 more houses were destroyed affecting over 250,000 people mainly in the San Vincente and La Paz departments. Both events were felt strongly throughout the region and as far away as Mexico City and Colombia. Two further people were killed, three more were injured and additional damage occurred in the epicentral area as the result of further earthquakes in the region on 17 February and 8 May. These earthquakes along with thousands of others form part of an ongoing sequence happening in the area. El Salvador sits on the western part of the Caribbean plate, where it is subducting the Cocos plate. Shallow intraplate (crustal) earthquakes occur within the crust of the overriding Caribbean plate, as in the February 13 event while deeper intraplate earthquakes occur within the subducting Cocos plate, as in the January 13 event. The damage, as a result of this sequence of earthquakes, has been estimated at US$ 3 billion.

On 28 February, an earthquake, with a magnitude of 6.8 Mw, occurred in Washington, USA. Over 400 people were injured and major damage occurred in the Seattle, Tacoma and Olympia areas. Several landslides were reported in the Tacoma area and liquefaction occurred in parts of Olympia and Seattle. The earthquake was felt from central Oregon to southern British Columbia and as far east as Montana.

Two fatal and damaging earthquakes occurred in Sichuan, China during 2001. The first, on 23 February with a magnitude of 5.6 Mw, killed 3 people, injured 109 more and destroyed or damaged over 60,000 homes in the Kanding and Yajiang Counties. The second event occurred on 23 May, with a magnitude of 5.3 Ms, killed 1 person and injured 566 others in the Ninglang County and killed 1 person and injured 39 others in the Yanyuan County. Eleven reservoirs, 4 power plants and 6 bridges were damaged as a result of these earthquakes.

In Western Honshu, Japan, on 24 March, an earthquake with a magnitude of 6.8 Mw, killed 2 people, injured 161 more and damaged or destroyed over 3,700 buildings in the Hiroshima area. Many water lines were broken and several railway tracks were damaged in the epicentral area. The earthquake was felt throughout western Japan from Kyoto to Kyushu and was also felt in South Korea.

On 12 April, an earthquake with a magnitude of 5.6 Mw, occurred in Yunnan, China. It killed 2 people, injured 190 more and destroyed or damaged over 30,000 homes in the Shidian area. On 27 October, a further, similar sized earthquake (magnitude 5.7 Mw) occurred in Yunnan and killed 1 person, injured 220 more and destroyed at least 3,400 buildings in the Yongsheng area. Yunnan Province is situated in southwest China to the east of the Tibetan Plateau and is one of the areas of China most prone to natural disasters.

In Afghanistan, on 1 June, an earthquake, with a magnitude of 5.0 Mb, killed 4 people, injured 20 more and destroyed several houses in the Parvan Province.

In Turkey, on 25 June, a magnitude 5.4 Mw earthquake injured 130 people and damaged 66 houses in the Osmaniye Province. Another magnitude 5.4 earthquake occurred in Turkey on 10 July and caused injury to 46 people and damaged 17 houses in the Erzurum region.

On 17 July, in northern Italy, 3 people were killed, from landslides, near Gargazzone and Val D'Ultimo and another died of a heart attack at Bolzano when a magnitude 5.0 Mb earthquake occurred in the region. Another 13 people were injured and minor damage occurred in the Merano area. The earthquake was felt throughout north eastern Italy, as far south as Venice and in parts of Austria, southern Germany, Slovenia and Switzerland.

One week later on 24 July, an earthquake, with a magnitude of 6.3 Mw, killed 1 person and caused injury to 3 more in Jaina, northern Chile. The epicentre was approximately 110 km east of the city of Iquique where minor damage and power, water and communication outages were reported. The earthquake also affected the cities of Arica, Pisagua and Putre.

On 26 July, over 100 houses and some older, historical buildings were damaged when a magnitude 6.5 Mw earthquake occurred in the Aegean Sea. Damage to the main water supply on Skyros, Greece was also reported.

In Bangladesh, on 19 December, a magnitude 6.8 Mw earthquake caused injury to over 80 people and caused severe damage to buildings in the old town of Dhaka.

Other notable world earthquakes during 2001 included; Jawa, Indonesia, on 28 June (magnitude 5.0 Mb) which injured several dozen people and caused damage to over 2,500 buildings in the Jawa Barat Province and Qinghai, China, on 14 November (magnitude 7.8 Mw) which caused damage in the Xidatan area.

The UK summary of earthquakes is covered in the summary for the 2001 bulletin of British earthquakes above.

THE ML 4.5 STORD/BOMLO, SOUTHWESTERN NORWAY, EARTHQUAKE OF AUGUST 12, 2000

E C Hicks and L Ottemoller

At 14:27 GMT on August 12, 2000, a magnitude (ML) 4.5 earthquake occurred near the islands of Stord and Bomlo in southwestern Norway, an area that has long been known to be seismically active. The earthquake was felt at distances up to 300 km. With a depth of 18 km, a location near the islands of Stord and Bomlo, and a reverse focal mechanism, the earthquake is quite similar to an earlier studied ML 4.4 earthquake, occurring in 1983. Both these, and an additional earthquake of similar size occurring in 1954 are located in the vicinity of the Hardangerfjord Shear Zone, with a NW dipping plane that separates the Precambrian basement to the southeast from mainly intrusive Caledonian rocks to the northwest. A total of 35 locatable aftershocks occurred within 72 hours after the main shock. However, the station configuration did in this case not provide location precision high enough to allow the aftershock distribution to be used in delineating the rupture area or associating the event with known geologic structures in the region. On the other hand, a detailed analysis of the differences in phase arrival times provided an upper limit on the relative location differences for the aftershocks of about 1.5 km. Since the source has an estimated size on the order of about 1 km, the analysis suggested that these aftershocks originate from the source volume of the main event or very close to it. Possible stress sources of importance in this area include the continental scale ridge-push force, regional stresses originating from postglacial uplift and local effects due to topography and crustal inhomogenities.

RECEIVER FUNCTION STRUCTURE BENEATH THREE SOUTHERN AFRICA SEISMIC BROADBAND STATIONS

V. Midzi and L. Ottemöller

The shear wave velocity structure beneath 3 southern African stations, Lusaka (LSZ), Lobatse (LBTB) and Boshof (BOSA) were estimated using the time domain inversion of stacked teleseismic receiver functions. Broadband teleseismic 3-component waveform data were used in a source equalisation procedure to estimate radial and transverse receiver functions for each station. The radial receiver functions were stacked according to the following criteria, an azimuthal interval of $\pm 15^{o}$, similar ray parameter and shape. The shield-based stations BOSA and LBTB had simple receiver functions, whilst LSZ, which is located in the Irumide belt, had more complicated ones. The lateral variation in receiver functions with azimuth as observed at each stations stems from lateral heterogeneities beneath each station. The velocity models were presented as P wave velocity models. From these models, the crust mantle transition zones beneath LSZ and BOSA were determined at depths of about 37-44km and 34-38km respectively. For LBTB, the northeast quadrant velocity model displayed a clear MCT at a depth range 40-45km, whilst the Moho depth in the southern quadrants is not as clear. Beneath all the stations, we observed a low velocity zone, which appears to correlate with cratonic velocity structure.

This feature is consistent with crustal structure results obtained in other cratonic or shield-based crustal studies. The results in this study contribute crustal structure information, which has been lacking at BOSA, LBTB and LSZ.

SEISWEB: A CLIENT-SERVER ARCHITECTURE BASED INTERACTIVE PROCESSING TOOL FOR EARTHQUAKE ANALYSIS

B. Moreno, L. Ottemöller, J. Havskov and K. A. Olsen

With advances in computer and information technology, client-server architecture based tools for accessing earthquake data through the Internet have become feasible. The SeisWeb tool was designed to investigate the feasibility of remote access to seismological databases through the Internet. The SeisWeb software was written in Java. It is platform independent and will work through a web browser or as a stand-alone application. The tool was designed to be database-oriented and to facilitate the most common basic functions of seismological processing. We hope that its simple graphical interface and easy access will make seismology more accessible to the public, increasing both interest and understanding. In this note we discuss the client-server architecture, processing and transfer speed, the graphical interface and security.

Up to now, the processing done to obtain earthquake information has not been transparent to the public. This could change with the development of a simple-to-use web-based processing system. Such a system could be offered to non-specialists to display the seismograms, even to pick phases and amplitudes, and to determine location and magnitude. The purpose of this project has been to investigate the issues relevant to web-based processing and to develop some prototype software (SeisWeb). In its simplest implementation, a SeisWeb user will be able to inspect data on a remote database and in a full implementation, perform interactive processing. Since our effort is also directed towards occasional users and non-experts, the plan is to first implement only the most general functions of an earthquake analysis system.

METHODOLOGICAL CONSIDERATIONS OF PROBABILISTIC SEISMIC HAZARD MAPPING, SOIL DYNAMICS AND EARTHQUAKE ENGINEERING

R M W Musson and PHO Henni

This paper presents a methodological discussion of several issues involved with the development of maps of seismic hazard. The points made are illustrated with worked examples, using Scotland as an illustrative case. The issues treated are divided under three headings: matters relating to the difference between hazard maps and site studies; matters concerned with the technical issues of mapping, and matters relating to the use to which hazard maps will be put. It is concluded that a hazard map cannot be an all-purpose substitute for site-specific studies, owing to the impracticality of ensuring all-round conservatism in a hazard map, and the lower level of detail (more broad-brush approach) in a regional mapping study. Also, since users of a hazard map are not necessarily going to be engineers, consideration should be given to the provision of maps expressed in parameters other than physical measures of ground motion. Intensity is useful here, since it relates to actual earthquake experience and to damage. One can also move to making maps of generic seismic risk even before one has data on the distribution of exposure and vulnerability. Discussion is made of the issue of testing the validity of hazard maps against real experience, with examples. If a map can be shown to accord with real observations, then it can be treated with greater confidence by users.

NAPOLEON'S EARTHQUAKE: THE SEISMICITY OF ST HELENA

R M W Musson and DN Holt

The historical seismicity of offshore areas is a difficult area of study, especially in cases of relatively remote islands in areas of generally low seismic activity, such as the Faroes or Shetlands. In this study a case is taken from the South Atlantic. It might be expected that a small island far from the mainland, like St Helena, would provide few records of historical earthquakes, but in fact the amount of material is surprisingly large. This is largely due to the strategic importance of the island as a naval base in historical times. In view of the landslide hazard in St Helena, the historical earthquake record becomes significant due to the possibility of earthquake-triggered landslides. However, none of the earthquakes felt on the island seem to have exceeded intensity 5 EMS. The strongest event occurred while Napoleon Bonaparte was in exile on the island, and seems to have been the only earthquake he ever felt.

TOWARDS A MACROSEISMIC SURVEY TEAM FOR SEVERE EARTHQUAKES IN EUROPE AND THE MEDITERRANEAN BASIN

R M W Musson, I Cecić, I. and D. Mayer-Rosa

A currently existing problem in Europe is the loss of data on the distribution of effects of large/ damaging earthquakes, due to the inability to gather this information effectively in the period immediately after an earthquake occurs. For obvious reasons, much earthquake damage has to be repaired or cleared up quickly, which means if the survey of damage is not made immediately, information on the distribution of the higher intensities will be lost. Existing field missions to earthquake damaged areas are generally made by engineers with the objective of understanding why structures failed, not with determining intensity distributions. Yet information on the macroseismic field is extremely valuable when it comes to extrapolating the likely effects of future earthquakes. A dedicated field team for making macroseismic surveys in Europe would not be expensive to maintain, but would ensure that important seismological data are not lost.

THE CRUSTAL STRUCTURE OF NORWAY FROM INVERSION OF TELESEISMIC RECEIVER FUNCTIONS

L. Ottemöller and V. Midzi

Teleseismic body waves from seismic broadband and short period stations were used to investigate the crustal structure of Norway through inversion of the receiver functions. The Moho depths of the Baltic Shield are quite well known from previous studies including seismic experiments and spectral ratio technique. However, the results on the details of the crustal structure are inconsistent. This study provided more detailed crustal structure information at 16 locations than previously known and generally confirmed Moho depth results obtained in earlier studies. Significant differences are seen at a few sites. The Moho for the various sites was found at depths between 28 and 44 km. In summary, the crustal thickness increases from the West Coast of Norway, away from the continental margin, towards the centre of the Baltic Shield and from Southwest to the Northeast. This corresponds to the increasing age of the crust. The P velocities in the crust at most sites show a gradual increase from about 6.0 to 7.1 km/s, without clear layering.

LATERAL VARIATION OF LG WAVE PROPAGATION IN SOUTHERN MEXICO

L. Ottemöller, N.M. Shapiro, S.K. Singh and J.F. Pacheco

In this study we investigated lateral variation of Lg wave propagation in southern Mexico from recordings of 92 crustal earthquakes along 591 travel paths. The efficiency of Lg propagation was measured in terms of Lg to Pn spectral ratio. It was found that Lg propagation is inefficient for travel paths through the Gulf of Mexico coastal plains and the Gulf of Tehuantepec, areas with thick layers of sediments. An average Lg quality factor, Q_{Lg}, as a function of frequency for southern Mexico was estimated for the efficient Lg travel paths. The relation obtained for Q_{Lg} in the frequency range 1.6 to 8 Hz is $Q_{Lg}(f)=204\ f^{0.85}$. The lateral variation of Q_{Lg}^{-1} was solved as a mixed-determined inverse tomography problem, separately for each frequency, in which a spatial smoothness constraint was imposed and a priori information was added in poorly covered regions. The spatial resolution obtained was about 200 km. It was found that the Trans Mexican Volcanic Belt, the Gulf of Mexico coastal plains, and the area east of 94ºW are characterized by lower than average Q_{Lg} values, i.e. higher attenuation. High Q_{Lg} values were obtained for the Mixteco-Oaxaca terranes, while for the Guerrero terrane values similar to the average were obtained. The results show a correlation between Q_{Lg} and crustal structure and provide valuable information on lateral variation of Q_{Lg}, which is needed for reliable prediction of ground motion during future earthquakes.

LG WAVE Q TOMOGRAPHY IN CENTRAL AMERICA

L. Ottemöller

The lateral variation of Lg wave spectral attenuation in Central America was studied through tomographic inversion at various frequencies between 0.5 and 5 Hz separately. The input data-set consisted of 558 travel paths recorded on short-period and broadband seismic stations in the region. The size and quality of the data-set were sufficient to resolve significant lateral variation in the Lg wave quality factor Q_{Lg}. The average dependence of Q_{Lg} with frequency was found to be $Q_{Lg}\ (f) = 182\ f^{\,0.84}$, corresponding to high attenuation. Low Q_{Lg} values in the Nicaraguan Depression presented the most significant variation from the average. The strong attenuation of

Lg waves in the Nicaraguan depression was also observed in the visual analysis of the seismograms. This observation is possibly explained by the near-surface low-velocity layers in the depression. Low Q_{Lg} values were also found along the chain of volcanos due to increased scattering and partial melting beneath the volcanic belt. This study is the first attempt to determine Q_{Lg} for Central America and to provide knowledge on attenuation of Lg waves needed for the prediction of ground motion during future earthquakes.

Q_{LG} TOMOGRAPHY IN COLOMBIA

A Ojeda and L Ottemöller

The crustal attenuation of Lg waves in Colombia was estimated and analysed using local seismological data from the National Seismological Network of Colombia. The selected dataset comprises 510 crustal earthquakes with a total of 2928 ray paths. The computed regional average for Q_{Lg} in the frequency band 0.5 to 5.0 Hz was found to be in good agreement with previously reported values for Mexico, Central America and Bolivia. In order to resolve the lateral heterogeneities in the attenuation of the crust we conducted independent tomographic inversions for 26 frequencies between 0.5 and 5.0 Hz. The resulting maps consistently confirm that heterogeneities in the crust exist and they are related to the main large tectonic features in the country. The highest attenuation in the region is caused by the presence of partially melted crust beneath the volcanic belts. Relatively high attenuation is also found in zones where the crust is composed of accreted oceanic rocks and near-surface low-velocity sedimentary layers. The estimated values of Q_{Lg} and their dependence on frequency is important for simulating ground motion amplitudes, which can be used for seismic hazard assessment.

SYNOPSIS OF EMS-98 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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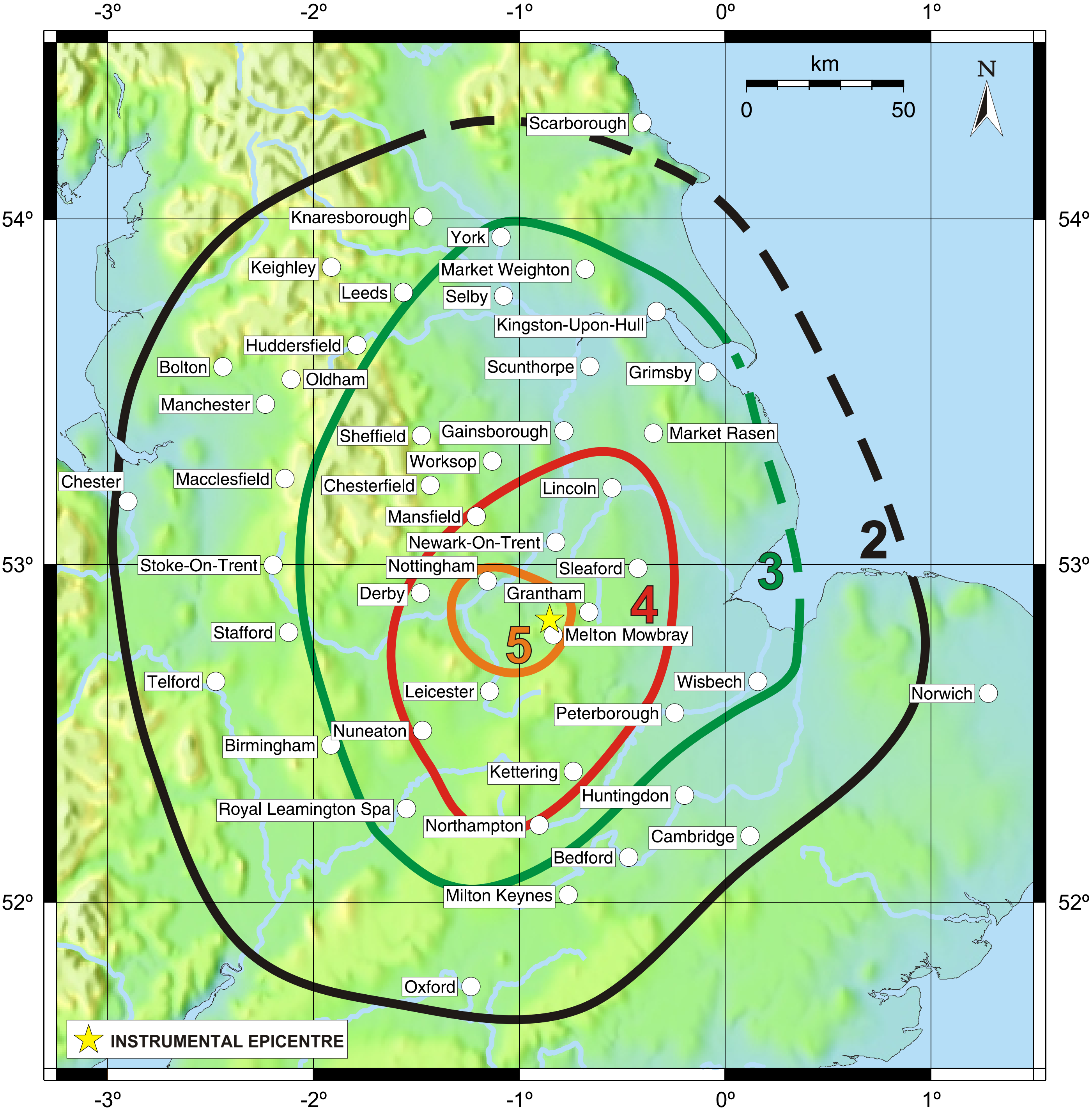
A complete description of the EMS-98 scale is given in: Grunthal, G., (Ed) 1998. European Macroseismic scale 1998. Cahiers du Centre European de Geodynamique et de Seismologie. Vol 15.

NATURAL ENVIRONMENT RESEARCH COUNCIL



Melton Mowbray Earthquake 28 October 2001 16:25 UTC (4.1 ML) - EMS Intensities