UK EARTHQUAKE MONITORING 1998/99

BGS Seismic Monitoring and Information Service

Tenth Annual Report

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BRITISH GEOLOGICAL SURVEY

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Global Seismology and Geomagnetism Group

UK Earthquake Monitoring 1998/99

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

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BRITISH GEOLOGICAL SURVEY

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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

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UK EARTHQUAKE MONITORING 1998/99

1. Executive Summary

The aims of the BGS 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. Following a history of seismic monitoring over the past 30 years, 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 a major financial input from the Natural Environment Research Council (NERC). This Customer Group is listed in Annex A.

In the tenth year of the project (April 1998 to March 1999), one additional strong-motion instrument and four large capacity data storage disks were installed. Four strong-motion records were captured during the year from two of the seventeen sites now equipped with these instruments. Some gaps still remain in station coverage; notably in Northern Ireland. Other areas covered by site-specific networks in Jersey, northern Scotland, Outer Hebrides and the Orkney Islands, are vulnerable to closure owing to their dependency on funds from the commissioning bodies.

Some 201 earthquakes were located by the monitoring network in 1998, with 31 of them having magnitudes of 2.0 ML or greater and 30 reported to be felt by people. The largest felt earthquake in the reporting year (April 1998 to March 1999), with a magnitude of 4.0 ML, occurred 4 km south of Arran, Strathclyde on 4 March 1999. It was felt over an area of 18,500 km^2 (Isoseismal 3) and the maximum intensity in the epicentral region was 5 EMS (European Macroseismic Scale, Annex H). The largest offshore event occurred near Great Yarmouth on 16 May 1998, with a magnitude of 3.8 ML. In addition to earthquakes, BGS frequently receives reports of seismic events, felt and heard, which on investigation prove to be sonic booms, in coalfield areas, where much of the activity is probably induced by mining (eg Newcastle-Under-Lyme) or spurious. During the reporting period, data on nine controlled explosions and eleven sonic events were processed and reported upon following public concern or media attention.

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

The potential of the network's data links and computing capabilities to provide an environmental monitoring capacity has been explored further using additional sensors. These now include radioactivity, ozone, sulphur dioxide, radon and NOx gases. Collaboration in this field is being explored with the Scottish and English Environment Agencies, Institute of Terrestrial Ecology (ITE), the water industry and the Meteorological Office.

2. Introduction

The UK earthquake monitoring and information service has developed as a result of the commitment of a group of organisations with an interest in the seismic hazard of the UK and the immediate effects of felt or damaging vibrations on people and structures. The current supporters of the programme, drawn from industry and central and local Government, are referred to as the 'Customer Group' and are listed in Annex A. The project formally started in April 1989 and the published Year 1 report includes details of the history of seismic monitoring by BGS since 1969, as well as the background to the establishment of the project. Earthquake monitoring information is required to refine our understanding of the level of seismic risk in the UK. Although seismic hazard/risk is low by world standards it is by no means negligible, particularly in respect to potentially hazardous installations and sensitive structures. This 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 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 events in order to allay any unnecessary worries. Most seismic events occur naturally but some are triggered by human activities such as mining subsidence, and other tremors (eg sonic booms and explosions) are often mistaken for earthquakes.

This Year 10 report to the Customer Group follows the format of the first nine annual reports in reiterating the programme objectives and highlighting some of the significant seismic events in the reporting period April 1998 to March 1999. The catalogue of earthquakes for the whole of 1998 is plotted to reflect the period for which revised data are available and to be consistent with the annual bulletin, which is produced as a separate volume. An updated map of epicentres since 1979 is also included for earthquakes with magnitude ≥2.5 ML; the threshold above which the data set is probably complete. Such events are normally felt by people.

To improve the capacity of the network to deliver on-scale data for the larger earthquakes, and to more effectively calculate their magnitudes, low-gain and strong motion instruments have been added to it. Low-gain instruments employ standard seismometers recording ground velocity but with the electronic amplifier gain reduced by a factor of 25. Strong motion instruments record ground acceleration for the larger felt earthquakes remaining on-scale up to 0.1g. One new strong motion system has been installed during the year, in Moray, northern Scotland, bringing the total to seventeen. 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 there is a pool of analysts familiar with extracting and processing data despite the infrequency of strong motion earthquakes.

Six temporary broadband stations have been installed throughout the country in collaboration with Leeds and Bristol universities. They record onto computer disks which contain up to three months of data which are then changed by an operator and analysed at the University of Leeds. The BGS broadband station in Edinburgh has been upgraded and linked 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, this 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 and northern Scotland. 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

3.1 Long-term

The initial overall objectives of the service were:

(i) To provide a database for seismic risk assessment using existing information together with that obtained from a uniform distribution of modern seismograph stations throughout the UK landmass. A mobile network of seismograph stations would be used for specific investigations of seismic events to supplement the background network.

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

These objectives and a strategy to meet them were described more fully in a proposal from BGS dated December 1987. The higher the density of seismograph stations in the network, the more accurate will be the response and the database. In discussion with the Customer Group, a 70 km average spacing of stations (Fig. 5) was agreed as a cost-effective way of achieving the main goals although it was recognised that the determination of some parameters (eg depths of focus and focal mechanisms) could only be approximate.

3.2 Short-term

In 1988, the Customer Group agreed to a reduced initial phase of development of the monitoring network to fit the limited funds likely to become available in the first few years. In this strategy, the following sacrifices were made:

(i) The mobile network could not be specifically supported.

(ii) The 70 km-spacing of stations could not cover the whole country. Advantage would be taken, where possible, of site-specific networks operated for other purposes and of existing recorders with spare channel capacity to add individual stations.

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

3.3 Summary of achievements since 1989

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

- The installation of seismograph stations to fill in the gaps for the 70 km spacing objective; from 84 stations in 1988 to 141 in 1999. Large areas have been filled in southern England, Irish Sea and northern Scotland.

- The detection capabilities of the network have gradually improved with increasing station coverage, and Figures 3 and 4 illustrate the change over the 10-year project period. Almost all magnitude 2.5 earthquakes are felt together with many in the 2.0-2.5 range, and, in 1988, there was poor coverage of such events in many parts of the country.

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

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

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

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

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

- A 3-component strong motion network of seventeen stations has been installed from Shetland to Jersey including four stations specifically commissioned by British Energy, MOD and the Jersey New Waterworks Company.

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

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

- The World Seismological Bulletin collection database has been published and is available on the Internet. An 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 is proving difficult to extract owing to the condition of the tapes and old replay equipment.

- The instrumental digital database is held in a readily accessible format (both for parameter and waveform data) and is updated continuously. Back-up copies are held outside the 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 is now in the DTI library.

- The potential for using the seismic network for multifunctional environmental monitoring has been proved at four sites near Edinburgh. A number of environmental sensors 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 Met Office has laid the basis of collaboration and meteorological quality control.

3.4 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 30-year catalogue and digital archive of earthquakes, during the past year, is summarised:

3.4.1 University collaboration

Bristol University; Mapping seismic discontinuities

A study at Bristol University, under the leadership of George Helffrich, has continued to look at seismic discontinuity mapping using teleseismic data (earthquakes outside the UK).

The earth's major seismic discontinuities in the mantle are at 410 and 660 km depth and are believed to be caused by phase changes in mantle minerals. Seismic waves generated by interaction with discontinuities are weak and usually buried in the noise but the high density of stations in the UK network provides the means to enhance the signal and suppress noise. The Bristol team is using UK and North American data to study the effect that subduction zones have on these seismic discontinuities and to infer their temperature and chemical state at depth. To date, results show that the discontinuities are deflected by the cooler temperatures in subducted slabs to a much greater degree than is observed in global studies using long period seismic waves. Temperatures are about 600°C at 350 km depth in the slab, and the thermal halo around the slab is broader than expected from thermal modelling. The work has provided the basis for further research through a NERC studentship.

A joint study involving Bristol University and the BGS is investigating scattering and heterogeneity in the crust and the deeper mantle using echoes from distant earthquakes.

One thinks of the earth's crust and mantle as a homogeneous ball of rock, but it isn't - continents and oceans otherwise wouldn't exist. The smaller scales of this heterogeneity reveal how the crust was formed: through faulting, magmatic growth and tectonic accretion. This work uses UK and foreign seismic networks to locate places in the crust that scatter seismic waves forming faint echoes following an earthquake. For crustal scatterers, nuclear tests in Kazakhstan will be used to interrogate the region around the test site and relate them to regional geological features and incorporate them into yield estimates from nuclear tests. Scattering also happens in the mantle. Prospecting for mantle scatterers will focus on three regions: one at the core-mantle boundary under northern Asia using northwestern Pacific earthquakes, another under the mid-Pacific at the core-mantle boundary using nuclear explosions at Muraroa, and lastly under the central Atlantic ocean near the Cape Verdes hotspot using mid-Atlantic fracture zone earthquakes. The scatterers will be related to the documented core-mantle boundary structures under Asia, the Pacific, and the location of the Cape Verdes hotspot. The work has provided the basis for further research through a NERC studentship.

Post-doctoral research at Bristol University, under the leadership of George Helffrich, is using the UK short-period network data to study changes in the time it takes seismic waves to cross the inner core.

In addition to providing the chronology for plate motion histories, geomagnetism gives life on the Earth a means of navigation and protection from the harmful effects of charged solar particle fluxes. To understand geomagnetism, we need to know the dynamical behaviour of the earth's core. Comprehension of core dynamics is at the level where two computer simulations of the Earth's geodynamo, in a three-dimensional spherical geometry, yield Earthlike magnetic fields. The simulations principally differ in the role played by viscous coupling between the inner and outer cores, and can be distinguished by their prescribed rates of inner core rotation. The inner core rotation rate also is related to the temperature and light element release profile along the inner core boundary and the toroidal magnetic field strength there. We are using the BGS's unique dataset, spanning 25 years, to definitively address this crucial issue concerning core dynamics, and to further elucidate the structure of the inner core.

Brunel University; Glaciotec project

The project, led by Iain Stewart, is a multi-disciplinary investigation of recent crustal movements, postglacial faulting and seismicity associated with the centre of glacio-isostatic uplift. It is an approved part of an International Association of Quaternary Research (INQUA) programme on 'Ice Sheets, Crustal Deformation and Seismicity'. The objectives are to compare and contrast crustal responses to deglaciation in the Fennoscandian, British and North American ice sheet domains, and to assess the influence of glacial deformation on contemporary seismicity patterns and seismic hazard. A reassessment of the extent to which the pattern of glacio-isostatic uplift in Northern Britain is related to the incidence of postglacial faulting and contemporary seismicity is being carried out using the BGS database of seismicity. The project combines field-based geological, geomorphological, sedimentological and palaeoenvironmental expertise with remotely sensed data from satellite and airborne imagery and seismological databases. In particular, current field-based investigations focus on re-appraising the displacement history of suspected postglacial faults and reconstructing recent relative sea-level changes recorded in coastal wetland sites along a transect that extends from the centre of glacio-isostatic uplift to its inferred margin. The aim is to better isolate the contemporary (<150 years) pattern of crustal uplift from sea-level changes, and to compare this with the changing locus and magnitude of glacio-isostatic recovery over preceding millennia. The project will also test whether the distribution of postglacial faults and present-day seismicity is influenced by the limits of the former Loch Lomond Stadial ice-sheet margins. It is hoped that this will feed into improved understanding of seismic hazard in northern Britain by providing a long term (Holocene) perspective on the pattern and magnitude of crustal movements. An abstract was submitted to the European Union of Geosciences in Strasbourg (Annex G) and Iain Stewart presented the results at the meeting in April 1999.

Leicester University; UK velocity model

The BGS database has continued to be used by Paul Denton to study velocity discontinuities in the crust, using Receiver Function Analysis techniques. A dataset has been identified at an epicentral distance of between 30 and 100 degrees, to look at the direct P-wave arrival and the P to S-wave conversions that occur at velocity discontinuities within the crust. A process of iteration and inversion will produce a coarse one-dimensional S-wave velocity structure beneath each recording station which, with 141 stations, will build up a UK-wide picture.

Leeds University

Leeds and Bristol Universities have been assisted in the installation of an array of broadband stations from northern Scotland to Jersey (Fig. 6). Data will be used to investigate discontinuities and scattering in the Earth's mantle and will be available to BGS for enhancement of its UK earthquake studies.

3.4.2 European collaboration

For a number of years through an EU project led by BGS, data exchange with neighbouring countries has been fostered and improved. This has led to more rapid information becoming available on larger transfrontier earthquakes and harmonisation of the catalogues of data used for hazard assessments. 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 and Norwegian workers have been provided with data on North Sea and English Channel earthquakes to improve attenuation models and constrain focal mechanisms.

Collaboration has commenced with the Faroese Museum of Natural History, Faroe Islands, with the intention of linking a small subnetwork of stations, to be based there, with the UK network. This will improve, considerably, the monitoring of seismic events offshore northern and western Scotland.

Major international projects that have drawn upon the UK database include the Global Seismic Hazard Assessment Programme (GSHAP), which is an IDNDR project, and the EC project "Basic European Earthquake Catalogue and Database" (BEECD) under the direction of IRRS-CNR, Milan, Italy.

3.4.3 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. Examples include support of the Dounreay seismic hazard case and the initiation of a new study for the North Sea by the HSE (Offshore Division).

Reinsurance

As reported last year, the British Geological Survey in conjunction with Hiscox Syndicates Ltd have produced a system intended to combine seismological and reinsurance techniques in a computer program that can quickly assess the earthquake risks to a reinsurance portfolio. It is simple to use and can be run on any PC using Windows 3.1 or higher. The user can type in details of a property portfolio within geographic regions known as Cresta accumulation zones in the industry. Optionally, information about the construction type and quality of the buildings to be reinsured can also be entered (if known). Up to twenty layers of reinsurance can then be analysed. The results are returned as the expected loss for each layer, its standard deviation, information on maximum losses and other reinsurance parameters. The probability of different loss levels affecting the whole portfolio can be shown as a graph. The results of each calculation can be stored in the program's own database for later retrieval.

The program has been named the Monica Seismic Risk System as it works on the principle of stochastic modelling, known as Monte Carlo simulation (MONte (I) CArlo). Using seismic source models that incorporate an analysis of the tectonic and seismological data in each region, the program runs many thousands of simulations of the regional earthquake activity from which it calculates the probability of different amounts of damage and loss. Utilising the BGS database and archives, regional data files have now been produced for: Australia SE, Australia W and S, Canada E, Canada W, Chile, Colombia, Ecuador, Egypt, Greece, Israel, Italy, Japan Central, Japan N, Japan S, Mexico, New Zealand, Panama, Peru, Philippines, Portugal, South Africa and Turkey. This adaptation of the BGS's seismological expertise has enabled the reinsurance industry to be brought into the sponsoring group for the UK Seismic Monitoring and Information Service.

A series of papers and presentations is underway to demonstrate the methodology to a wider audience.

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, eight three-component strong motion records have been recorded for earthquakes with magnitudes between 1.1 and 4.0 ML at distances of between 3 and 135 km. Four of these records were written in the past year. The values of acceleration measured from these instruments are less than those expected from the attenuation laws currently used for the UK. Of necessity, these laws have been imported from more highly seismic regions using earthquakes with larger magnitudes and the build-up of UK records will eventually permit more appropriate relationships to be established for use by engineers in this country.

Parliamentary questions and advice to the Public Authorities, Industry and media

Over 1000 enquiries have been answered during the year, with intense interest following felt UK and world earthquakes. A response was provided to DETR for a question from an MP concerning seismic activity.

Data exchange and world reporting

BGS data is exchanged regularly with world agencies to help locate and improve focal mechanism parameters for earthquakes outside the UK and, as a quid pro quo, BGS receives data on UK earthquakes and world events of relevance to the UK, from the 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). Data from earthquakes and explosions ≥2.5 ML within 1000 km of the UK have been processed and submitted to the provisional international data centre in Washington. The UK network recorded the Indian nuclear test on 13 May 1998 and a seismogram recorded on the Hereford network is shown in Figure 22.

Earthquake statistics

The UK instrumental database is almost 30 years long although completeness in the early years, to 1978, is probably only at 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 Plate 1, 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.

Focal mechanisms

Earthquake focal mechanisms are a basic tool used in the investigation of both local and regional tectonics, providing information on the nature of the brittle crust.

BGS data is used as input to produce earthquake focal mechanisms. In the past, mechanisms could only be obtained for the largest events but as a result of the expansion of the UK network over the years, an increasing number of mechanisms are being obtained; most recently for the Arran earthquake. Focal mechanisms are also being obtained for very small magnitude events in areas with an optimum azimuthal coverage by dense local networks, for example North Wales and Cornwall.

Public Understanding of Science

A number of presentations have been given to school and university students and other interested parties. The BGS was featured in the two geology TV series "Essential Guide to Rocks" and "Earth Story". Radio interviews have been conducted following significant earthquakes and a contribution has been made to the BBC's Earthworks series due to be broadcast in developing countries later in the year. The Internet home page has been a source of information for both the public, media and other organisations.

4. Development of the monitoring network

4.1 Station distribution

The network developed to March 1999, with rapid-access upgrades, is shown in Figure 1 with its detection capability in Figure 3. The scheduled programme for 1998/99 had as its aims:

(i) Further installation of the QNX operating system.

(ii) Progress year 2000 compliance of data acquisition and analysis systems.

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

(iv) Introduction of two new strong motion systems at sub-network digital acquisition centres, priorities being Moray and northern Scotland.

(v) Pursue opportunities for capturing more strong motion data in collaboration with the nuclear industry.

(vi) Collaborate with universities and AWE to secure further broadband data.

(vii) 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.

The QNX systems (i) have been running successfully alongside the Lowlands and Eskdalemuir SEISLOG's, and another system is due to be installed in Paisley. Progress has been made on year 2000 compliance (ii) with the installation of Y2K patches to all the computers in the field. The installation of additional four gigabyte disks (iii) has been fulfilled; at Orkney, Minch, East Anglia and Cornwall. The strong motion network (iv) has been enhanced with the installation of one strong motion station, in Moray, which is recorded onto the rapid-access system. This brings the total number to seventeen. During the year, a further four strong motion records have been obtained from the Annan, Locharbriggs, Boston and Arran earthquakes (v). Collaboration with the universities of Bristol and Leeds has been maintained (vi) with the installation of six temporary broadband stations at existing BGS sites. The BGS proposal to take over and upgrade the MOD broadband stations has not been funded but lower cost options are being investigated in the hope of maintaining some of the stations. Contact with archives outside BGS has been maintained (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. The "importation" of such records from plate margin zones, however, may detract from the realism of analyses conducted in intraplate areas such as the UK. In recognition of the importance of measured strong ground motions, therefore, the project has focused on developing a distribution of 3-component instruments, which would remain on-scale for the larger British earthquakes when the high sensitivity network saturates.

The present distribution of strong motion instruments together with the temporary broadband and low-gain instruments, microphones and the environmental stations, is shown in Figure 6. Fourteen of the 17 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 four earthquakes this year; the Annan, Locharbriggs, Boston and Arran 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 only rarely will a magnitude 6.0 event cause saturation. The largest known earthquake in the several hundred year historical record, occurred near the Dogger Bank in 1931 with an estimated magnitude of 6.1 ML.

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 an upgrade for Hunterston has been discussed.

(iii) The 13 stations in northern Scotland and the Orkney Islands, supported by an oil company consortium and HSE, has continued with funding assured until March 2000.

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 network was not year 2000 (Y2K) compliant and considerable effort has been put into solving the problems with the successful installation of Y2K patches on the existing SEISLOG recording systems.

New data acquisition equipment, using the QNX operating system, is in its final stage of testing and has been running successfully alongside the Lowlands and Eskdalemuir SEISLOG's. A third system is scheduled for installation in Paisley. QNX gives a number of advantages: increased processing power, larger memory capacity (from 4 Mb to upwards of 32 Mb), improved communication links using Ethernet cards and ISDN links (digital telephone lines), together with greater portability.

Through the participation in an EU-funded project, coordinated by the European Mediterranean Seismological Centre (EMSC), BGS has developed the capability of providing rapid alerts and data from larger European earthquakes (magnitudes ≥5.0). It depends on coincident event triggers on three (Lownet, Hereford and Cornwall) out of the UK subnetworks when data is retrieved and event times submitted in less than 1 hour to the EMSC coordination centre at Bruyeres-le-Chatel near Paris. A second strand to the project has resulted in an upgrade of the broadband sensor in Edinburgh and the rapid transmission of data from it, via satellite, to facilitate focal mechanism determinations. The final project report was submitted to Brussels in December 1998.

Thirteen of the networks in the UK have four gigabyte disk storage, (four installed in the past year), allowing up to 10 days of continuous data to be recorded in a ring buffer, together with extra storage for event files which are needed during swarms such as the Blackford series in

1998. These large capacity disks help prevent potential losses as the old analogue Geostore recorders are decommissioned and reliance swings to the event-triggered systems which can miss spurious events, small earthquakes and sonic booms. Nine networks have one gigabyte disk storage, which provides a three-day window of continuous data.

4.5 Environmental monitoring

Environmental monitoring is becoming increasingly important in modern life. Many city centres now have air pollution monitoring equipment but the background 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. The existing infrastructure of the UK seismograph monitoring network with its remote stations giving continuous on-line data from the Shetland Islands to Jersey, can potentially provide a cost-effective environmental monitoring network. Users can inspect the data in real-time or transfer it at intervals via modem or the Internet. In principle, any environmental sensor can be interfaced and sampled at, say, once per minute. To this end, four environmental stations (one in collaboration with ITE - Institute of Terrestrial Ecology) have been operating in Scotland where air and ground temperature, ozone, radioactivity, radon, UVB, NOx gases and humidity data are being transmitted to a base station. The stations have the capacity to transmit data from 16 environmental sensors simultaneously. Selected 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. An EC funded collaborative project with the BGS Analytical and Regional Geochemistry Group has been under way since September 1998. The project is led by Dr R A Nicholson and its purpose is to explore earthquake prediction potential through the measurement of radon flux. A radon monitoring site has been installed near Blackford in Perthshire, Scotland with the data transmitted to Edinburgh, where it is recorded continuously.

Presentations were given to SEPA and the EA on the potential for using the existing infrastructure of the UK network to record environmental parameters.

5. Seismic activity in Year 10

5.1 Earthquakes located for 1998

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 1998 published and distributed in April 1999 (Walker, 1999). A map of the 201 events located in 1998 is reproduced here as Figure 11 and a catalogue of those with magnitudes of 2.0 or greater is given in Annex B. Eight in that magnitude category, together with 22 smaller ones, are known to have been felt. In the period since BGS extended its modern seismic monitoring in the UK (1979 to March 1999), almost all of the earthquakes with magnitudes ≥2.5 ML are believed to have been detected. The distribution of such events for that period

(Fig. 12) is, therefore, largely unbiased by the distribution of seismic monitoring stations for the onshore region. Accuracy of individual locations, however, will vary across the country.

5.2 Significant events

Highlights of the seismic activity during the tenth year of the project (April 1998 to March 1999) are given below:

(i) An earthquake on 3 May, with a magnitude of 3.5 ML was located near Jura. A macroseismic survey was carried out and 240 responses were received It showed that the earthquake was felt over an area of 12,000 km^2 (Isoseismal 3). The highest intensities were reached on the Islands of Colonsay and Jura, where an intensity of 4 EMS was assigned from reports describing “the whole house shaking”, “loud bangs and rumbles”, and “objects rattling and falling down”. The earthquake was felt throughout most of Argyll and Bute, as far north as the Glencoe area, towards the Isle of Arran in the east and Southend, Kintyre in the south. A seismogram of the event recorded on the Lowlands network is shown in Figure 13. This is the first event that has been felt in the area, since the magnitude 3.0 ML Colonsay earthquake, on 26 January 1990, which was felt with intensities of at least 4 EMS in the epicentral area. Earthquakes of this size occur on average two times a year.

(ii) The largest offshore earthquake occurred in the southern North Sea on 16 May. It had a magnitude of 3.8 ML and was located approximately 60 km NE of Great Yarmouth. The Coastguard, Police, local gas and oil rig operators were contacted but no felt reports were received. A further six events occurred in the North Sea area during the year, with magnitudes ranging between 1.8 and 2.8 ML, and were located using both the BGS and Norwegian networks.

(iii) On 3 April, an earthquake, with a magnitude of 1.1 ML, occurred in the Annan area of the Dumfries and Galloway region of Scotland. It was recorded on the strong motion instrument at Chapelcross, some 3 km away, where accelerations of 3.7, 9.6 and 6.3 mms^{-2} for the vertical, NS and EW components, respectively, were measured.

(iv) On 31 May, two earthquakes, with magnitudes of 2.6 and 1.7 ML, occurred 8 minutes apart in the Bristol Channel; no felt reports were received. These are the largest events in the area since the magnitude 2.8 ML Bristol Channel earthquake, on 1 January 1994, which was felt with intensities of at least 4 EMS.

(v) On 23 June, an earthquake, with a magnitude of 3.5 ML, occurred in the north Atlantic near Hatton Bank, some 540 km west of the Outer Hebrides in UK-claimed territory. It was located using stations from northern Scotland and Iceland and represents the first seismicity to be detected in the area.

(vi) Two felt earthquakes with magnitudes of 2.0 and 1.4 ML, occurred in the Locharbriggs area of Dumfries and Galloway, with intensities of at least 3 EMS on 21 and 23 July, respectively. Felt reports described “a rumble lasted 5-10 seconds and neighbours rushed into the streets” and “the whole house shook”. It was recorded on the strong motion instrument at Chapelcross, some 28 km away, where accelerations of 1.1, 0.3 and 0.4 mms^{-2} for the vertical, NS and EW components, respectively, were measured.

(vii) Near Doune, Central Scotland, an earthquake was detected on 27 September with a magnitude of 1.2 ML. It was not felt, but located in the same area as the swarm of events which occurred in 1997, with magnitudes between 0.9 and 2.7 ML, of which six were felt by local residents.

(viii) Near Beauly, Highland, two earthquakes, with magnitudes of 0.9 and 1.1 ML, occurred on 28 September. They locate in an area which historically has been active in the last century (two earthquakes with magnitudes of 5.1 ML on 13 August, 1816 and 18 September, 1901) but which has remained quiet since then.

(ix) On 7 October, an earthquake, with a magnitude of 2.8 ML, occurred near Grimsby. It was located close to an airport and a major road and occurred at a depth of 30 km. All these factors are thought to have contributed to the fact that no felt reports were received for an onshore earthquake of this size. The depth is unusual for British earthquakes.

(x) On 16 October, an earthquake, with a magnitude of 2.7 ML, occurred in the Menai Strait, Gwynedd. A macroseismic survey was carried out and questionnaires were placed in a local weekly newspaper, resulting in 41 replies which indicated a maximum intensity of 4 EMS. The earthquake was felt in Port Dinorwic, Caernarvon, Bangor and Llangefni where residents described “heard a loud rumble”, “the ground shook” and “the house shook”. A seismogram of the event recorded on the North Wales network is shown in Figure 14.

(xi) Near Boston, Lincolnshire, an earthquake, with a magnitude of 2.8 ML occurred on 21 January. Earthquakes of this size are usually felt when they occur onshore but enquiries to local police stations, post offices and coastguards, revealed that no felt reports were received. The time of day (11:10 UTC) and the depth of the earthquake (22.8 km) contributed to the lack of felt effects at the surface.

(xii) The largest earthquake, with a magnitude of 4.0 ML, occurred 4 km south of Arran on 4 March. A small aftershock 14 minutes later was also recorded, with a magnitude of 1.6 ML. The mainshock was felt over an area of 18,500 km^2. A macroseismic survey yielded over 1000 replies and the resulting map of felt effects is shown in Plate 2. The highest observed intensity was 5 EMS at Lamlash, Arran, where in a number of cases objects such as ornaments, pictures or toys fell or were displaced, but in a few cases heavy objects were also said to have been displaced, including two washing machines, a cooker, a microwave and a sofa. Although the area has been seismically active with small magnitude earthquakes, this magnitude 4.0 is the largest in both the instrumental and historical catalogues. A seismogram of the earthquake recorded on the Borders network is shown in Figure 15. The nearest 3-component strong motion instrument to record the earthquake was 135 km distant and accelerations of 1.4, 4.0 and 3.6 mms^{-2}, were recorded for the vertical, NS and EW components, respectively. A seismogram from the strong motion instrument in the Borders is shown in Figure 16.

(xiii) Three earthquakes were detected in the Blackford area of Tayside during the reporting year, with magnitudes of 0.4, 1.0 and 1.4 ML. This is an area that has continued to be active; 49 events in 1997, of which five were felt by local residents and 10 events in 1998 of which three were felt. In 1979, the magnitude 3.2 ML Ochil Hills earthquake was felt with a maximum intensity of 5 EMS.

(xiv) In North Wales, six events, with magnitudes ranging from 0.1 to 0.8 ML, were located on the Lleyn Peninsula, in the same area and at similar depths as the magnitude 5.4 ML Lleyn earthquake of 19 July 1984, which was felt throughout England and Wales and into Scotland and Ireland.

(xv) The coalfield areas of central Scotland, Yorkshire, Staffordshire, Wales, Midlands and Nottinghamshire continued to experience earthquake activity of a shallow nature which is believed to be mining induced. Some 38 coalfield events, with magnitudes ranging between 0.6 and 1.9 ML, were detected in the year. Ten of these were reported felt by local residents. Six events, with magnitudes ranging between 0.8 and 1.8 ML, were located near Clackmannan in the central region of Scotland; four were reported felt. This is an area, which has experienced many such mining induced events in the past. A seismogram of the largest Clackmannan event recorded on the Lowlands network, is shown in Figure 17.

Following the closure of Monktonhall Colliery near Edinburgh, in March 1997, no further events have been detected.

(xvi) Near Newcastle-under-Lyme, Staffordshire, six shallow events occurred, with magnitudes ranging between 1.1 and 1.5 ML. Only one of these events was felt by local residents, in the Keele area of Staffordshire.

(xvii) In other coalfield areas, small events were located near Oxton, Nottinghamshire (0.9 ML, 1 May 1998 and 0.7 ML, 13 October 1998; felt in Oxton), Doncaster, South Yorkshire (1.9 ML, 5 May 1998; felt in Doncaster, and 1.0 ML, 1 June 1998), Worksop, Nottinghamshire (1.6 ML, 22 May 1998 and 1.2 ML, 19 January 1999), New Ollerton, Nottinghamshire (1.8 ML, 6 October 1998 and 0.6 ML, 9 October 1998), Coventry, West Midlands (1.2 ML, 6 November 1998), Tuxford, Nottinghamshire (1.0 ML, 3 December 1998), New Tredegar, Mid Glamorgan (1.0 ML, 3 March 1999), Bedlinog, Mid Glamorgan (1.1 ML, 8 and 18 March 1999) and Linby, Nottinghamshire (0.7 ML, 17 March 1999). These events are probably related to present-day coal mining activity.

(xviii) Elsewhere in the country, many seismic events have been reported felt or heard like small earthquakes but, on analysis, have been proved to be sonic booms (Fig. 18). Specific examples are: Bournemouth (22 April 1998), Southern Scotland (8 May 1998), North Wales (19 October 1998), Lancashire (7 December 1998), Grampian (1 February 1999), Cumbria (8 and 9 February 1999), Shropshire (15 February 1999) and Lincolnshire (15 March 1999).

(xix) Reports have been received of other man-made events. On 24 September 1998 the RAF dropped five 1000 lb high explosive bombs on Garve Island (7 km east of Cape Wrath) as part of an exercise, four hit the target and one detonated at sea. The resulting four seismic waves were detected at the BGS seismometer situated at the Cape Wrath lighthouse. The air waves were detected, just over 3 minutes later, on the BGS microphone, situated approximately 3 km south of the Dounreay Nuclear Establishment (approximately 60 km east of Garve Island). Felt reports, from the Dounreay Nuclear Establishment, described “windows rattled and the building shook”. In January 1999, a similar exercise was conducted and similar felt effects were reported. A seismogram of the event is shown in Figure 19 and the air-wave, recorded at a microphone some 60 km away, is shown in Figure 20. Offshore Dunbar, Scotland, a WWII mine was detonated and recorded on the Torness network. A seismogram is shown in Figure 21.

5.3 Azores earthquake

An earthquake with a magnitude of 6.0, on 9 July on the island of Faial in the Azores, resulted in the deaths of 9 people, injured 56 more and left 1,500 homeless. Extensive damage (Plate 3) was reported throughout the region, with intensities of 7 and 8 EMS within 10 km of the epicentre. Minor damage occurred in the islands of Pico and Terceira some 30 and 120 km from the epicentre, respectively. In the following eight months some 12,250 aftershocks were recorded, 460 were felt.

5.4 Global earthquakes

The monitoring network detects large earthquakes elsewhere in the world for which selected data is made available to European and International agencies. Examples are given below.

(i) A destructive earthquake occurred on 30 May, with a magnitude of 6.9 Ms, in the Hindu Kush region near the Afghanistan and Tajikistan border. The earthquake killed 4000 people and injured many thousands more in the same region as the one which killed over 2,300 on 4 February 1998. Between them they caused approximately 70% of the world death total for 1998 and destroyed or damaged over 9,000 homes in the Badakhshan and Takhar Provinces. A seismogram of the event recorded on the Orkney network is shown in Figure 23.

(ii) A damaging earthquake, near the coast of Papua New Guinea, on 17 July, with a magnitude of 7.1 Ms, resulted in the deaths of over 2,000 people. Thousands more were injured, approximately 10,000 were made homeless and hundreds are still missing as a result of a tsunami (one of the most devastating this century) generated in the Sissano area. Maximum wave heights were estimated at 10 metres. Several villages were destroyed and others were extensively damaged. Further afield, in Japan, wave heights of up to 15 cm were observed, and in New Zealand, up to 6 cm.

(iii) On 21 January 1999, an earthquake, with a magnitude of 5.9 Mb occurred in Colombia. At least 2,000 people were killed, over 5,000 were injured and about 250,000 left homeless. The most affected city was Armenia (Plate 4) where over 900 people were killed and about 60% of the buildings were destroyed, including the police and fire stations. The cities of Calarca and Pereira were also affected with 60% of the buildings destroyed. Landslides blocked several roads. Damage occurred in Caldas, Huila, Quindio, Risaralda, Tolima and Valle del Cauca Departments. This was a relatively small earthquake with around 200 such events occurring worldwide, each year. A seismogram of the event recorded on the Hereford network is shown in Figure 24.

6. The National Seismological Archive (NSA)

6.1 Identification, curation and cataloguing

Cataloguing of all NSA material has now been completed at the main level of detail. Future work may improve on this by adding further detail to parts of the catalogue. Additionally, the long-term seismogram microfilming project has now been completed, with all NSA held seismograms now microfilmed, as well as all externally held seismograms that are accessible. A copy film set has been sent for holding at BGS Keyworth as a backup. The Lapworth Museum's West Bromwich Observatory material (relating to JJ Shaw) was loaned to the NSA by Birmingham University and selected primary material from it has been also microfilmed.

Further research during the course of this year has resulted in the updating of the UK Historical Seismological Observatories report to Version 3 and the Seismological Bulletins report to Version 2. This was principally from information gleaned from a fuller examination of the papers of ATJ Dollar which included the discovery of three previously unknown observatories (Bristol, Kenilworth and Leamington Spa), fuller information on seventeen other locations and biographical detail on many seismological workers.

Research on the Isle of Wight has resulted in the identification of John Milne material held by both the Carisbrooke Castle Museum and privately. This is detailed in two reports (Annex F). The highlights of this material are a collection of Milne lantern slides, many with seismological content, two more Oxford Observatory seismograms, an E.W Pollard (Binstead Observatory) seismogram and others as yet unidentified, but being photographed and sent to the NSA.

A final catalogue has been produced of NSA held World-Wide Standard Seismograph Network (WWSSN) microfilmed seismograms, as part of a project to complete a full, online NSA database. The international WWSSN microfilming project stopped in October 1992 (it was operating around 2 years in arrears) and the NSA has a span of analogue records covering from January 1966 to September 1990, numbering around 3 million seismograms.

During the reporting year, a number of acquisitions have been made: copies of E W Pollard's autobiographical notes, seismological notes and photographs; copies of the Selfridges seismological archive and photographs; F L Vanderplank's seismological scrapbook, macroseismic notes on the Bristol 1934 earthquake and photographs; the Fort Augustus Jaggar shock recorder, formerly installed at Dunira, Comrie, was traced and rescued from imminent destruction. It now resides in the NSA; biographical notes and further information on the following seismological workers has been obtained: C F Powell, A Lacroix, T Anderson, T A Jaggar, F Perret, R H Worth, A Watkins, W J Sollas, Revd. T E Espin, H W Fisher, E Tillotson, T E Bonney, Revd. H Pain, Prince B Galitzin, Mr Esdaile, J J Shaw, A J Ewing, C Davison; notes on the use of the Jaggar shock recorder, by Powell & Jaggar, have been found; copies of BGS-held archival notes and photos by A G McGregor of work on Montserrat in 1936 have been incorporated.

The following section reports on 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 now 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. Two seismograms have been discovered on the Isle of Wight, amongst Milne material.

Rathfarnham: Material from the Rathfarnham Castle Observatory, Dublin (1916-1964), are 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 now been examined and catalogued (reports WL/99/14 and WL/99/17 discussed above).

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

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.

6.2 Storage and Inspection facilities

The National Seismological Archive has been visited this year by five researchers, including Prof. J. Sclater from UCSD, Scripps School of Oceanography, (researching seismicity in the SE Indian Ocean), and A. Bayasgalan from Mongolia (researching Mongolian earthquakes), both with colleagues from Cambridge University. Many data requests and enquiries have been answered from scientists and researchers world-wide. The NSA Internet Web pages continue to be updated as new work is completed, with reports being made available for reading online or for download (address http://www.gsrg.nmh.ac.uk/~phoh/nsahome.htm).

6.3 Digital records

The programme of digitising old 1" analogue tapes is continuing following the upgrade of computer digitising software but it is proving difficult to extract data owing to the condition of the tapes and old replay equipment.

7. Dissemination of results

7.1 Near-immediate response

Customer Group members have continued to receive seismic alerts by Fax (Annex C) whenever an event has been reported to be felt or heard by more than two individuals. In the case of series of events in coalfield areas, only the more significant ones are reported in this way. Some 41 alerts have been issued to the Customer Group during the year.

The bulletin board, on a captive process on the central computer in Murchison House, has continued to be maintained on a routine basis for UK and global earthquake information. It contains continually updated seismic alert information together with the most recent 3 months, at least, of provisional data from the routine analysis of the UK network. Throughout the year, an updated catalogue listing of recent earthquakes (1 month) and seismic alerts, giving details of UK and global earthquakes, has been available through an Internet home page (address: http://www.gsrg.nmh.ac.uk/). Questionnaires and updated information on the Jura, Menai Strait and Arran earthquakes 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, some 50,000 visits have been logged.

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 1998, it was issued within 3 months.

8. Programme for 1999/00

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, as opportunities arise, further strong motion and broad band instruments will be installed. Specific advances anticipated for 1999/00, subject to the continuation of funding at least at the current level and without any unexpected closures of site specific networks, are:

(i) Further installation of the QNX operating system.

(ii) Extend coverage across to the Faroe Islands in collaboration with the Faroese Museum of Natural History and the oil industry GEM (Geotechnical Environment and Metocean) group.

(iii) Progress evaluation of year 2000 provisions.

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

(v) Introduction of two new strong motion systems at sub-network digital acquisition centres, priorities being northern Scotland and Swansea.

(vi) Pursue opportunities for capturing more strong motion data in collaboration with the nuclear industry.

(vii) Collaborate with universities to secure further broad band data.

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

9. Acknowledgements

We particularly wish to thank the Customer Group (listed in Annex A) for their participation, financial support and input of data and equipment to the project. Station operators and landowners throughout the UK have made an important contribution and the technical and scientific staff in BGS (listed in Annex D) have been at the sharp end of the operation. The work is supported by the Natural Environment Research Council and is published with the approval of the Director of the British Geological Survey (NERC).

10. References

Walker, A.B., (editor), 1999. Bulletin of British earthquakes 1998, Brit.Geol.Surv. Tech. Rep. No. WL/99/01.

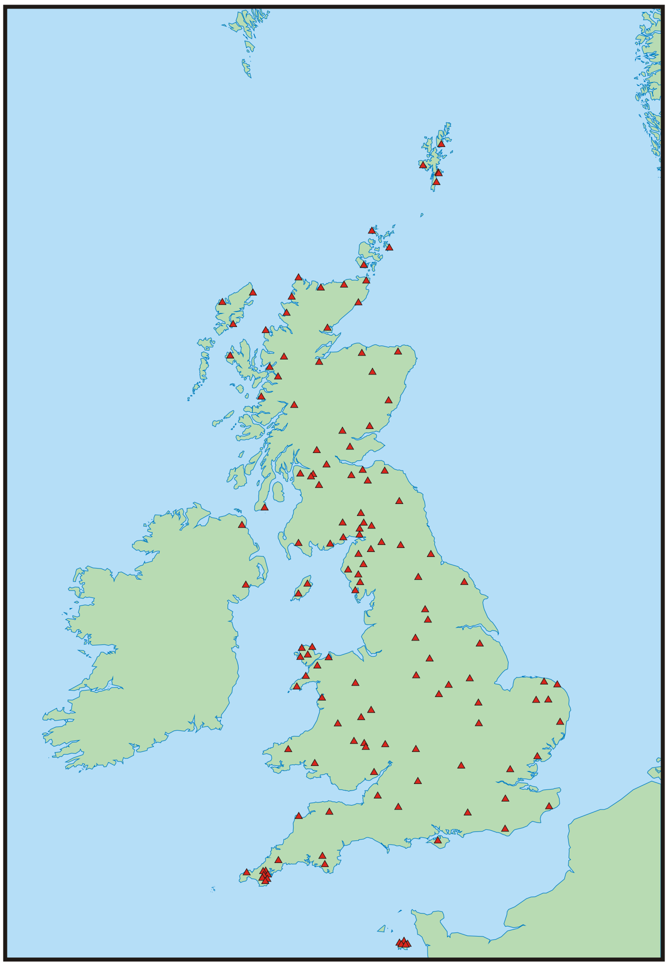

Figure 1. BGS rapid access seismograph network operational March 1999.

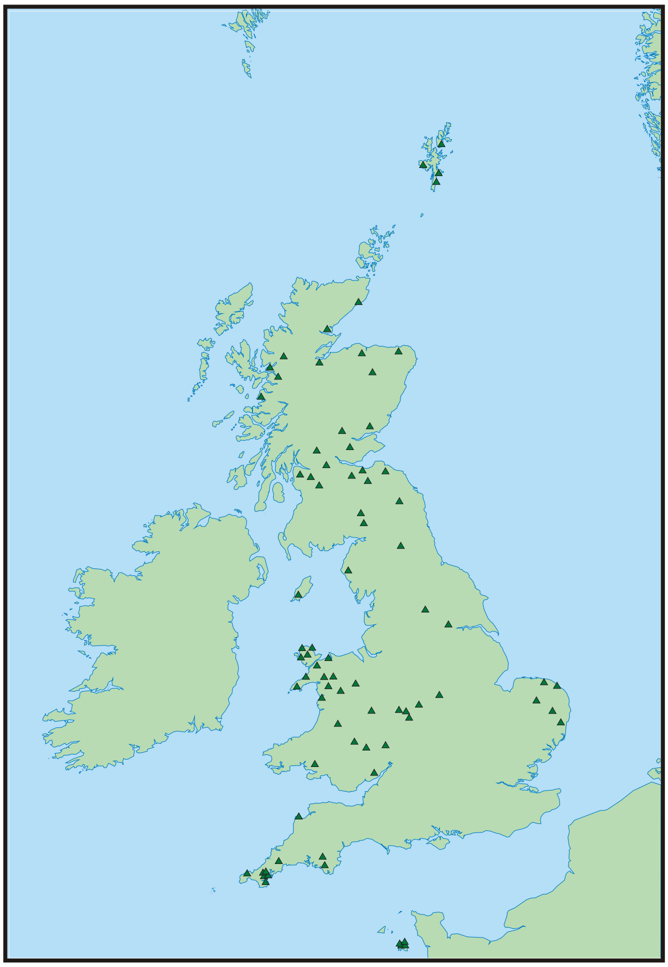

Figure 2. BGS seismograph network in 1988 prior to the commencement of the UK monitoring enhancement project.

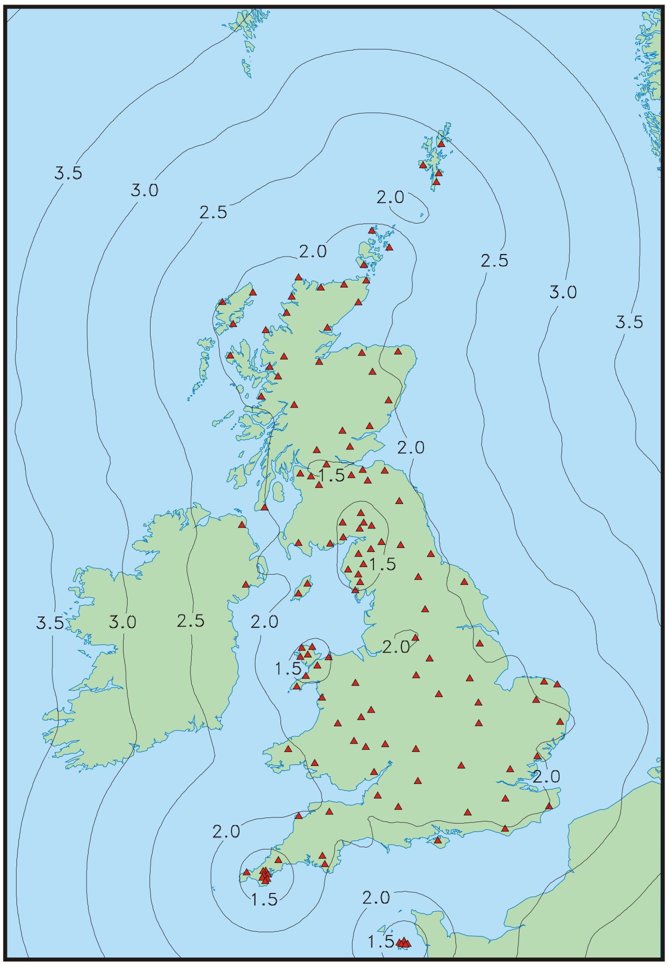

Figure 3. Detection capability of seismograph network, March 2000. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.

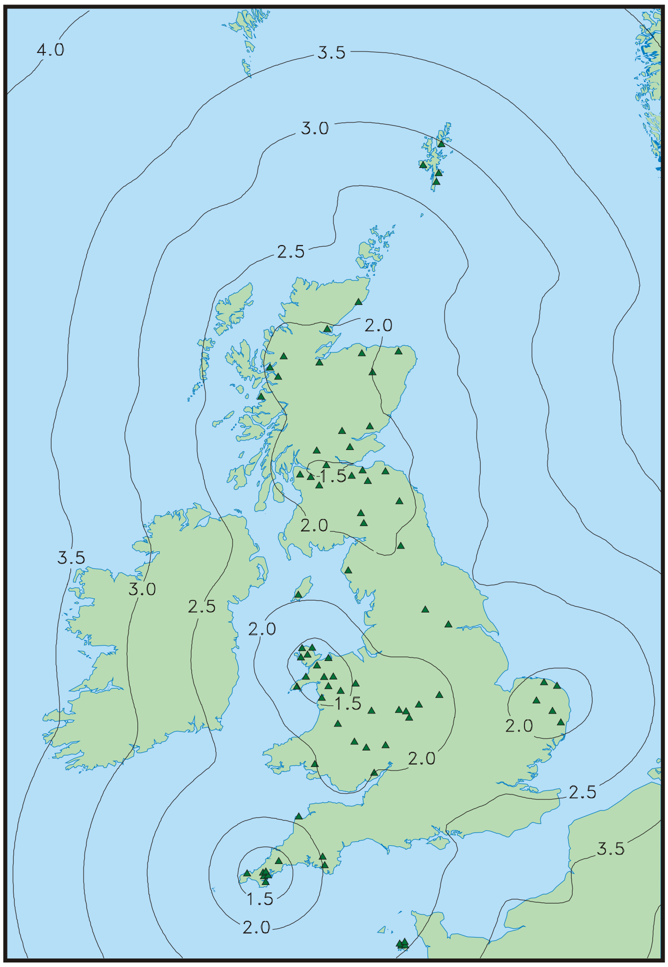

Figure 4. Detection capability of seismograph network, 1988. Contour values are Richter local magnitude (ML) for 20 nanometres of noise and S-wave amplitude twice that at the fifth nearest station.

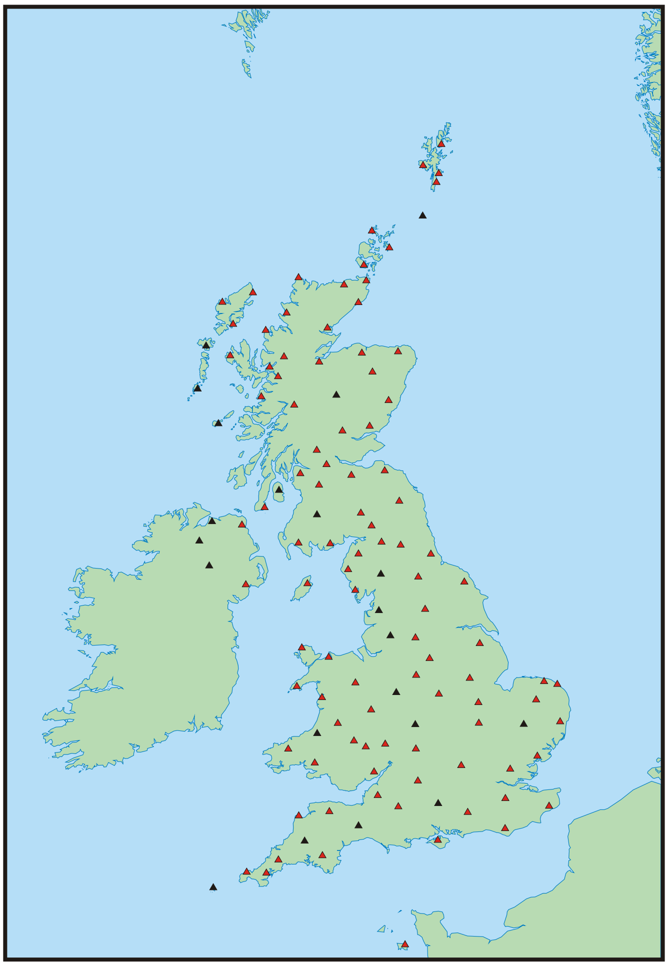

Figure 5. Proposed long-term background seismic monitoring network with an average station spacing of 70 km. Colour coding shows existing coverage (red) and proposed stations (black).

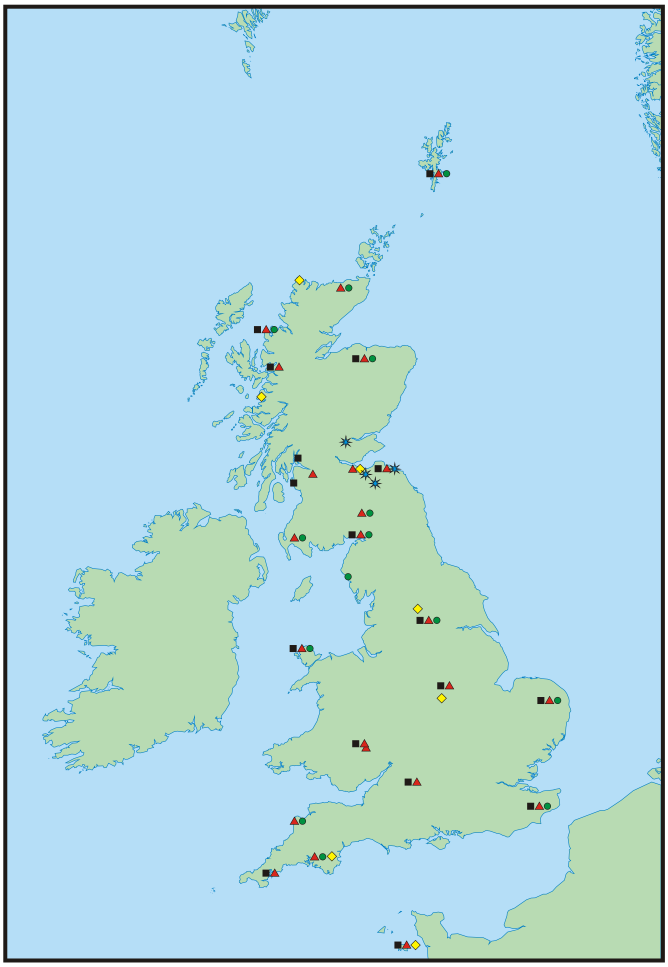

Figure 6. BGS network of strong motion instruments (black), low sensitivity (red), broadband (yellow), microphones (green) and environmental stations (blue) in March 2000.

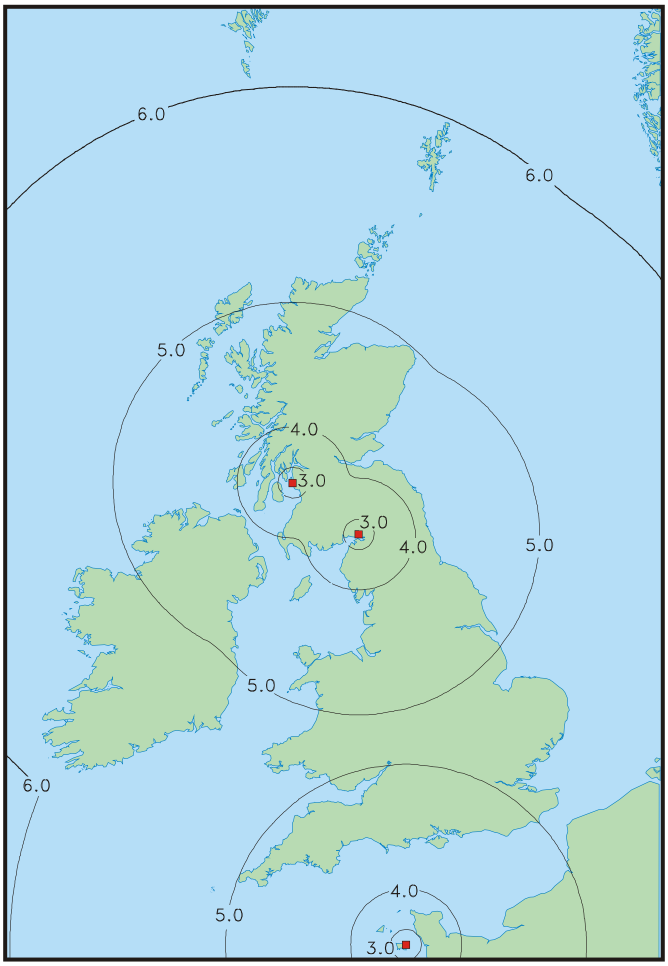

Figure 7. Minimum Richter local magnitude (ML) detectable by the strong motion network operational December 1992.

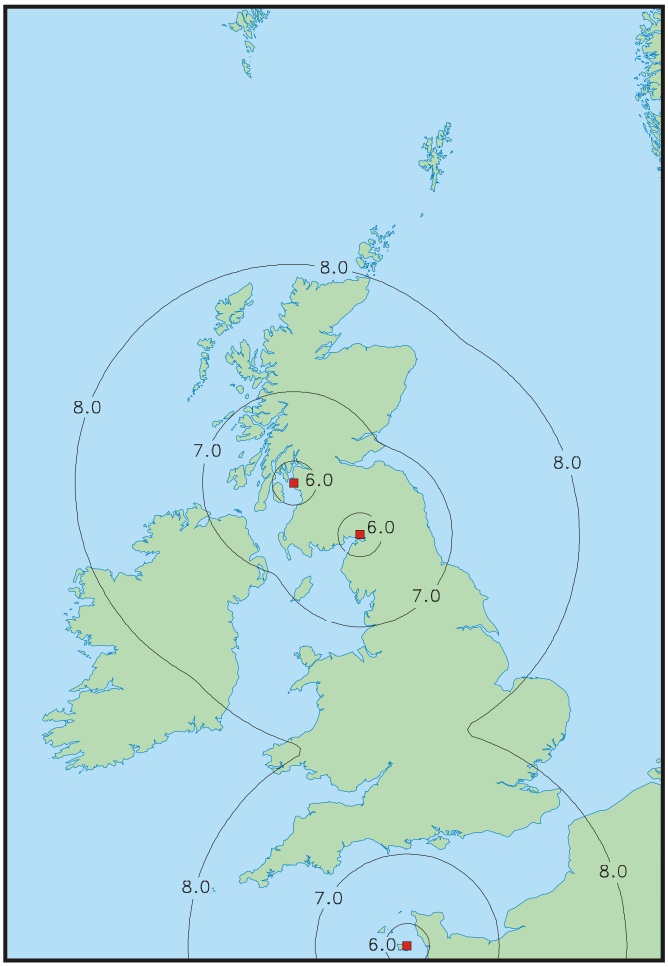

Figure 8. Maximum Richter local magnitude (ML) which will not saturate the strong motion network operational December 1992.

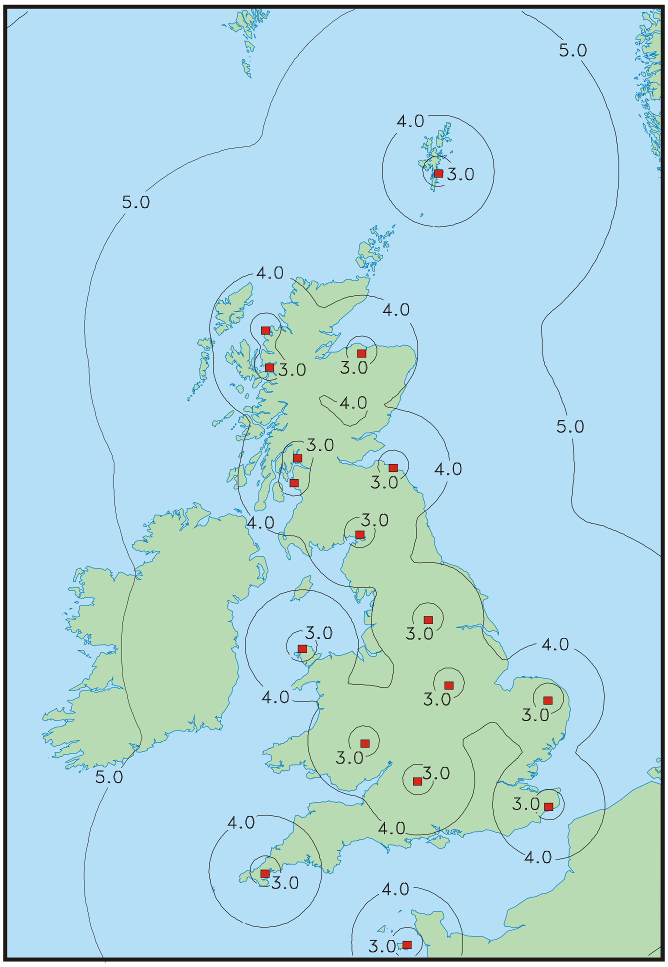

Figure 9. Minimum Richter local magnitude (ML) detectable by the strong motion network operational March 2000.

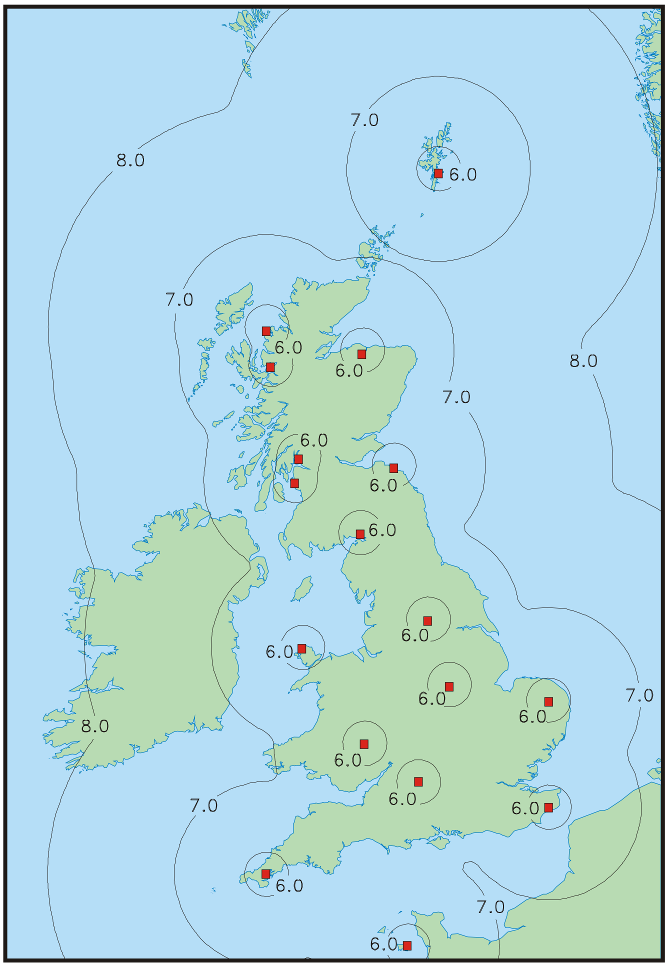

Figure 10. Maximum Richter local magnitude (ML) which will not saturate the strong motion network operational March 2000.

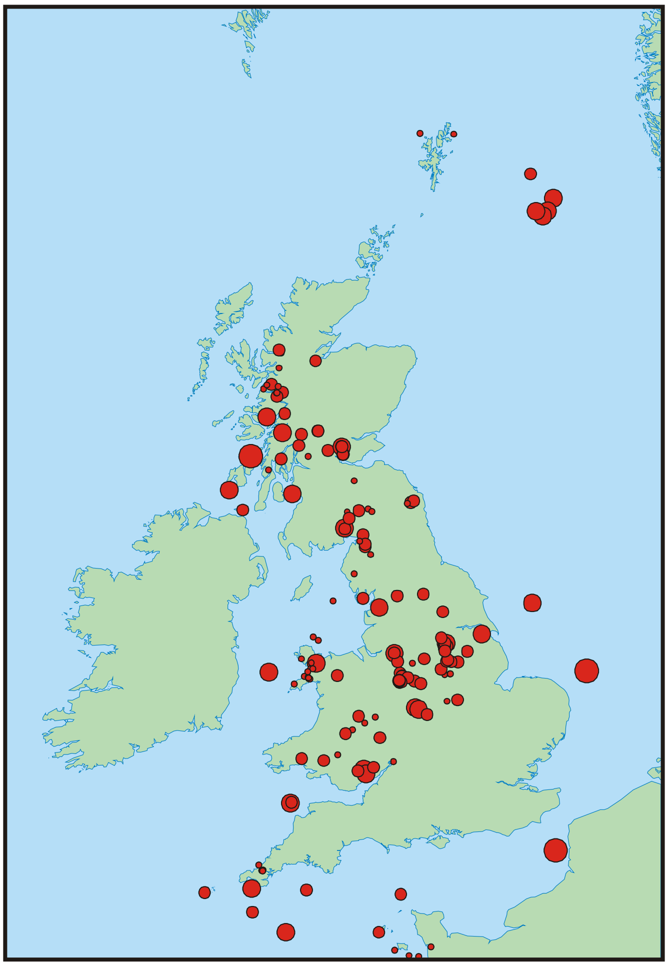

Figure 11. Epicentres of all UK earthquakes located in 1998.

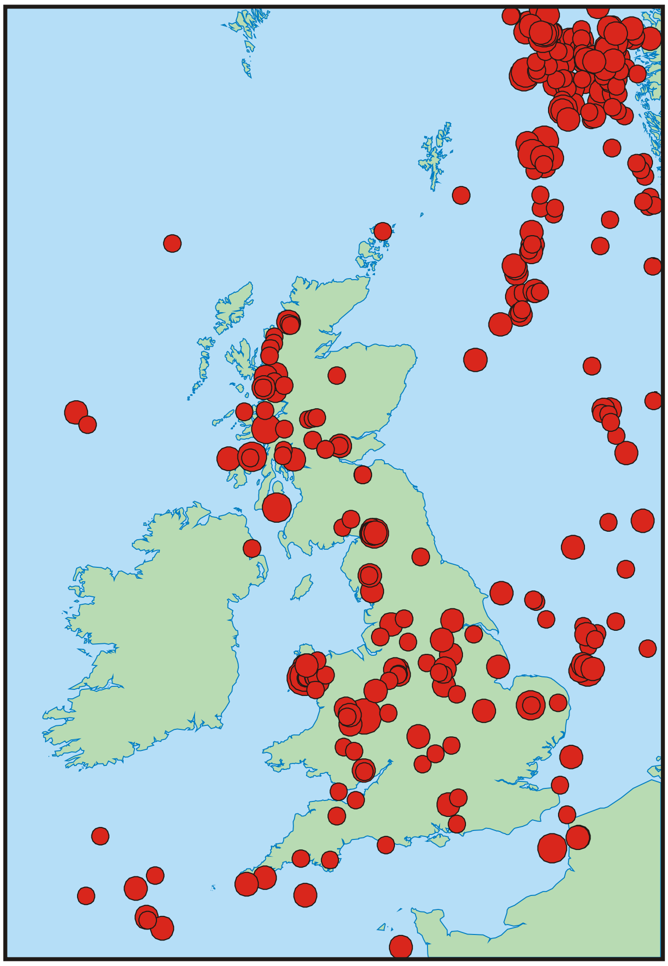

Figure 12. Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 1999.

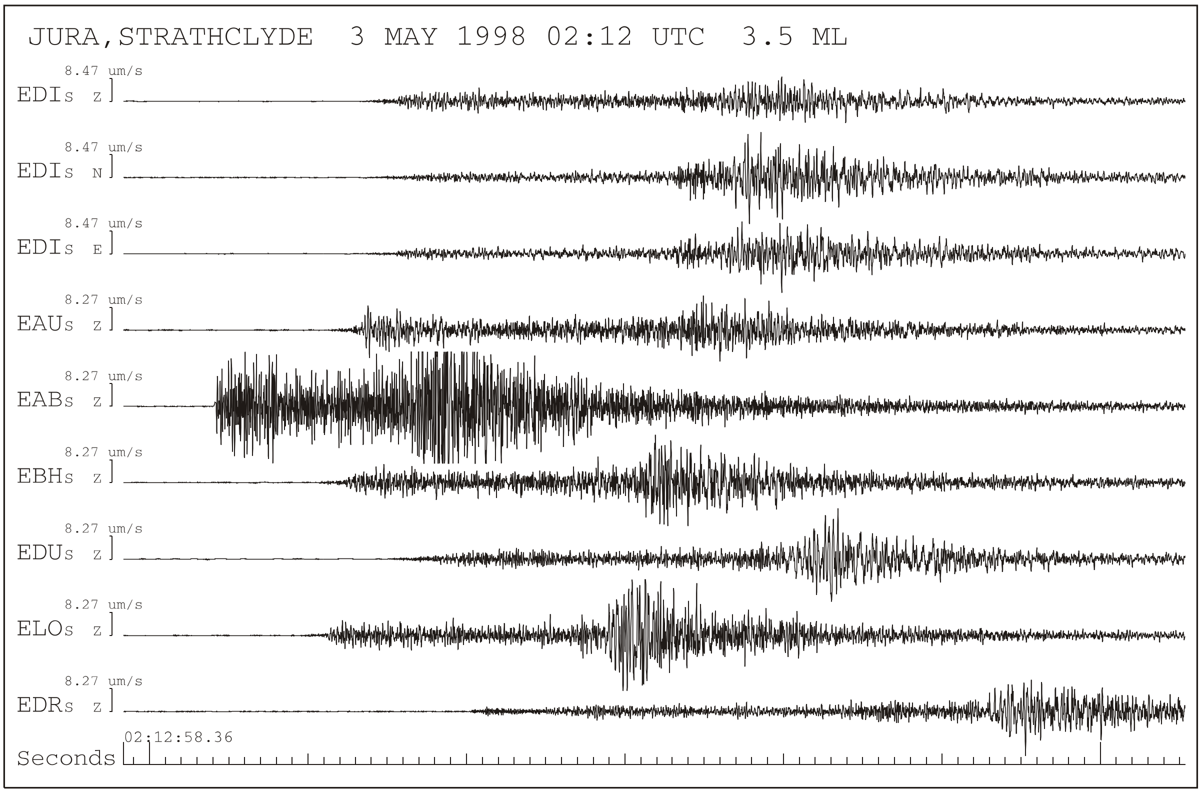

Figure 13. Seismograms recorded on the LOWNET network around Edinburgh from a magnitude 3.5 ML earthquake felt in the Strathclyde area on 3 May 1998 02:12 UTC. Three letter codes refer to stations in Annex E.

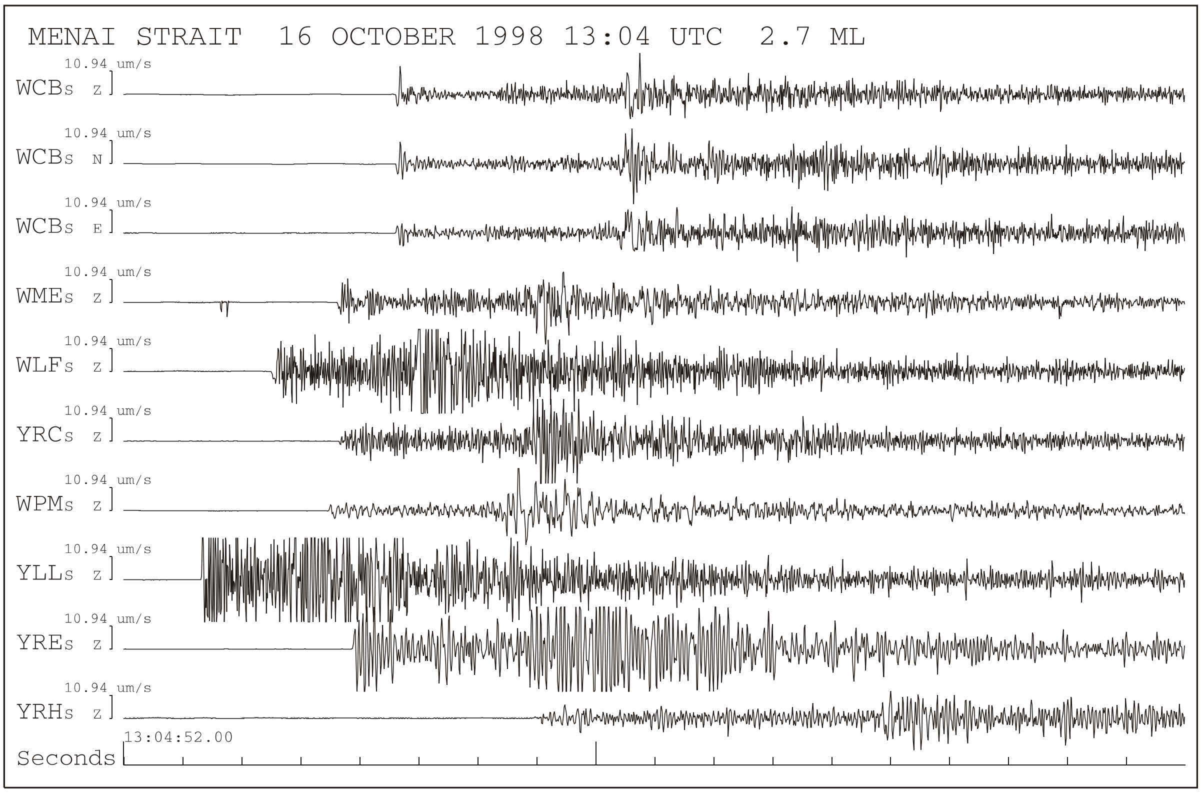

Figure 14. Seismograms recorded on the North Wales network from a magnitude 2.7 ML earthquake felt in the Gwynedd area on 16 October 1998 13:04 UTC. Three letter codes refer to stations in Annex E.

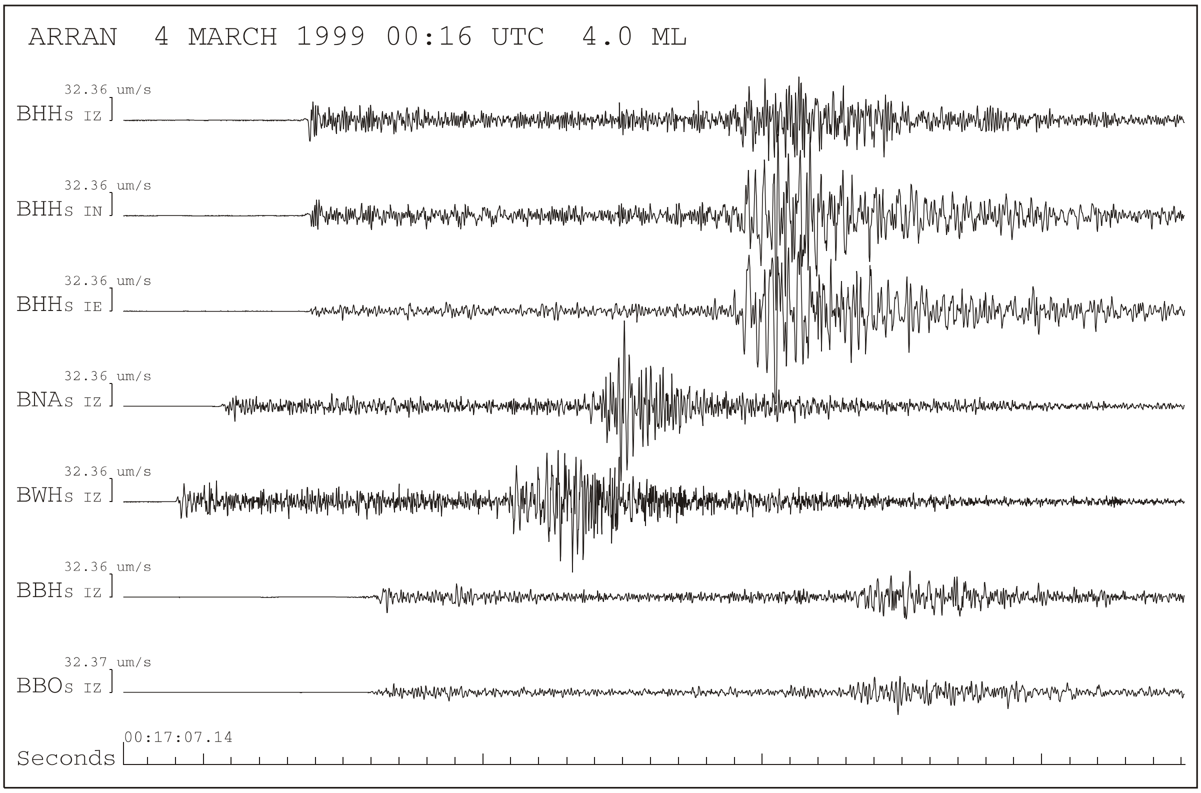

Figure 15. Seismograms recorded on the Borders network from a magnitude 4.0 ML earthquake felt in the South West area of Scotland on 4 March 1999 00:16 UTC. Three letter codes refer to stations in Annex E.

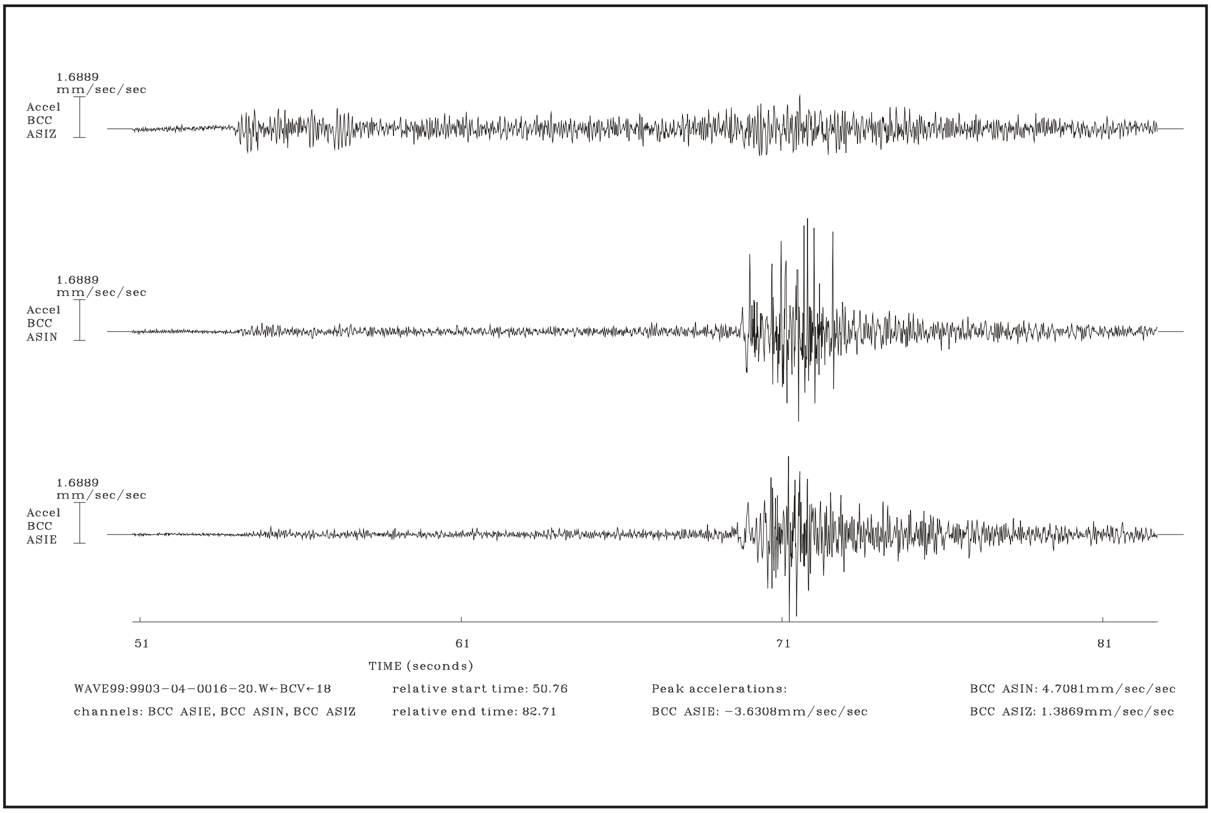

Figure 16. Seismograms recorded on the strong motion instruments near Chapelcross, Borders from the Isle of Arran earthquake with a magnitude of 4.0 ML on 4 March 1999 00:16 UTC. Three letter codes refer to stations in Annex E.

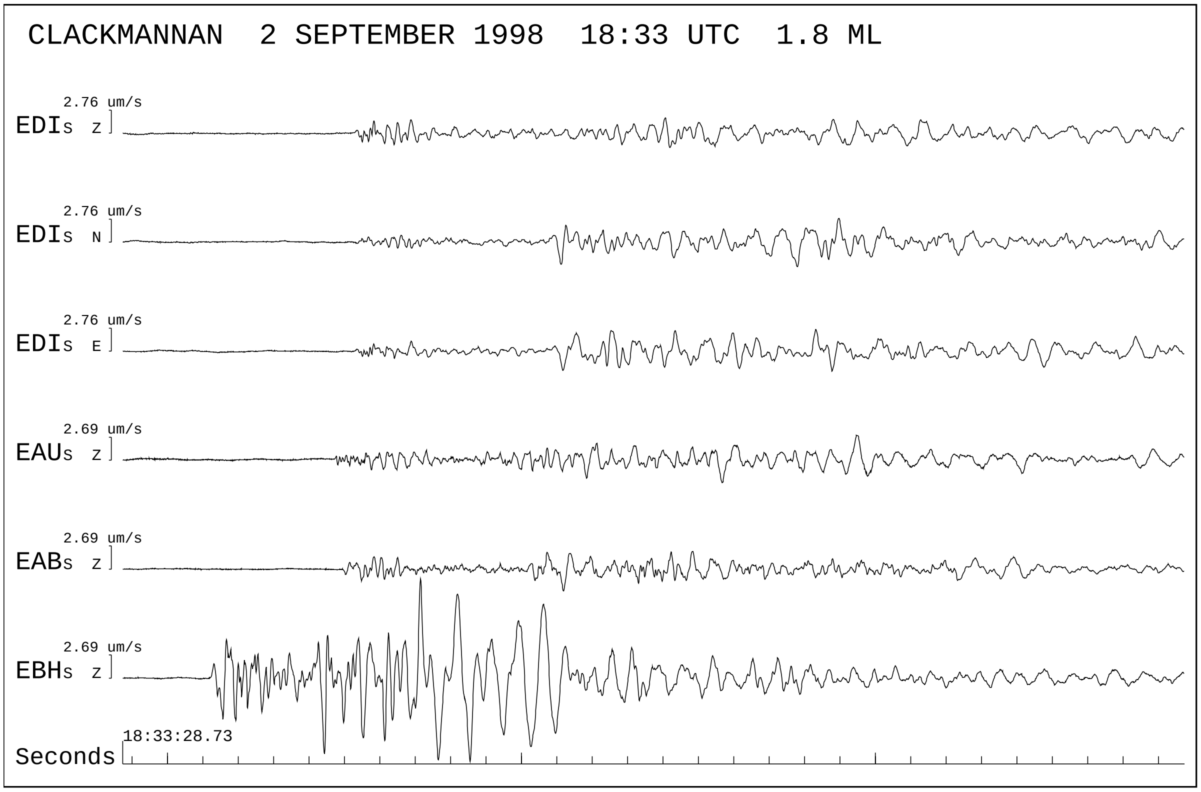

Figure 17. Seismograms recorded on the LOWNET network around Edinburgh from a magnitude 1.8 ML coalfield event felt in the Clackmannan area on 2 September 1998 18:33 UTC. Three letter codes refer to stations in Annex E.

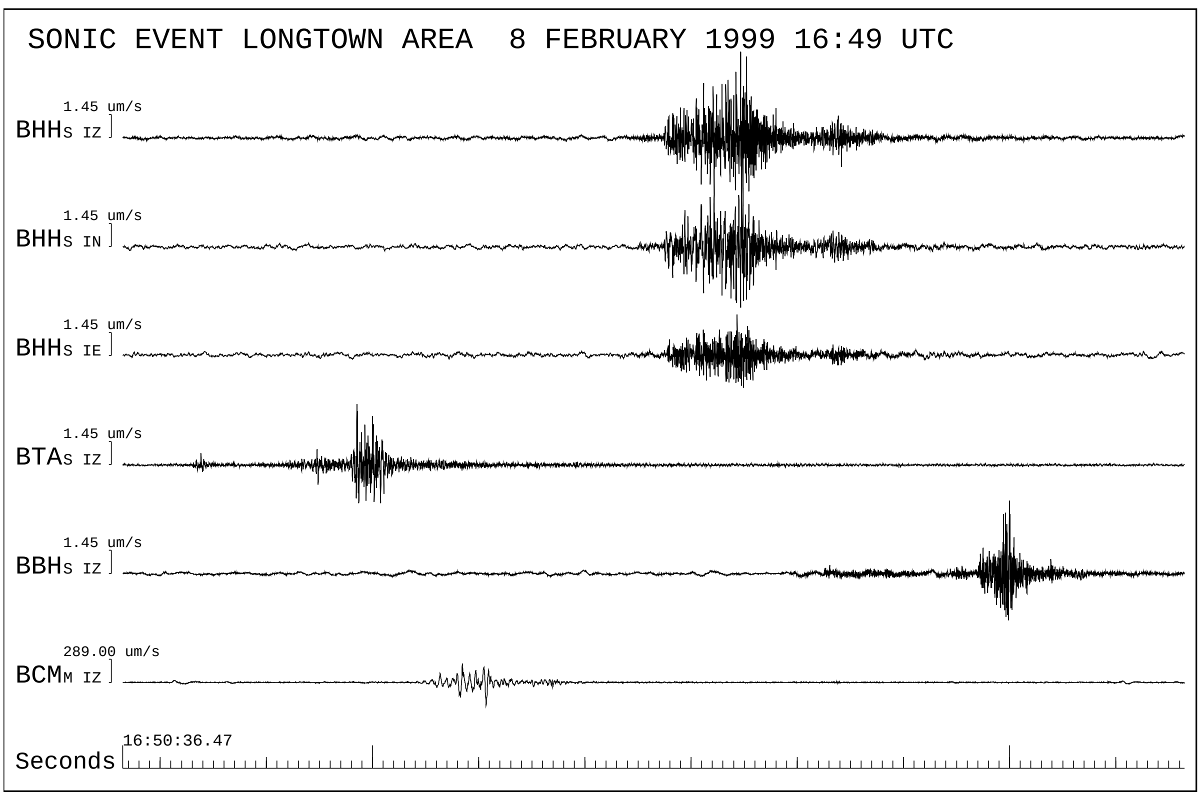

Figure 18. Seismograms recorded on the Borders network from a sonic event felt in the Cumbria area on 8 February 1999 16:49 UTC. Three letter codes refer to stations in Annex E.

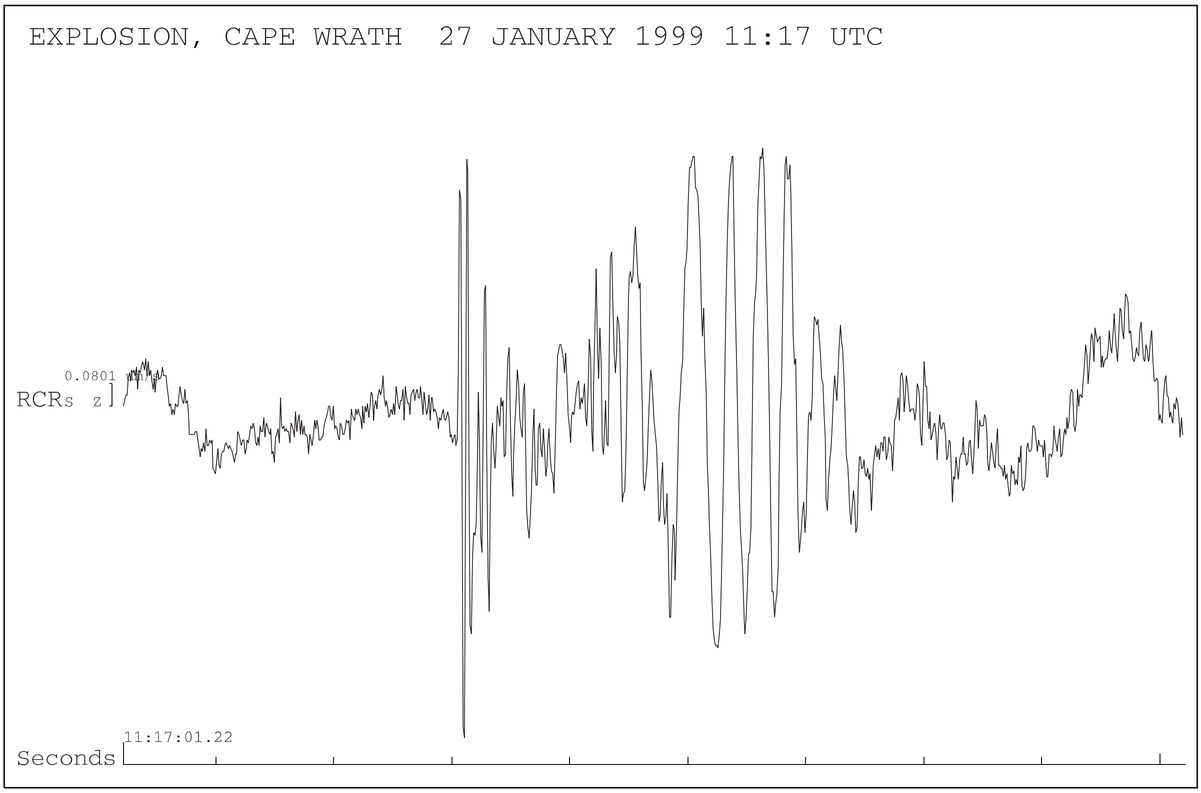

Figure 19. Seismogram recorded on the Minch network from a Cape Wrath explosion on 27 January 1999 11:17 UTC. Three letter codes refer to stations in Annex E.

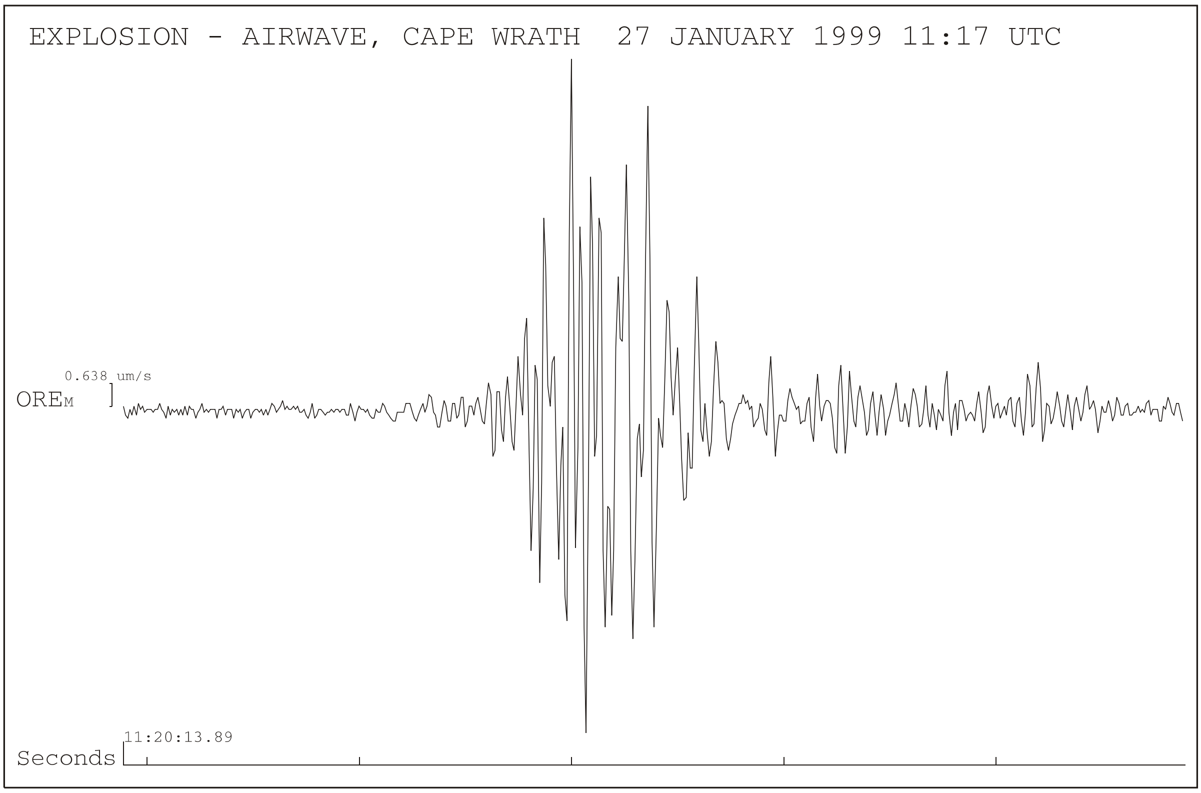

Figure 20. Seismogram recorded on the Reay station from a Cape Wrath explosion on 27 January 1999 11:17 UTC. Three letter codes refer to stations in Annex E.

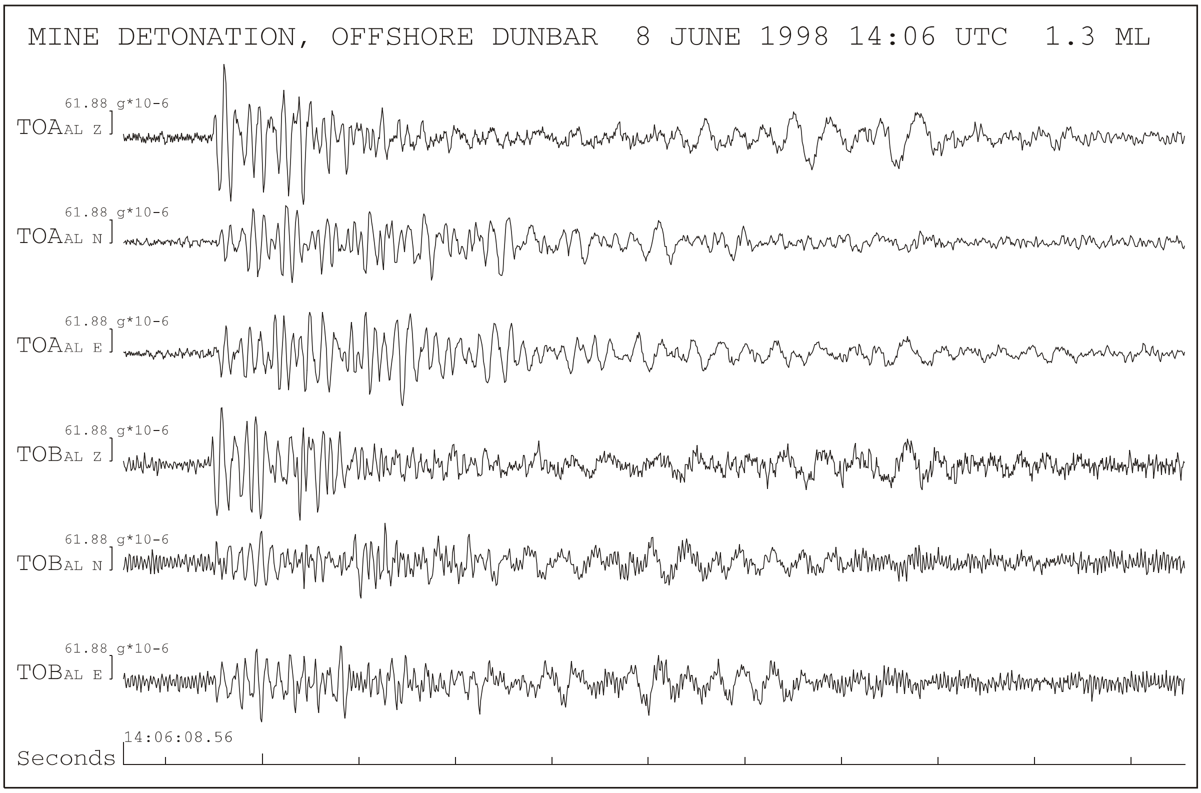

Figure 21. Seismograms recorded on the Torness network from a magnitude 1.3 ML mine detonation off Dunbar on 8 June 1998 14:06 UTC. Three letter codes refer to stations in Annex E.

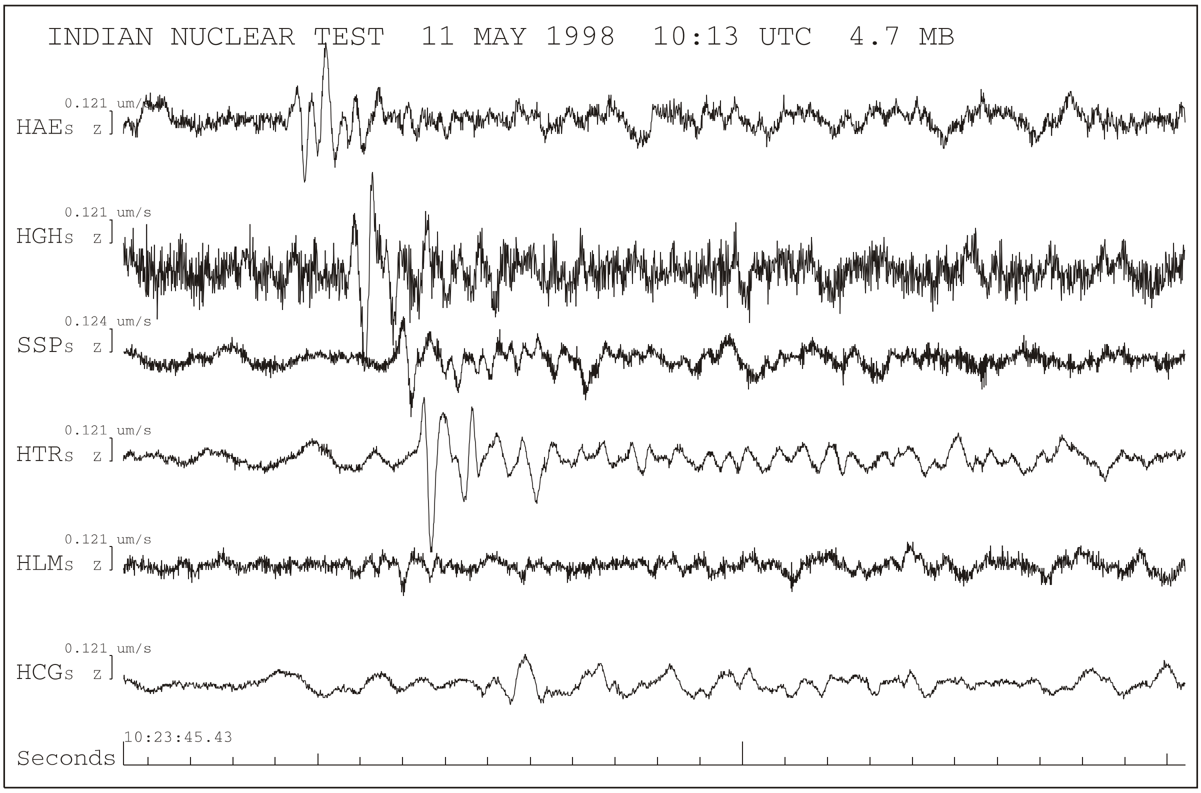

Figure 22. Seismograms recorded on the Hereford network from a magnitude 4.7 MB Indian nuclear test on 11 May 1998 10:13 UTC. Three letter codes refer to stations in Annex E.

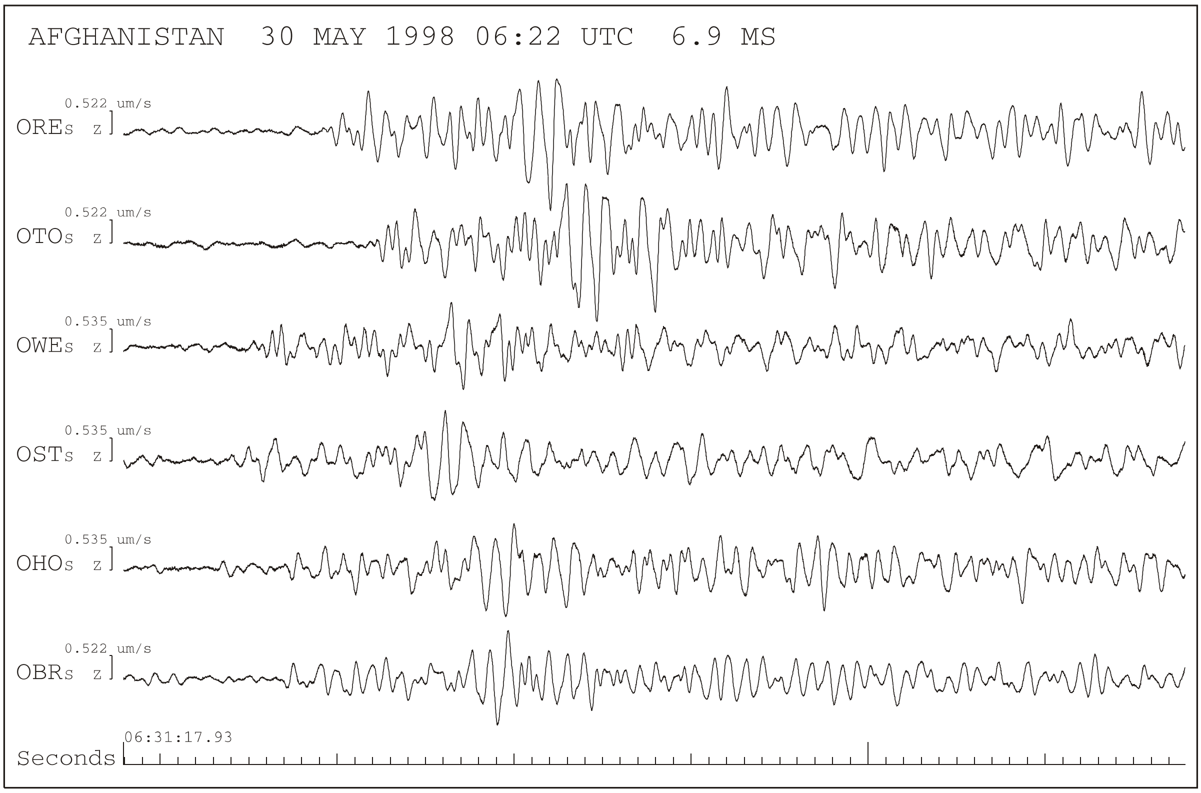

Figure 23. Seismograms recorded on the Orkney network from a magnitude 6.9 MS earthquake in Afghanistan on 30 May 1998 06:22 UTC. Three letter codes refer to stations in Annex E.

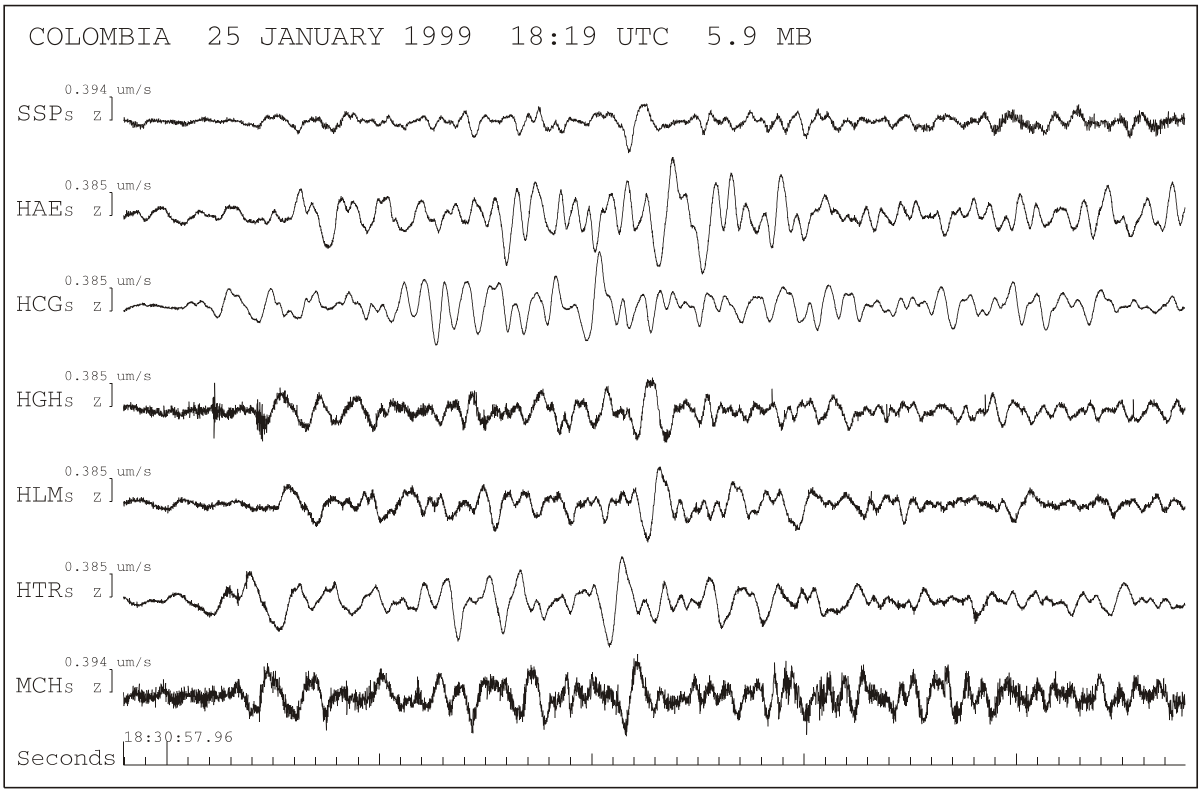

Figure 24. Seismograms recorded on the Hereford network from a magnitude 5.9 MB earthquake in Colombia on 25 January 1999 18:19 UTC. Three letter codes refer to stations in Annex E.

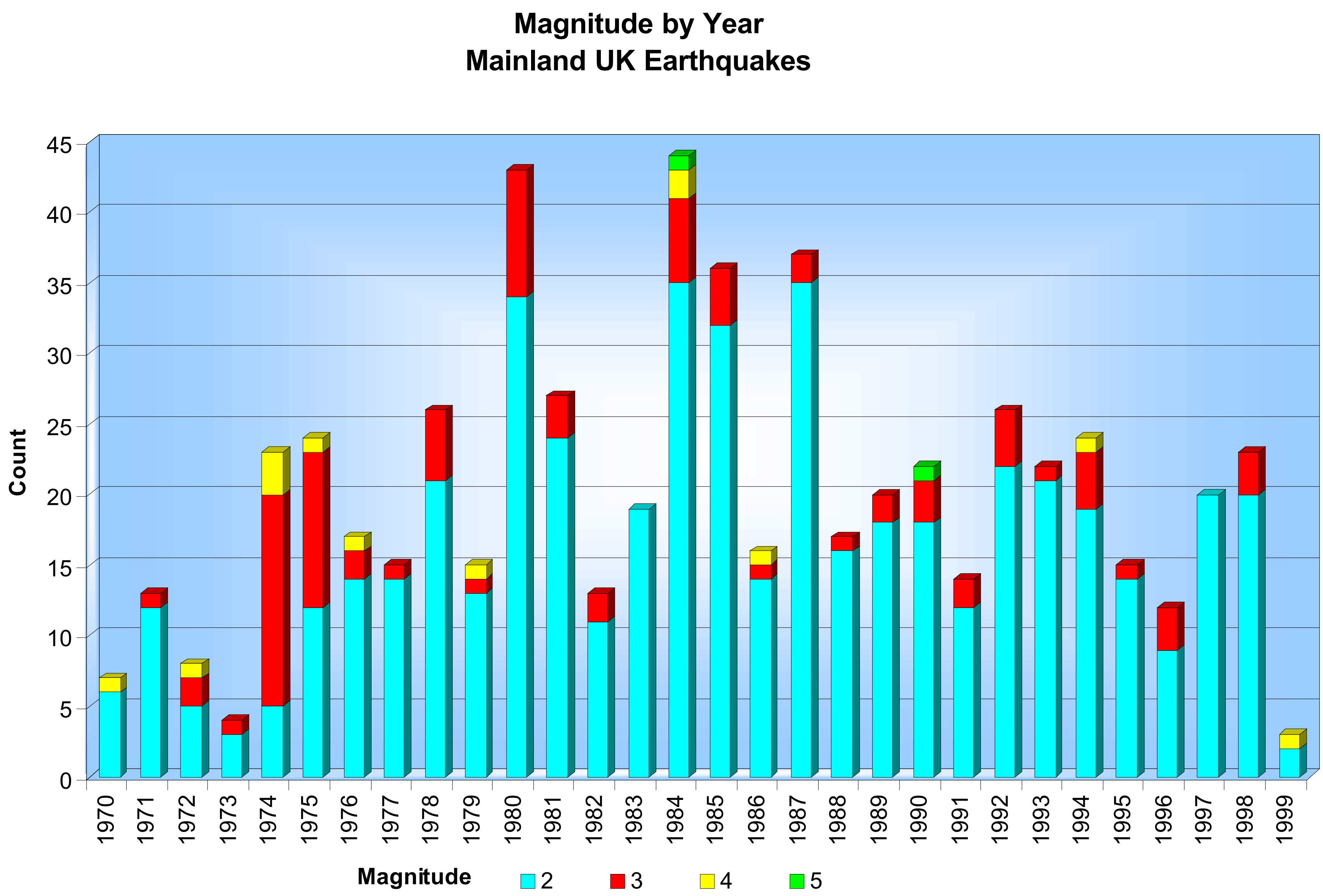

Plate 1. Histogram of UK seismicity 2.0 ML and above for the period 1970 - March 1999.

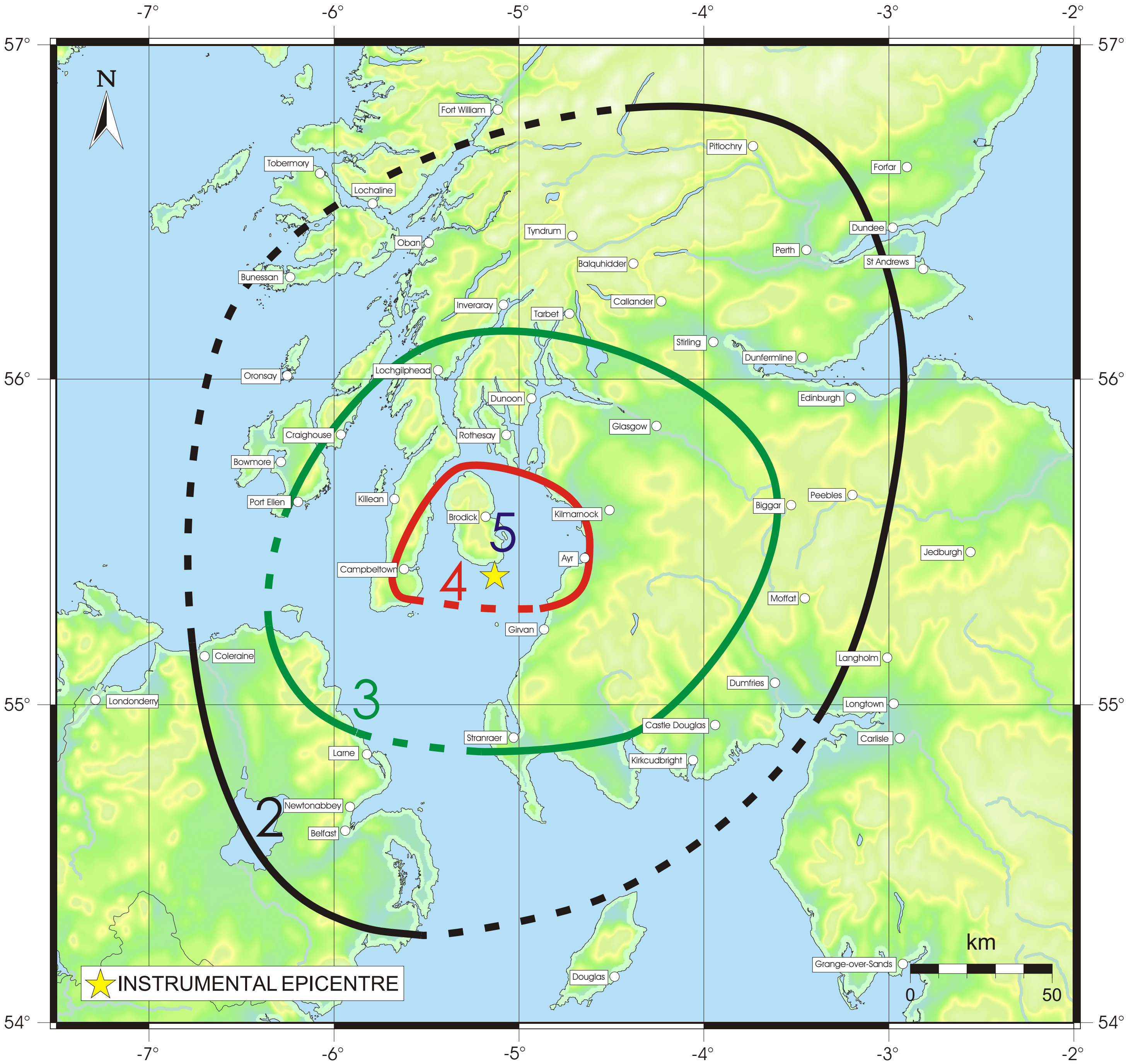

Plate 2. Isle of Arran earthquake 4 March 1999 00:16 UTC, magnitude 4.0 ML - EMS Intensities.

Plate 3. Earthquake damage in the Espalhafatos region from the Azores Islands earthquake 9 July 1998 05:19 UTC, magnitude 6.0 Ms. (Photograph supplied by Mr Fernando Carrilho, Instituto de Meteorologia, Portugal).

Plate 4. Earthquake damage in the Armenia region from the Colombia earthquake 25 January 1999 18:19 UTC, magnitude 5.9 Mb. (Photograph supplied by Mr Fabio Taucer, European Commission).

CONTRIBUTORS TO THE PROJECT

British Energy

British Nuclear Fuels plc

BNFL Magnox Generation

Department of the Environment, Transport and the Regions

Faroese Museum of Natural History

Natural Environment Research Council

Nuclear Installations Inspectorate

Renfrewshire Council

Scottish Coal

Scottish Hydro-Electric plc

Welsh Office

Western Frontiers Association

Atomic Weapons Establishment (Data only)

Customer Group Members (not contributing in Year Ten)

British Gas/Transco

Health and Safety Executive

International Seismological Centre

Scottish Office

United Kingdom Atomic Energy Authority

United Kingdom Nirex Limited

University of Exeter

EARTHQUAKES WITH MAGNITUDE 2.0 AND ABOVE, RECORDED IN THE UK AND OFFSHORE WATERS:1998

YearMoDy	HrMnSecs	Lat	Lon	kmE	kmN	Dep	Mag	Locality	Int	No	DM	Gap	RMS	ERH	ERZ	SQD	Comments
19980101	185527.5	49.37	-4.71	203.3	-55.9	15.0	2.3	ENGLISH CHANNEL		31	22	356	0.55			D*D	
19980127	083615.1	50.51	1.24	629.5	72.8	2.8	3.1	STRAIT OF DOVER		18	68	233	0.36	3.1	4.5	C*D	
19980208	055127.3	49.96	-5.50	149.1	12.8	12.4	2.4	PENZANCE,CORNWALL	4+	12	22	277	0.02	0.4	0.4	A*D	FELT SW CORNWALL...
19980211	203919.3	51.63	-3.01	329.8	193.2	5.2	2.3	CWMBRAN,GWENT	3+	6	14	129	0.06	1.0	1.3	B*C	FELT CWMBRAN...
19980217	142630.1	53.48	-1.15	456.4	398.7	0.1	2.0	DONCASTER,SOUTH YORKS	3+	8	36	123	0.13	0.8	1.5	A*C	C/F,FELT MALTBY...
19980307	020859.4	56.42	-5.28	197.8	729.8	5.9	2.7	OBAN,STRATHCLYDE	4+	13	64	195	0.11	1.0	2.8	B*D	FELT OBAN...
19980326	205204.5	56.25	-3.75	291.5	707.5	5.3	2.2	BLACKFORD,TAYSIDE	3+	9	15	106	0.06	0.4	0.7	A*C	FELT BLACKFORD...
19980503	021246.7	56.06	-6.05	147.8	692.7	12.9	3.5	OFF JURA,STRATHCLYDE	4	12	85	163	0.11	0.9	1.7	A*D	FELT LOCHGILPHEAD...
19980505	003318.2	59.54	1.51	598.4	1078.1	5.2	2.3	NORTHERN NORTH SEA		15	163	126	0.43	2.3	3.6	C*D	
19980505	004413.0	59.47	1.69	609.0	1070.3	15.0	2.3	NORTHERN NORTH SEA		9	176	280	0.33	14.2	17.8	D*D	
19980516	235456.3	53.02	2.15	678.6	355.2	0.2	3.8	SOUTHERN NORTH SEA		15	52	290	0.14	2.3	2.0	B*D	
19980531	125552.5	51.19	-4.71	210.5	147.0	14.6	2.6	BRISTOL CHANNEL		5	27	213	0.22	7.7	17.2	D*D	
19980621	192339.6	54.02	0.94	592.7	462.0	25.2	2.8	SOUTHERN NORTH SEA		12	104	229	0.26	3.3	3.3	C*D	
19980706	155025.4	56.63	-5.70	173.2	754.3	13.2	2.2	LOCHALINE,HIGHLAND		11	34	200	0.24	3.4	7.2	C*D	
19980720	073827.6	55.57	-6.54	114.0	639.6	6.1	2.4	ISLAY,STRATHCLYDE		12	60	211	0.11	1.2	1.8	B*D	
19980721	071701.4	55.10	-3.63	295.8	579.9	12.8	2.0	LOCHARBRIGGS,D & G	3+	8	8	134	0.09	0.7	1.6	A*B	FELT LOCHARBRIGGS...
19980731	105606.8	53.34	-2.38	374.8	382.8	9.0	2.3	ALTRINCHAM,G MANCHESTER		11	42	131	0.07	0.4	10.6	C*C	
19980808	220710.1	53.99	-2.75	350.9	454.7	11.1	2.3	GALGATE,LANCASHIRE		21	45	66	0.10	0.4	1.9	A*C	
19980825	224034.0	59.54	1.84	616.9	1078.3	18.5	2.3	NORTHERN NORTH SEA		15	181	189	0.45	4.2	6.9	C*D	
19980831	122314.3	53.03	-5.33	176.6	353.1	9.2	2.1	IRISH SEA		9	52	176	0.04	0.5		C*D	55KM SW OF HOLYHEAD
19980915	023306.9	55.56	-4.96	213.5	633.6	12.8	2.1	FIRTH OF CLYDE		12	35	143	0.11	0.8	2.3	B*C	
19980928	162936.6	52.55	-1.81	413.0	294.5	7.5	2.0	SUTTON COLDFIELD,W MID		9	40	163	0.08	0.3	1.2	A*C	
19981004	105957.0	59.71	2.02	626.0	1098.4	9.1	2.6	NORTHERN NORTH SEA		19	185	163	0.51	3.1	4.7	D*D	
19981007	183942.8	53.60	-0.29	512.8	413.1	30.7	2.8	GRIMSBY,HUMBERSIDE		15	16	143	0.12	0.7	0.5	A*C	13KM NW OF GRIMSBY
19981016	130451.1	53.18	-4.23	251.1	367.2	11.9	2.7	MENAI STRAIT,GWYNEDD	4	9	6	80	0.03	0.2	0.4	A*A	FELT FELINHELI...
19981123	134334.8	51.70	-3.07	326.4	200.8	15.0	2.0	PONTYPOOL,GWENT		9	19	67	0.08	0.7	1.7	A*B	
19981209	080640.2	52.57	-1.89	407.6	297.4	7.9	2.0	WALSALL,WEST MIDLANDS		9	43	152	0.12	0.9		C*C	

BRITISH GEOLOGICAL SURVEY
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P A MERRIMAN	- BNFL	J P McFARLANE	- SCOTTISH NUCLEAR
H TUR	- BNFL CAPEN	P W WINTER	- AEA
U MICHIE	- NIREX	P J BUCKLEY	- HSE
J BETHELL	- NUCLEAR ELEC	V KATHIGAYAN	- HSE OFFSHORE
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L J OLIVER	- HYDRO ELEC	P McCORMACK	- PAISLEY OBSERVATORY
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R WILLEMANN	- ISC	D W HOLLIDAY	- BGS, KEYWORTH
D J MALLARD	- CONSULTANT	H J HEASON	- BGS PRESS OFFICE
C FLAWS	- SCOTTISH COAL	S MONRO	- DYNAMIC EARTH

FROM: Bennett Simpson
DATE: 19 October 1998
TIME: 18:40 BST
PAGES TO FOLLOW: 1

SEISMIC ALERT: SONIC EVENT NORTH WALES 19 OCTOBER 1998 15:03 UTC

BGS have received numerous calls from residents of Holyhead, Porthmadog, Pwllheli, Groeslon, Llangefni, Bryngwian and Chwilog of a felt event at approximately 15:00 UTC today. Felt reports described "the house shook", "windows rattled" and "the garaged door rattled". Data from the BGS rapid-access network in North Wales was examined and a signal consistent with a sonic origin was recorded at around 15:03 UTC.

RAF Flying Complaints and RAF Valley were contacted and they could not confirm if military aircraft were operational in the area at the time.

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

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U MICHIE	- NIREX	P J BUCKLEY	- HSE
J BETHELL	- NUCLEAR ELEC	V KATHIGAYAN	- HSE OFFSHORE
C F ALLEN	- MAGNOX ELEC	A W B JACOB	- DIAS
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D J MALLARD	- CONSULTANT	H J HEASON	- BGS PRESS OFFICE
C FLAWS	- SCOTTISH COAL	S MONRO	- DYNAMIC EARTH
		C MCDONALD	- HYDRO ELEC

FROM: Davie Galloway/Glenn Ford
DATE: 4 March 1999
TIME: 02:30 UTC
PAGES TO FOLLOW:

SEISMIC ALERT: ARRAN, STRATHCLYDE 4 MARCH 1999 00:16 UTC 4.0 ML

BGS have received reports, from the Police, the Coastguard and residents in the Argyll and Strathclyde areas, of a felt event at approximately 00:15 UTC this morning (4 March 1999). Felt reports describe "felt vibrations through the floor and walls", "we were woken from sleep" and "the whole building trembled". The BGS rapid-access network detected an event approximately 4 km south of the Island of Arran at 00:16 UTC. An aftershock, with a magnitude of 1.6 ML, was detected approximately 14 minutes later at the same location. The following preliminary information is available for the magnitude 4.0 ML earthquake.

DATE	:	4 March 1999
ORIGIN TIME	:	00:16 51.7s UTC
LAT/LONG	:	55.40° North / 5.24° West
GRID REF	:	194.60 kmE / 616.35 kmN
DEPTH	:	19 km
MAGNITUDE	:	4.0 ML
INTENSITY	:	4+
LOCALITY	:	Isle of Arran, Strathclyde (4km south of Arran)

This is the largest event in the general area since a magnitude 4.1 ML event on 27 January 1927, which locates approximately 55 km north of today's event and the largest in the UK since the magnitude 4.0 ML Norwich event on 15 February 1994, which was felt with intensities of 5 EMS.

A seismogram of the earthquake, as recorded on the BGS Paisley network, and a map of instrumental seismicity within 50 km of the epicentre, are attached.

BGS STAFF WITH INPUT TO THE PROJECT

Ms Rose A R Aitken
Ms Jacqueline Bott
Dr Chris W A Browitt
Mr Peter S Day
Mr Daniel Dawes
Mrs Jane Exton
Mr Glenn D Ford
Mr Charlie J Fyfe
Mr Davie D Galloway
Ms Helen Gordon
Mr Paul H O Henni
Dr David J Kerridge
Mr John Laughlin
Mr John H Lovell
Dr Roger M W Musson
Mr Dave L Petrie
Mr John D Riddick
Ms Maureen E A Ritchie
Mr Bennett A Simpson
Mr Dave A Stewart
Mr William A Velzian
Ms Alice B Walker

GEOGRAPHICAL CO-ORDINATES OF SEISMOGRAPH STATIONS USED BY BGS: MARCH 1999

Code	Name	Lat	Lon	GrE (Kms)	GrN (Kms)	Ht (M)	Yrs Open	Comp	Agency
SHETLAND									
LRW	LERWICK	60.1360	-1.1779	445.66	1139.27	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 1999

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 1999

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	CHARNWOOD FST	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 1999

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. From left to right the column headers stand for Latitude, Longitude, Easting, Northing, Height, Year station opened, number of seismometers at the station and the agency operating the station.

2. The ‘R’ against some station components indicates that station details have been registered with international agencies for data exchange purposes.

3. Agency codes:

   BGS: British Geological Survey
   DIAS: Dublin Institute of Advanced Studies

4. ‘m’ in component column represents a low frequency microphone.

5. ‘*’ next to station code indicates they have been removed from their original network and the signal transmitted to the Cumbria network.

6. ‘**’ next to station code indicates the station is also transmitting data to the Cumbria network.

BGS Seismology reports

WL/98/03	Walker, A.B. UK Earthquake monitoring 1997/98, BGS Seismic Monitoring and Information Service, Ninth Annual Report. June 1998.
WL/98/26	Musson, R.M.W., 1998. Historical seismicity of the Western Frontiers area, October 1998.
WL/98/31	Musson, R.M.W. and Ziska, H., 1998. A preliminary report on the seismicity of the Faroe Islands, December 1998.
WL/99/01	Walker, A.B. (ed), Ford, G.D., Galloway, D.D. and Simpson, B.A. Bulletin of British Earthquakes, 1998. March 1999.
WL/99/06	Galloway, D.D. and Henni, P.H.O., 1998. The Aviemore earthquake of 28 August 1995. January 1999.
WL/99/13	Lovell, J.H. & P.H.O. Henni. UK Historical Seismological Observatories (pre-1970) Version 3. March 1999.
WL/99/14	Lovell, J.H. A Catalogue of Archive Material associated with John Milne, F.R.S. March 1999.
WL/99/15	Lovell, J.H. The Dr ATJ Dollar Papers Held in the National Seismological Archive. March 1999.
WL/99/16	Henni, P.H.O., J.H Lovell & K.I.G. Lawrie. Seismological Bulletins held in the National Seismological Archive (NSA), Version 2. March 1999.
WL/99/17	Lovell, J.H., 1999. Scientific Visitors to John Milne's Observatory at Shide, Isle of Wight. March 1999.
WL/99/18	Henni, P.H.O. & K.I.G. Lawrie. The National Seismological Archive WWSSN Microfilm collection [Final report]. March 1999.

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

External Publications

Feignier, B., Mezcua, J., Baptie, B., Papaioannou, C., Schindelé, F., Bock, G., Smriglio, G. and Sleeman, R., 1998. A Rapid Warning System for Earthquakes in the European-Mediterranean Region. Final Report May 1996 – August 1998. EC Contract ENV4-CT96-0282.

Galloway, D.D. and Walker, A.B., 1999. A summary of earthquakes in 1998. The Society for Earthquake and Civil Engineering dynamics (SECED) Newsletter. Vol 13 No 1, February 1999.

Musson, R.M.W., 1998. Inference and assumption in historical seismology, Surveys in Geophysics, vol 19 no 2, pp 189-203.

Musson, R.M.W., 1998. A self-parsing file format for earthquake catalogue and data files, Seismological Research Letters, vol 69 no 3, pp 248-250.

Musson, R.M.W., 1998. On the use of Monte Carlo simulations for seismic hazard assessment, Proc. 6th US National Conf. on Eq. Eng., 12 pp.

Musson, R.M.W., 1998. Intensity assignments from historical earthquake data: issues of certainty and quality, Annali di Geofisica, vol 41, no 1, pp 79-91.

Musson, R.M.W., 1998. The Barrow-in-Furness earthquake of 15 February 1865: Liquefaction from a very small magnitude event, Pure and Applied Geophysics, vol 152, pp 733-745.

Musson, R.M.W., 1999. Historical earthquakes in Britain, NERC News, Spring 1999, pp 16-17.

Stewart, I.S., Firth, C.R., Rust, D.J. and Walker A.B., 1999. Interactions between glacial unloading, postglacial faulting and present-day seismicity in the Scottish Highlands. Proceedings of the European Union of Geosciences, April 1999, Strasbourg.

UK EARTHQUAKE MONITORING 1997/98 BGS SEISMIC MONITORING AND INFORMATION SERVICE: NINTH ANNUAL REPORT

A B Walker

The aims of the Service are to develop and maintain a national database of seismic activity in the UK for use in seismic hazard assessment, and to provide near-immediate responses to the occurrence, or reported occurrence, of significant events. Following a history of seismic monitoring over the past 29 years, 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 a major financial input from the Natural Environment Research Council (NERC). This Customer Group is listed in Annex A.

In the ninth year of the project (April 1997 to March 1998), two additional strong motion instruments and four large capacity data storage disks have been installed. Some gaps still remain in station coverage; notably in Northern Ireland. Other areas covered by site-specific networks in northern Scotland, Outer Hebrides and the Orkney Islands, are vulnerable to closure owing to their dependency on funds from commissioning bodies.

Some 235 earthquakes were located by the monitoring network in 1997, with 33 of them having magnitudes of 2.0 or greater and 37 reported to be felt by people. The largest felt earthquake in the reporting year (April 1997 to March 1998), with a magnitude of 2.8 ML, occurred near Dartmouth, Devon, on 16 October 1997. It was felt over an area of 1400 km^2 and the maximum intensity in the epicentral region was 4 EMS (European Macroseismic Scale, Annex H). The largest offshore event was in the northern North Sea on 13 May 1997, with a magnitude of 3.4 ML. In addition to earthquakes, BGS frequently receives reports of seismic events, felt and heard, which on investigation prove to be sonic booms, in coalfield areas, where much of the activity is probably induced by mining (eg Newcastle-Under-Lyme) or spurious. During the reporting period, data on two controlled explosions and six sonic events were processed and reported upon following public concern or media attention.

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

The potential of the network's data links and computing capabilities to provide an environmental monitoring capacity has been explored further using additional sensors. These now include radioactivity, ozone, sulphur dioxide and NOx gases. This area of Research and Development has been enhanced through an informal linkage with the Institute of Terrestrial Ecology based at the Bush Estate near Edinburgh.

HISTORICAL SEISMICITY OF THE WESTERN FRONTIERS AREA

R M W Musson

This report describes investigations made into the historical seismicity of the area to the north and west of Scotland, often referred to, in the context of hydrocarbons exploration, as the Western Frontiers. Since this area is mostly sea, there is a limit to the amount of historical work that can be done. The investigation made concentrated on examining historical archive material in the old counties of Sutherland and Caithness, also the Orkneys Islands, the Shetlands, and the Outer Hebrides, supplemented to some extent by material from other relevant archives (e.g. the British Library Newspaper Dept. at Colindale). Since these are the regional archives that are of relevance to possible Western Frontiers seismicity, all historical earthquakes reported for this area are discussed, in order to give a regional perspective on the historical seismicity and levels of documentation. A number of hitherto unknown earthquakes were found, including one in 1686 felt only on the island of Borrera (St Kilda).

The results show that the seismicity of the area is very low even by UK standards. Consideration of the state of historical knowledge of the area suggests that no significant, damaging earthquake has occurred in Caithness, Orkney, Shetland or Eastern Sutherland since at least as far back as 1600. The seismic history of Western Sutherland and the Hebrides, however, is more uncertain, and a magnitude 4 ML earthquake occurring before 1830, or possibly even later, would quite likely go unreported. With increasing distance from shore, the likelihood of observing historical earthquakes decreases rapidly; however, one can be reasonably confident that no very large earthquake has occurred in the offshore rift systems in the period after 1600. As to seismicity before 1600, no conclusions can be drawn, as historical records are too scarce before this date.

A PRELIMINARY REPORT ON THE SEISMICITY OF THE FAROE ISLANDS

R M W Musson and H Ziska

The Faroe Islands are in an area of low seismicity; very little earthquake activity is known there. However, because of possible undersea slope stability problems, even low levels of seismic activity in the waters between the Faroes and the British Isles are of concern to those involved with offshore hydrocarbon exploration. Also, to some extent it can be argued that because no investigation of Faroes seismicity has hitherto been made, coupled with the difficulty of observing offshore seismicity, the seismicity of this area should be characterised as unknown as much as low. This report reviews what little is presently known about the seismicity of the Faroes as a prelude to a thorough study.

A sequence of small earthquakes was observed on Suđuroy in 1967, but two earlier events investigated that might have been attributed to earthquakes were probably not seismic in nature. Two historical works consulted on the natural history of the Faroes do not mention earthquakes having occurred there.

BULLETIN OF BRITISH EARTHQUAKES 1998

A B Walker (editor)

There have been 201 earthquakes located by the monitoring network during the year, with 31 of them having magnitudes 2.0 ML or greater. Of these, 8 are known to have been felt, together with a further 22 smaller ones, bringing the total to 30 felt earthquakes in 1998.

The largest onshore earthquake occurred on 3 May, with a magnitude of 3.5 ML; and was located near Jura (Appendix A1). A macroseismic survey was carried out and 240 responses were received. The earthquake was felt over an area of 12,000 km^2. The highest intensities were reached on the Islands of Colonsay and Jura, where an intensity of 4 EMS was assigned from reports describing “the whole house shaking”, “loud bangs and rumbles”, and “objects rattling and falling down”. The earthquake was felt throughout most of Argyll and Bute, as far north as the Glencoe area, towards the Isle of Arran in the east and Southend, Kintyre in the south. This is the first event that has been felt in the area since the magnitude 3.0 ML Colonsay earthquake, on 26 January 1990, which was felt with intensities of at least 4 EMS in the epicentral area.

The largest offshore earthquake occurred in the southern North Sea on 16 May. It had a magnitude of 3.8 ML and was located approximately 60 km NE of Great Yarmouth. The Coastguard, Police and local gas and oil rig operators were contacted but no felt reports were received. A further six events occurred in the North Sea area during the year, with magnitudes between 1.7 and 2.8 ML, and were located using both the BGS and Norwegian networks.

Near Onich, Highland, an earthquake, with a magnitude of 1.5 ML, occurred on 8 January. It was felt in the village of Onich, where local residents described “a large rumble like thunder”, “the house trembled” and “we thought it was a landslide” indicating an intensity of at least 3 EMS.

On 27 January, an earthquake, with a magnitude of 3.1 ML, occurred in the Strait of Dover. The Dover Coastguard and LDG in France were contacted, but both confirmed that no felt reports were received.

On 8 February, an earthquake, with a magnitude of 2.4 ML, occurred 15 km south of Penzance, Cornwall. Felt reports were received from Penzance, Land’s End and St. Ives, which described its effects as “sounded like a train under the house” and “light fittings rattled”, indicating an intensity of at least 4 EMS.

On 11 February, an earthquake with a magnitude of 2.3 ML, occurred in the Cwmbran area of Gwent. It was felt throughout Cwmbran and Newport with intensities of at least 3 EMS. Felt reports described “windows and doors rattling” and “felt like the wall was moving”. In 1974, the same area was affected by two felt events, the largest with magnitude 4.1 ML, which caused damage to chimneys and roofs.

On 5 March, two earthquakes, with magnitudes of 1.9 and 1.7 ML, occurred in the Killin area of the Central region of Scotland. Felt reports were received from Killin, Balquhidder and Glen Lochay which described “loud rumble like an airplane flying past” and “loud rumbling sound”, indicating intensities of at least 3 EMS.

Near Oban, Strathclyde, an earthquake, with a magnitude of 2.7 ML, occurred on 7 March. It was felt throughout the Oban area, where many people described “we were woken up from sleep” and “we heard a loud bang”, indicating intensities of at least 4 EMS in the epicentral area.

On 3 April, an earthquake, with a magnitude of 1.1 ML, occurred in the Annan area of the Dumfries and Galloway region of Scotland. It was recorded on the strong motion instrument, some 3 km away, where accelerations of 3.7, 8.2 and 8.4 mm/s^2, for the vertical, NS and EW components, respectively, were measured.

On 31 May, two earthquakes, with magnitudes of 2.6 and 1.7 ML, occurred 8 minutes apart, in the Bristol Channel; no felt reports were received. These are the largest events in the area since the magnitude 2.8 ML Bristol Channel earthquake, on 1 January 1994, which was felt with intensities of at least 4 EMS in the epicentral area.

On 23 June, an earthquake, with a magnitude of 3.5 ML, occurred in the north Atlantic near Hatton Bank, some 540 km west of the Outer Hebrides. It was located using stations from northern Scotland and Iceland and represents the first seismicity to be detected in the area.

Two felt earthquakes with magnitudes of 2.0 and 1.4 ML, occurred in the Locharbriggs area of Dumfries and Galloway, with intensities of at least 3 EMS on 21 and 23 July, respectively. Felt reports described “a rumble lasted 5-10 seconds and neighbours rushed into the streets” and “the whole house shook”. A fault plane solution of the largest event showed dominant strike slip motion on planes striking north-south or east-west (Appendix A2).

Near Beauly, Highland, two earthquakes, with magnitudes of 0.9 and 1.1 ML, occurred on 28 September. They locate in an area which historically has been active (two earthquakes with magnitudes of 5.1 ML on 13 August, 1816 and 18 September, 1901) but which has remained quiet since then.

On 16 October, an earthquake, with a magnitude of 2.7 ML, occurred in the Menai Straits, Gwynedd (Appendix 3). A macroseismic survey was carried out and questionnaires were placed in a local weekly newspaper, resulting in 41 replies which indicated a maximum intensity of 4 EMS. The earthquake was felt in Port Dinorwic, Caernarvon, Bangor and Llangefni where residents described “heard a loud rumble”, “the ground shook” and “the house shook”.

Near Doune, Central Scotland, one earthquake was detected during 1998 with a magnitude of 1.2 ML. It was not felt but located in the same area as the swarm of events which occurred in 1997, with magnitudes between 0.9 and 2.7 ML, of which six were felt by local residents.

A swarm of ten earthquakes, two felt by local residents, were detected in the Blackford area of Tayside during 1998, with magnitudes ranging between 0.4 and 2.2 ML. The largest, occurred on 26 March and was felt in Blackford, Alva, Gleneagles and Glendevon. The felt reports described “the whole house and furniture shook” and “felt like an underground explosion”, indicating intensities of at least 3 EMS. This is an area that has continued to be active; 49 events occurred in 1997, of which five were felt by local residents. In 1979, the magnitude 3.2 ML Ochil Hills earthquake was felt with a maximum intensity of 5 EMS.

In North Wales, seven events with magnitudes between 0.1 to 0.8 ML, were located on the Lleyn Peninsula, in the same area and at similar depths 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 central Scotland, Yorkshire, Staffordshire, West Midlands and Nottinghamshire continued to experience shallow earthquake activity which is believed to be mining induced. Some 54 coalfield events, with magnitudes ranging between 0.6 and 2.0 ML, were detected in the year. Sixteen of these were reported felt by local residents.

Near Newcastle-under-Lyme, Staffordshire, 24 shallow events occurred with magnitudes between 0.9 and 1.6 ML. Seven of these events were felt by local residents in the Keele, Whitmore and Newcastle-under-Lyme areas of Staffordshire.

Seven events, with magnitudes between 0.8 and 1.8 ML, were located near Clackmannan in the central region of Scotland. Four of these were felt by local residents in Clackmannan, Coalsnaughton, Dollar and Shannockhill. This is an area which has experienced many such mining induced events in the past.

THE AVIEMORE EARTHQUAKE OF 28 AUGUST 1995

D D Galloway and P H O Henni

On 28 August 1995, an earthquake, with a magnitude of 2.7 ML, occurred near Aviemore, Highland. It was felt over approximately 1400 km^2 (Isoseismal 3) and the maximum intensity was 4 EMS (European Macroseismic Scale, Grünthal 1993, Appendix A) which was observed at Aviemore, Avielochan, Boat of Garten, Carrbridge, Dulnain Bridge, Granton-on-Spey and Kincraig. Slight damage (small cracks in plaster) was reported at Aviemore and Boat of Garten.

The location parameters of the event were determined using phase data from the BGS seismograph networks in Moray, Kyle and LOWNET (around Edinburgh). The earthquake had an epicentre approximately 7 km NNW of Aviemore and a computed focal depth of 8.8 km in the upper crust.

UK HISTORICAL SEISMOLOGICAL OBSERVATORIES (PRE-1970) VERSION 3

J H Lovell & P H O Henni

The National Seismological Archive (NSA), maintained by the British Geological Survey (BGS) in Edinburgh, has undertaken an initiative to publish as much information as possible on historical seismological observatories in the UK. Examination of material curated in the NSA, enquiries to local libraries, museums and other public bodies, and searches of published journals, has revealed much new information. Updates have been made to many observatory entries, and newly found observatories described where possible. This version of the report is also presented in an updateable form on the Internet

A CATALOGUE OF ARCHIVE MATERIAL ASSOCIATED WITH JOHN MILNE, F.R.S.

J H Lovell

A search has been made for archive material associated with John Milne. His archives are dispersed throughout the UK, and have been augmented by additional collections from later workers. A catalogue has been made of these surviving archives, and is presented as a guide to researchers, in the hope of stimulating interest in Milne and finding hitherto unknown material.

THE DR ATJ DOLLAR PAPERS HELD IN THE NATIONAL SEISMOLOGICAL ARCHIVE

J H Lovell

The seismological and other collections of Dr ATJ Dollar, held in the National Seismological Archive (NSA), have been examined and catalogued as part of an NSA initiative on the study of the history of seismology. A large amount of previously unknown detail on UK seismology in the first half of this century has been revealed, and is now being incorporated into a series of reports.

SEISMOLOGICAL BULLETINS HELD IN THE NATIONAL SEISMOLOGICAL ARCHIVE (NSA), VERSION 2

P H O Henni, J H Lovell and K I G Lawrie

This report provides a reference work to the bulletin holdings of the National Seismological Archive at BGS. The collection includes over 14,500 bulletins from the UK and other countries. The full catalogue is available as an on-line searchable database; the present report is a summary that allows the extent of the holdings to be examined.

SCIENTIFIC VISITORS TO JOHN MILNE'S OBSERVATORY AT SHIDE, ISLE OF WIGHT.

J H Lovell

John Milne's Visitors' Book is a record of about 2000 visitors received at his observatory at Shide, Isle of Wight between 1895 and 1919, and by the Oxford Observatory until 1931 after Milne's work was transferred there in 1919. As part of studies currently being undertaken of the history of seismology in the UK, an abstract has been prepared of those visitors with known and probable scientific associations, and of several other notable visitors. It is presented as a testament to Milne's scientific and personal appeal, and in the hope of discovering lost archival material.

THE NATIONAL SEISMOLOGICAL ARCHIVE WWSSN MICROFILM COLLECTION [FINAL REPORT]

P H O Henni and K I G Lawrie

The worldwide Standard Seismograph Network operated between 1966 and 1990 and produced a huge collection of seismograms (over 3,000,000) over this period. A nearly complete collection is held by of the National Seismological Archive at BGS for the benefit of researchers. It is one of the very few such holdings in the world. This report provides a final definitive catalogue of the NSA's holdings. An on-line database has also been made available.

A RAPID WARNING SYSTEM FOR EARTHQUAKES IN THE EUROPEAN-MEDITERRANEAN REGION

B Feignier, J Mezcua, B Baptie, C Papaioannou, F Schindelé, G Bock, G Smriglio, and R Sleeman

Every year a few damaging earthquakes occur in the European-Mediterranean region (e.g., the recent destructive events in Mascara, Algeria on 18/08/1994, Kozani, Greece on 13/05/1995, Aeghion, Greece on 15/06/1995, Annecy, France on 15/07/1996 among others). It is therefore indispensable to operate a real-time warning system in order to provide rapidly reliable estimates of the location, depth and magnitude of these seismic events. Their basic hypocentral coordinates are extremely important both for the scientific community and for the European and national authorities dealing with natural hazards and relief organization. Since most of the epicentres are located in and around the Mediterranean Sea, as displayed on the cover page of this report for the period 1964 - 1992 (ISC catalogue), such a monitoring system must be operational at the European scale. This system must rely on a continuous monitoring of the seismicity and real-time location routines must give accurate results even for medium-size earthquakes.

In order to provide this information in a timely manner, the European-Mediterranean Seismological Centre (EMSC) started federating a network of seismic networks exchanging their data in quasi real-time a few years ago. In the framework of this project, it was intended to build on this system by connecting new networks and by improving the data processing in order to achieve higher accuracy in the determination of the earthquake focal parameters. These enhancements would then allow the EMSC to rapidly provide relevant information regarding earthquakes of magnitudes above 5.0 occurring in the European-Mediterranean region.

Five meetings, gathering all the participants, have been held during this 28-month project. These meetings were also attended by an external advisor, Dr. Mayer-Rosa, whose role was to provide advice and guidance to the participants. This external help proved very useful in streamlining efforts and initiatives within the project. At the end of the project, it was decided by the participants to organize an international workshop to publicize the results obtained. The topic of « Rapid Warning Systems for Earthquakes » was selected by the European Seismological Commission (ESC) for a specific workshop during the 26th ESC General Assembly which took place in Tel Aviv from August 23 to 29, 1998. This workshop was well-attended and provided the ideal forum for informing European seismologists of the project results.

This final report first describes the project rationale and objectives. Then, the project major achievements concerning data transmission, processing and access are detailed. Finally, case studies of earthquakes which occurred during the project are presented in order to illustrate the numerous improvements brought to the overall procedure.

SUMMARY OF EARTHQUAKES IN 1998

D D Galloway and A B Walker

Overseas

This year was not exceptional in terms of worldwide earthquakes (Figure 1). There was one 'great' earthquake (magnitude over 8.0), five 'major' earthquakes (magnitudes between 7.0 and 7.9) and 59 'strong' earthquakes (magnitudes between 6.0 and 6.9). These numbers are less than the long-term averages for these magnitude ranges, which are 1, 18 and 120, respectively. The number of people killed by earthquakes during 1998 was 8,930 (Table 1), which is consistent with the long-term average of 8,700.

The two most disastrous earthquakes during the year occurred on 4 February and 30 May, with magnitudes of 6.1 and 6.9 Ms, respectively, in the Hindu Kush region near the Afghanistan and Tajikistan border. Between them they caused the deaths of at least 6,323 people (approximately 70% of the death total for 1998), injured many thousands more, destroyed or damaged over 9,000 homes leaving many thousands homeless in the Badakhshan and Takhar Provinces. In this same region, on 20 February and 11 December, earthquakes with magnitudes of 5.8 and 5.1 Mb, respectively resulted in the deaths of 6 more people, and the February event induced an avalanche which destroyed 35 homes and left 300 people homeless.

The one ‘great’ earthquake of the year, with a magnitude of 8.0 Ms, occurred on 25 March in the Balleny Islands region in the Southern Ocean, Antarctica. No damage or casualties were reported due to the earthquake occurring in a remote, sparsely populated area.

The year started off with a destructive earthquake in the Shangyi and Zhangbei area of NE China on 10 January. It had a magnitude of 5.8 Mb and killed 70 people, injured 11,500 more and damaged over 70,000 homes leaving 44,000 families homeless. Damage to parts of the Great Wall of China in NW Hebei Province was also reported. The same day, a magnitude 6.2 Ms earthquake occurred in Guatemala and injured 24 people in Guatemala City and in the Quezaltenango and San Marcos Departments.

In Austria, on 12 April, one person was killed (as a result of a heart attack) at Bovec, Slovenia during a magnitude 5.7 Ms earthquake in the region. Over 700 people were left homeless in the Bovec-Kobarid area, Slovenia, after damage to buildings and landslides occurred. Minor damage also occurred at Arnoldstein, Austria. The earthquake was felt strongly throughout Austria, Slovenia and NE Italy as well as in parts of Croatia, Germany and Hungary.

On 14 March, an earthquake with a magnitude of 6.9 Ms, killed 5 people and caused injury to 50 others in Golbaf, northern Iran. Over 2,000 houses were destroyed, 10,000 people were left homeless and 1,200 livestock were killed. Water, electricity and communications were also severely damaged or disrupted in the area.

In Perugia, Central Italy, on 26 March, one person died of a heart attack during a magnitude 5.4 Mb earthquake in the area. Additional minor damage to buildings, already weakened by the earthquakes of 26 September 1997, and their aftershocks, was reported. A week later, on 3 April, a magnitude 5.1 Mb earthquake occurred in the same region and caused injury to five people and damaged or destroyed over 300 homes.

In northern Iran, an earthquake, with a magnitude of 5.7 Ms, killed 12 people, caused injury to 20 more and severely damaged 600 homes in the area between Birjand and Gonabad on 10 April.

On 22 May, in the Aiquile-Totora area of central Bolivia, an earthquake with a magnitude of 6.6 Ms caused extensive damage to approximately 80% of the buildings at Aiquile and 70% at Totora. At least 105 people were killed and over 150 were injured. This was, in fact, a complex earthquake set with at least two larger events occurring about 8 and 12 seconds after the first.

In the Adana and Ceyhan area of Turkey, on 27 June, an earthquake with a magnitude of 6.2 Ms killed at least 145 people and injured 1,500 more. Over 17,000 homes were destroyed and 6 major buildings collapsed in the Adana Province. This earthquake was also felt in Cyprus, Israel and Syria. A week later, on 4 July, over 500 people were injured in the same area during a magnitude 5.0 Mb earthquake. Another two damaging earthquakes occurred in Turkey during the year. The first, on 13 April, with a relatively small magnitude of 4.8 Ms, injured 11 people and damaged or destroyed several buildings at Karliova. The second, on 14 December, with a magnitude of 4.5 Mb, injured 2 people, collapsed 20 houses and damaged 118 more at Kayseri.

On 9 July, 10 people were killed, more than 100 were injured and over 1,000 were left homeless on Faial as a result of a magnitude 6.0 Ms earthquake in the Azores Islands. Some minor damage also occurred on Pico and Terceira.

On 17 July, an earthquake with a magnitude of 5.5 Mb, occurred in Taiwan. It killed 5 people, injured 27 more, caused damage to several buildings and induced landslides in Chia-i County.

A damaging earthquake, near the coast of Papua New Guinea, on 17 July, with a magnitude of 7.1 Ms, resulted in the deaths of at least 2,183 people. Thousands more were injured, approximately 10,000 were made homeless and hundreds are still missing as a result of a tsunami (one of the most devastating this century) generated in the Sissano area. Maximum wave heights were estimated at 10 metres. Several villages were completely and others were extensively damaged. Further afield, in Japan, wave heights of up to 15 cm were observed, and in New Zealand, up to 6 cm.

On 29 July, near the coast of central Chile, an earthquake with a magnitude of 6.3 Mb, killed 2 people and injured many more. Four miners were also injured when trapped underground at the Boton de Oro gold mine.

In Ecuador, on 4 August, 3 people were killed and forty injured in the Bahia de Caraquez-Canoa area. Approximately 60% of the buildings at Canoa were severely damaged. Electricity, telephone and water services were widely disrupted and the majority of buildings, with three or more stories, were damaged at Bahia de Caraquez. Considerable damage was reported from many other parts of western Manabi Province and landslides blocked the roads between Bahia de Caraquez and Canoa.

Several fatal and damaging earthquakes occurred in Southern Xinjiang, China during 1998. The largest, on 27 August, with a magnitude of 6.4 Ms, killed 3 people, injured 7 others and destroyed or damaged over 21,000 houses in Jiashi County. The others occurred on 19 March, 28 May, 28 July and 2 August, with magnitudes of 5.6 Ms, 5.6 Ms, 5.3 Mb and 5.6 Mb, respectively. A further 30 people were injured, thousands of buildings were destroyed leaving thousands homeless and over 5,000 livestock were killed as a result of these earthquakes.

In southern Italy, approximately 430 km SE of the damaging earthquakes of 26 September 1997, an earthquake, with a magnitude of 5.2 Mb, killed 2 people, injured 12 more and damaged several buildings in the Castelluccio-Lauria area on 9 September.

In Indonesia, on 28 September, one person was killed, many more were injured and over 200 were made homeless as 38 buildings collapsed and 62 were damaged in the Malang area, Jawa during a magnitude 6.3 Mb earthquake.

In the NW Balkan region, one person died from a heart attack, 17 people were injured and some damage occurred in the Valjevo-Belgrade area, Yugoslavia as a result of a magnitude 5.3 Ms earthquake on 29 September.

On 18 October, near the coast of Nicaragua, an earthquake with a magnitude of 4.4 Ms, injured 3 people, destroyed 2 houses and severely damaged 45 others in the Ticuantepe area. This was the largest in a swarm of over 200 events which occurred in the area on 18 and 19 October.

In southern Iran, on 13 November, an earthquake, with a magnitude of 5.3 Mb, killed 5 people, injured 105 more, damaged about 850 houses and caused several landslides in the Bigherd-Khonj area.

On 19 November, 5 people were killed and at least 1,543 others were injured in the Huaping, Ninglang and Yongsheng Counties of Yunnan, China. Extensive damage to roads and houses occurred in the epicentral area and landslides blocked a river in the region. Prior to this event, on 26 October, an earthquake with a magnitude of 5.6 Ms, injured 28 people and damaged over 700 buildings in the Lijiang area of Yunnan, China.

On 29 November, an earthquake with a magnitude of 7.7 Ms, occurred in the Ceram Sea, Indonesia, killing 34 people and injuring 153 others on Mangole and Taliabu, and killing another 7 and injuring 8 more on Manado, Sulawesi. A timber factory sustained extensive damage, dozens of houses were destroyed and landslides and rockslides were also reported on Mangole. The earthquake was felt throughout many islands of Indonesia.

The UK summary of earthquakes is covered in the summary for the 1998 bulletin of British earthquakes above.

INFERENCE AND ASSUMPTION IN HISTORICAL SEISMOLOGY

R M W Musson

The principal aim in studies of historical earthquakes is usually to be able to derive parameters for past earthquakes from macroseismic or other data and thus extend back in time parametric earthquake catalogues, often with improved seismic hazard studies as the ultimate goal. In cases of relatively recent historical earthquakes, for example, those of the 18th and 19th centuries, it is often the case that there is such an abundance of available macroseismic data that estimating earthquake parameters is relatively straightforward. For earlier historical periods, especially medieval and earlier, and also for areas where settlement or documentation are sparse, the situation is much harder. The seismologist often finds that he has only a few data points (or even one) for an earthquake that nevertheless appears to be regionally significant.

In such cases, it is natural that the investigator will attempt to make the most of the available data, expanding it by making working assumptions, and from these deriving conclusions by inference (i.e. the process of proceeding logically from some premise). This can be seen in a number of existing studies; in some cases extremely slight data are so magnified by the use of inference that one must regard the results as tentative in the extreme. Two main types of inference can be distinguished. The first type is inference from documentation. This is where assumptions are made such as: "the absence of a report of the earthquake from this monastic chronicle indicates that at this locality the earthquake was not felt". The second type is inference from seismicity. Here one deals with arguments such as "all recent earthquakes felt at town X are events occurring in seismic zone Y, therefore this ancient earthquake which is only reported at town X probably also occurred in this zone".

While in many cases such assumptions may very well be correct, they are usually not testable - or at least untested. Furthermore, it is possible to produce numerous contrary examples. It is concluded that the use of inference to amplify poor data must be made very transparent to the end user of the results, to avoid misleading appearances of accuracy. In many cases it may be best to abandon the quest for parameters altogether and admit that the data are inadequate.

A SELF-PARSING FILE FORMAT FOR EARTHQUAKE CATALOGUE AND DATA FILES

R M W Musson

In modern seismology it is a fairly common need to process files of earthquake epicentres by computer in order to perform some task, which might be as simple as merely plotting them on a map, or might be some more complex statistical analysis connected with seismic hazard or earthquake prediction research. The software used for such analyses is usually highly specialised; it cannot be purchased from commercial sources, and must be written specially for the task in hand, usually by the seismologist himself or a colleague. The tendency is therefore for different individuals to use their own input format for earthquake catalogue data. Previously the only moves to try and improve matters have been the introduction of new “standard formats”, which merely add to the number of formats available.

This paper demonstrates a system for handling earthquake data input such that a program written using this system can read virtually any data file that meets a few basic standards, whatever the format. This is accomplished by prefacing the data file with a single line of format coding, which the program reads and uses to parse the rest of the data file.

ON THE USE OF MONTE CARLO SIMULATIONS FOR SEISMIC HAZARD ASSESSMENT

R M W Musson

The use of Monte Carlo techniques in seismic hazard analysis is best known as a means of treating uncertainty in Probabilistic Seismic Hazard Assessment (PSHA) calculations. Different input parameters for the PSHA calculations are selected using Monte Carlo techniques rather than a logic tree. However, Monte Carlo techniques can also be used in a more direct manner: they can be used to generate large numbers of synthetic earthquake catalogues from which the probability of different levels of ground motion can be derived. This method is not new, but seems to be under-utilised. While it may lack the precision of conventional PHSA methods for low probability calculations, it has a number of advantages. The technique is very flexible. It is very easy to modify the form of the seismicity model used, for example, to introduce non-Poissonian behaviour, without extensive reprogramming. Uncertainty in input parameters can also be modelled very flexibly - for example, by the use of a standard deviation rather than by the discrete branches of a logic tree. In addition (and this advantage is perhaps not as trivial as it may sound) the simplicity of the method means that its principles can be grasped by the layman, which is useful when results have to be explained to people outside the seismological/engineering communities, such as planners and politicians.

INTENSITY ASSIGNMENTS FROM HISTORICAL EARTHQUAKE DATA: ISSUES OF CERTAINTY AND QUALITY

R M W Musson

The use of macroseismic data in assessing parameters for historical earthquakes for use in seismic hazard assessment, has thrown more attention on the way in which these data are treated. The processes involved in selecting which macroseismic data from a historical earthquake survive to the present day can be modelled as a series of filters, most of which are outside the control of the seismologist/historian, and which cause distortion in the resulting picture of the earthquake. The ways in which the data become distorted should be taken into account when interpreting the data as intensity values. One can usefully discriminate between the certainty of an intensity assignment (how well the data fits the scale) and the quality of an intensity assignment (how well one can trust that the value is a true reflection of what really happened). The expression of uncertainty is usually in the form of ranged intensity values; the expression of quality requires an extra symbol or rating of some sort. A system is presented for three types of quality problems: reliability of intensity assessment, locational certainty or uncertainty, and veracity of the original data. Each of these is treated as a binary variable, giving a final quality code ranging from 0 (best) to 7 (worst). This single integer quality code preserves three types of information which can then be expanded as required by computer programs designed to handle macroseismic data.

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

R M W Musson

High intensity and liquefaction phenomena are usually associated only with relatively large magnitude earthquakes. An earthquake in 1865 in the north west of England demonstrates that a sufficiently shallow small event can also produce liquefaction. The effects are well-documented in historical sources and include sand fountaining. Modern investigation is confined to documentary evidence owing to the tidal environment of the area where liquefaction occurred. Analysis shows that the felt area of the earthquake was probably only about 200 km^2; however, heavy damage occurred in the village of Rampside and the maximum intensity is assessed at 8. The magnitude was probably in the range 2.5-3.5 ML.

HISTORICAL EARTHQUAKES IN BRITAIN

R M W Musson

In areas of low seismicity such as the UK, modern instrumental monitoring provides an insufficient account of the distribution of earthquakes for use in seismic hazard estimates. By undertaking historical earthquake studies, in which the techniques of the historian are used in combination with those of the seismologist, earthquake catalogues can be extended back in time for several hundred years. The development of macroseismic methods of assessing earthquake parameters, correlated using modern macroseismic and instrumental data, means that such catalogues of historical earthquakes can be fully numerate.

INTERACTIONS BETWEEN GLACIAL UNLOADING, POSTGLACIAL FAULTING AND PRESENT-DAY SEISMICITY IN THE SCOTTISH HIGHLANDS

I S Stewart, C R Firth, D J Rust and A B Walker

Contemporary seismicity paints an enigmatic portrait of crustal movements in northern Britain. Although some seismic activity clusters on major arterial faults, such as the Great Glen Fault and Highland Boundary Fault, in regional terms earthquakes fail to illuminate tectonic lineaments or geological provinces. Instead, the region's moderate, low-magnitude (M<5) seismicity is concentrated in the western Highlands, where it is clustered in isolated pockets of activity rather than being diffuse. This regional skew in earthquake activity has recently been attributed to the effects of glaciation, since the centres of the extensive Devensian and the more local Younger Dryas stadial (Loch Lomond Readvance: 11,000 - 10,000 yr. BP) ice masses were located in the western Highlands. In particular, an apparent association between the distribution of contemporary seismicity, inferred postglacial faults and the Younger Dryas ice limits implies that the region's glacial inheritance continues to influence its present-day seismotectonics.

Preferential fault activity along former ice margins is not unexpected, since it is here that the crust responds differentially, from glacial rebound within the ice limits to minimal uplift (or even subsidence) of the ice-free areas beyond. Furthermore, zones of enhanced present-day seismicity in Kintail and around Ben Nevis coincide with areas where significant ice thicknesses accumulated during Younger Dryas times, suggesting that the spatial distribution of glacial loads are as significant as their geographic limits. Analysis of high-resolution airborne imagery and fieldwork in the Kintail region shows that postglacial surface displacements are not restricted to isolated, discrete faults, as highlighted by previous workers, but instead are distributed across a broad network of comparatively minor structures. The magnitude of inferred postglacial displacements, however, are considerably less than previouly reported estimates.

Although the results support a link between glacial loading and seismotectonics, in the absence of well-constrained focal mechanisms the nature of the interaction remains speculative. One possibility is that differential glacial unloading along ice margins 'opened up' the main basement faults allowing them to be now preferentially reactivated in the present-day tectonic regime. Another is that differential glacioisostatic movements continue around the former (Younger Dryas) ice margins, and that the associated low-level seismicity is an expression of residual glacial, rather than tectonic, deformation. These contrasting schemes ensure that the contemporary seismic hazard in the former glaciated terrain of northern Britain remains poorly understood.

SYNOPSIS OF EMS-92 INTENSITY SCALE

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

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

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

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

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

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

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

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

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

10 - **Very destructive**
Many ordinary buildings collapse.

11 - **Devastating**
Most ordinary buildings collapse.

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

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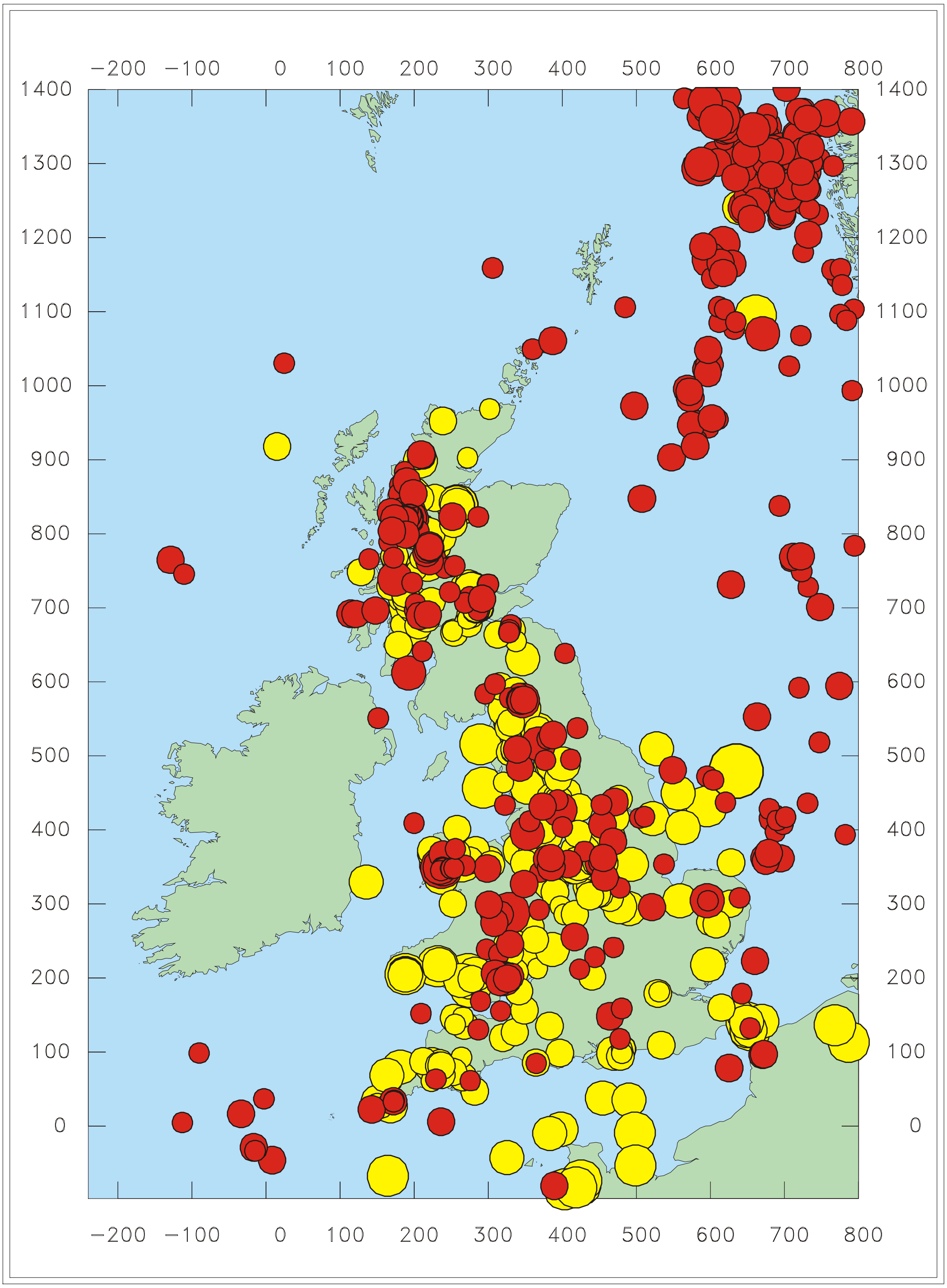
A complete description of the EMS-92 scale is given in: Grunthal, G., (Ed) 1993. European Macroseismic scale 1992 (up-dated MSK-scale). Cahiers du Centre European de Geodynamique et de Seismologie. Vol 7.

Natural Environment Research Council



UK Seismicity greater than 2.5 ML, 1382 - March 1999. Yellow circles denote historical seismicity (pre 1970).