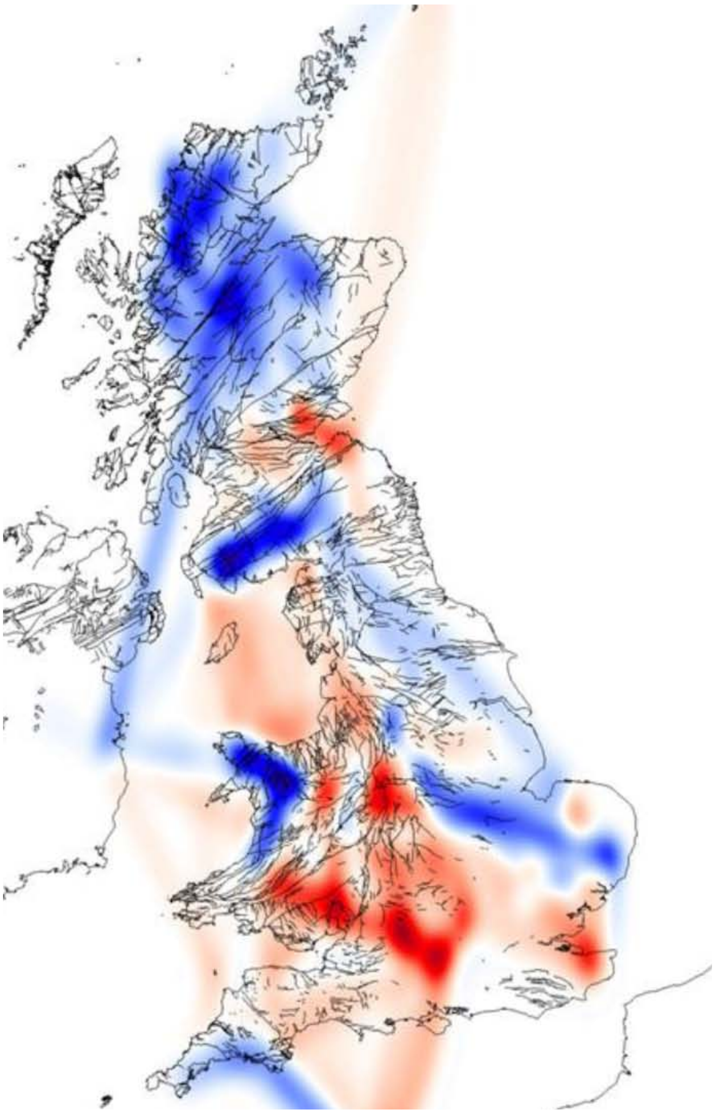
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

UK Earthquake Monitoring 2010/2011

BGS Seismic Monitoring and Information Service

Twenty-second Annual Report



BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT OR/11/031

UK Earthquake Monitoring 2010/2011

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Front cover

Group velocity map of the UK for 5 second period Rayleigh waves (from Nicholson, 2011)

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Summary

The British Geological Survey (BGS) operates a network of seismometers throughout the UK in order to acquire seismic data on a long-term basis. The aims of the Seismic Monitoring and Information Service are to develop and maintain a national database of seismic activity in the UK for use in seismic hazard assessment, and to provide near-immediate responses to the occurrence, or reported occurrence, of significant events. The project is supported by a group of organisations under the chairmanship of the Department of Communities and Local Government (DCLG) with major financial input from the Natural Environment Research Council (NERC).

In the 22nd year of the project, three new broadband seismograph stations were established, giving a total of 33 broadband stations. Real-time data from all broadband stations and nearly all other short period stations are being transferred directly to Edinburgh for near real-time detection and location of seismic events as well as archival and storage of continuous data. We have also upgraded data acquisition hardware at most broadband stations to improve local storage and data communications.

All significant events were reported rapidly to the Customer Group through seismic alerts sent by e-mail. The alerts were also published on the Internet (http://www.earthquakes.bgs.ac.uk). Monthly seismic bulletins were issued six weeks in arrears and compiled in a finalised annual bulletin (Galloway, 2011). In all reporting areas, scheduled targets have been met.

Three papers have been published in peer-reviewed journals. Seven presentations were made at international conferences. Three BGS internal reports were prepared along with four confidential reports. We have continued to collaborate widely with academic partners across the UK and overseas on a number of research initiatives.

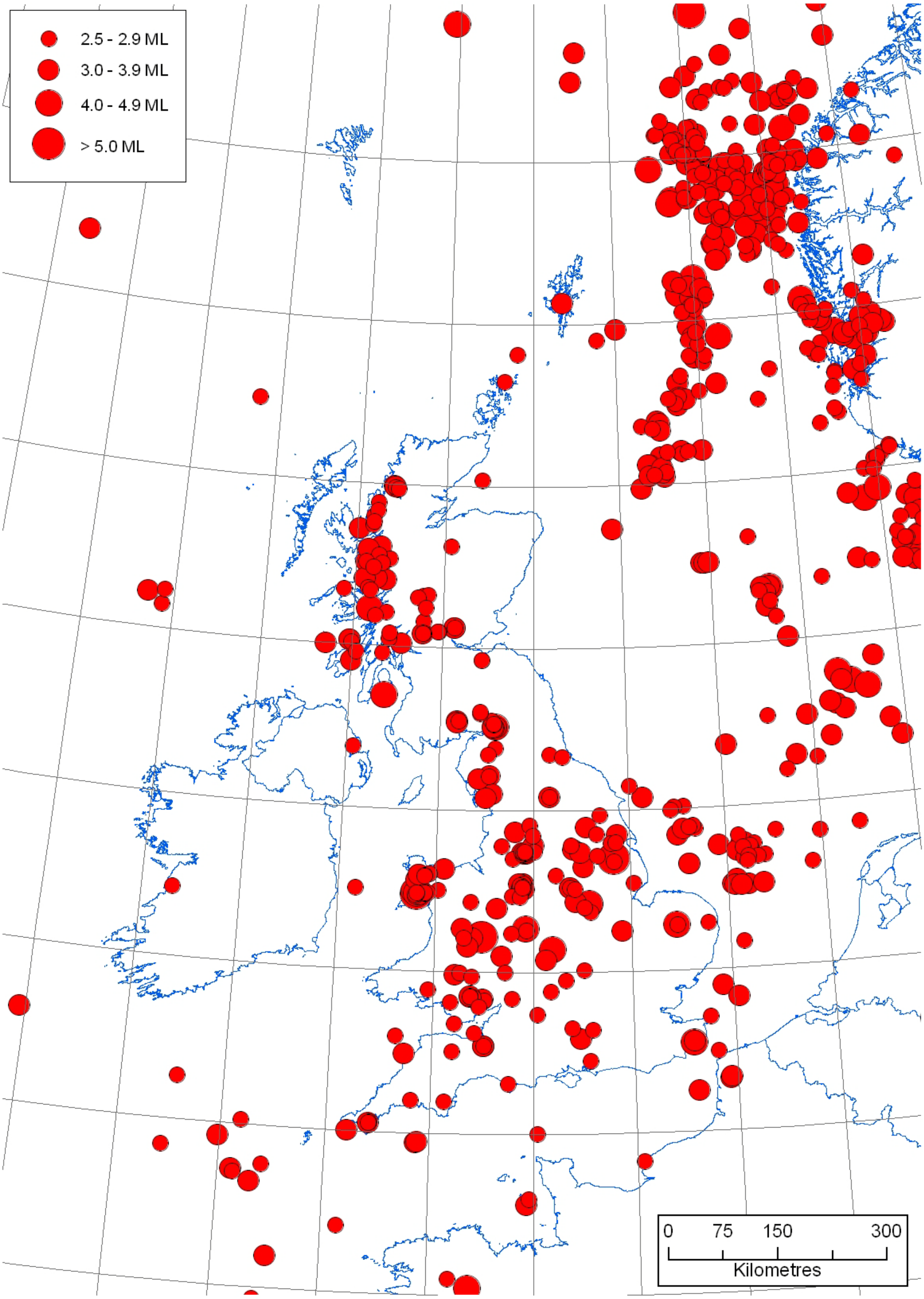
Introduction

The BGS Seismic 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 supporters of the project, drawn from industry and central and local government are referred to as the Customer Group.

Almost every week, seismic events are reported to be felt somewhere in the UK. A small number of these prove to be sonic booms or are spurious, but a large proportion are natural or mining-induced earthquakes often felt at intensities which cause concern and, occasionally, some damage. The Information Service aims to rapidly identify these various sources and causes of seismic events, which are felt or heard.

In an average year, about 150 earthquakes are detected and located by BGS with around 15% being felt by people. Historically, the largest known British earthquake occurred on the Dogger Bank in 1931, with a magnitude of 6.1 M_L. Fortunately, it was 60 miles offshore but it was still powerful enough to cause minor damage to buildings on the east coast of England. The most damaging UK earthquake known in the last 400 years was in the Colchester area (1884) with the modest magnitude of 4.6 M_L. Some 1200 buildings needed repairs and, in the worst cases, walls, chimneys and roofs collapsed.

Long term earthquake monitoring is required to refine our understanding of the level of seismic hazard in the UK. Although seismic hazard and risk are low by world standards they are by no means negligible, particularly with respect to potentially hazardous installations and sensitive structures. The monitoring results help 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, seismic monitoring provides objective information to verify the nature of seismic events or to confirm false alarms, which might result from locally generated instrument triggers.



Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 2011.

Introduction

Monitoring Network

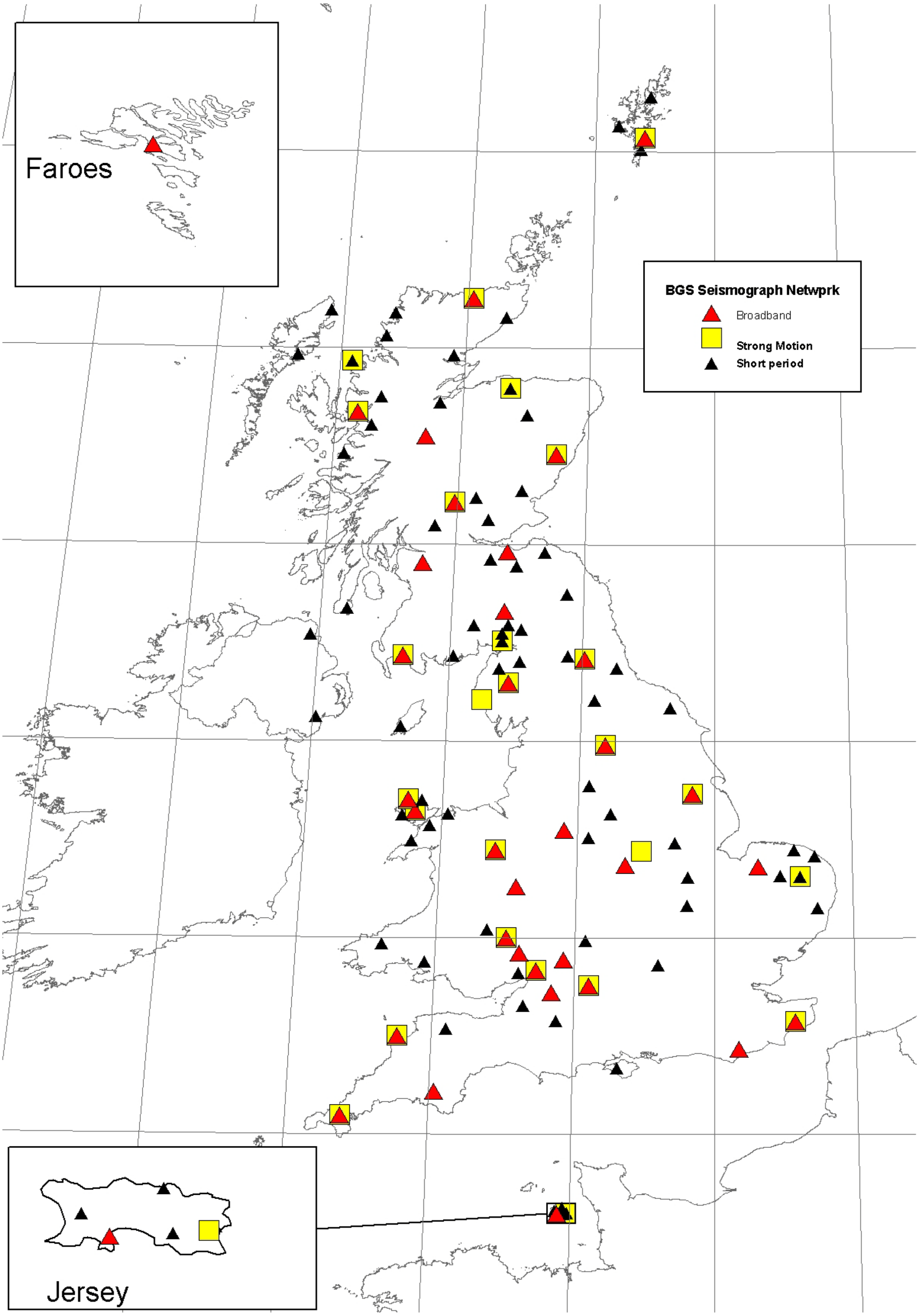
The BGS National Earthquake Monitoring project started in April 1989, building on local networks of seismograph stations, which had been installed previously for various purposes. By the late nineties, the number of stations reached its peak of 146 stations, with an average spacing of 70 km. We are now in the process of a major upgrade, with the installation of broadband seismometers that will provide high quality data for both monitoring and scientific research.

In the late 1960s BGS installed a network of eight seismograph stations centred on Edinburgh, with data transmitted to the recording site in Edinburgh by radio, over distances of up to 100 km. Data were recorded on a slow running FM magnetic tape system. Over the next thirty years the network grew in size, both in response to specific events, such as the Lleyn Peninsula earthquake in 1984, and as a result of specific initiatives, such as monitoring North Sea seismicity, reaching a peak of 146 stations by the late nineties.

The network was divided into a number of sub-networks, each consisting of up to ten 'outstation' seismometers radio-linked to a central site, where the continuous data are recorded digitally. Each sub-network was accessed several times each day using Internet or dial-up modems to transfer any automatically detected event to the BGS offices in Edinburgh. Once transferred, the events were analysed to provide a rapid response for location and magnitude.

However, scientific objectives, such as accurately measuring the attenuation of seismic waves, or accurate determination of source parameters, were restricted by both the limited bandwidth and dynamic range of the seismic data acquisition. The extremely wide dynamic range of natural seismic signals means that instrumentation capable of recording small local micro-earthquakes will not remain on scale for larger signals.

This year we have continued with our plans to upgrade the BGS seismograph network. Over the next few years we intend to develop a network of 40-50 broadband seismograph stations across the UK with near real-time data transfer to Edinburgh. These stations will provide high quality data with a larger dynamic range and over a wider frequency band for many years to come. So far, we have installed 33 broadband sensors at stations across the UK along with 26 strong motion accelerometers with high dynamic range recording for recording very large signals.



BGS seismograph stations, March 2011.

Achievements

Network Development

Broadband sensors with 24-bit acquisition are being deployed to improve the scientific value of the data and improve the services provided to customers. We continue to improve our near real-time data processing capability including the detection and location of significant seismic events in the UK and offshore area.

In the last year three new broadband stations were installed at: Invergeldie (near Comrie, Perthshire), Lambshiel (Teesdale) and Wylfa (Anglesey). This takes the total number of broadband stations operated by BGS to 33. Continuous data from all broadband stations are transmitted in real-time to Edinburgh, where they are used for analysis and archived. In addition, we receive continuous real-time data from all short period stations, except for stations in the Borders and Minch networks. Event data from these networks is downloaded using a dial-up connection.

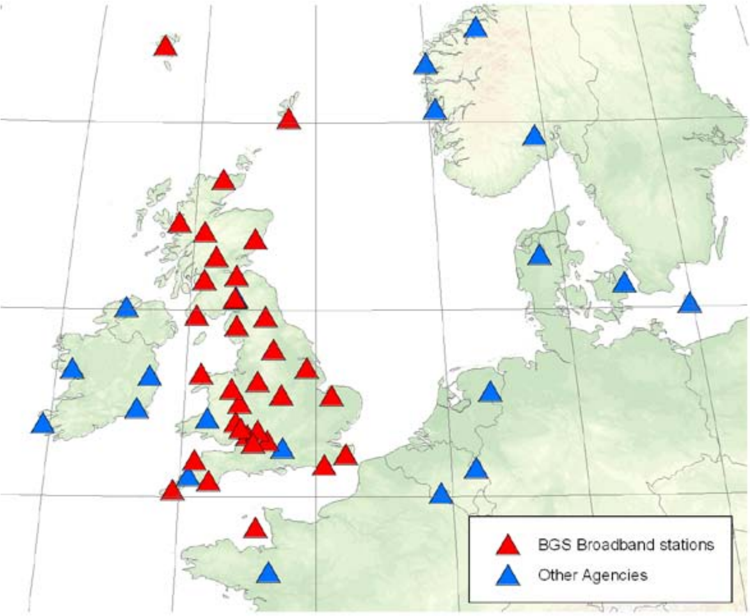
Work is almost complete on a new broadband station in Norfolk. In addition, we have carried out a site survey for a new broadband station in the Isle of Man. A station will be installed here in summer 2011.

Data acquisition hardware at most broadband stations was upgraded to improve local storage and data communications. New power reset units that allow remote power cycling of hardware have also been installed at a number of stations.

During September 2010, BGS worked with the Iceland Meteorological Office (IMO) to establish five new broadband stations around Eyjafjallajokull and Katla volcanoes. As a result, we now receive real-time data from these stations to help improve early warning and forecasting of any future eruptions of these volcanoes.

We maintain a pool of seismometers that can be rapidly deployed for studying aftershock sequences, earthquake swarms and specific studies. These instruments were deployed to capture aftershocks following the earthquakes at Folkestone and Market Rasen. In the case of Market Rasen, four instruments were deployed within 48 hours of the mainshock, and successfully recorded a number of aftershocks in the following months.

We have continued to improve our detection capability in offshore areas by incorporating data from seismic stations operated by European partner agencies into our near real-time processing. In particular, by including a number of new stations in Ireland we hope to improve detection capability in the southwest approaches and the Irish Sea.

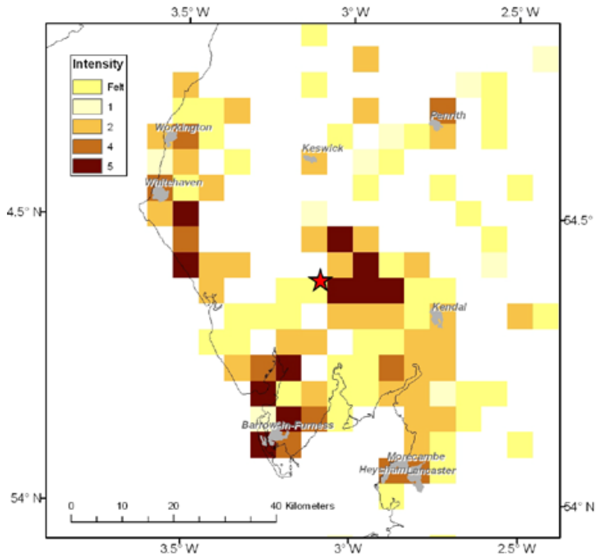


Real-time broadband stations used by BGS.

We are continuing to refine our use of the EarthWorm software (developed by the US Geological Survey and contributed to by BGS) for the automatic detection, location and notification of earthquake activity in the UK and immediate offshore area. Our analysts received alerts of both the Coniston earthquake (21/12/2010, 3.5 ML) and the Ripon earthquake (3/1/2011, 3.6 ML) within a few minutes of occurrence. This provides analysts with rapid notification of a possible event and allows them to quickly confirm that an event has happened and to manually analyse all available data. The automatic locations for both events were within 10 km of the final location determined by analysts.

Additionally, our EarlyBird alert system continues to provide rapid notification of potentially damaging earthquakes anywhere in the world using data from over 200 stations throughout the world.

Continuous data from all our broadband and most of our short period stations are now online within the BGS storage area network. The completeness of these data can be easily checked to gain an accurate picture of network performance. In general, we find that the data from most broadband stations are over 95% complete. Data losses result from failure of outstation hardware, communications problems, or failure of central data processing. The data acquisition is able to recover from short breaks in communications links to outstations by re-requesting missing packets of data from local data buffers, but failure of outstation hardware requires intervention by local operators or maintenance visits.



Macroseismic data from the Coniston earthquake, 21 December 2010.

Achievements

Information Dissemination

It is a requirement of the Information Service that objective data and information be distributed rapidly and effectively after an event. Customer Group members have received notification by e-mail whenever an event was felt or heard by more than two individuals.

Notifications were issued for 26 UK events within the reporting period, one of which was for an explosion near Stansted Airport, and for 29 global earthquakes. Notifications for all local earthquakes were issued to Customer Group members within two hours of a member of the 24-hour on-call team being notified. The alerts include earthquake parameters, reports from members of the public, damage and background information. In addition, three enquiries were received from Nuclear Power Stations after alarms triggered; Hartlepool on 10 October 2010 and Chapelcross, twice, on 31 October 2010. In each case a response was given within 15 minutes.

An up-to-date catalogue of recent events continues to be available on the Seismology web pages. This is updated whenever a new event is located. Our automatic macroseismic processing system remains a key part of our response to felt events and is used to produce macroseismic maps for the seismology web pages that are updated in near real-time as data is contributed. This was used to collate and process macroseismic data for a number of events in the course of the year. We received 693 replies following the Coniston earthquake on 21 December 2010 (3.5 ML), 1,228 after the Ripon earthquake on 3 January 2011 (3.6 ML) and 234 following the Glenuig earthquake on 23 January 2011 (3.5 ML).

Data from the questionnaires are grouped by location into 5x5 km squares using postcodes and an intensity value is assigned to each square, given at least five responses are received from any square. Where fewer responses are received (especially the case in sparsely populated areas) the intensity is either given as “felt” or “not felt” (which is also defined as intensity 1). These data are processed automatically to produce the macroseismic maps for the seismology web pages.

Preliminary monthly bulletins of seismic information were produced and distributed to the Customer Group within six weeks of the end of each month. The project aim is to publish on CD, the revised annual Bulletin of British Earthquakes within six months of the end of a calendar year. For 2010, it was issued in July 2011.

Collaboration and Data Exchange

Data from the seismograph network are freely available for academic use and we have continued to collaborate with researchers at academic institutes within the UK throughout the past year, as well as exchanging data with European and world agencies.

A PhD student at Edinburgh University, funded partially by BGS, has used ambient seismic noise recorded on broadband stations across the UK to derive the first surface wave group velocity maps of the UK using only ambient seismic noise. Another PhD student at Edinburgh University started a project to study and develop new methods to construct seismic signals from noise. A BGS CASE student at the University of Cambridge is using recordings of distant earthquakes to image upper mantle structure under the UK and investigate causes of regional uplift of the British Isles.

The European Mediterranean Seismological Centre (EMSC), BGS and others have continued to collaborate on development of online macroseismic surveys, now within the framework of an European Seismological Commission (ESC) working group in Internet Seismology. BGS is working with ETHZ, NORSAR, INGV and others on the SHARE project (Seismic Hazard Harmonisation in Europe) and hosted a Workshop in Edinburgh in March this year (2011). Scientists from five different countries attended to discuss problems of assessing seismic activity rates for major fault structures in Europe.

We are working closely with Concern Worldwide to explore scientific information needs and the dynamics of knowledge exchange within the contexts of both disaster preparedness and response.

During 2010, BGS worked with the Iceland Meteorological Office (IMO) to establish five new broadband stations around Eyjafjallajokull and Katla volcanoes to improve early warning capability for any future eruptions.

BGS data are exchanged regularly with European and world agencies to help improve source parameters for earthquakes outside the UK. Phase data for global and regional earthquakes are distributed to the (EMSC) to assist with relocation of regional earthquakes and rapid determination of source parameters for destructive earthquakes. BGS data for 34 events were supplied to the EMSC. EarlyBird automatic alerts are also sent to the EMSC. Phase data for global earthquakes are sent to both the National Earthquake Information Centre (NEIC) at the USGS and the International Seismological Centre (ISC), an agency providing definitive information on earthquake hypocentres. This year, data from 487 teleseismic events were sent. Data from the BGS broadband stations are transmitted to both ORFEUS, the regional data centre for broadband data, and IRIS (Incorporated Research in Seismology), the leading global data centre for waveform data, in near real-time.

Achievements

Communicating Our Science

An important part of the BGS mission is to provide accurate, impartial information in a timely fashion to our stakeholders, the public and the media. We promote understanding of Earth Sciences by engaging with schools through our "School Seismology" project and by creating dynamic web pages with background information and topical content.

This year we have continued to develop the way we present our seismic information on the web. As well as real-time data and rapid alert information, we have generated specific web pages for significant earthquakes in the UK and around the world. These document the parameters of these events and provide information on the tectonic setting and background seismic activity in the region. For example for the recent Tohoku earthquake in Japan, we created web content that provided detailed information on the earthquake, including video interviews with scientists, details of numbers and distribution of the aftershocks, the possibility of a tsunami in the British Isles and also a frequently asked questions page.

We organised a seismology session at one of Europe's largest science festivals, The British Science Festival, called 'Earthquake perception, protection and prediction'. This generated a huge amount of media interest and the story hit all of the UK's national papers.

Web pages were also generated to communicate our research such as 'Is earthquake activity increasing?', 'Are yesterday's earthquakes tomorrow's disasters?' and 'Creating "virtual seismometers" deep inside the Earth'.

We actively use Twitter, Facebook, Audioboo and YouTube to post earthquake alerts, to provide news of new web pages, and showcase podcasts and videos of our seismologists. Facebook also offers a way for the public to engage with us by asking questions related to various postings.

The UK School Seismology Project (UKSSP) continues to grow and create new partnerships. The aim of the project is to develop specific resources for teaching and learning seismology in UK schools, including an inexpensive seismometer that is robust enough to be used in schools, but still sensitive enough to record earthquakes from the other side of the world. These provide teachers and students with the excitement of being able to record their own real scientific data and help students conduct investigations using their own data.

Northern Ireland has now joined the UK school seismology project, in addition to exhibits set up at the W5 science centre in Belfast and the visitor centre at Marble Arch Caves, a total of six schools have been trained and provided with sensors making the project a truly national enterprise.

BGS assisted the National Science Learning Centre develop a Continuing Professional Development (CPD) course for teachers on "Earthquakes and other Natural Hazards" which has now run (with assistance from UKSSP staff) at three separate Science Learning Centres, receiving excellent feedback from teachers attending.

A second tranche of funding for the UKSSP has been won from the Petroleum Exploration Society of Great Britain, which will enable partnerships with eight university earth science departments across the UK to continue the roll out of resources to new schools.

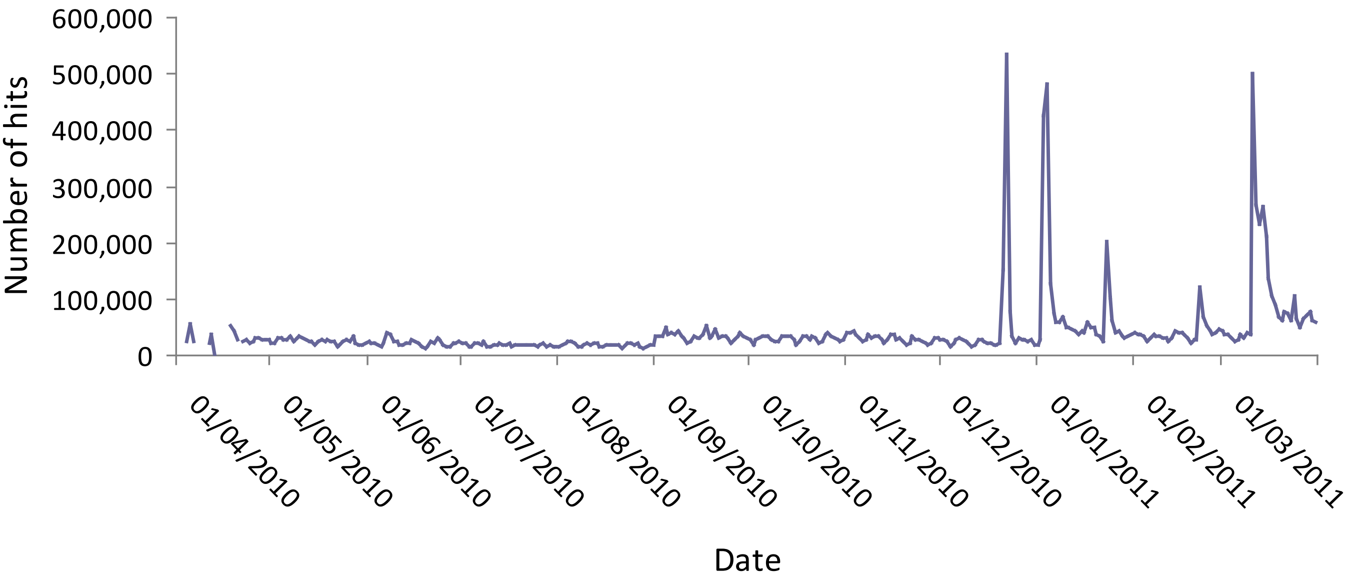
BGS are taking the lead in an EU funded initiative that will run from 2010-14 and will enable school seismology projects in the UK, France, Switzerland and Italy to set up a data exchange system and to share best practice in teaching activities and resources.

The BGS Open Day attracted 923 visitors with many of them visiting the interactive earthquake display. A further 132 school pupils from 7 different schools visited during the following Schools Week.

The seismology web site continues to be widely accessed, with over 780,000 visitors logged in the year (over 140 million hits).

Significant peaks (over 10,000 more than the monthly average) were observed following the Coniston earthquake (December 2010), the Ripon earthquake (January 2011) and the Japan earthquake (March 2011). Smaller peaks were also observed following the Glenuig and Christchurch earthquakes (January and February, 2011)

BGS remains a principal point of contact for the public and the media for information on earthquakes and seismicity, both in the UK and overseas. During 2010-2011, 808 enquiries were answered. These were logged using a new enquiries tracking database. Some 166 of these were from the media, many of which led to TV and radio interviews, particularly after the New Zealand and Japan earthquakes.



Usage statistics for the BGS Earthquakes web server.

Seismic Activity

The details of all earthquakes, felt explosions and sonic booms detected by the BGS seismic network have been published in monthly bulletins and compiled in the BGS Annual Bulletin for 2010, published and distributed in July 2011 (Galloway, 2011).

There were 98 local earthquakes located by the monitoring network during 2010-2011, with 31 having magnitudes of 2.0 ML or greater, and twelve having magnitudes of 3.0 ML or greater. Thirteen events with a magnitude of 2.0 ML or greater were reported felt, together with a further four smaller ones, bringing the total to seventeen felt earthquakes in 2010-2011.

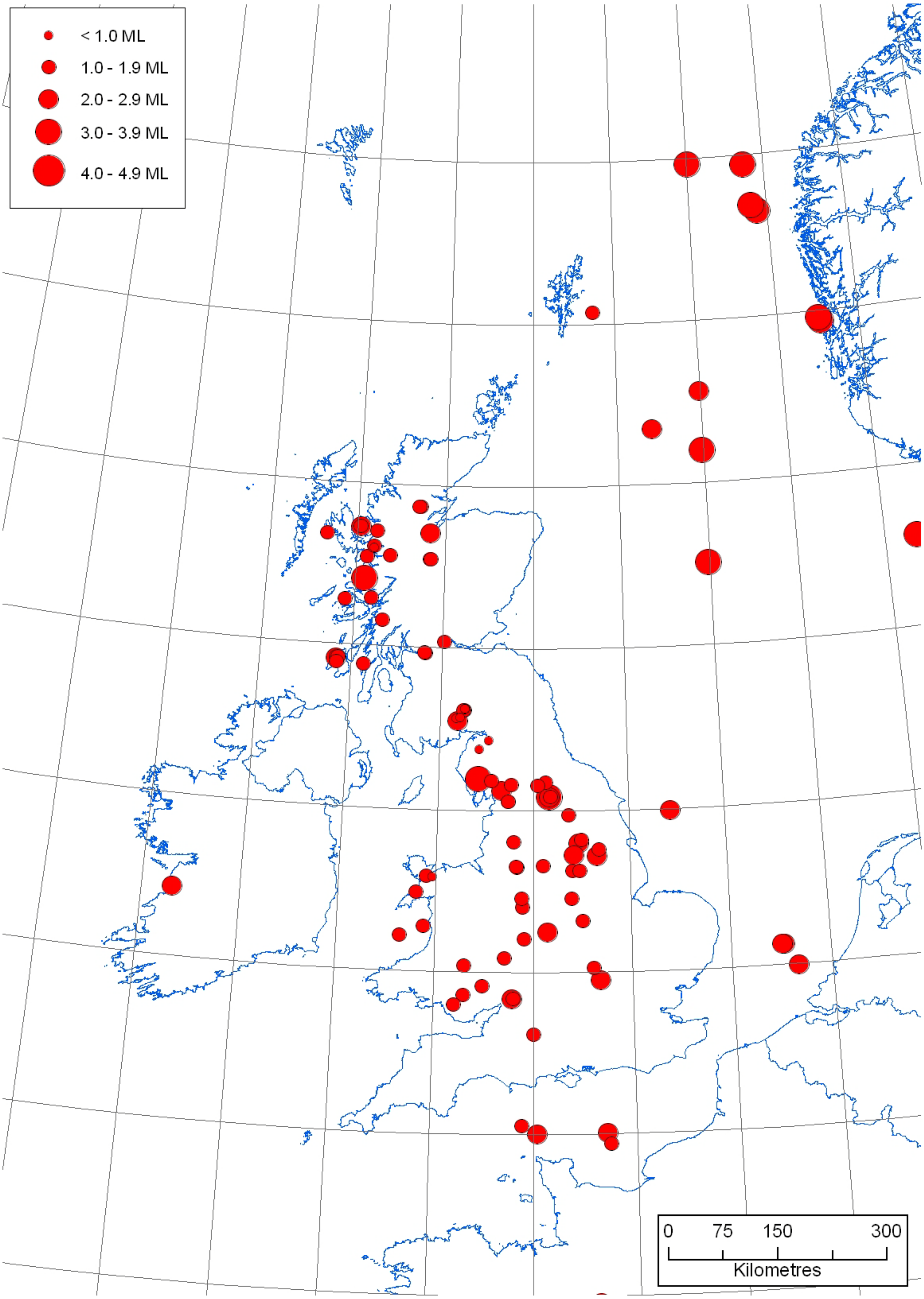
A magnitude 3.5 ML earthquake occurred near Coniston, Cumbria at 22:59 on 21 December. Over 800 of the people who completed our online survey felt the earthquake. The earthquake was felt as far away as Preston (75 km south) and Castle Douglas (80 km north). The results show that the maximum intensity experienced was 5 EMS, which was observed over an area extending approximately 25 km to the northeast and 35 km to the south of the epicentre. There were no reports of damage to property.

A magnitude 3.6 ML earthquake occurred near Ripon, North Yorkshire at 21:03 UTC on 3 January 2011. This was the largest earthquake detected in the general area since a magnitude 2.8 ML event on 4 June 1970 in the Pennines.

A magnitude 3.5 ML earthquake occurred at Glenuig, Highland at 06:02 UTC on 23 January 2011. The earthquake was felt on Skye and Mull, and in Inverness and Oban with a maximum intensity of 4 EMS. This was the largest earthquake detected in this area since the magnitude 3.5 ML event on 10 January 2008 near Glenfinnan. Historically, the largest earthquakes to have occurred nearby were the magnitude 3.6 Moidart event that occurred on 14 October 1902 and the magnitude 3.2 Moidart event of 1 February 1809.

The largest offshore earthquake occurred off the Norwegian coast with a magnitude of 3.8 ML. Nine further events with magnitude of 3 and above occurred in the North Sea and adjacent waters during the year.

The UK monitoring network also detects large earthquakes from around the world, depending on the event size and epicentral distance. Recordings of such earthquakes can be used to provide valuable information on the properties of the crust and upper mantle under the UK, which, in turn, helps to improve location capabilities for local earthquakes. During the period April 2010 to March 2011, a total of 487 teleseismic earthquakes were detected and analysed.



Epicentres of all earthquakes in and around the UK detected in the reporting period (1 April 2010 – 31 March 2011).

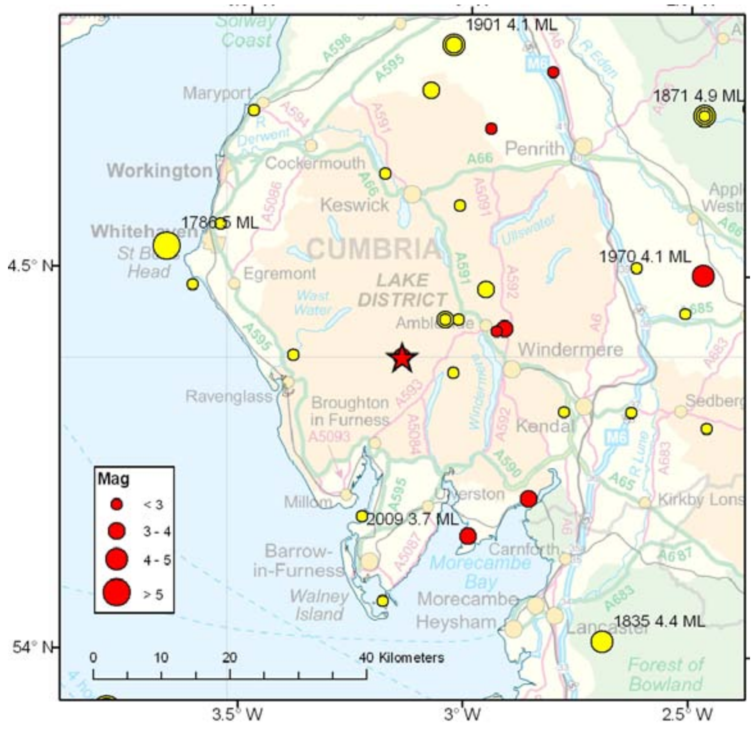
Seismic Activity

The Coniston Earthquake, 21 December 2010

Numerous reports were received from members of the public in and around Coniston on 21 December 2010, following a magnitude 3.5 ML earthquake. Our online questionnaire was used to collect macroseismic data. The maximum observed intensity was 5 EMS.

This earthquake occurred on 21 December 2010 at 22:59 UTC, with an epicentre only a few kilometres west of Coniston. The instrumental magnitude was determined at 3.5 ML, and initial reports suggested that the earthquake had been felt throughout Cumbria and further afield. A total of 693 online macroseismic questionnaires were completed by members of the public.

The highest intensity experienced was 5 EMS, which was observed over an area extending approximately 15 kilometres to the east of the epicentre. However, high intensities were also observed to the southwest, around Barrow-in-Furness and to the west around Whitehaven, resulting in a large number of replies.



Instrumental (red) and historical (yellow) seismicity of the Coniston area.

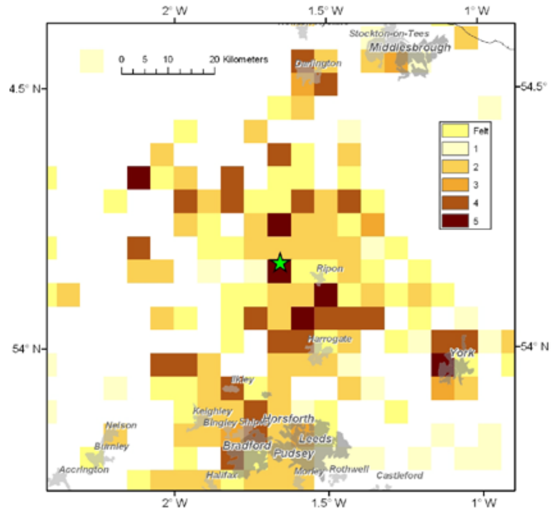
Comments received included descriptions of the earthquake as “feeling like a very heavy truck or train going past”, or that “the whole house shook”. Some people also “heard a deep rumble that lasted for about 3-4 seconds”. There were no reports of damage to property.

The most credible distant reports were from towns such as Kirkcudbright, Castle Douglas, and Dalbeattie (80-90 km) to the north; Blackpool, Lytham St. Annes and Preston (60-75 km) to the south; the Isle of Man (90 km) to the west; and to the east, the earthquake was reported as having been felt in the west of County Durham (around 90 km).

This was the largest earthquake detected in this area since the magnitude 3.0 ML event on 12 September 1988 near Ambleside. Magnitude 3.1 ML events also occurred in Ambleside in 1885 and 1911. Historically, a number of larger earthquakes have occurred in and around the Lake District, most notably, a magnitude 4.1 ML event in 1970 near Kirby Stephen and a magnitude 5.0 ML event in 1786 near Whitehaven.

Seismic Activity

The Ripon Earthquake, 3 January 2011

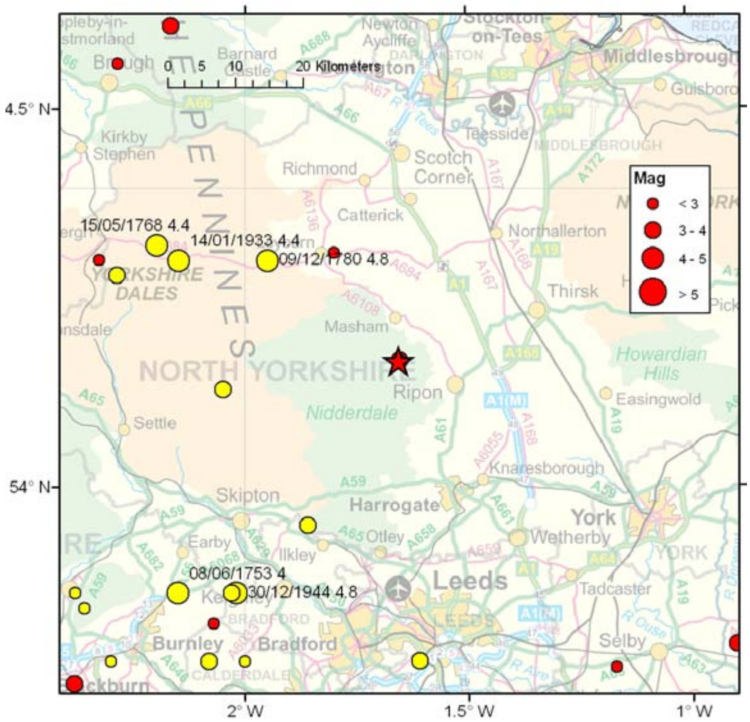


Macroseismic data from the earthquake.

Significant media and public interest was created on 3 January 2011 when a magnitude 3.6 ML earthquake struck Ripon. The earthquake was widely felt across the north of England with a maximum observed intensity of 5 EMS.

The earthquake occurred on 3 January 2011 at 21:03 UTC, with an epicentre only a few kilometres west of Ripon. The instrumental magnitude was determined at 3.6 ML, and initial reports suggested that the earthquake had been felt widely throughout north Yorkshire. A total of 1,228 online macroseismic questionnaires were completed by members of the public.

The highest intensity experienced was 5 EMS, which was observed close to the epicentre in and around Ripon. Reports of intensity 4 extended south to Harrogate and Ilkley and southeast to York, as well as to the north.



Instrumental (red) and historical (yellow) seismicity of the Ripon area.

Comments received included descriptions of the earthquake as feeling like a "low-flying helicopter or aeroplane going past, or that the whole house shook". Some people also heard a deep rumble. There were no reports of damage to property.

The most credible distant reports were from the following places: to the south, the earthquake was felt in Sheffield and towns in the Manchester area (80-90 km) and to the north, the earthquake was reported as having been felt in several areas between Middlesbrough (50km) and Newcastle-upon-Tyne (90km).

Relatively little instrumentally recorded seismicity has been observed in this general area, the closest being a magnitude 2.8 earthquake in the Pennines in 1970. However, there have been a number of significant historical earthquakes nearby. In 1933 a magnitude 4.4 earthquake in Wensleydale, to the northwest, caused much alarm and some minor damage. There were also magnitude 4.4 and 4.8 earthquakes in Wensleydale in 1768 and 1780, respectively. To the southwest, a magnitude 4.8 earthquake near Skipton in 1944 caused minor damage to chimney pots and masonry in Skipton and was felt throughout the north of England.

Partial collapse of unreinforced historic buildings was common in the CBD.

Seismic Activity

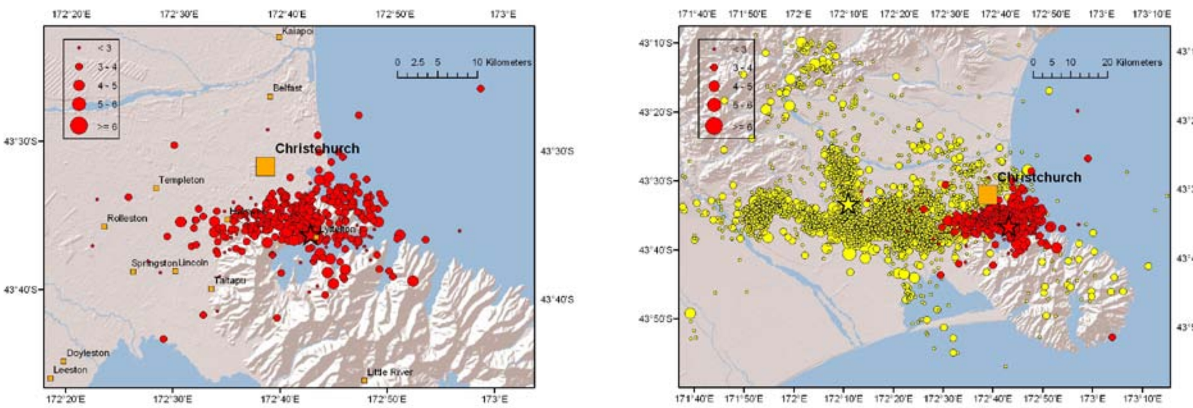
The Christchurch Earthquake, 22 February 2011

The magnitude 6.3 Christchurch (New Zealand) earthquake was the most damaging since the Hawke's Bay earthquake in 1931. It killed 172 people, seriously injured over 160 and made 10,000 people homeless. With 40% of buildings in the central business district damaged beyond repair the total cost is estimated to be as high as USD 8 billion (source: AIR Worldwide). A BGS engineering geologist joined the UK's EEFIT (Earthquake Engineering Field Investigation Team) mission to survey damage and study the geological effects in the city.

A magnitude 6.3 earthquake struck the South Island of New Zealand at 12:51 local time on 22 February 2011, resulting in many deaths and severe damage to the central business district (CBD) of Christchurch and the port town of Lyttleton. The epicentre was located in the Port Hills, 10km southeast of the CBD and 5km north of Lyttleton. Thousands of buildings were heavily damaged and New Zealand's first ever national state of emergency was declared and the CBD was evacuated and remained closed for over two months.

The earthquake was one of a series of aftershocks following the magnitude 7.1 Darfield earthquake on 4 September 2010, 40 km west of the city and which caused moderate damage but no loss of life.

The Canterbury region has a short but steady history of large intra-plate earthquakes including events in 1888, 1929, 1968 and 2010. However, none of these was near Christchurch The fault rupture was about 14km long, 7km deep and occurred on a previously unknown 'blind' reverse fault with a right-lateral oblique strike-slip mechanism that ruptured upwards from a depth of 5km to 1km. The



The aftershocks of the magnitude 6.3 earthquake (red circles) map out the fault rupture south of Christchurch. The magnitude 7.1 earthquake on 4 September 2010, also had many hundreds of aftershocks (yellow circles).

ground in the Port Hills and southern city – on the hanging-wall – rose by up to 40cm while the land on the foot-wall – under the city centre – subsided by up to 15cm due a combination of fault slip, compaction and consolidation, and left parts of the city more susceptible to coastal flooding. At least 170 landslides, mostly rock falls, affected 30km^2 of the Port Hills, the eroded flank of an extinct 6 million-year-old volcano. Very strong vertical peak ground accelerations up to 1.42g were recorded by GeoNets strong-motion accelerographs, and set a new record for New Zealand. Felt intensities in the city were 8 MM (Modified Mercalli). Extensive liquefaction and lateral spreading was widespread on recent alluvial planes, estuaries, and earth embankments affecting buried assets, transport infrastructure and foundations.

David Boon (BGS) provided geotechnical and landslide expertise for the Earthquake Engineering Field Investigation Team (EEFIT) mission to the affected region. The team, led by Mathew Free of Arup, also included experts in structural and geotechnical earthquake engineering, GIS and remote sensing, special structures and infrastructure. The team made a detailed survey of damage and the performance of structures, including an assessment of the performance of strengthening measures. They also investigated both the geological and socio-economic effects of the earthquake as well as the disaster management procedures. Details can be found in Free et al (2011).

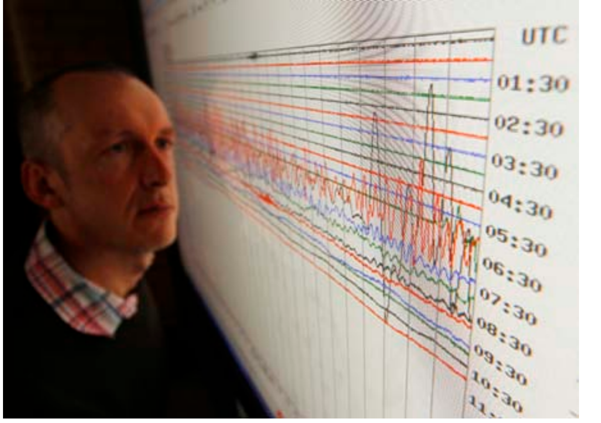
Several factors contributed to the exceptionally strong ground-shaking and widespread liquefaction: the shallow source depth; the position of the steep 65 degree southward dipping reverse fault with respect to the city; amplification due to thick quaternary sediments beneath the city; topographic amplification; and the ‘hanging-wall’ effect.

The city’s many well-loved unreinforced masonry historic buildings were vulnerable and the collapse of one pre-80s high-rise structure contributed significantly to the death toll. Well-maintained and retrofitted masonry buildings performed much better, sustaining only low levels of damage. Collapse of pre-cast concrete stairwells hindered relief efforts in many high-rise structures, and liquefaction caused many slab and pile foundation failures affecting low, medium and high-rise structures.

These observations highlight the importance of applying earthquake building codes to pre-code structures.

Acknowledgments: EEFIT, GNS Science and John Berrill.

Demolition of a partially collapsed multi-story car park in Christchurch City. Courtesy of EEFIT.

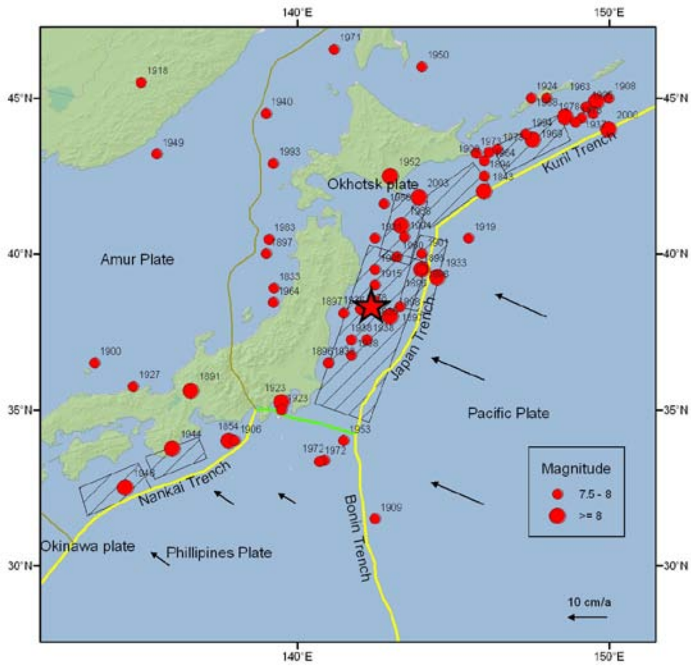


Seismic Activity

The Japan Earthquake, 11 March 2011

The magnitude 9.0 Mw Great Tohoku earthquake that struck Japan on March 11, 2011 was the fourth largest earthquake ever recorded. The earthquake generated a devastating tsunami that caused destruction along the eastern seaboard of the island of Honshu. Over 28,000 people were killed or are missing and many tens of thousands displaced.

At 00:56 GMT on Friday 11 March 2011 a 300 km long segment of the plate boundary east of the Japanese Island of Honshu ruptured in a magnitude 9.0 earthquake. It is another recent example of a mega-thrust earthquake at a boundary between two of the Earth's tectonic plates. Even in a country as used to earthquakes as Japan, the magnitude of the earthquake was unprecedented in recent history. Previously, Japan's most destructive earthquake was the magnitude 7.9 Great Kanto earthquake of 1923 that occurred south of Tokyo, killing over 140,000 people.



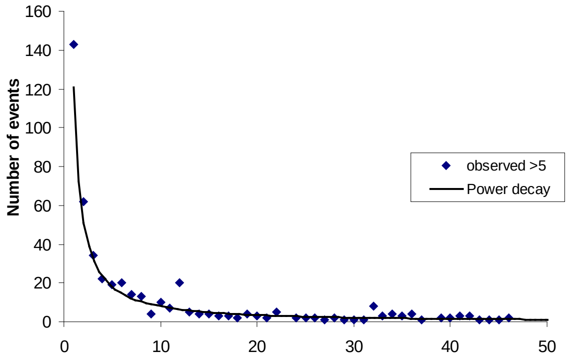
Earthquakes with magnitude greater than 7.5 in and around Honshu since 1800. Approximate rupture planes for a number of events with magnitude greater than 8 are shown by the hatched areas. The epicentre of the 11 March 20011 event is marked by the star.

The actual amount of slip on the fault surface may have exceeded thirty metres. This motion would have resulted in several metres of uplift of the seafloor, displacing huge volumes of water and causing the tsunami, which surged many kilometres inland. Field survey results indicate the highest run-up height was 38 metres in Iwate Prefecture. Tide gauge recordings in Japan range from 1 to 7 metres. Three-metre waves were observed by eyewitnesses in the Kuril Islands, Russia. Two-metre waves were observed at tide gauges in South America, Hawaii, and the west coast of the United States.

Large earthquakes in the same subduction zone in 1611, 1896 and 1933 also produced devastating tsunami waves on the Sanriku coast. The magnitude 8.5 Mw earthquake of 1896 resulted in tsunami run-ups of 38 metres leaving at least 27,000 dead. The magnitude 8.6 earthquake in 1933 produced tsunami run-ups of 29 metres on the Sanriku coast and caused over 3000 deaths. There is also historical and geological evidence of another similar tsunami that affected the region in 896, caused by an earthquake with a magnitude in excess of 8 and possibly as high as 9.

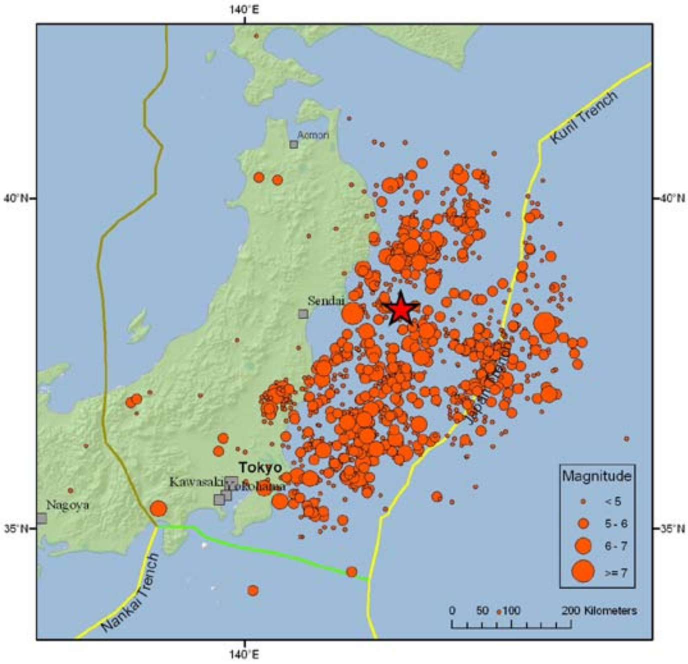
Northern Honshu lies on the Okhotsk Plate, a continental plate which some authors consider part of the North American plate. East of Honshu, the oceanic Pacific plate is moving west at around 8 cm/year and is being subducted underneath the Okhotsk plate along the line of the Japan Trench. South of Tokyo, Honshu lies on the Amur plate, which some authors consider part of Eurasia. To the east, the Philippines oceanic plate is being subducted under Southern Japan along the line of the Nankai trench.

Earthquakes of this size are always followed by extensive sequences of aftershocks which may last many months



Decay in the daily number of aftershocks.

or even years, and may contain many thousands of earthquakes. At the time of writing there had been at least 450 aftershocks greater than magnitude 5, 54 greater than magnitude 6 and one greater than magnitude 7. The spatial distribution of the aftershocks maps out the approximate area of the mainshock rupture. Aftershocks decrease in frequency as a function of time following the mainshock. This decay in the rate of aftershocks obeys a well known power law known as Omori's Law. Roughly speaking, we might expect that after ten days the rate of aftershocks to be around ten times less frequent than they were on the first day. Such models can be used to estimate the probability of future aftershocks. For example, thirty days after the mainshock there was a probability of roughly 10% that there would be a magnitude 7 or greater aftershock in the next three days.



Aftershocks of the magnitude 9.0 Tohoku earthquake of 11 March 2011.

Scientific Objectives

Local Earthquake Tomography

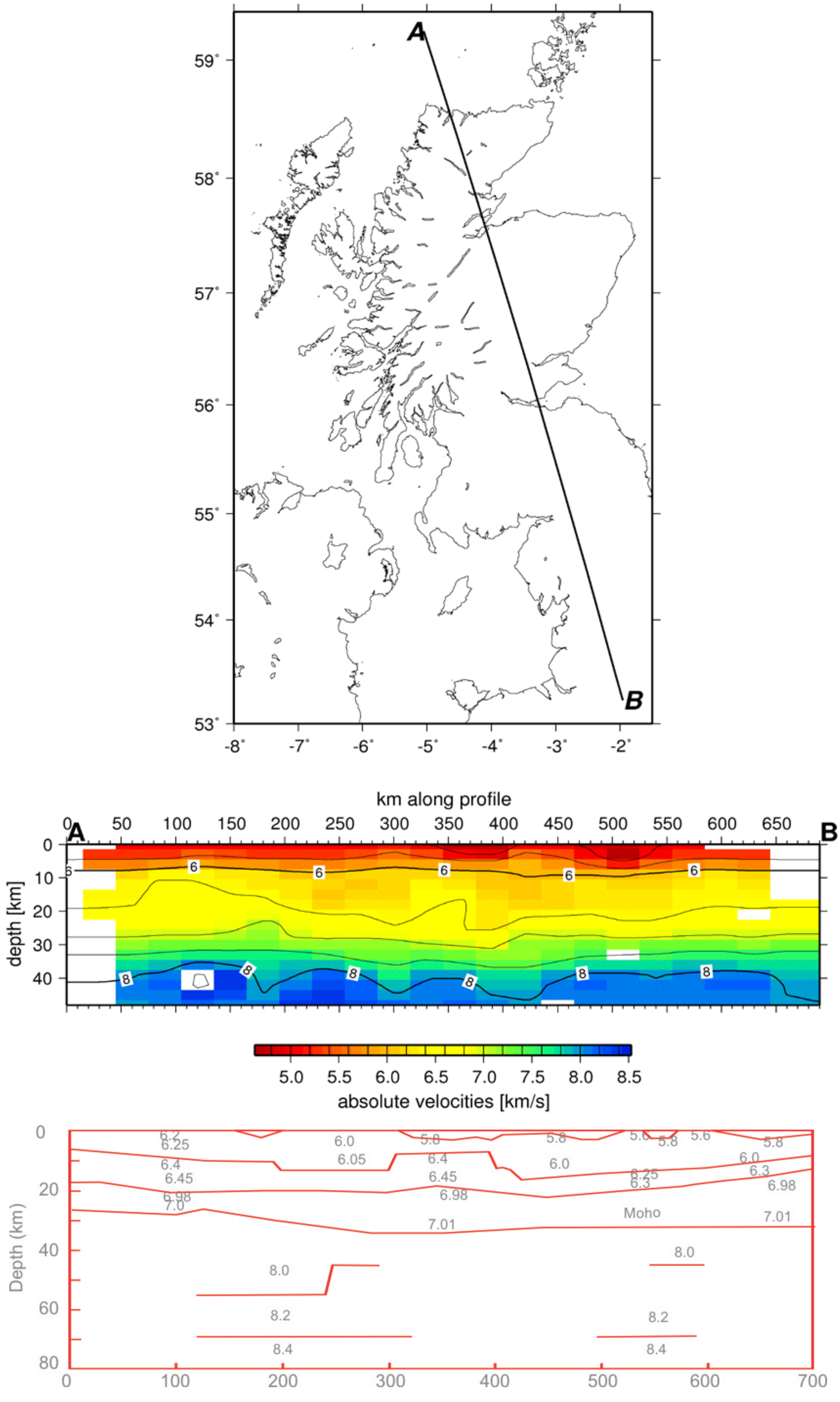
We are continuing to use the arrival times of local earthquakes recorded at BGS seismograph stations to construct a 3D model of seismic velocity in the Earth's crust beneath Scotland. Relocation of older events and the addition of data from the RUSH II experiment have provided good resolution results and a model that compares well with seismic refraction and wide-angle reflection results.

We are implementing local earthquake tomography to develop a 3D velocity model for Scotland. A database of over 400 high quality, relocated earthquakes has been developed. These events were recorded at the BGS national network and at stations from the RUSH II experiment (Ascenio et al, 2003), a temporary deployment of 21 broadband sensors across Scotland between 2001 and 2003.

To obtain the initial model used for the inversion we used the method of Kissling et al (1994) to determine a best-fitting 1D velocity model. This is done by joint inversion of hypocentres, velocity and station delay to minimise RMS residuals for all events. A large number of different possible layer configurations were tried to get the optimal 1D model and to test its robustness. P-wave arrival times were then inverted simultaneously for velocity and hypocentre parameters using the SIMULPS code (Thurber 1983).

In order to estimate the resolution of the models attained, synthetic tests were carried out. The principal test was the so-called 'chequerboard' test (Humphreys and Clayton, 1988) where a synthetic model is created divided into alternating regions of high and low velocity. Arrival times are then found for each event by ray tracing through the synthetic model. These times are used instead of real arrival times in an inversion using the same starting model and parameters as for real data. The model is best resolved at mid-crustal depths beneath central Scotland.

In 1974 a major explosion seismic project, the Lithospheric Seismic Profile in Britain (LISPB), was carried out. This was a refraction and wide-angle reflection experiment that gave a detailed 2D velocity model along a line from Cape Wrath, to the border near Carlisle and on into England, (Bamford et al., 1978). A vertical cross-section through the 3D tomography model along the line of LISPB profile shows that the model agrees well with the LISPB results in terms of relative velocity. However the absolute velocities are higher near the surface in the tomography study. The reason for this is still under investigation.



Comparison of cross-section through the 3-D tomographic model of Vp (b) along the line of the LISPB profile A-B (a) with the published interpretation of the original refraction data profile from Bamford et al (1978).

Ambient Noise Tomography

Recent research has shown that information about Earth structure between a pair of seismic stations can be extracted from cross-correlation of continuous background noise recorded at each station. This approach has been applied by Nicholson (2011) to produce the first surface wave group velocity maps of the British Isles using only ambient seismic noise.

Conventional 3D seismological models of the Earth are generally obtained from recordings of waves that have travelled to a given receiver from a single, known, energy source, for example, an earthquake. However, seismic waves propagate inside the Earth all the time, created by sources such as wind, ocean water movement, human-related activity and small-scale rock fracturing. Such waves are commonly regarded as “noise” by seismologists. However, these waves also reflect, refract and diffract from exactly the same heterogeneities as do waves from single active sources.

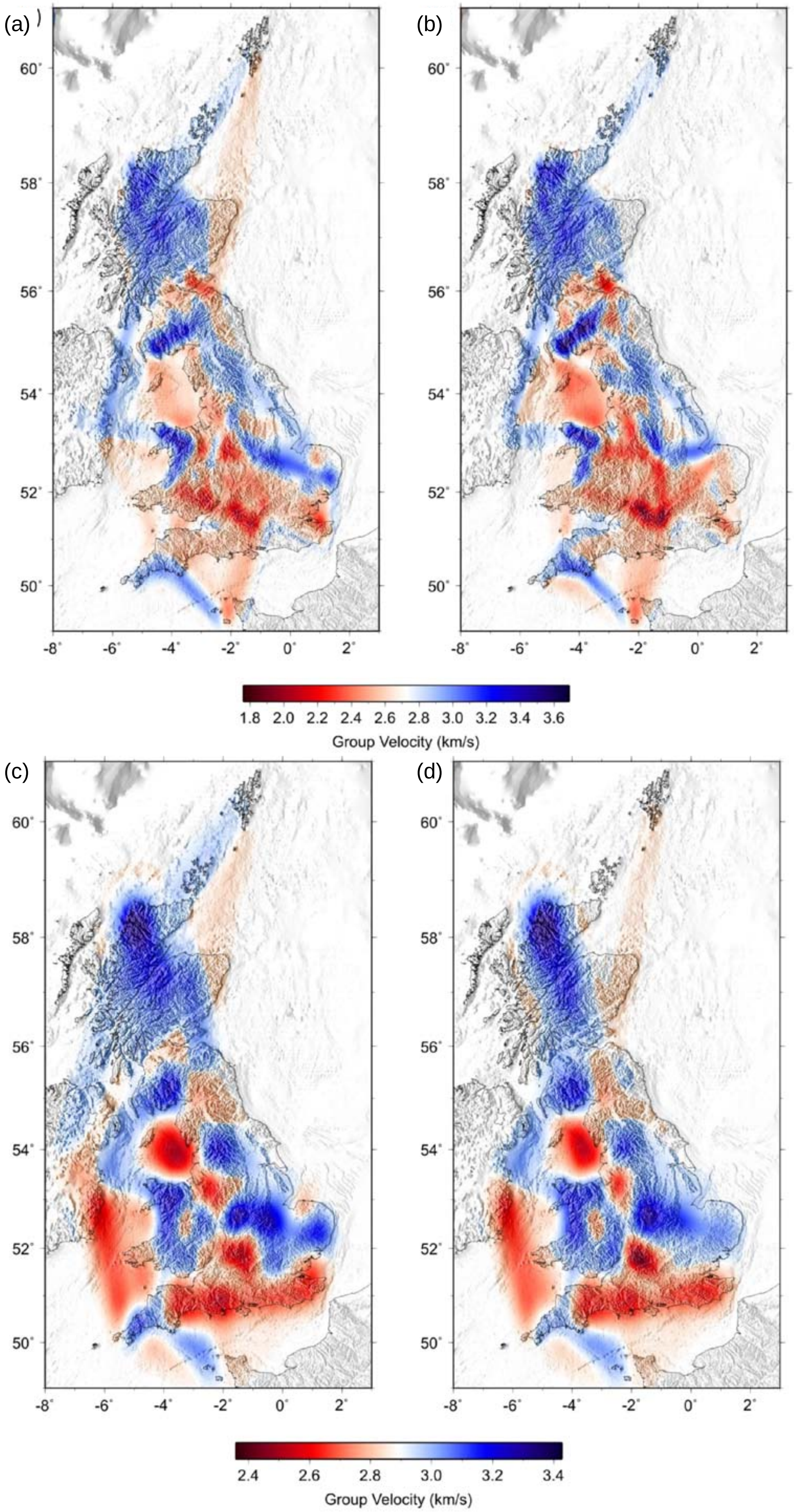
Recent advances in theory (e.g. Wapenaar, 2004) have shown that the cross correlation of the random wavefield between two seismic stations can provide an estimate of the Green’s function between the stations. This has been confirmed using seismic data (Shapiro and Campillo, 2004). Nicholson et al (2010) have used data from broadband stations across Scotland to construct surface wave Green’s Functions, which are then used to produce maps of the variation in surface wave velocities at different periods.

Nicholson (2011) constructs Green’s functions from ambient noise data to produce the first surface wave group velocity maps of the UK for Rayleigh waves at different periods. These highlight a number of interesting features that can be correlated with the spatial variation in known geology.

High velocities across the Scottish Highlands are consistent with the crystalline Lewisian and Dalradian complexes. South of the Highlands Boundary fault and north of the Southern Uplands fault, a NW-SE trending low velocity anomaly is consistent with the dominantly sedimentary rocks of the Midland Valley. The lowest velocity part of the Midland Valley occurs across the Firth of Forth syncline. Immediately south of the Midland Valley, a high velocity, NW-SE trending anomaly across the Southern Uplands can be attributed to the Southern Uplands accretionary complex.

There is the significant slow anomaly in the English Midlands, approximately located within the Midland Platform, a region of Precambrian basement. The low velocities obtained may be a result of a relatively thick crust in this region. An extensive low velocity anomaly occurs in the Irish Sea basin.

Other high velocity anomalies can be attributed to granitic intrusions in Cornwall and north-west Wales and the limestone rocks of the Pennines in northern England.



Group velocity maps of the British Isles for Rayleigh waves with periods of 5 seconds (a and b) and 12 seconds (c and d) from cross-correlations of ambient seismic noise. (a) and (c) show well constrained paths and paths with uncertainties estimated from inter-station distance. (b) and (d) show well-constrained paths only.

Scientific Objectives

Global Earthquake Model (GEM) Project

The Global Earthquake Model (GEM) is a global collaboration that aims to establish uniform, open standards to calculate and communicate earthquake risk worldwide. BGS jointly lead a GEM module to develop a new, state-of-the-art, global catalogue of historical earthquakes.

The GEM project (Global Earthquake Model) is a major international project to address the issue of earthquake hazard and risk in a consistent way across the whole planet. Ultimately the aim is a resource that will be available to a wide range of communities (engineers, insurers, planners etc) covering all aspects of earthquake hazard, and especially risk - most similar projects in the past, such as GSHAP (Global Seismic Hazard Assessment Programme) have stopped at hazard. Extending the analysis to risk involves collecting data on exposure and vulnerability, no easy task.

To facilitate the organisation of the project, the work has been divided into a number of modules. Some of these are regional, for instance, the SHARE project (Seismic Hazard Harmonisation in Europe), which will create the basic hazard assessment module for Europe. Others are thematic in nature - for instance, the Faulted Earth module is working on compiling a database of major active faults in the world.

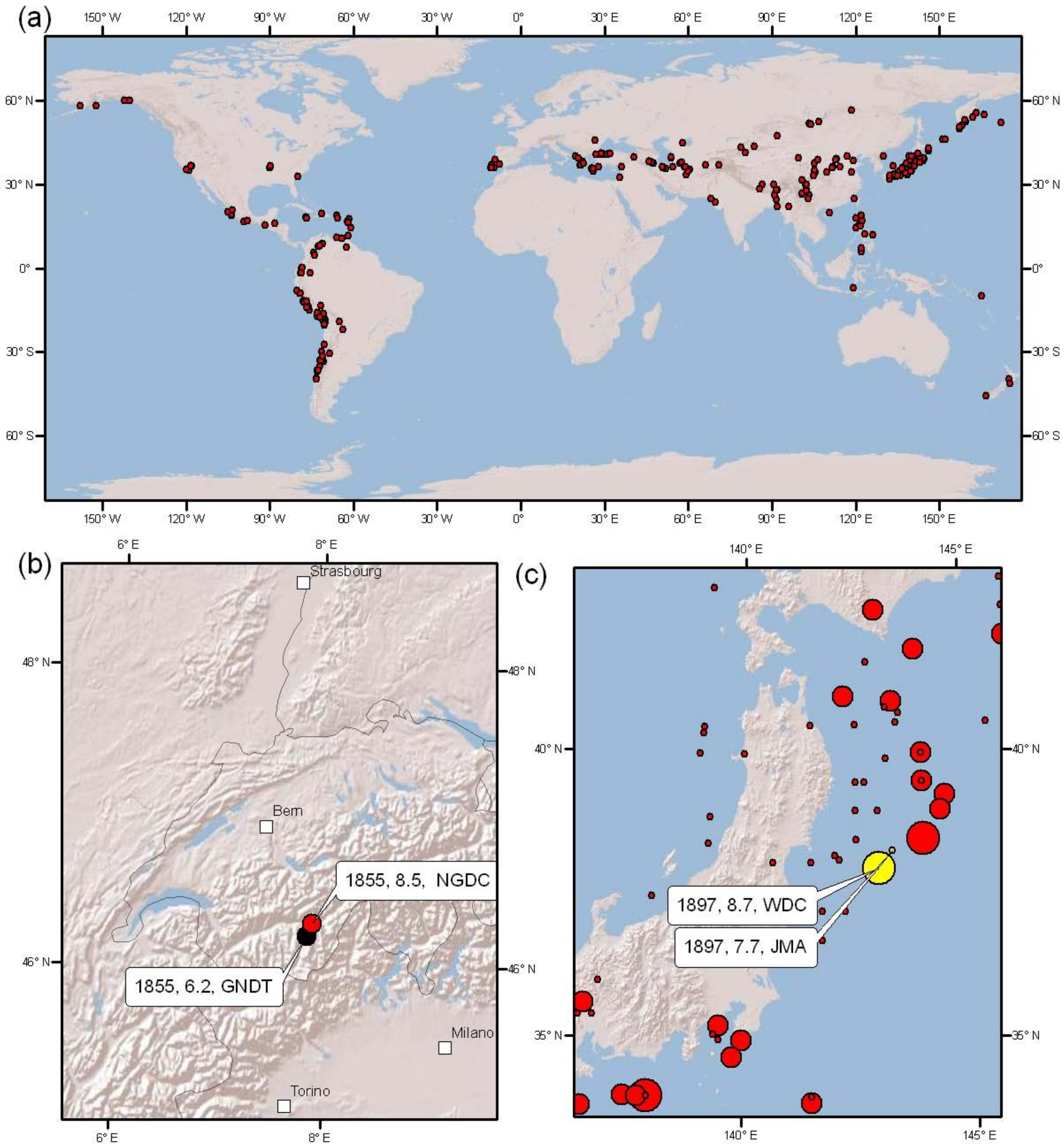
Two modules deal with the input earthquake catalogues used for seismic hazard assessments: one for instrumentally recorded earthquakes from 1900 onwards; the other for historical earthquakes from before 1900 that can be studied only from macroseismic data.

The second of these modules has the title "Global Earthquake History" (GEH) and is being led jointly by INGV, Milan and BGS, Edinburgh.

The module has two objectives. The first is establishing a distributed, online resource, to be called “Global Archive of Historical Earthquake Studies”, where both reports and intensity data points (when available) can be uploaded, organised and made available to the public. The second is supplying GEM with the best global parametric earthquake catalogue ($M_w \geq 7.0$) that can be compiled from current resources providing, as far as possible, a link to the background information.

The present situation with respect to global resources for historical earthquakes is surprisingly poor. Probably the most-used source is the NGDC "Significant Earthquake Database" maintained by NOAA (National Oceanic and Atmospheric Administration; NGDC is the National Geophysical Data Center). However, this catalogue contains a number of errors. For example, the catalogue lists the largest historical earthquake in Europe as a magnitude of 8.5 that occurred in Switzerland in 1855. While this particular earthquake was one of Switzerland's largest, its true magnitude was only 6.4 Mw.

If such errors can be found in modern catalogues for relatively recent earthquakes, it is clearly a major task to sort out fact from fiction for the whole period from 1000-1900 (possibly extending back to 1 AD). The GEH project will seek to engage local experts on every continent to assist in this challenging work.



The BGS world seismicity database contains data from multiple catalogues for events prior to 1900 (a). Magnitudes assigned to the 1855 Visp earthquake in Switzerland by two different agencies (b). Magnitudes assigned to an event in 1897 east of Honshu by two different agencies. Such discrepancies will results in differences in seismic hazard analyses.

Villagers in Kashmir participate in a community risk mapping exercise (Concern Worldwide).

Scientific Objectives

Enhancing Knowledge Exchange

Although our scientific understanding of earthquakes is advanced, the extent to which this understanding is successfully informing decision-making is variable. In a new two year project funded by NERC, BGS is developing mechanisms to facilitate greater knowledge exchange between seismologists and the organisations making such decisions.

Governments, bodies like the UN, international and national non-governmental organisations (NGOs), and community groups undertake earthquake risk reduction and preparedness activities at national, regional and local levels. Understanding earthquake hazard is critical for developing and implementing effective risk reduction strategies. However, the extent to which seismological knowledge is successfully accessed, understood and applied by these groups is variable. The 2010 Haiti earthquake highlighted to devastating effect the vulnerability of these groups and the communities that they work with.

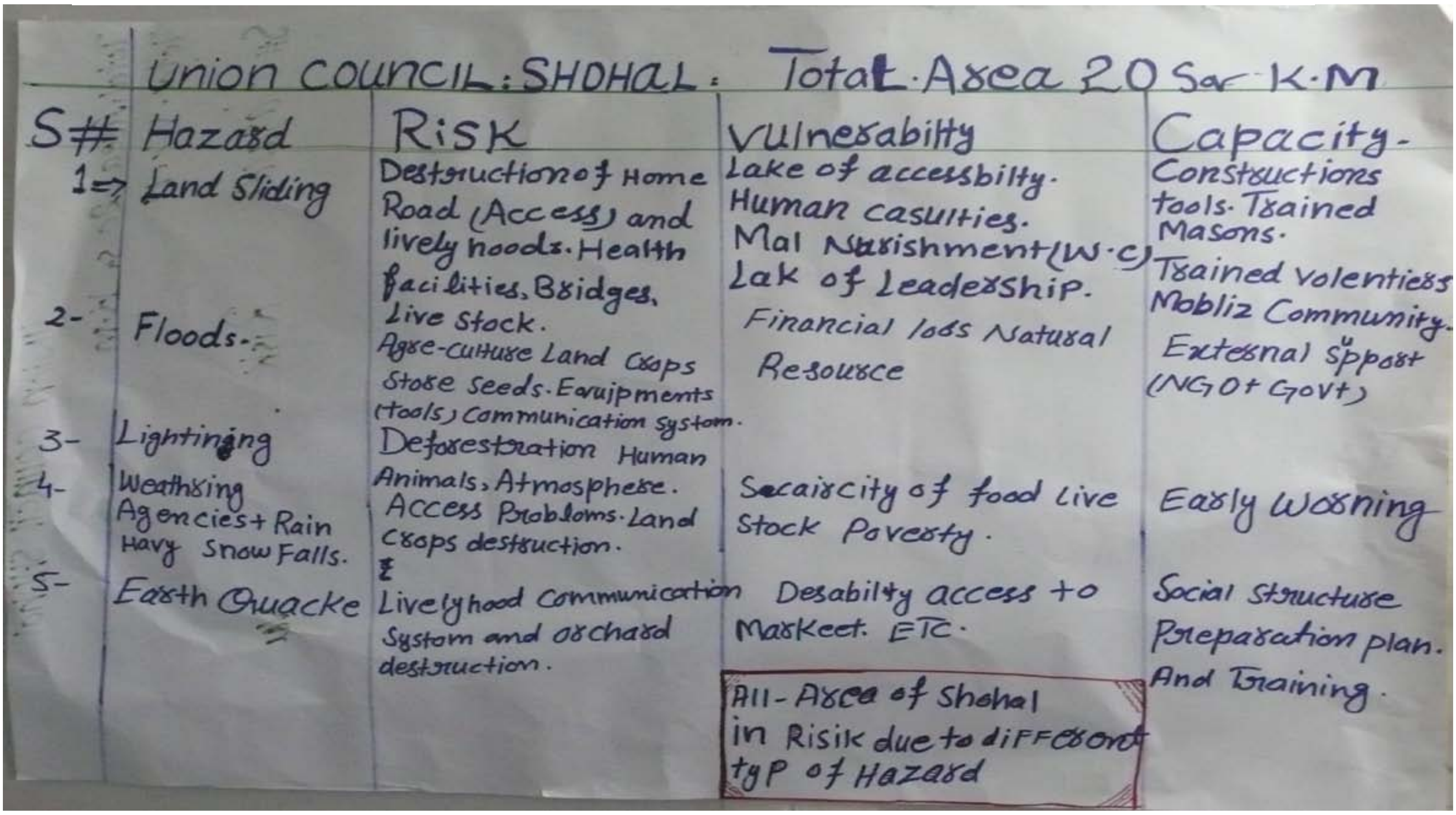
Seismologists have long served the needs of the engineering sector but providing fit-for-purpose information that can be used for decision-making by relief and development organisations presents new challenges for both science and scientists.

Relief and development NGOs tend to operate in complex and challenging environments, often working with very vulnerable people, and with limited budgets. Communities may be exposed to a range of hazards, as well as other threats relating to poverty, disease and conflict.

The project will address a number of key issues. Firstly, scientists often have a limited understanding of how their information can be used. Secondly, as non-experts, NGOs need to be able to assess reliability of information (this assumes that the information needs are known). Thirdly, misunderstanding of scientific concepts (such as a recurrence interval), can have a significant effect on decision-making. Fourthly, the need to communicate scientific results in a way that is directly relevant to NGO programming.

To do this, we are working closely with Concern Worldwide, and their programmes in Bangladesh and Haiti. Concern is an Irish NGO that regularly responds to major emergencies and has long-term development programmes in 29 of the world's poorest countries. Bangladesh and Haiti are both multi-hazard environments and experience relatively frequent climate-related disasters. Working with these programmes allows us to explore scientific information needs and the dynamics of knowledge exchange within the contexts of both disaster preparedness and response.

Damage to UN headquarters in Port-au-Prince, Haiti. (Concern Worldwide)



Union Council: SHOHAL. Total Area 20 Sqr K.M

S#	Hazard	Risk	Vulnerabilty	Capacity
1	Land Sliding	Destruction of Home Road (Access) and livelyhoods. Health facilities, Bridges, Live Stock.	Lake of accessbilty. Human casulties. Mal Nurishment (W.C) Lak of Leadership.	Constructions tools. Trained Masons. Trained volentiers Mobliz Community.
2-	Floods	Agre-culture Land Crops Store Seeds. Equipments (tools) Communication system.	Financial loss Natural Resource	External Suppost (NGO+Govt)
3-	Lightinging	Deforestration Human Animals, Atmosphere.		
4-	Weathering Agencies + Rain Havy Snow Falls.	Access Problems. Land Crops destruction.	Secaircity of food Live Stock Poverty.	Early Worning
5-	Earth Quacke	Livelyhood Communication System and orchard destruction.	Desabilty access to Market. ETC.	Social Structure Preparation plan. And Training.

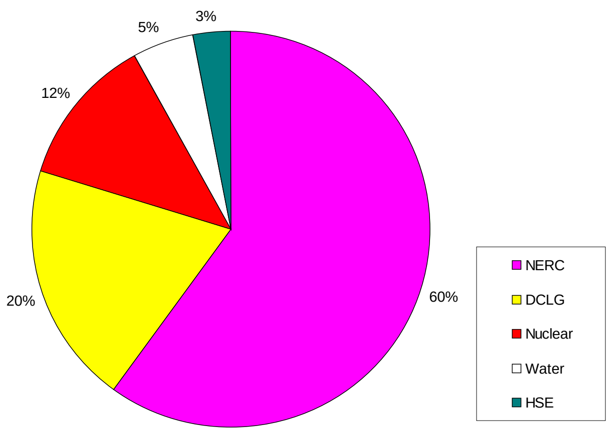
All-Area of Shohal in Risik due to different typ of Hazard

Results of the community risk mapping exercise in Kashmir (P. Crichton, Concern Worldwide).

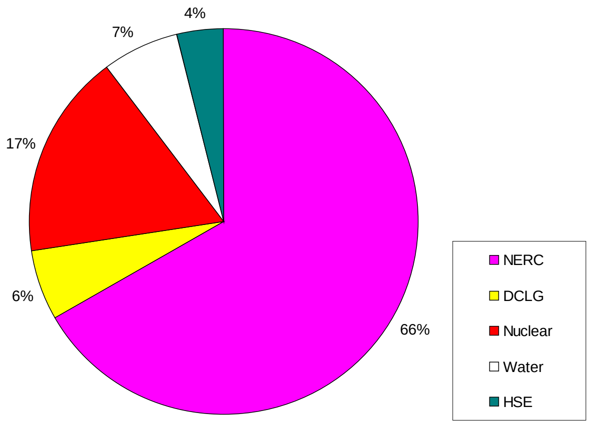
Funding and Expenditure

In 2010-2011 the project received a total of £607k from NERC. This was matched by a total contribution of £407k from the customer group drawn from industry, regulatory bodies and central and local government.

Funding Received 2010-2011



Funding Expected 2011-2012



The projected income for 2011-2012 is considerably reduced mainly due to a reduction in the level of funding from DCLG imposed by government spending constraints. The NERC contribution for 2011-2012 is also reduced and stands at £520k. The total expected customer group contribution currently stands at £262k. Currently, other potential sponsors are being explored.

Acknowledgements

This work would not be possible without the continued support of the Customer Group. Station operators and landowners throughout the UK have made an important contribution and the BGS technical and analysis staff have been at the sharp end of the operation. The work is supported by the Natural Environment Research Council and this report is published with the approval of the Director of the British Geological Survey (NERC).

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Appendix 1 The Project Team

BGS Seismic Monitoring and Information Service	
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Roger Musson	Seismic Hazard
Alice Walker	UK & Regional Seismicity
Susanne Sargeant	Seismic Hazard
Richard Luckett	Seismic Data Processing
Outreach	
Aoife O'Mongain	Media and Communications
Analysis Team	
Glenn Ford	Seismic Analyst
Davie Galloway	Seismic Analyst
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John Laughlin	Senior Electronics
Andy Blythe	Field Engineer
Heiko Buxel	Field Engineer
John Hume	Field Engineer
Computing Support	
Dave Scott	Software Engineer
Consultant	
David Kerridge	Theme Leader

Appendix 2 Publications

BGS Internal Reports

Baptie, B. 2011. Earthquake Monitoring 2009/2010, BGS Seismic Monitoring and Information Service, Twenty first Annual Report, BGS Internal Report OR/11/003.

Galloway, D. D., 2010. Bulletin of British earthquakes 2009, BGS Report OR/10/028.

Galloway, D. D., 2011. Bulletin of British earthquakes 2010, BGS Report OR/11/029.

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

External Publications

Loughlin, S.C., Luckett, R., Ryan, G., Christopher, T., Hards, V.; De Angelis, S., Jones, L., Strutt, M., 2010. An overview of lava dome evolution, dome collapse and cyclicity at Soufriere Hills Volcano, Montserrat, 2005-2007, *Geophys. Res. Lett*., 37 (1), L00E16.

Luckett, R., 2010. Local Earthquake Tomography in the UK, Observatories and Research Facilities for European Seismology (ORFEUS) Seismological Observatory Coordination Meeting, Dublin, 2010.

Musson, R.M.W., 2010. Draft standard internet macroseismic questionnaire, 32nd General Assembly of the European Seismological Commission (ESC), Montpellier, Book of Abstracts and Papers.

Musson, R.M.W., 2010. Interpreting intraplate tectonics for seismic hazard: A UK historical perspective, 32nd General Assembly of the European Seismological Commission (ESC), Montpellier, Book of Abstracts and Papers.

Musson, R.M.W., 2010. The earliest earthquake records of the British Isles, 32nd General Assembly of the European Seismological Commission (ESC), Montpellier, Book of Abstracts and Papers.

Musson, R.M.W., 2010. Conservatism in intraplate PSHA studies, Proceedings of the Ninth U.S. National and Tenth Canadian Conference on Earthquake Engineering, Toronto, 25-29 July 2010, Paper # 286.

Nicolson, H., Curtis, A., Baptie, B. and Galetti, E., 2011. Seismic interferometry and ambient noise tomography in the British Isles, Proceedings of the Geologists' Association, *in press*.

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Appendix 3 Publication Summaries

An overview of lava dome evolution, dome collapse and cyclicity at Soufriere Hills Volcano, Montserrat, 2005-2007

S. Loughlin et al.

The third episode of lava dome growth at Soufrière Hills Volcano, Montserrat was characterised by higher average magma discharge rates than either previous dome growth episode at this volcano and yet fewer collapses. During sustained dome growth at moderate-high average rates (>6 m3/s), we identified 2-6 week discharge pulses that each supplied c.20 Mm3 magma from depth. Our observations are consistent with some existing models but we explain discrepancies by a combination of higher volatile contents and higher ascent rates. Cycles of c. 11-16 days were evident in rockfall, LP rockfall and shallow LP earthquake counts related to dome growth and degassing. We speculate that degassing at the conduit margins together with stick-slip conduit flow may drive these cycles. Only one major collapse >10 Mm3 occurred during the third episode (on May 20, 2006) as a new magma pulse entered the dome and coincided with heavy rainfall.

Local earthquake tomography in the UK

R. Luckett

The British Geological survey have arrival time data for earthquakes in the British Isles going back to at least 1970. For the first 30 years these phases were recorded by an ever expanding number of 1 Hz instruments. Since then the number of instruments has been decreasing as local networks are being replaced with single broadband instruments. Until now there has been limited knowledge of the seismic velocity structure of Britain and the 1000s of arrivals in the archive made local earthquake tomography an obvious method to remedy this. Such tomography was completed this year for England and Wales by Anthony Hardwick for his PhD thesis at Leicester University but he didn't have enough time to include Scotland. The author is using standard earthquake tomography methods and the BGS data set for Scotland to finish the UK 3D velocity model. The problem is in path coverage with events occurring mainly in one of two general locations and much of the country very poorly represented.

Draft standard internet macroseismic questionnaire

R.M.W. Musson and members of the ESC WG “Internet macroseismology”

For many years an international standard for macroseismic questionnaires has been a “long-felt want”. In times past it was not a realisable goal because of cultural differences in the ways that questionnaires have been circulated. The rapid growth in use of the internet as a medium for collecting macroseismic information removes that obstacle, and a standard questionnaire form becomes practical. In order to try and achieve this, the ESC WG “Internet macroseismology” held an email discussion by means of a circulating discussion document. This document contained a section for each potential feature of a macroseismic questionnaire, for instance, asking about the position of the observer, asking about rattling windows, and so on. Over several iterations, members of the WG added their ideas to each section, paying attention to such things as whether the information was useful or only collected out of habit. Finally, the lead author attempted to synthesise the discussion in the form of an actual draft questionnaire, which is still open for comment. It can be viewed at the WG’s website, http://seismologist.co.uk/ESC_internet_macroseismology.html.

Interpreting intraplate tectonics for seismic hazard: A UK historical perspective

R.M.W. Musson

It has always been notoriously difficult to relate the occurrence of earthquakes to geological structures in intraplate regions, and this is as true of the British Isles as anywhere else. The seismicity of the UK is markedly non-uniform in spatial distribution, yet clear divisions between relatively seismic and relatively aseismic regions find no obvious geological explanation. A variety of attempts have been made to find over-arching tectonic models for UK seismicity, and some have found their way into hazard studies since research into UK seismic hazard started in the mid 1970s. This paper takes a historical look at how different seismic hazard studies in the UK have attempted to incorporate geological and tectonic thinking over the course of the past three decades (or in some cases have ignored it altogether).

The earliest earthquake records of the British Isles

R.M.W. Musson

The UK may be an area of generally low seismicity, but the wealth of historical documentation to some extent compensates for this. The earthquake catalogue can be extended back in time into the first millennium AD. However, the quality of the information available decreases considerably as one goes back in time, and for many early events it is difficult to tell if what is being described is even really an earthquake, since many could be landslides. Curiously, most of the earliest accounts of earthquakes are from Ireland, which is almost aseismic in modern times. Medieval chronicle records are often scrupulous about describing the date of an event, but say nothing about the effects, no doubt due the interest of the chronicler being in the earthquake as a portent. Where damage is described, it is usually either to cathedrals, or generic descriptions without localities. This means that locating events and assessing magnitude tends to be difficult and associated with very large uncertainties.

Conservatism in intraplate PSHA studies

R.M.W. Musson

When conducting probabilistic seismic hazard studies for seismic design, it is conventional, in addition to trying to cover the range of epistemic uncertainties, to opt consciously for decisions that tend towards the conservative, for obvious safety-related reasons. In hazard mapping studies, however, this constraint does not apply, since it is generally considered bad practice to take seismic design parameters from a map. Specifically, it can be shown that seismic hazard maps cannot be equally conservative over the whole area; therefore there is not really any reason to make them conservative at all. For intraplate areas, for instance, a typical problem relates to locations in proximity to past isolated damaging earthquakes. Whether one treats these as stationary events or as floating within a structural source zone is likely to depend on the purpose of the study. It was a project requirement in a recent hazard mapping study in the UK to treat the analysis in a non-conservative way; the resulting PGA values proved to be considerably lower than those obtained in previous studies. This naturally led to a desire to understand the reason for such a drop, of the order of a factor of three in some places. In this paper, the differences between a consciously conservative analysis and a non-conservative analysis are broken down into components to examine the impact of ground motion model, seismic stationarity, minimum magnitude, source model design and other factors contributing to the difference between the value that might appear on a map, compared to what might be found in a report intended for engineering design. It is shown that no single factor is dominant, and a combination of design decisions contribute to the difference in values.

Seismic interferometry and ambient noise tomography in the British Isles

H. Nicolson, A. Curtis, B. Baptie and E. Galetti

Traditional methods of imaging the Earth’s subsurface using seismic waves require an identifiable, impulsive source of seismic energy, for example an earthquake or explosive source. Naturally occurring, ambient seismic waves form an ever-present source of energy that is conventionally regarded as unusable since it is not impulsive. As such it is generally removed from seismic data and subsequent analysis. A new method known as seismic interferometry can be used to extract useful information about the Earth’s subsurface from the ambient noise wavefield. Consequently, seismic interferometry is an important new tool for exploring areas which are otherwise seismically quiescent, such as the British Isles in which there are relatively fewstrong earthquakes. One of the possible applications of seismic interferometry is ambient noise tomography (ANT). ANT is a way of using interferometry to image subsurface seismic velocity variations using seismic (surface) waves extracted from the background ambient vibrations of the Earth. To date, ANT has been used to successfully image the Earth’s crust and upper-mantle on regional and continental scales in many locations and has the power to resolve major geological features such as sedimentary basins and igneous and metamorphic cores. Here we provide a review of seismic interferometry and ANT, and show that the seismic interferometry method works well within the British Isles. We illustrate the usefulness of the method in seismically quiescent areas by presenting the first surface wave group velocity maps of the Scottish Highlands using only ambient seismic noise. These maps show low velocity anomalies in sedimentary basins such as the Moray Firth, and high velocity anomalies in igneous and metamorphic centres such as the Lewisian complex. They also suggest that the

Moho shallows from south to north across Scotland which agrees with previous geophysical studies in the region.

Ground-Motion Difference between Two Moderate-Size Intraplate Earthquakes in the United Kingdom

L. Ottemöller and S. Sargeant

Two moderate-size earthquakes occurred in the United Kingdom, the first near Folkestone in 2007 with Mw 4.0 and the second near Market Rasen in 2008 with Mw 4.5. Both were strongly felt and caused some nonstructural damage. The earthquakes occurred at significantly different depths, the Folkestone earthquake at 5 km and the Market Rasen earthquake at 20 km. We determined the seismic moment and the stress drop of the two mainshocks, and two smaller earthquakes in the same locations, by modeling the source displacement spectra. We found stress drops of 30±34 bar and 344±136 bar for the Folkestone and Market Rasen mainshocks, respectively. This is a significant difference considering the earthquakes are only 275 km apart and both are of intraplate origin. We applied the stochastic ground-motion modeling technique and used the stress drop and seismic moment to compute vertical component peak ground acceleration. The modeled ground motions are consistent with the observations. We also computed vertical peak ground acceleration for a hypothetical Mw 6.0 high stress-drop (200 bar) earthquake and found that it would be 4.6 m/sec2 at 20 km hypocentral distance.

A revised local magnitude scale for the UK

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Magnitudes of British earthquakes are determined using the scale as it was originally defined for Southern California. The anelastic attenuation correction is therefore unlikely to be appropriate given that the UK is located within an intraplate region with relatively low levels of seismicity. Therefore, we have used data from British earthquakes recorded from the year 2000 onwards to develop a UK-specific local magnitude scale. We determine a separate scale for North Sea earthquakes recorded in the UK where the impact of the large graben structures on wave propagation must also be considered. Finally, we determine a new relationship between ML and Mw.

CONTRIBUTORS TO THE PROJECT 2010 / 2011

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