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The seismicity of the British Isles

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Abstract
A new and homogeneous catalogue of earthquakes in the British Isles has been produced, including events of magnitude 4 M_L and greater to 1700 and events of 3 M_L and greater thereafter. The distribution of seismicity is uneven, with some areas (*e.g.* Ireland) almost aseismic. Magnitude/frequency analysis shows that a double-truncated exponential distribution gives a better fit than a classic Gutenberg-Richter linear fit. The calculated b value for the linear part of the exponential distribution is 0.94 with a maximum magnitude of 6.2 M_L.

Key words *seismicity – British Isles – historical earthquakes*

1. Introduction

The U.K. is not a country generally associated in the public mind with earthquakes. However, while the U.K. is nowhere near in the same league as high seismicity areas such as California and Japan, it nevertheless has a moderate rate of seismicity, sufficiently high to pose a potential hazard to sensitive installations such as dams and chemical plants. As a result, the last twelve years have seen a large effort by BGS (British Geological Survey) and others to improve instrumental monitoring of earthquakes and to research and revise the historical seismicity. The results of this research are summed up in a new catalogue of British earthquakes (Musson, 1994) which draws on the various studies available (*e.g.*, Principia, 1982; Soil Mechanics, 1982; Ambraseys and Melville, 1983; Burton *et al.*, 1984). A synopsis of the work is presented here.

This catalogue contains 502 earthquakes and fulfills two functions: in the first instance it forms a reasonably consistent catalogue of the larger British earthquakes, here defined as events with magnitude greater than or equal to 4.0 M_L. In the second instance it also contains a large number of smaller earthquakes, particularly those of interest through having been felt, although no sort of completeness is claimed for these smaller events. Magnitude values are given as Local Magnitude (M_L) and are either instrumentally calculated, as part of routine BGS determinations or using historical seismograms (*e.g.*, Neilson and Burton, 1984), or estimated from macroseismic data (Musson, 1996).

The catalogue covers the offshore areas as well as mainland U.K., and can be considered to cover the area between 10°W-4°E and 49°N-62°N. This includes all of Ireland and some earthquakes in northern France that were also felt in the U.K. Earthquakes outside this area are also included if they were felt in the U.K. This includes, for instance, the 1992 Roermond earthquake, but not the 1755 Lisbon earthquake which only generated seiche or tsunami effects and is not known to have been actually felt in the U.K.

The completeness of the catalogue is considered here only as a personal estimate based on knowledge of historical and geographical factors which might result in an earthquake being overlooked. It should be viewed in three sections, by date, as follows:

Before 1700 – Here only the larger earthquakes, those estimated as being above magnitude 4.0, are included. The discrimination between events greater or less than this value is by no means certain, and no sort of completeness is expected for this part of the catalogue.

1700-1970 – For this period the intention is to include all events greater than magnitude 4.0, as far as possible all events greater than magnitude 3.0 that were felt on the mainland of the U.K., and a few smaller events that were notable in some way. This part of the catalogue is reasonably complete above magnitude 4, though some events in areas with little population, especially before 1800, may be missing.

After 1970 – Instrumental monitoring of British earthquakes started about 1970, and after this date all events recorded by the BGS within the limits of the catalogue area and greater than magnitude 3.0 M_L are included. Also included are some smaller earthquakes that were felt. The catalogue is probably complete above 3.5 M_L for 1970-1980 and above 3.0 M_L thereafter (the BGS database is considered complete above 2.5 M_L for 1981 onwards). Completion date is 31 December 1993.

2. The distribution of British earthquakes in space

Figure 1 shows a map of the earthquakes in the catalogue excluding those that fall outside the main area of the catalogue (*e.g.* the 1992 Roermond earthquake). It is clear from this map that the spatial distribution of earthquakes is neither uniform nor random. In Scotland most earthquakes are concentrated on the west coast, between Ullapool and Dunoon, with the addition of centres of activity near the Great Glen at Inverness and Glen Spean, and a small area around Comrie, Perthshire, and extending south to Stirling and Glasgow. The Outer Hebrides, the extreme north and most of the east of Scotland are virtually devoid of earthquakes. For the north-west of Scotland the absence of early written records, the small population, and the recent lack of recording instruments means that there may be a data gap.

Further south a similar irregularity is seen. Most earthquakes south of the Scottish border will be found in Wales, the Welsh borders, NW England, SW England and the northern part of the English Midlands. The northeast of England seems to be very quiet; the southeast has a higher rate of activity, with a number of earthquakes which seem to be «one-off» occurrences, plus important centres of activity near Chichester and Dover.

Offshore, there is significant activity in the English Channel and off the coast of Humberside. Because only the larger events in these places are likely to be felt onshore, the catalogue is probably under-representative of the true rate of earthquake activity in these zones. The Central Grabens of the North Sea are now known to be active features, only because of the instrumental monitoring over the last fifteen years (Musson *et al.*, 1993; Walker, 1994).

The whole of Ireland is practically free of earthquakes. This is clearly genuine as for most of Ireland the historical sources are quite adequate, and modern instrumental monitoring shows only a very low occurrence of even very small events.

Certain centres can be identified as showing typical patterns of activity. For example, the Caernarvon area of North-West Wales is one of the most seismically active places in the whole U.K. Both large and small earthquakes, usually accompanied by many aftershocks, occur at regular intervals. It is tempting to ascribe several early earthquakes of unknown epicentre (*e.g.* that of 20 February 1247) to this area just because it seems to be such a favoured site for large earthquakes.

In South Wales, on the other hand, although a line of major epicentres can be traced from Pembroke to Newport, only the Swansea area shows consistent recurrence. Since the latest large earthquake here was in 1906 (excluding the smaller 1930 event), it may be that another earthquake in this area is due relatively soon. The Hereford-Shropshire area also produced large earthquakes in 1863, 1896, 1926 and 1990, but none of these share a common epicentre (accuracy of epicentral location being estimated at less than 5 km for all these events).

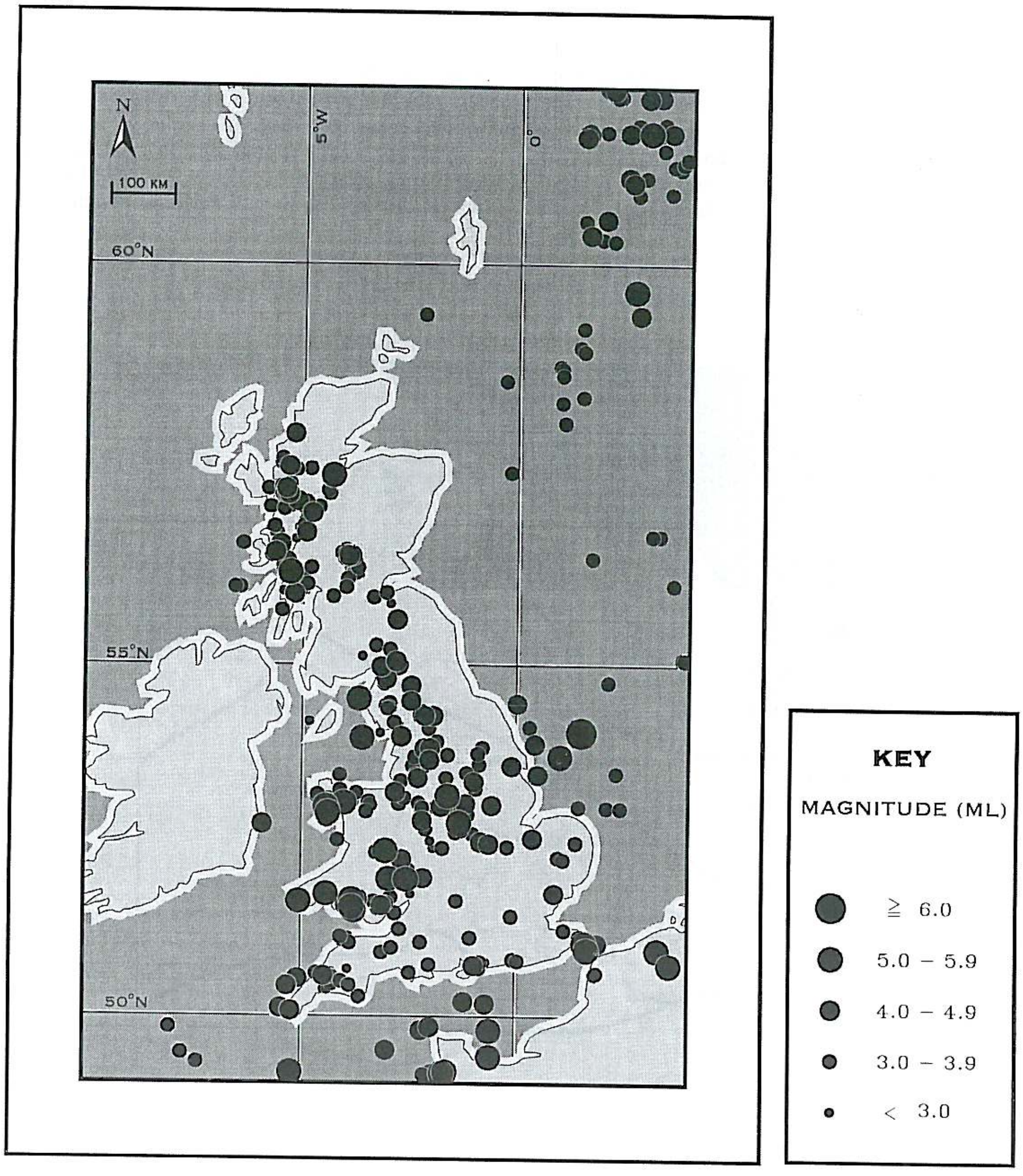

Fig. 1. The seismicity of the U.K. This map shows events ≥ 3.0 M_L since 1700, and well-located events ≥ 4.0 M_L of earlier date. Symbol size is proportional to magnitude as shown in the key.

In the south-west of England the most prominent centre is the Helston-Constantine area, just north of the Lizard Peninsula. This seems to be regularly active, but earthquakes there have tended not to exceed 4.0 M_L.

The Chichester area is interesting in that it seems to regularly produce small, quite intense earthquakes (presumed, therefore, to be very shallow), but it is uncertain whether there is the likelihood of a larger earthquake there. The largest recorded was that of 1963, which had a rather higher instrumental magnitude than was implied by its felt area.

The area of the Dover Straits is particularly significant because of the occurrence there of two of the largest British earthquakes in 1382

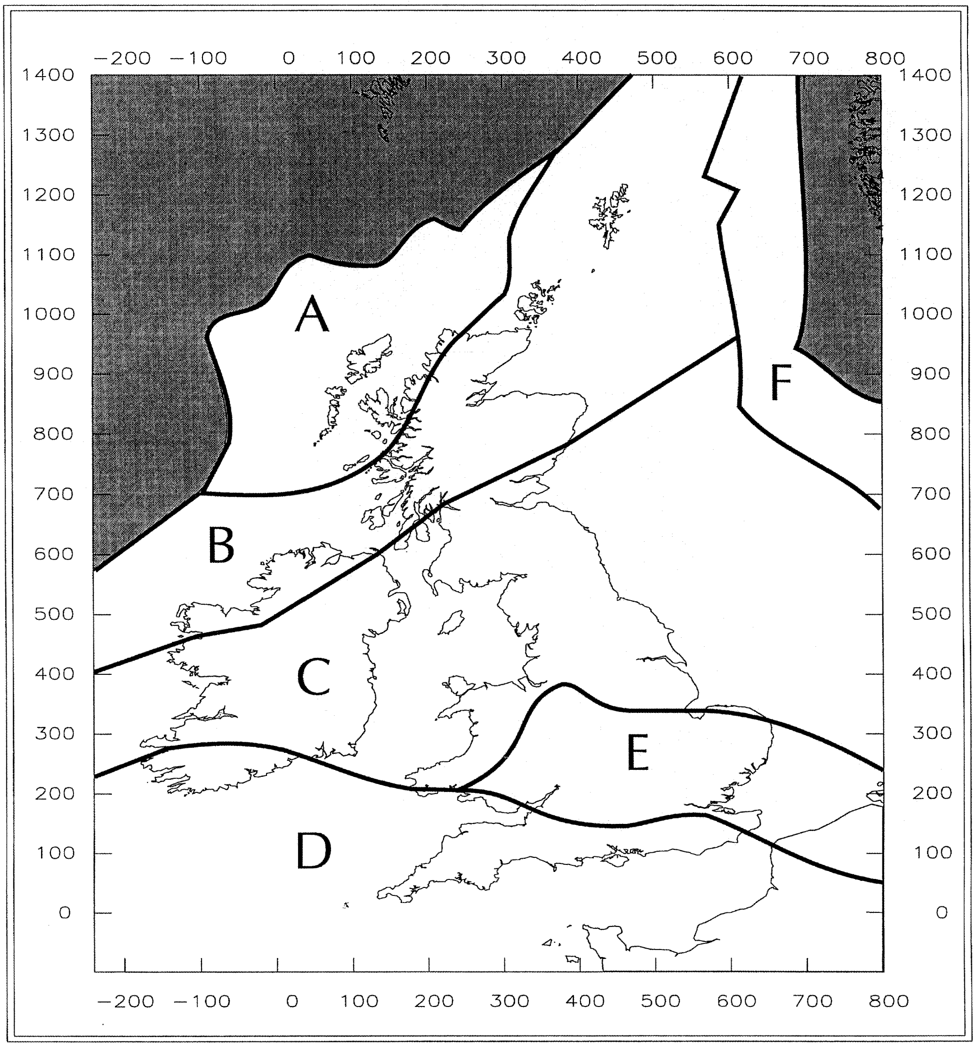

Fig. 2. Major structural divisions of the U.K.: A = Hebrides Microcraton; B = Metamorphic Caledonides; C = Non-metamorphic Caledonides; D = Variscides; E = London-Brabant Massif; F = North Sea Grabens.

and 1580 (both of magnitude about 5¾ M_L). Since 1580 the only earthquakes there have been much smaller, raising the question of whether there is a danger of another 1580-style earthquake in the near future. The area may be structurally continuous with a zone of activity running east through Belgium, in which case it could be argued that stress in this area since 1580 has been released further east. This does not rule out another 1580-type earthquake in the future, but it is impossible to estimate how soon it might occur.

In the north of England seismic activity occurs over a more or less continuous area from Leicester to Carlisle. The most prominent centres of repeating activity here are the upper end of Wensleydale, and to a lesser extent the Skipton area.

In Scotland, although earthquakes are frequent along the west coast, they are less commonly of high magnitude, and only two Scottish events in the catalogue (1880 and 1901) reach 5.0 M_L or greater. The swarm activity at Comrie and the Ochil Hills is famous, but these two centres differ in that the Ochil Hills area has never produced anything over about 3½ M_L, whereas the Comrie earthquakes have reached at least 4¾ M_L.

Jersey has also experienced a number of significant earthquakes, chiefly originating to the east of the island, in the Cotentin peninsula area. The most recent event to be felt on Jersey, however, though not so large as some historical events, had an offshore epicentre quite close to the island (Walker, 1991).

There is a lack of correlation between this pattern and the structural geology of the U.K. Figure 2 shows the major crustal subdivisions, adapted from Whittaker *et al.* (1989). The boundaries between areas of moderate or high seismicity and areas of very low seismicity, for instance the sharp dividing line running SE from Inverness, do not correspond to any known major structural feature. And the major boundaries and structural features shown in fig. 2 are not reflected in the pattern of seismicity either as dividing lines between zones of differing rates of seismicity nor as lineations marked by earthquakes.

A correlation can be deduced, however, at least for Scotland, between the more seismically active area and the limits of the last glaciation (fig. 3). There is evidence to suggest that the seismicity of Scotland may have been higher immediately following the unloading of the ice sheets (Davenport *et al.*, 1989). It can be conjectured that seismicity triggered by isostatic movement reactivated a number of ancient faults, and those that have a favourable

Fig. 3. Distribution of ice in Scotland during the Younger Dryas (Loch Lomond Readvance), from Dawson (1992).

orientation to the present crustal stress direction (NW-SE, from the opening of the Mid-Atlantic Ridge), *i.e.* predominantly N-S or E-W faults, have remained active. However, this doesn't seem to apply, for instance, in Ireland.

3. The distribution of British earthquakes in time

It has long been realised that larger earthquakes occur less frequently than smaller earthquakes, the relationship being exponential, *i.e.* roughly ten times as many earthquakes larger than 4 M_L occur in a particular time period than earthquakes larger than magnitude 5 M_L. This can be expressed by the formula

$$\log N = a - b\,M$$

where N is the number of earthquakes per year exceeding a given magnitude M. The constant a reflects the absolute level of seismicity in an area, and the value of b has generally been found to be consistently close to 1.0.

Figure 4 shows that this holds true for the U.K. This graph shows an analysis for the area 10°W to 2°E and 49°N to 59°N. This deliberately excludes the northern North Sea area which is of high seismicity and completely under-represented in the catalogue before 1970 because of the impossibility of detecting smaller events in this area before that date. The data plotted are derived in three different ways: for magnitudes 3.0-4.0 M_L only data since 1970 are used. For magnitudes 4.1-5.4, data since 1700 are used, and for 5.5 and above, data since 1300 are used. This gives three different normalisation periods of 23, 293 and 693 years.

A least-squares regression to this data gives the relationship

$$\log N = 3.82 - 1.03\,M$$

which is roughly what one would expect, and is shown by the dashed line in fig. 4. The bump in the data in fig. 4 around magnitude 5 M_L is probably due to the fact that chance

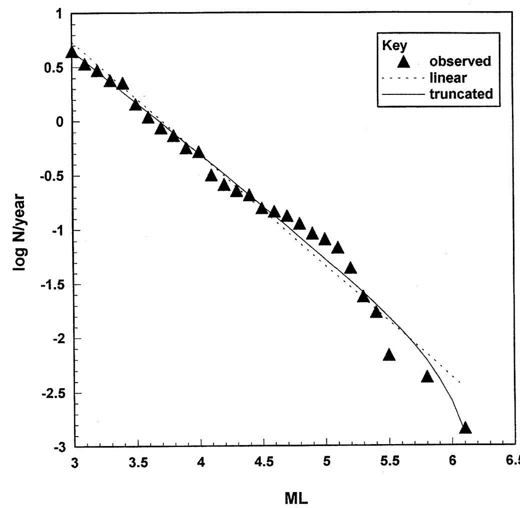

Fig. 4. Magnitude-frequency distribution for the U.K. (excluding the Northern North Sea). Solid triangles are observed data; the dotted line is a linear fit and the solid line is the preferred truncated fit.

fluctuations in the occurrences of the larger, rarer earthquakes happen to have produced a clustering of events of around 4.8-5.2 in magnitude in the recent period for which we have the best observations.

However, the above equation does tend to overpredict the occurrence of the larger earthquakes, and it may therefore be better to use a truncated exponential relationship of the form

$$N = \alpha \left[\frac{\exp(-\beta M) - \exp(-\beta M_u)}{1 - \exp(-\beta M_u)} \right]$$

(Cornell and Vanmarcke, 1969) where α and β are related to a and b ($\beta = b \ln 10$) and M_u is maximum magnitude. A least-squares fit to the data gives values of 3023.82 and 2.17 for α and β respectively – the β value of 2.17 equates to a b value of 0.94. M_u is calculated as 6.23. This is shown as the solid line in fig. 4 and gives a better fit to the data than the simple linear exponential, certainly with regard to the higher magnitude data.

One can therefore draw the following conclusions about average recurrence – the U.K. may expect:

an earthquake of 3.7 M_L or larger every 1 year
an earthquake of 4.7 M_L or larger every 10 years
an earthquake of 5.6 M_L or larger every 100 years.

From these statistics it would appear that the likely maximum earthquake for the U.K. is 6.2 M_L, although the reliability of this figure is open to debate.

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