Shale gas, NW England earthquakes, and UK regulation
Briefing note for DECC SAG

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Summary:

Shale gas drilling will be attempted in the UK for many years into the future, so legislation needs to be clarified and enforcement strengthened. The 2011 Blackpool earthquakes (Fig 1) were certainly linked to shale gas fracture activity. Similar earthquakes CAN be expected in future (in contrast to assertions by the developer, Cuadrilla). Public education is needed. Much better site specific prediction by developers could be made. Improved mandatory monitoring of microseismicity during fracturing is possible. Much better baseline gas measurement before during and after frac is needed. Gas leaks to aquifers and surface occur along casing rather than by frac. Disposal of flow-back water after frac, by injection into the subsurface appears more problematic than deep frac, and surface land remediation also needs to be considered. The April 2012 Traffic Light proposal by DECC consultants is experimental for frac, and still requires validation by multi-year monitoring.

1) Definition of shale gas and frac

Shale gas has been produced commercially from shales since drilling at Fredonia in New York in 1821, some 38 years before liquid oil. The term shale-gas is usually applied to deep gas thermally generated millions of years ago, but can include shallow biogenic gas formed since the last glaciation (such as that burning at Kimmeridge, Dorset). The products are typically 90% or more methane, and sometimes with associated C_{2-5} hydrocarbons, and CO2.

Fracturing, or "Frac(k)" is a term encompassing artificial breakage of the subsurface rock by injecting fluid. This is a common and very well established process in global oil production and coal bed methane extraction. "Fracturing" was applied to shale gas production since 1982 exploitation of the Barnet Shale of Texas. This routine has now been developed to be applied from boreholes radiating 1-2km horizontally away from a central drilling pad, which are then progressively fractured by packing off the furthest section of hole and increasing fluid pressure to form tensile fractures which are propped open with quartz sand or glass spheres. The packers are then withdrawn, installed closer to the borehole pad, and the process repeated. A typical borehole may undergo 4 or 8 fracture episodes within days. The gas is produced at low pressure, and thus needs to be used locally or compressed to feed into a regional grid. Gas can leak from open holes and along casing.

Fracturing is an established drilling technique which needs regulation

2) Shale gas prospects in the UK

Shale gas in the Bowland Basin of Lancashire and offshore Irish Sea is considered to be the premier UK prospect, because of the organic quality of the shales and the maturity with history of oil and gas production. Other prospects include the Cleveland Basin of N Yorkshire (associated with conventional fields and high maturity); Lower Palaeozoic shale basins on the Midland Microcraton (a high risk because no conventional gas has been proved in this play), Pennsylvanian shales in the Stainmore and Northumberland Basin system (high risk because no conventional gas discoveries exist) and Jurassic shales in Wessex and Weald basins (Selley 2005, Smith et al 2010).

An important factor in producing shale gas is the density (number) of boreholes, which is initially at 3km spacing – because one borehole can easily access 1.5km laterally. The drainage zone of each borehole is tens to hundreds of metres. Consequently it is probable that the initial drilling campaigns will be followed by infill campaigns at 5-10 and 15-20 years subsequent to initial discovery.
If permiited, shale gas drilling will be a long-term feature of the UK onshore

3) Background facts on the Blackpool events

Two earthquakes were recorded near Blackpool (Fig 1): the first on 1 April 2011 (M 2.3) at 3.6 ±1.0 km depth, 23 reports of surface shaking were received. The second, on 27 May, was an M 1.5 event at 2.0 ±1.0 km depth, with one report of surface shaking. These were close to the Preese Hall drilling site, operated by Cuadrilla Resources, where fracturing fluids were being injected at 2-3 km (BGS 2011a, 2011b). Additional monitoring was one seismometer emplaced by BGS after the 1 April event, and this enabled much better location of the event. It is important that seismograms of both events are very similar, showing that they had a similar cause – agreed to be the borehole stimulation. The events are interpreted to originate from the same fault plane.
Two earthquakes occurred on the same fault, certainly linked to drilling and within hours of the fracturing.

4) Seismicity in NW England

Northwest England is a seismically active part of the UK (Fig 1). Earthquakes up to M 3.9 have been recorded in recent history and are registered on the BGS database. Earthquakes induced by shale gas fracturing are within natural ranges.

There are multiple reasons for seismicity. Firstly the UK is subject to global tectonics, horizontal forces are transmitted through continental plates. Examples of four long-duration effects are related 1) to northwards compression due Alpine mountain building from 10 million yr ago, 2) to eastwards extension by being on the edge of Europe from 60 million yr ago, and 3) to northeast dextral shear relating to the earth’s rotation. Additional effects (4) are due to the continued buoyant uplift of the UK, after ice sheet melting 13,000 yr ago. This uplift is a likely cause of historical M 5.9 events in the UK.

The Bowland Basin, which is the geological location of this drilling, is also known to contain many faults, which are easy to re-activate. Examination of the surface mapping (Fig. 1) shows that N-S faults similar to those active during the earthquakes occur at 1-4km intervals in the coalfields to the south (Liverpool to Warrington), and hence can be expected in the less well mapped buried Bowland Shale.

NW England is weakly seismically active and natural earthquakes can be expected. It will be impossible to avoid drilling close to faults.

5) Report on earthquakes

Cuadrilla (2011) have commissioned and published a science based report on the earthquakes. Notable points include
A) Fracturing usually induces seismicity of 0.8 – the Blackpool events are exceptional, being about 100x “normal”
B) There are many N-S faults in this region, locating boreholes more than 1km away from all these faults will be impossible
C) The borehole was deformed for 170 metres in a vertical section – showing not just one fault, but small motions along many bedding layers. It is unclear how this affects the gas seal between rock and borehole casing, to prevent gas escape vertically along the borehole axis into the Sherwood Sandstone aquifer.
D) Laboratory examination of core shows that the bedding planes, dipping WNW within the shale, moved in a N-S direction, and have very low cohesion – ie are very easy to slip. These planes are common.
E) Natural seals above the shale to stop gas reaching the surface are: the thick Millstone Grit, which will absorb leaked gas into deep saline pores; the thin Manchester marl evaporites, which are possibly too thin to be effective. Engineered seals to prevent gas leakage will be vital around the boreholes.
F) Future boreholes could be drilled to fracture less rock, more slowly, and recover the water (reduce excess pressures) much more rapidly, or use new gel technologies rather than water. This may reduce the risk of triggering seismicity.
G) The arguments (p 50) that this was an “unlucky” fault are weak, relying on unsupported generic assumptions, rather than evidence for this geographic region.
H) The bedding planes in this region are at 35 degrees dip, rising to 80 degrees dip in the deepest part of the borehole. Given the measured low friction on these surfaces – seismic slippage is unavoidable in such rocks.
The report is thorough and clearly demonstrates HOW the seismicity occurred.
It is not clear WHY these earthquakes were triggered.
Avoiding faults for future drilling is unlikely.

6) Opinion on report and other factors

The Cuadrilla report makes a case that this injection site was “unlucky” to encounter a fault. However the bedding layers of this particular shale are very slippery (as measured in the laboratory) and very steeply dipping. Imagine a pile of A4 paper tilted to a 40 degrees slope …. In this basin there are many faults – intersecting more faults with continued drilling is very probable. Exclusion zones from drilling could be suggested around faults – that is very difficult as even modern seismic cannot clearly resolve these faults, and zones of hundred of metres would be excluded, so that much of the shale gas resource would be sterilized.

The assertions made by Cuadrilla that such circumstances are unlikely in the future are very doubtful, and require site specific cases to be made.

By omission of any evidence, and the assertion that only two seismic survey stations were available, it can be inferred that no local microseismic arrays were deployed by Cuadrilla during the fracturing jobs. That is very surprising, as other shale gas companies in the USA manage to achieve much better monitoring practice. The depth of detection may be an issue, but regulators should challenge this assertion, as longer surveys or improved processing can help.

Many publicly expressed objections to Fracturing are not founded on the earthquake issue, but relate to a package of “rejecting fossil fuels” and “hydrocarbon industrialisation” (Tyndall 2011). It is possible, as with CCS, that some objectors use the high media profile of earthquakes to engage in a proxy war against fossil fuel. It is manifestly true that if shale gas augments existing fossil fuel use, then greenhouse and ocean acidification effects are made worse. However, it is also possible that shale gas will encourage fuel switching from coal to gas, and so reduce CO2 emissions. However shale gas drilling can induce fugitive emissions of gas from the borehole during fracturing stimulation, and leakage around the casing during production (Osborn et al 2011), these need legislation to prevent contamination and reduce Life Cycle emissions..
The report asserts a positive future view, but this is clearly a very difficult set of geological circumstances. There is no mechanism proposed to identify low risk areas, how to monitor during the fracturing jobs, and no method to establish baseline gas before, during or after fracturing.

7) Water use

A common accusation relating to shale gas drilling, is that immense quantities of water are consumed. This is undoubtedly true during the initial borehole. However the drilling industry can, if licensed appropriately, choose to recover 75 to 90% of the injected water and reuse that in subsequent bore holes especially from the same drilling pad from where up to 34 holes may radiate laterally. Thus the water use per borehole is much less. Water use can be further reduced by using more expensive gas or gel fracturing methods.

Multiple additives can be placed in the drilling water with functions ranging from suppression of microbial action, through to corrosion inhibition. Water recovered from the subsurface can be expected to become highly mineralized, and some of this mineralization may contain abundant NORM (naturally occurring radioactive material), which can need special licensing and disposal conditions as in North Sea operations.
Water recycling can be achieved, if mandated. Analyses are required.

8) Risk to water supplies

There have been many anecdotal reports of contaminated agricultural and drinking water boreholes from the USA. However there is minimal evidence to link these allegations to fracturing (Osborn et al 2011). Undoubtedly methane gas exists in some boreholes, but this can be natural shallow biogenic origin, or could be leaking upwards around the steel casing emplaced in boreholes. No conclusive link to deep fracturing has yet been established.

Methane gas can originate from multiple sources in the shallow earth's crust. To determine the source of gas and link this to fracturing, it is possible to use C and H isotopes in the methane, which can usually provide discrimination between shallow and deep derived gas. Additionally it may be possible to develop noble gas monitoring using natural isotope ratios. To enable such discriminations to occur, a programme of baseline investigation of natural groundwater and soil gas contents is essential before drilling.
Strong rules on baseline monitoring may be needed, especially above the subsurface regional geological seal, and in shallow surface boreholes around wellheads.

9) Level of risk

The induced earthquakes are small, even in a UK context. Similar magnitude earthquakes occur during coal mining, filling of large water reservoirs, deep geothermal exploitation, and oil production offshore. If future drilling produces similar events, there is no compelling safety concern. Will continued drilling produce larger seismic events? That is harder to answer. It is possible, in theory, for multiple small events to build stress such that a large event occurs subsequently. Against that argument is the modern and historical record of seismicity in north-west England, showing that even the largest natural events are only M2.5-3.9. So there is a high risk of further seismicity, but the effects are likely to be small.

Will groundwater be polluted? Established fracturing operations in the USA provide no clear examples of groundwater contamination since 1982. If the well casings are well cemented to surrounding rock, then release of deep shale gas or release of shallow biogenic gas can be eliminated. Strong rules on borehole integrity and better monitoring before during and after fracturing are needed.
The level of risk from seismicity is low, but better monitoring is needed

10) Regulation and risks during shale gas exploration and production

The perception of risk during shale gas exploration is widely reported in popular media. This is seldom based on, or inclusive of, scientific evidence. Consequently several states, notably New York in the USA, France and Bulgaria in the EU, have enacted blanket bans on shale gas exploration during 2011 and 2012.

By contrast, the USA, being by far the most active in shale gas exploration globally, has a diversity of views and legal approaches at Federal and State level. An exhaustive review has not been undertaken for this DECC note, but prominent recent reports on shale gas activity are still contradictory, with no general concensus. These include: 1) the EPA (2011) on Pavillion Wyoming where drilling fluids and hydrocarbons have been detected in potable aquifers- although the source of these contaminants is unclear. 2) The EPA announced on 23 June 2011 that they will examine claims of water pollution (eg Osborn 2011) related to drilling in Texas, North Dakota, Pennsylvania, Colorado and Louisiana. On 14 Feb 2012 the EPA stated that for Washington County

Pennsylvania “legitimate concerns have emerged regarding potential environmental impacts” 3) Earthquakes on 24 and 31 December 2011 of M 2.7 and M 4.0 (ie significant) in Ohio USA, are linked to injection of waste water from shale gas fracturing activity (Fischetti 2012) (4) The Energy Institute of the University of Texas at Austin (EIUT 2012) has produced a suite of findings from a USA national investigation, which fail to link shale gas exploitation with contamination, although the review is based on historical events which may not yet fully recognize a developing awareness of problems. Stronger regulation and enforcement is recommended.

The EIUT review focused on: a) Environmental and health effects, b) Public perceptions c) State and federal regulations. Several state of the art points are made on the evidence of accident and contamination:
- Researchers found no evidence of aquifer contamination from hydraulic fracturing chemicals in the subsurface by fracturing operations, and observed no leakage from hydraulic fracturing at depth.
- Many reports of groundwater contamination occur in conventional oil and gas operations (e.g., failure of well-bore casing and cementing) and are not unique to hydraulic fracturing.
- Methane found in water wells within some shale gas areas (e.g., Marcellus Shale) can most likely be traced to natural sources, and likely was present before the onset of shale gas operations.
- Surface spills of fracturing fluids appear to pose greater risks to groundwater sources than from hydraulic fracturing itself.
- Blowouts — uncontrolled fluid releases during construction or operation — are a rare occurrence, but subsurface blowouts appear to be under-reported.

On the regulatory adequacy, the EIUT report found that
- Primary regulatory authority for shale gas is at the state level, and many federal requirements have been delegated to the states.
- Most state oil and gas regulations were written well before shale gas development became widespread.
- Some states have revised regulations specifically for shale gas development, with particular focus on three areas of concern:
    - Disclosure of hydraulic fracturing chemicals
    - Proper casing of wells to prevent aquifer contamination
    - Management of wastewater from flowback and produced water
- Gaps remain in the regulation of well casing and cementing, water withdrawal and usage, and waste storage and disposal.
- Regulations should focus on the most urgent issues, such as spill prevention — which may pose greater risk than hydraulic fracturing itself.

And on enforcement of existing regulations, the EIUT report found that
- Enforcement capacity is highly variable among the states, particularly when measured by the ratio of staff to numbers of inspections conducted.
- Most violations recorded are of the type associated with conventional gas drilling rather than being specific to hydraulic fracturing and shale gas production.
- Enforcement actions tend to emphasize surface incidents more than subsurface contaminant releases, perhaps because they are easier to observe.

It is here suggested that many of these principles have relevance in a UK setting, and are in-line with conclusions drawn from UK evidence before the EIUT report. Stronger enforcement of regulation will require additional staffing. ***Strong and appropriate licensing is needed, together with a means of detecting contamination of groundwaters***

11) DECC report April 2012

A report was commissioned by DECC to undertake expert examination of the Curadrilla (2011) reports and suggestions for continued drilling and frac. The DECC report concludes with many similar points made in this Briefing Note. Additionally some important recommendations are made to enable drilling and frac to continue. These are first that much more detailed microseismic monitoring should occur; second that a frac job should be started with short-duration tests followed by monitoring, to gain site-specific data on micro-tremors; third that a traffic-light warning system should be used based on earthquake magnitude. This last point is not well explained in the report, but could logically and conventionally be based on the sampling statistics of earthquakes, where large numbers of very low magnitude events can be measured, but the frequency of high magnitude events is very uncertain. Taking a 0.5 limit initially is likely to have been chosen to give a statistically acceptable frequency (less than 1-5% per year) of earthquakes greater than 3.0. The upper limit of 3.0 is derived from historical records in this region of earthquakes caused by mining subsidence. That is acceptable as a pragmatic approach. But it should be realized that frac involves inflation of the rock, not deflation, and that only a short time series is available. Several publications suggest that a serial inflation of the rock, during during several frac boreholes in the same geographic region, will inject increased cumulatively volumes of water, so there is a possibility that earthquakes could increase in frequency and magnitude (Corbyn 2011, Nicol et al 2011). This is not a routinely accepted hypothesis, but has a sufficiently high impact outcome that it is well worth specifying that microseismic monitoring to seek evidence of increased earthquake frequencies (shorter intervening time periods) and larger energies should continue for several years after the initial frac have been undertaken.

The DECC report of April 2012, agrees independently with most of this Nov 2011 note. However it fails to explain the Traffic Lights reasoning underlying limiting measured seismicity to M0.5, and does not explain that this is a newly emerging topic of prediction. It is here recommended that microseismic monitoring continues, less intensively, for several years in case sequential frac can coalesce to induce rare M3-5 earthquakes.

12) Possible licensing conditions

In summary, drilling for shale gas in the UK entails minimal new technology, and minimal new operating practice. What is needed is enforcement of best practice. The risk of earthquake and gas leakage is particular to the exact geological circumstance, and the UK can be expected to be more at risk than the USA from fracturing seismicity. However there is a strong case that the seismicity will be similar to that historically experienced due to coal mining operations in the UK, and less than that experienced from oilfield operations beneath Paris, Los Angeles, of Houston; or gas storage operations beneath Paris or Berlin.

Earthquakes are unpredictable, except in a statistical way. So it is certain that natural processes of background seismicity will continue, and it is possible that seismic events may be accelerated by drilling activity. Any such occurrences will undoubtedly be conflated, by media and green NGO, with shale gas drilling. However, accurate prediction of earthquakes is certainly not completely understood, and active seismic monitoring should be maintained for several years around each exploitation area, to ensure that adverse trends of more frequent, or larger magnitude, seismicity do not develop unexpectedly.

The security and performance of operations will depend upon the licensing conditions, and on the enforcement, imposed by UK government. Particular attention should be directed at;

1) Minimizing drilling water utilization and subsurface and surface discharge by encouraging maximum water recycling. Analyses are needed.
2) Baseline assessment of soil and aquifer gases before drilling.
3) Gas monitoring at surface after drilling, in shallow boreholes around the borehole site.
4) Gas monitoring after drilling, downhole outside the casing above the regional seal rock and below the shallow potable aquifer.
5) Explicit assessment of seismic hazard for the initial proving wells in a new region, combined with improved availability of public information.
6) Exclusion zones around N-S faults could be considered, but if this is similar to the 1km of horizontal borehole radius plus the 100m zone of fracturing, then that eliminates most of the shale resource.
7) Mandatory monitoring of micro-seismicity during drilling operations, and especially intense monitoring during the fracturing operation. This will provide very accurate location of micro-earthquakes in 3D through time.
8) A traffic-light system of operation for seismic hazard has been used successfully in some geothermal operations. The DECC (2012) report suggests transferring that to shale gas, with a limit for intervention at M 0.5. However that will depend on the geological setting, and assumptions of limiting seismic magnitude. Accurate forecasting of seismic events is not fully established, and some contradictory evidence exists, such that it will be useful to maintain background monitoring locally during several years, to asses the trend of (micro)seismic intensity and frequency.
9) Borehole casing needs to be well cemented to surrounding rock, especially below the near-surface 500m b.o.d., and aquifer zones. That is not always easy.
10) Future boreholes can be drilled and fracturing using less water volumes, and extracting the water rapidly to reduce over-pressures, ie to reduce the "drivers" for seismicity. Alternative technologies for inducing fracturing are becoming available – such as zero water frac using petroleum gas (propane) gel from GasFrac (Calgary). These can greatly reduce contamination by drilling fluids, or contamination by waste water
11) Fugitive gas emission from open holes during fracturing, and around casing during production need specific attention to be minimised.

12) Shale gas operations continue to be contentious worldwide, especially in the USA. DECC and DEFRA should maintain a watching and horizon-scanning role on regulatory activity in other nations.

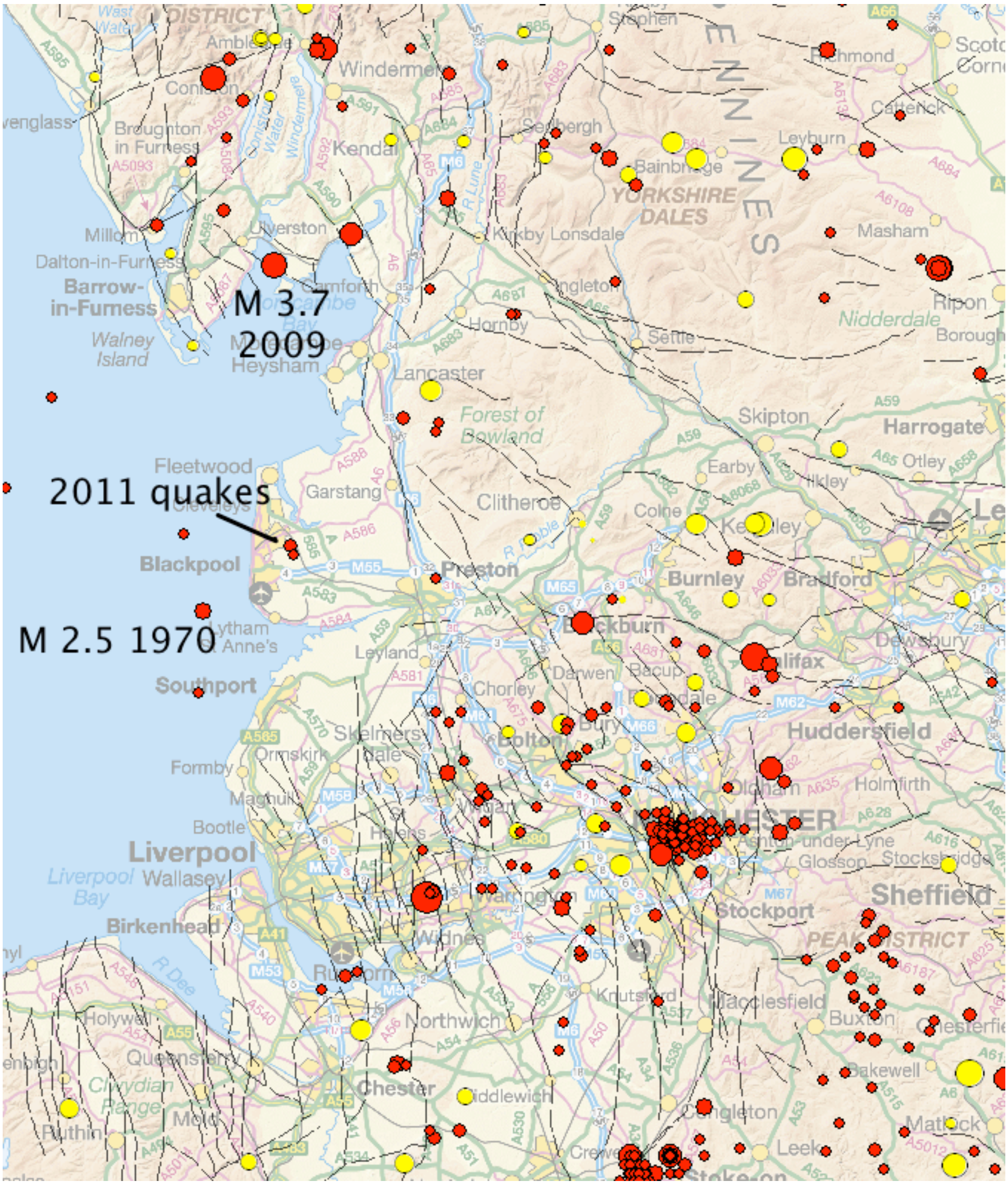

Figure 1 Historical records of earthquake seismicity in NW England - from BGS database. Black dashed lines are mapped (large) geological faults. Red dots show instrumentally detected earthquakes in proportion to Magnitude. Yellow dots are historical earthquakes, with less geographic and Magnitude resolution.
http://maps.bgs.ac.uk/GeoIndex/default.aspx (Theme: hazards)
Note the cluster of similar M 1-2 seismicity from Manchester coal mining and also the M 3.7 Ulverston quake of 2009, the M 2.5 offshore of Blackpool in 1970

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