UKArray – *Monitoring the UK's Seismic Activity*

Context. Seismic waves from earthquakes contain information about both the earthquakes themselves and the structure and properties of the Earth. By analysing seismic waves recorded by dense arrays of sensors, we construct 3D images, and infer values of crucial parameters of the subsurface. In addition, monitoring changes over time allows us to understand and model Earth processes and structures on a variety of scales. This is important both for natural hazard assessment, and for independent monitoring of subsurface-related industrial activity such as hydrocarbon production and waste storage.

In the UK, images of the Earth's crust cannot resolve details less than several tens of kilometres across due to the limited number of sensors in the permanent UK seismic monitoring network operated by the British Geological Survey. This similarly limits our ability to detect and locate small earthquakes, and to interpret or attribute them to specific fault zones, and to either natural or industrial activity.

Proposal. **A budget of £562k** should be made available to purchase & install a large transportable array of forty seismic sensors to be deployed across the UK. These will provide new, detailed models of the Earth's crust under the UK, high resolution images of active fault zones, and near real-time information about both natural and man-made seismic activity including the low magnitude earthquakes commonly associated with industrial activity. The data can also be used to answer fundamental scientific questions about the shallow and deep Earth, for example in the NERC Theme Action Plan "Deep Earth control on the habitable planet", and to address important issues relating to the future use of the Earth's sub-surface both as a source for sustainable energy and as a means of energy and waste storage.

For example, the recent 'traffic-light' system outlined by DECC will require hydraulic fracture stimulation ('fracking') to cease if earthquakes with magnitude of 0.5 or greater occur. However, the existing network of permanent seismic sensors in the UK can not reliably detect events of magnitude lower than 2.0 and there are several thousands of earthquakes of magnitude 0.0 or above that are undetected each year in the UK.. This highlights the urgent need improve our capability to detect small earthquakes in order to support and regulate industrial activities. In addition, operators will only be required to monitor during fluid injection, and over a limited area; recent studies have shown that the monitoring should be for much longer (~2 years after cessation of fluid injection) and over a broader area (~20km^2) to fully characterise the true nature and extent of any induced seismicity.

This array consists of two *inter-linked* and *co-dependent* components:

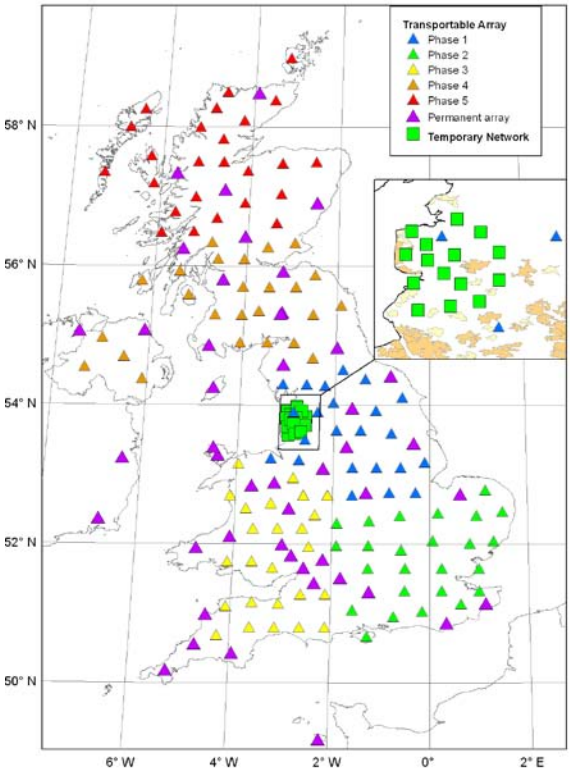
1. A distributed network of 15 seismic sensors deployed in an area of predicted future industrial activity such as the Bowland Basin in Lancashire. This will remain in place for at least two years – before, during and after hydrocarbon exploration and potential production.
2. A transportable array of 25 sensors that moves progressively across the UK, filling gaps between stations in the existing UK array, and spending at least 12 months in each location.

Component 1 provides:

- ***Essential baseline data*** to enable new research into both the nature and hazard of seismic activity induced by future industrial activities such as fracking operations involved in both *conventional and unconventional hydrocarbon exploration and production*.
- ***Accurate and independent*** estimates of locations and magnitudes of seismic events, to effectively monitor human-induced seismicity and properly regulate subsurface production and storage.
- ***Knowledge to inform public perceptions and debate*** into benefits & hazards of industrial activities.
- **New, high resolution information** about active fault systems and sub-surface stresses that can be used to identify areas where the hazard from induced earthquakes may be higher.
- Constraints on the attenuation of seismic waves in the Earth's Crust under the UK that will lead to an improved magnitude scale for small, induced earthquakes and to more effective regulation.
- **Implementable and quantitative thresholds for an effective traffic light system**, and assessments of how these might change as our knowledge improves over time.

Component 2 provides:

- Characterisation of local background seismicity rates ***across the whole of the UK*** over a period of five years; industrially interesting or sensitive areas may be targeted first.
- **New detailed images** and models of the UK's shallow and deep crust, and upper mantle using seismic surface and body waves. These models would have **unprecedented spatial resolution** within the UK, and the shallow crustal models are likely to be of commercial interest.
- Observational data to explore the deeper Earth and its processes, which would interest a broad **spectrum of scientists in the UK and internationally**.
- Initial deployment of the transportable array component in the north of England, surrounding the proposed baseline monitoring array in Lancashire, will additionally allow a **cost/benefit analysis** of a broader dense network for industrial monitoring and hazard assessment.
- Subsequent redeployment of the array in southeast England would both fill the "London gap" in the existing permanent monitoring network, and provide baseline information about areas of exploration and future production in this area. ***Such baseline information is crucial if subsurface-related safety and environmental concerns are to be addressed, and future industrial activity is to be policed effectively***.



The transportable array progressively covers the entire UK over a five year period, starting in the north of England in Phase 1, then the South-East in Phase 2, while a dense network of sensors remains for a longer period in an area of industrial interest such as the Bowland Basin.

Budget Breakdown. A hardware budget of **£462k** (excluding VAT) will fund the purchase of 40 broadband seismometers and high dynamic range data loggers, along with all other hardware required to operate a network of temporary stations including batteries, solar panels and cabling. In addition, we propose to use wireless routers to transmit data in near real-time to the British Geological Survey over mobile phone internet connections, a method of telemetry used for a number of existing permanent stations. These data will be combined with data from the permanent network of seismometers for near real-time earthquake detection and location, as well as being archived, rapidly distributed to other scientists in the UK, and made available to international data centres. The additional ongoing cost of the data telemetry for the entire array is estimated to be **£20k per annum for 5 years**.

Item	Unit Cost	Number	Cost
CMG-3ESP broadband seismometer	4,650	40	186,000
DM24/EAM data logger	4,000	40	160,000
Outstation hardware	2,500	40	100,000
Wireless modem	400	40	16,000
Telemetry	20,000 per annum	5	100,000
Total			**562,000**

Principle Researchers. The research will be led by a team of researchers with extensive experience of deployment of seismic instrumentation to both record seismic activity and image the Earth's interior. This team comprises of: Andrew Curtis (University of Edinburgh), Brian Baptie (British Geological Survey), Mike Kendall (University of Bristol) and Richard England (University of Leicester).