Geomechanical Study of Bowland Shale Seismicity

EXECUTIVE SUMMARY

2 November 2011

Background

The *Geo-mechanical Study of Bowland Shale Seismicity* study was commissioned by Cuadrilla Resources and carried out by a team of independent experts from across Europe. It was commissioned to establish why there was unusual seismic activity in the vicinity of Cuadrilla's Preese Hall-1 well on Lancashire's Fylde coast, approximately 3.5 kilometres east of the outer limits of Blackpool. The main objects of the study were two seismic events: One of magnitude 2.3 on April 1st 2011 and one of magnitude 1.5 on May 27th 2011.

These events were reportedly felt by a small number of people but neither had any structural impact on the surface above. Following the second event Cuadrilla immediately ceased activity at the Preese Hall site and commissioned this scientific report, which uses geological information, observations made during stimulation treatments in the well and modelling, to consider the cause and implications of the seismic events.

Benefits of Shale Gas to the UK

The creation of a shale gas industry in the UK, with Cuadrilla's Lancashire site at its hub, offers a substantial and sustainable economic benefit to the British economy. Economic development consultancy Regeneris has said that Cuadrilla's operations alone could create up 5,600 high-pay high-skills jobs in the UK, of which 1,700 will be based in Lancashire.

The scale of Cuadrilla's operations is expected to generate a new cluster of specialist skills and investment in the Lancashire area, attracting both domestic and international specialist companies. We would also expect Lancashire to serve as a long-term base for UK shale expertise with firms securing overseas and other UK contracts in subsequent waves of shale production while retaining a Lancashire base.

The purpose of the report was as follows

1. Establish the cause of seismicity
2. Estimate the maximum magnitude of seismic events induced by future fluid injection
3. Evaluate the potential for fracing fluid to escape into permeable rock levels and shallow water aquifers
4. Evaluate whether the seismic hazard related to a fault slippage could cause any damage on the surface
5. Identify procedures to minimize the likelihood and mitigate the magnitude of seismic events

These five points are addressed in more detail below.

Conclusion

The report concludes that it is highly probable that the fracing at Preese Hall-1 well triggered the recorded seismic events. This was due to an unusual combination of factors including the specific geology of the well site, coupled with the pressure exerted by water injection. This combination of geological factors was rare and would be unlikely to occur together again at future well sites. If these factors were to combine again in the future local geology limits seismic events to around magnitude 3 on the Richter scale as a worst-case scenario.

Cuadrilla's water injection operations take place over 3km below the earth's surface. This significantly reduces the likelihood of a seismic event of magnitude 3 or less on the Richter scale having any impact at all at the surface.

Using their findings, the report sets out an early detection system to monitor seismic activity at Cuadrilla's drilling site and, in the unlikely event of future significant seismic activity have established a series of steps to take in order to reduce seismicity.

1. Establishing the cause of seismicity

The report indicates that a number of factors coincided to cause the seismic events.

- The Preese Hall-1 well encountered a pre-existing critically stressed fault
- The fault was transmissible so it accepted large quantities of fluid
- The fault was brittle enough to fail seismically
- The repeated seismicity was most likely induced by repeated direct injection of fluid into the same fault zone
- The strongest events took place around ten hours after the injection because the pressure spread out over a larger area
- It is unlikely that the actual opening of the hydraulic fractures induced the seismic events because there is a delay of many hours between the injection of fluid and the strongest seismic event. Fluid pressure on the fault, however, has a natural time scale which fits with the observed delay.
- The chance of any one of these factors occurring is small, therefore the probability of a repeat occurrence of a fracture-induced seismic event with similar magnitude in the Bowland basin is very low.

2. Estimate the maximum magnitude of seismic events induced by future fluid injection

The report uses a model to simulate the maximum possible magnitude that could be expected to be triggered by future operations.

The model suggests that it is unlikely that another well in the Bowland basin will encounter a similar fault with the same critical stresses and high permeability into which fluid can be pumped.

Even in such an unlikely scenario, the maximum magnitude is likely not to exceed magnitude 3. This is based on modelling and practical experience of the seismicity in geothermal injections.

Using their analysis, the report authors have proposed an early detection system that could be used by Cuadrilla for mitigating the escalation of seismic events and in turn, the chance of any future seismic event exceeding safe limits.

3. Evaluate the potential for fracing fluid to escape into permeable rock levels and shallow water aquifers

The fracing carried out by Cuadrilla in the Bowland basin occurs at a depth of around 3km, whereas groundwater aquifers do not exist beyond a depth of around 300m.

There is a very thick, impermeable formation of rock above the Bowland shale which acts as a confinement layer.

There is another rock barrier above this impermeable layer that will prevent any fluid migrating upward. The confinement layer and the barrier prevent any fluid getting into permeable layers of rock above.

4. Evaluate whether the seismic hazard related to a fault slippage could cause any damage on the surface

Even the theoretical maximum seismic event of magnitude 3 would not present a risk to personal safety or damage to property on the surface.

In the Lancashire area of the UK, there have been many mining-induced seismic events at comparatively shallow depths of around one kilometre below the surface, that measured up to 3 on the Richter scale. The Preese Hall-1 well is more than 1.5 kilometres below the earth's surface so events of similar strength are very unlikely to cause any damage at the surface.

5. Identify procedures to minimize the likelihood and mitigate the magnitude of seismic events

Although the report indicates that the probability of a repeat occurrence of a fracture-induced seismic event is very low due to the unlikelihood of specific factors combining in the same way again, using their analysis, the report authors have proposed an early detection system that could be used by Cuadrilla for mitigating the escalation of seismic events and in turn, the chance of any future seismic event exceeding safe limits.

The aim of this early detection system is to build in an extra layer of safety to Cuadrilla's operations and ensure that any future operations don't cause damage at the surface.

The report proposes that Cuadrilla monitors seismic activity at its drill sites and reacts in specific ways if certain internationally accepted levels are exceeded.

Based on the internationally accepted German standard for safe ground vibrations, a very conservative maximum seismic magnitude of 2.6 is proposed as a maximum level allowed. An event of this magnitude, at this depth, ensures that no damage at all could be done to surface structures near a well that is fracture stimulated.

Using observations from the Preese Hall-1 well, the report suggests that the largest magnitude event follows a series of smaller events, many of which measure below 1 on the Richter Scale and were previously undetected. These can act as an early warning of future seismicity. The report also shows that the largest event tends to occur post-injection and that the maximum post-injection increase has been estimated to be 0.9 magnitude units. Therefore to ensure the safe limit of magnitude 2.6 is never breached the report recommends that mitigation measures be taken upon detection of an event measuring magnitude 1.7.

One such measure to prevent seismic events from escalating is to take fluid back out through the well to reduce the pressure it exerts on the geology and to reduce the volume of fluid stored in the fracture system.

In addition the report recommends injecting water in intervals of the well which are close to faults – which can be identified using image logs – should be avoided.

The early detection system proposed in the report is as follows:

- Level 1: If no seismic events above magnitude 0 are recorded, regular operation can continue

- Level 2: If an event of between 0 and 1.7 is encountered the company should continue monitoring seismicity after injection until seismicity falls back to lower levels.

- Level 3: If a seismic event of more than 1.7 is encountered, the company should stop water injection and release pressure in the well, to reduce the pressure it exerts, while continuing to monitor.