Shale gas: challenges and opportunities

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What is shale gas?

Shales are fine-grained sedimentary rocks, formed over millions of years by the compaction of fine particles of mud. Organic matter can become trapped in the layers as they are compacted, and are gradually converted through heat and pressure into hydrocarbons (petroleum and natural gas). The main component of shale gas, and the primary reason for its extraction, is methane, which makes up between 70% and 90% of shale gas, together with smaller amounts of other light hydrocarbons, carbon dioxide, oxygen, nitrogen, hydrogen sulphide, radon and rare gases.

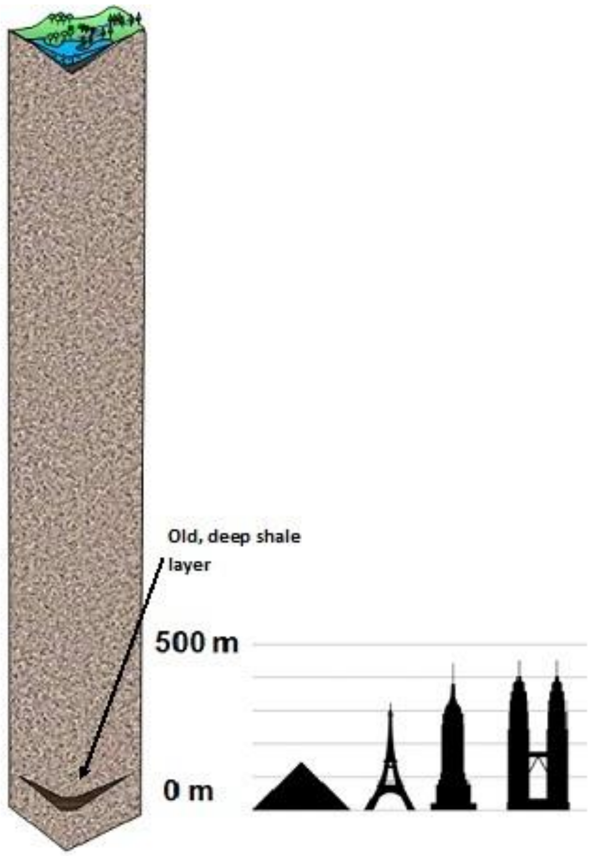

Figure 1: Relative scales of the typical depth of shale-gas bearing formations, and some of the tallest man-made structures. This is the typical depth for thermogenic decomposition of organic matter into methane gas. (© NERC)

There are large sedimentary basins in the UK which contain significant shale sections. Exploration for shale gas in the UK is still at an early stage, so there is currently no clear consensus about how much shale gas is under the ground and the prospects for extracting it economically. Nevertheless, most geologists agree that there are reasonably significant onshore resources, most likely in the Lower Carboniferous around the Pennines, in Jurassic layers in the Weald and Wessex, in the Upper Cambrian in the Midlands, and possibly in the Lower Palaeozoic black slate of Wales and South West England. Whether these resources are exploited will depend on economic, environmental, social, and regulatory constraints. There are large resources worldwide.

In 'conventional' hydrocarbon reservoirs, oil and gas have migrated from where they were formed, upwards through permeable rock such as sandstone, to become trapped beneath an impermeable bounding layer. When gas is instead formed in impermeable shale and cannot migrate, it is trapped within the shale both as adsorbed molecules on grain surfaces and as free gas. Because shale is not permeable enough to allow the gas to flow to a well bore (as is the case for 'conventional' gas extraction), shale gas is extracted by other means, and is referred to as an 'unconventional' resource.

How is shale gas extracted?

Shale gas is extracted using hydraulic fracturing (also known as 'fracking'), a process used in the oil industry since the mid-twentieth century. In order to produce gas economically, this is used in conjunction with horizontal drilling. A conventional well bore is drilled and, on reaching the shale, is directed horizontally (Fig. 2). Fracking fluid is injected, opening up fissures in the rock and allowing the gas to be extracted. Some of the fluid returns to the surface as 'flowback water'.

Fracking fluid consists mainly of water and sand, which acts as 'proppant' to keep fractures open. Small quantities of chemicals are added (usually less than 0.5%) to enable the fluid to pass easily through fractures, to kill bacteria and to prevent build up of scale in the well. Such chemicals are also often used in conventional hydrocarbons drilling. The composition of flowback water largely reflects that of the fracking fluid, but it also contains materials from drilling operations and from the shale itself, and may include small quantities of zinc, chromium, nickel, arsenic, sodium, calcium, magnesium, uranium, radium, chlorides, radon and various organic compounds.

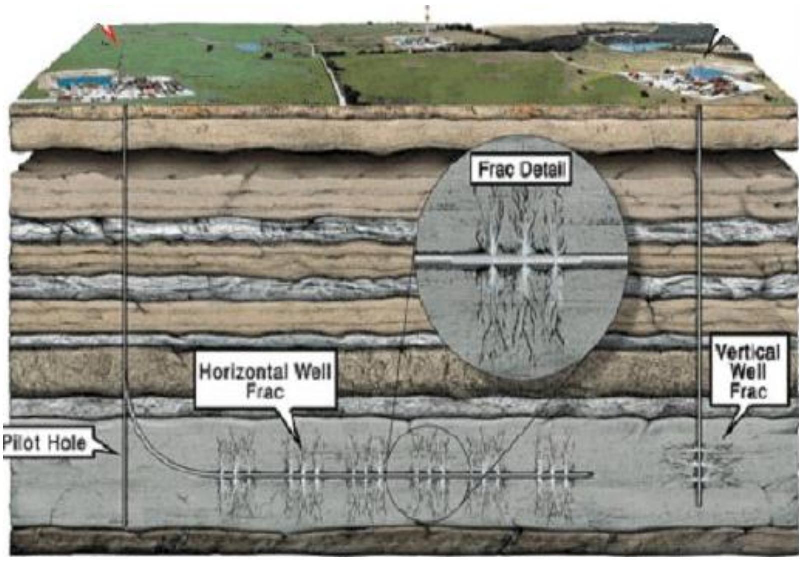

Figure 2: Schematic representation of shale gas operations. Most shale gas plays are at 2km to 5km depth, with drinking water aquifers within the first few hundred metres below the surface. Not to scale. (© B J Services)

Can it be extracted safely?

There are risks and challenges associated with the extraction of any mineral resource, including shale gas. It is important that such activity is appropriately regulated, and risks identified and managed. Three areas of potential risk which have given rise to particular concern among policy-makers and the public are: groundwater contamination; water sourcing and disposal; and induced seismicity. The environmental impact of carbon emissions resulting from the use of shale gas is not addressed here – see our Climate Change Statement at www.geolsoc.org.uk/climatechange.

1. Groundwater contamination

In the UK, groundwater provides 35% of our drinking water. Groundwater is also important to support surface water flow and regulate the health of ecosystems. Concerns have been raised about the possible contamination of groundwater by methane, fracking fluid chemicals, and dissolved contaminants in flowback water, as a result of shale gas operations.

In Britain, most aquifers used for drinking water lie within the first 300 metres below the surface, while fracking operations would take place at a depth of more than two kilometres. Assuming wells are properly constructed, contamination of groundwater through migration of methane and fracking fluids from shale formations to shallow aquifers through stimulated fractures could only take place if the fractures are able to propagate vertically through the intervening layers of rock. Recent analysis of fracking operations in the USA, combined with data obtained from natural fracturing of rocks, indicates that the probability of a stimulated fracture exceeding a height of 350 metres is around 1 per cent (Fig. 3). The analysis suggests that if a separation distance of at least 600 metres is maintained between aquifers and fracture zones, the risk of a fracture propagating to the aquifer and causing contamination is extremely low.[1] Confidence in this result would be increased by conducting similar analyses for UK shale formations.

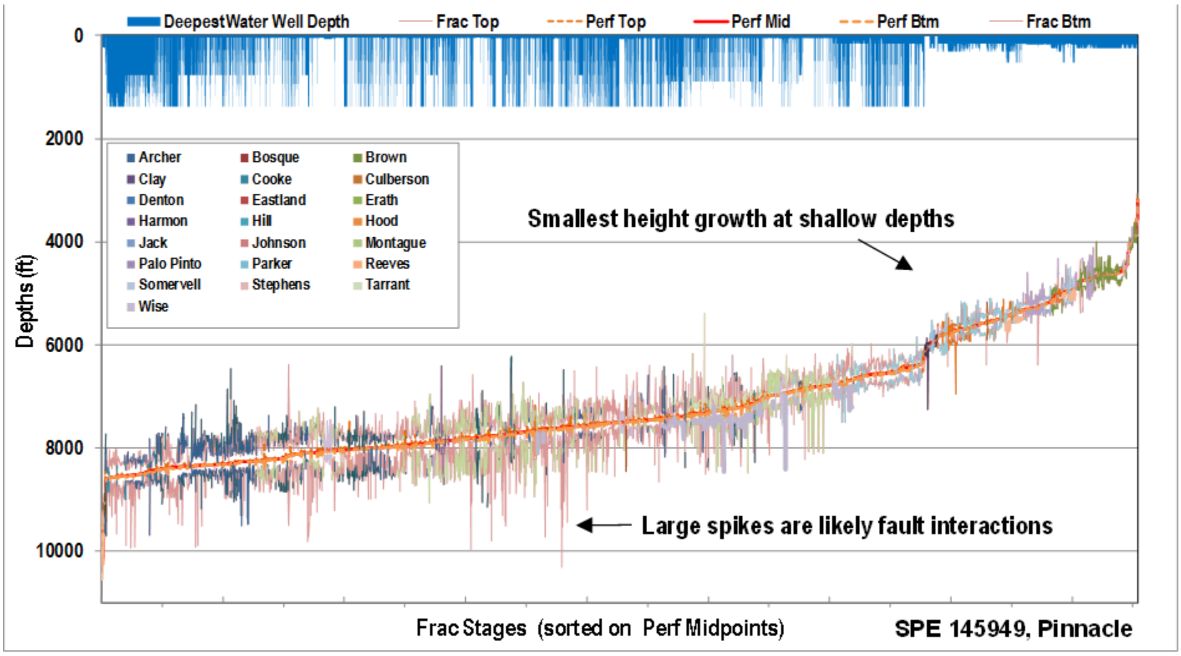

Figure 3: Data from the Barnett Shale (Texas, USA), obtained by Halliburton. Spikes represent fracture propagation depths. The tallest spikes are associated with fault linkage and propagation through pre-existing planes of mechanical weakness. The trend shows that with increasing depth, fracture magnitude increases, as a direct function of the increasing tensile strength of rocks with depth due to increasing pressure. (From Fisher, K., &Warpinski, N. 2011[2])

There are recorded instances of methane in groundwater in the USA in areas where shale gas operations have taken place. A more likely cause than migration through fractures is methane leakage at the well site itself, due to poor design or construction, or subsequent damage. (Historically, onshore US hydrocarbons operations have not always been effectively regulated, and in some areas there is a lack of records relating to well design and construction.) Methane can also occur naturally in shallow groundwater. Geochemical analysis can distinguish this from thermogenic methane from deep shale formations. Baseline studies of methane in groundwater, such as that currently being carried out by the British Geological Survey for areas of the UK likely to be prospective for shale gas, will enable any increase due to shale gas operations to be quantified. Fracking chemicals and contaminants in groundwater can also be caused by leakage due to poor well integrity, as well as by leaks and spills from surface operations.

2. Water sourcing and disposal

Between 9,000m^3 and 29,000m^3 of water is required to drill and carry out multi-stage fracturing of each well in US operations, with multiple wells often located on a single 'well pad'. In areas where fresh water supplies are already under stress (or at times when this is the case), abstracting fresh water at this level for shale gas extraction is therefore likely to cause additional stress. For shale gas to meet 10% of UK gas demand would require 1.2-1.6 million m^3 of water annually. However, this represents only about 0.01% of licensed annual water abstraction for England and Wales in 2010.[3] Saline or recycled water is increasingly being used for shale gas extraction, and work is underway to develop better integrated water management solutions.

Some of the fluid remains in the deep sub-surface, where it aids retention of the mechanical integrity of the rock. Between 20% and 80% returns to the surface as flowback water, where it must be managed safely. In small amounts, this can be disposed of in standard industrial water treatment plants. Larger volumes of fluid require specialist processing for disposal or re-use. Flowback water may contain Naturally Occurring Radioactive Materials (NORM) at low levels, as is the case in conventional oil and gas extraction and some areas of mining, and procedures for their effective management are well-established.

3. Induced seismicity

Induced seismicity – the release of energy stored in the Earth's crust triggered by human activity – is known to be caused by activities such as mining, deep quarrying, geothermal energy production and underground fluid disposal.

In 2011, two seismic events of magnitude 2.3 and 1.5 took place in Lancashire, close to a fracking test site operated by Cuadrilla. Operations were suspended, and subsequent studies have suggested that hydraulic fracturing is likely to have been the cause, by reactivating an existing fault.

The maximum magnitude of any seismic event is dependent on the mechanical strength of the rock. The crust in most of the UK is relatively weak, and unable to store sufficient energy for large seismic events. This means that the largest natural earthquake we can expect is likely to be no greater than magnitude 6. However, based on our understanding of the mechanical strength of shale and case studies of fracking operations in the USA, it is extremely unlikely that seismic events induced by fracking will ever reach a magnitude greater than 3. These are likely to be detectable by few people and are highly unlikely to cause any structural damage at the surface. To minimise the risk of seismic events even at this level, operators should avoid drilling through or near faults, and microseismicity should be monitored in real time before, during and after fracking, with effective management systems in place to respond to the results, including monitoring possible damage to well integrity.

What further work is needed if shale gas exploration and production is to go ahead?

Many of the risks associated with shale gas extraction are shared with other hydrocarbons operations, and are already robustly regulated in the UK. In order that risks particular to shale gas are effectively managed, and to ensure public confidence in any future shale gas operations especially as they move beyond small-scale exploration, further regulation is likely to be required in some areas. This should be consistent and scientifically well-founded. The geoscience community is well-placed to advise on the development of such regulation, and will play vital roles in implementing it. Continuing research and development is essential, as is the gathering of baseline data (including methane and geochemical groundwater surveys and seismic monitoring), to underpin effective regulation. While lessons can be learned from overseas operations, carefully regulated and managed exploratory operations in the UK would provide valuable data to help address future risks.

[1] Davies, R.J., et al., Hydraulic fractures: How far can they go?, Marine and Petroleum Geology (2012)
[2] Fisher, K., & Warpinski, N., Hydraulic Fracture-Height Growth: Real Data, SPE 145949 (2011)
[3] Broderick, J., et al., Shale Gas: an updated assessment of environmental and climate change impacts (2011)

To find out more, visit www.geolsoc.org.uk/shalegas or email policy@geolsoc.org.uk.