

Institution: University of Strathclyde
Unit of Assessment: 14
Title of case study: Research on geological uncertainty informs UK Government policies on shale gas and radioactive waste disposal
<p>1. Summary of the impact</p> <p>Research into the quantification and reduction of geological uncertainty has directly resulted in changes to UK government policy relating to the subsurface as a geological resource. Through Prof Shipton's membership of the Royal Society/Royal Academy of Engineering (Joint Academies) expert working group on risks associated with shale gas extraction in the UK, her research has informed the Department of Energy and Climate Change on ways to calculate and mitigate the risk of seismicity and associated undesirable fluid flow. The Joint Academies report resulted in the lifting of the UK Government embargo on fracking in Dec 2012, allowing exploration for shale gas in the UK to resume, with associated economic and societal benefits of an enhanced UK gas resource. Prof Lunn's membership of the UK Government Committee for Radioactive Waste Management (CoRWM) (2008-present) has resulted in her research informing the substantial changes made to the siting policy for UK radioactive waste disposal from February 2013.</p>
<p>2. Underpinning research</p> <p>Context: Shale gas trapped in very low permeability rock is extracted by pumping fluids in at pressures high enough to fracture (frack) the rock formation, creating connected fracture surfaces that release gas from the rock to the borehole. Engineering the fracking process requires tens of so-called "frack jobs" in each well to access as large a surface area within the rock volume as possible while minimising environmental impacts. Two concerns commonly raised are 1) inducing seismicity large enough to be felt at the surface and 2) opening new pathways out of the target formation that might allow gas and/or contaminated water into aquifers, or to the surface. The first onshore fracking for shale gas in the UK occurred in April 2011. Ten hours after two of five "frack jobs", two magnitude 2 tremors were felt by the local population. Subsequent investigations by the operator (Cuadrilla) and the British Geological Survey showed slip had occurred on a fault zone passing close to the well, which had not been identified by site investigation prior to drilling. Although seismicity was two orders of magnitude smaller than that regularly felt near old coalfields, public outcry resulted in DECC imposing an embargo on fracking for shale gas in the UK. Earthquakes (of any size) occur by slip on a rupture patch, creating new fractures, or more commonly, reopening previously sealed existing geological features (a fault zone, mineral vein, or material contrast between rock types). The size of a pre-existing fault places an upper limit on the magnitude of an earthquake on that fault. High-pressure injection during fracking alters the effective stress around the borehole, bringing pre-existing planes of weakness closer to failure. To characterise the risk posed by fracking, an operator must know the location, size and orientation of any likely weaknesses, and the current in-situ stress state (how close weaknesses are to slipping). It is, therefore, desirable to: 1) Develop a geological model (e.g. from existing map data and legacy 2D seismic data) to constrain the geometry of features at depth, as well as their likely evolution (stress history) to enable prediction of small-scale features; 2) Collect 3D seismic data (a 3D image of subsurface features with ~10 m vertical resolution); 3) Drill exploratory boreholes, which are a complete record of the rocks along a 1D transect, and which are one source of data on in-situ stress; 4) Collect "background" seismic activity (generally only for magnitudes over +2), providing data on the current stress state and locations of large features. Ideally an operator would collect data from each of these sources and check that they were consistent. In practice, some or all of these steps are often omitted by industry even in conventional hydrocarbon settings.</p> <p>Key Research findings: Collaborative research into characterising geological uncertainty by Shipton and Lunn has demonstrated that:</p> <ul style="list-style-type: none"> • Geological data are inherently under-constrained and are, therefore inherently equivocal: multiple geological models can honour a given set of geological data. The researchers showed for the first time that it is possible to develop workflow protocols to improve the quality of geological interpretation and the quantification of the associated uncertainties [1]. From a dataset of 184 academic and industry experts, only 29% were able to pick the correct interpretation of a 3D seismic image. Only 18 of the experts validated their interpretation by checking geometric and evolutionary feasibility, 94% of the 18 experts chose the correct interpretation and the remainder <i>knew that they were wrong</i>. The research showed that there are key steps that interpreters can make to develop more robust subsurface geological models.

- Reactivation and propagation of fractures is highly dependent on local stresses, and especially their temporal evolution [5, 6]. In fracking there will be very strong dynamic stress changes local to the boreholes as successive “frack jobs” take place. The results of this research suggest that careful characterization of baseline stress prior to each frack job will result in a better outcome (though these papers do not explicitly address shale gas).
- The heterogeneity of fault/fracture systems [2] means data pooling from multiple sites is required to quantify fault structural geological uncertainty [3]. Data from multiple sites can bound uncertainty in bulk fault parameters, such as fault length and thickness (fault thickness can be determined from borehole data; fault length, which is directly related to the maximum magnitude of an earthquake that a given fault can host, cannot). This is a key example of the kind of open-source data pooling that will be necessary to provide the best and safest outcomes in a developing on-shore shale gas industry in the UK.
- Microseismic events (magnitudes down to minus 2) can be triggered by exceptionally small changes in pressure and so can be used as a tool for mapping the hydraulically conductive fractures in a rock volume, thus reducing structural uncertainty as well as providing information on the flow properties of the conductive fractures [4]. This research shows novel geophysical tools that can be used to constrain the geometry and properties of features previously considered to be below resolution of 3D seismic techniques, thereby increasing the level of certainty in site investigations and providing data for the most effective engineering of multiple frack jobs.

Key Researchers at Strathclyde: R Lunn joined the Dept. of Civil Engineering in 2005 (Senior Lecturer; Reader 2008-2010; Professor 2010); Z Shipton was appointed as Professor in the Department of Civil Engineering in 2010; S Pytharouli joined the department in 2007 as a PDRA to Prof Lunn, and was appointed Lecturer in 2009.

3. References to the research

The quality of the research is exemplified by references 1 and 4.

References 4 and 6 are part of the REF2014 submission for UoA14

- 1 Bond C.E., Lunn R.J., Shipton Z.K., & Lunn A. 2012. What makes an expert effective at interpreting seismic images? *Geology*, v. 40, p. 75–78, doi:10.1130/G32375.1
- 2 Lunn R.J., Shipton Z. K. & Bright A. M. 2008. How can we improve estimates of bulk fault zone hydraulic properties? *Geological Society, London, Special Publications* 299, The internal structure of fault zones: fluid flow and mechanical properties. doi: 10.1144/SP299.13
- 3 Shipton Z.K., Soden A.M., Kirkpatrick J.D., Bright A.M. & Lunn R.J. 2006. How thick is a fault? Fault displacement-thickness scaling revisited. *American Geophysical Union Geophysical Monograph Series*, 170, 193-198. doi: 10.1029/170GM19
- 4 Pytharouli S.I., Lunn R.J., Shipton Z.K., Kirkpatrick J.D., & do Nascimento A.F. 2011. Microseismicity illuminates open fractures in the shallow crust. *Geophysical Research Letters*, v. 38, L02402, doi:10.1029/2010GL045875
- 5 Moir, H., Lunn R.J., Shipton Z.K., & Kirkpatrick, J.D., 2010. Simulating brittle fault evolution from networks of pre-existing joints within crystalline rock, *Journal of Structural Geology*, v.32 1742-1753. doi:10.1016/j.jsg.2009.08.016
- 6 Lunn R.J., Willson J.P., Shipton Z.K. & Moir H. 2008. Simulating brittle fault growth from pre-existing structures. *Journal of Geophysical Research*. doi:10.1029/2007JB005388.

Other evidence for quality of research

Paper 1: Runner up for best research contribution at DEVEX 2011 (oil & gas industry conference)
 Paper 4: Highlighted on the cover of *Geophysical Research Letters*, in the American Geophysical Union magazine, *EoS*, and the American Geological Institute magazine, *EARTH*. Subject of three invited talks at major international conferences (American Geophysical Union (AGU) San Francisco 2006; “Simpósio Brasileiro de Geofísica” Brazil 2006; AGU San Francisco 2010). The research was funded by grants to Lunn, Shipton and Pytharouli totalling £673k. [NERC standard grant NE/E005365/1 (2007), NERC CASE studentship NE/F013728/1 with Midland Valley Exploration (2008), EPSRC awards EP/K005812/1 (2012) and UKCCSRC C1-19 (2013)].

4. Details of the impact

Process from research to impact: The vehicle for policy change has been Shipton’s membership of the Royal Society and Royal Academy of Engineering working group on Shale gas extraction in the UK (Feb 2012 to present) and Lunn’s membership of the UK Government Committee for Radioactive Waste Management (CoRWM) (2008-present).

Impact case study (REF3b)

The UK Government's Chief Scientific Adviser asked the Royal Society and the Royal Academy of Engineering to carry out an "independent review of the scientific and engineering evidence relating to the technical aspects of the risks associated with hydraulic fracturing" to inform UK government on shale gas extraction. Prof Shipton was recommended for the joint academies working group by Prof Boulton, the leader of the Royal Society's policy advice group, based predominantly on research track-record [Source A]. The working group terms of reference were: What are the major risks associated with hydraulic fracturing as a means to extract shale gas in the UK, including geological risks, such as seismicity, and environmental risks, such as groundwater contamination? Can these risks be effectively managed? If so, how? The working group first met to review the scientific and engineering evidence in February 2012 and their report, *Shale gas extraction in the UK: a review of hydraulic fracturing*, published in June 2012 [Source B], includes explicit recommendations originating from Lunn and Shipton's research, addressing (a) the need for careful site characterisation (ref. 1), (b) data pooling (refs. 2 and 3), (c) the need for detailed *in situ* stress characterisation (refs. 5 and 6), and (d) microseismic monitoring (ref. 4). The report was launched at a media briefing and Prof Shipton (one of 4 working group members to act as media representatives) was quoted extensively in the national press, Radio 4 and the World Service. Shipton has since participated in other media events and a briefing for MPs at the House of Commons (July 2013). The working group continue to be consulted nationally and internationally (e.g. Chinese delegation to the UK in July). The working group were invited to meet with DECC on 14/6/13, where Shipton presented a policy brief on "Reducing geological uncertainties related to fracking". Shipton led a workshop for Scottish Government Energy Team (May 2012) on unconventional gas, presenting results of the Joint Academies report and the reasons for the large variation in estimates in UK and global reserves (geological uncertainty being a big factor). As a result of this workshop the Energy Team convened a Scottish Government Expert Scientific Group on Unconventional Oil and Gas in June 2013, of which Shipton is now a member. Shipton was also an expert reviewer of the New Zealand Government's guidelines on Guidelines on Hydraulic Fracturing and Related Activities for Oil and Gas Development (July 2013).

Types of Impact: The immediate benefit of the research is on the UK government in terms of regulations and policies relating to exploration for shale gas and to the disposal of radioactive waste. The longer term impact will be on the UK public in terms of energy supply/security, and to energy companies.

Lifting the fracking embargo – new policy and regulations. In December 2012, the Energy and Climate Change Secretary announced that, after reviewing the evidence in the report, exploratory drilling for shale gas could resume in the UK, subject to new controls to mitigate the risks of seismic activity [Sources C and D]. In July 2013, DECC published the guidance document "About shale gas and hydraulic fracturing (fracking)" [Source E]. To gain a frack consent, DECC now requires operators to develop a Hydraulic Fracturing Programme (HFP), a detailed risk assessment describing the "control and mitigation measures for fracture containment and for any potential induced seismicity". An HFP requires operators to conduct detailed geological modelling to delineate any faults in the area of a well to be fracked, characterise the local stress fields, and monitor for small seismic events on those (or any unidentified) faults. "Guidelines for UK Well Operators on Onshore Shale Gas Wells" [Source F] published by the newly formed UK Onshore Operators Group contains details of the HFP and emphasises that "Operators should not overlook the potential presence of faults that cannot be detected given the limits of seismic reflection surveys." The UK is the only country so far to have plans to regulate induced seismicity. The EU is currently looking into shale gas regulation, with the UK's approach considered best practice.

Economic impact - gas exploration. Multi-£M investment, investigation and development of fracking for shale gas in the UK was only made possible by the lifting of the embargo arising, in part, from the Strathclyde research. Since the lifting of the embargo in 2012, UK shale gas exploration has resumed, with "around 10 companies at present...looking at drilling 20 to 40 wells before 2015" (Ken Cronin, UKOOG chief executive, 2/5/13). This exploratory drilling is essential for operators to make informed licence applications to UK's 14th onshore licencing round in 2014. Lord Browne, Chairman of Cuadrilla told the Guardian (12/3/13) that his company intended to invest billions of pounds over 10 years in UK shale gas. Duarte Figuera, the head of the newly formed DECC Office of Unconventional Gas and Oil has suggested that several £100M will be spent by operators in the UK 14th round even if no reserves are proved (ESGOS conference, 20/9/2013).

Benefits to the consumer. Although the plummeting gas price seen in the US is unlikely to be

Impact case study (REF3b)

replicated in the UK due to differences in the mineral rights and licencing regulations, there are significant energy security benefits to the UK in prolonging its supply of indigenous gas. A report by the Institute of Directors said that shale gas could supply up to 1/3 of peak gas by 2030, could lower net imports by £8Bn, bring in an investment of £3.7Bn and support over 70,000 jobs. Shale gas is a labour intensive industry and requires jobs across the supply chain, therefore UK shale gas extraction will impact contractors, and create local jobs. The Energy and Climate Change Committee has said “While it is difficult to say with any accuracy how many jobs a successful UK shale gas industry would create, estimates range from the thousands to the tens of thousands” [Source G].

Public debate and understanding. Publication of the Joint Academies report, and subsequent media coverage, has stimulated public debate and has helped to allay public fears about the risk of seismicity. There has been a key shift in the focus of the “anti” debate away from earthquake risk and water contamination towards the climate change risks (e.g. interview with Caroline Lucas MP Radio 4 Today Programme 20/8/13): this represents a real result for evidence-based policy. Lifting the fracking embargo has sent a positive message globally about the relative magnitudes of risks associated with shale gas.

UK radioactive waste disposal – policy change. The same underlying research that informed and generated shale gas policy has resulted in substantial changes to the siting policy for UK radioactive waste disposal. Policy change has been influenced through Prof Lunn's membership of the UK Government Committee for Radioactive Waste Management (CoRWM) (2008-present) [source H]. CoRWM provides independent scrutiny and advice to Ministers on radioactive waste management and disposal. Development of a new policy began in February 2013, as a consequence of West Cumbria withdrawing from the previous siting process. CoRWM's policy advice (16/4/2013), the geological aspects of which were led by Prof Lunn, has resulted in a new approach to consideration of geological uncertainty; geological information will be considered earlier and uncertainty will be presented explicitly [Source I]. This will increase the chances of successfully siting a UK geological disposal facility (GDF) for higher activity radioactive waste; a policy outcome to which the UK government is committed (Managing Radioactive Waste Safely White Paper) and without which, planning permission cannot be granted for new-build nuclear power. Greenpeace lodged an application for judicial review of the new nuclear reactor at Hinkley Point C in May 2012, on the premise that planning permission should not have been granted without having a credible policy in place for dealing with radioactive waste. If successful, this application would have halted the UK's entire Nuclear New Build Programme. Greenpeace eventually withdrew their application on 27/10/13, because the launch of the Government's proposed new siting process provided a credible way forward for dealing with nuclear waste [Source J].

5. Sources to corroborate the impact

- A. Statement from Chair of the Royal Society and Royal Academy of Engineering working group
- B. Royal Society and Royal Academy of Engineering report on *Shale gas extraction in the UK: a review of hydraulic fracturing* <http://royalsociety.org/policy/projects/shale-gas-extraction/>
- C. Written statement from Minister Ed Davey, 13/12/12, <https://www.gov.uk/government/speeches/written-ministerial-statement-by-edward-davey-exploration-for-shale-gas>
- D. DECC step-by step response to joint academies report, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/49541/7269-government-response-sg-report-.pdf
- E. DECC Guidelines on Fracking, 30/7/13, <https://www.gov.uk/government/publications/about-shale-gas-and-hydraulic-fracturing-fracking/about-shale-gas-and-hydraulic-fracturing-fracking>
- F. UKOOG Shale Gas guidelines www.ukoog.org.uk/elements/pdfs/ShaleGasWellGuidelines.pdf
- G. Energy and Climate Change committee - 7th Report: The Impact of Shale Gas on Energy Markets. <http://www.publications.parliament.uk/pa/cm201213/cmselect/cmenergy/785/78502.htm>
- H. Statement from expert geoscientist on CoRWM
- I. Geological Disposal Facility siting process review www.gov.uk/government/consultations/geological-disposal-facility-siting-process-review
- J. Greenpeace withdraws application for judicial review <http://www.independent.co.uk/news/uk/home-news/greenpeace-abandons-hinkley-point-lost-cause-8906372.html>