British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Can shale gas be extracted safely?

Groundwater, well integrity, use of water

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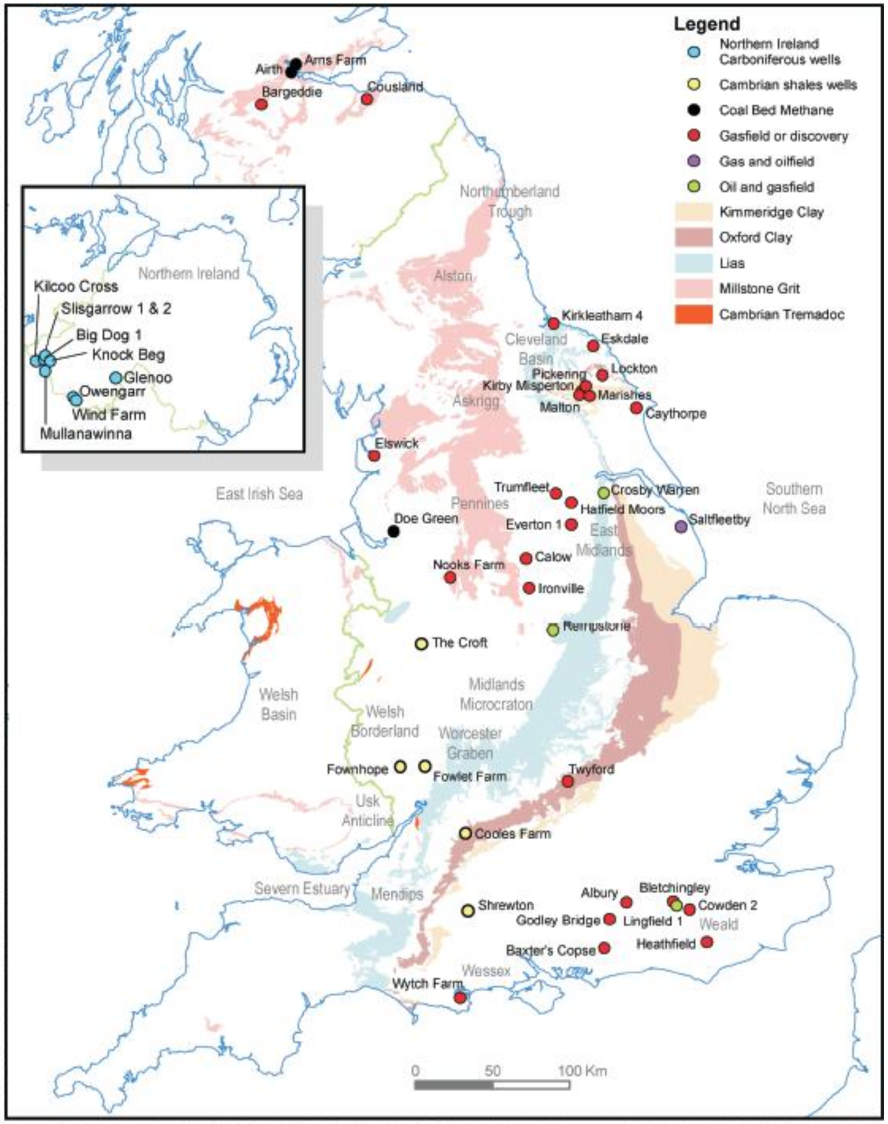
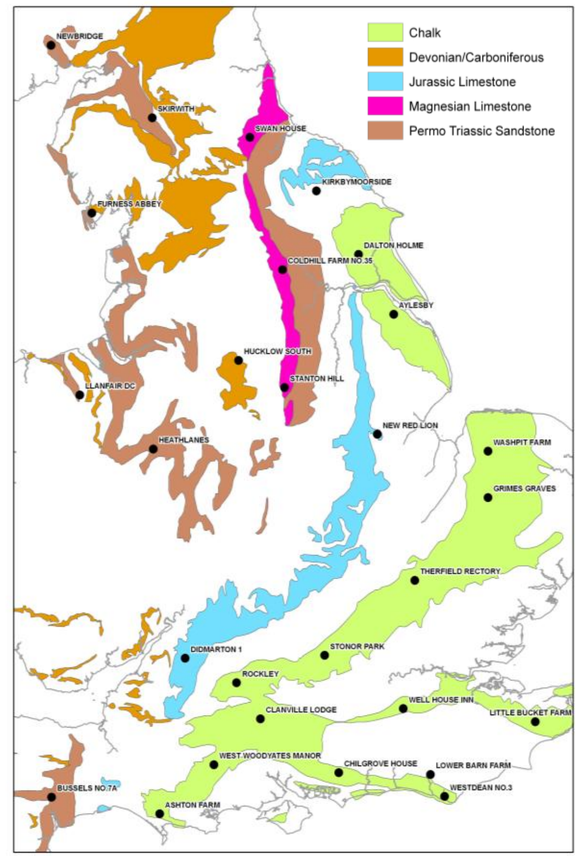
Introduction

- Groundwater in the UK in relation to shale gas

- Environmental issues associated with Shale Gas:
  - Water requirements and demands
  - Potential pollutants and sources
  - Pollutant pathways
  - Wastewater treatment

Shale and aquifer distribution





Groundwater protection

- Risk-based approach to management and protection: groundwater quality and resources
- Environmental objectives established by EU and UK legislation (e.g. WFD, GWD)
- Proactive and reactive resource protection:
  - Groundwater Protection Policy (GP3)
  - Legal instruments: regulations, permits and notices
  - Supporting tools:
    - Risk assessment tools: GWV maps, SPZs, models
    - Industry codes of practice and guidance
    - Monitoring

Water consumption

- Each well may require 250 – 4000m^3 of water to drill, then 7000–23,000m^3 for hydraulic fracturing[a]. Example of published estimates (per well)[b]:

Shale Play	Drilling (m^3)	Fracking (m^3)	Total (m^3)
Barnett (US)	950	14000	14950
Haynesville (US)	2300	19000	22300
Fayetteville (US)	250	19000	19250
Marcellus (US)	300	21000	21300
Eagle Ford (US)	500	23000	23500
Bowland Shale (UK)	900	8400	9300

- Variation reflects complexity of drilling, geological conditions, total depth/number of fracking stages.

[a] Range obtained from various published sources (mostly US).
[b] University of Texas (2012) and Cuadrilla

Water demand

- To meet 10% UK demand from shale gas over 20 year period - projected water requirement[a]:

  25 - 33 million cubic metres

- Equivalent to an annual water demand of:

  1.2 -1.6 million cubic metres

- Licenced annual water abstraction for England and Wales (2010) :

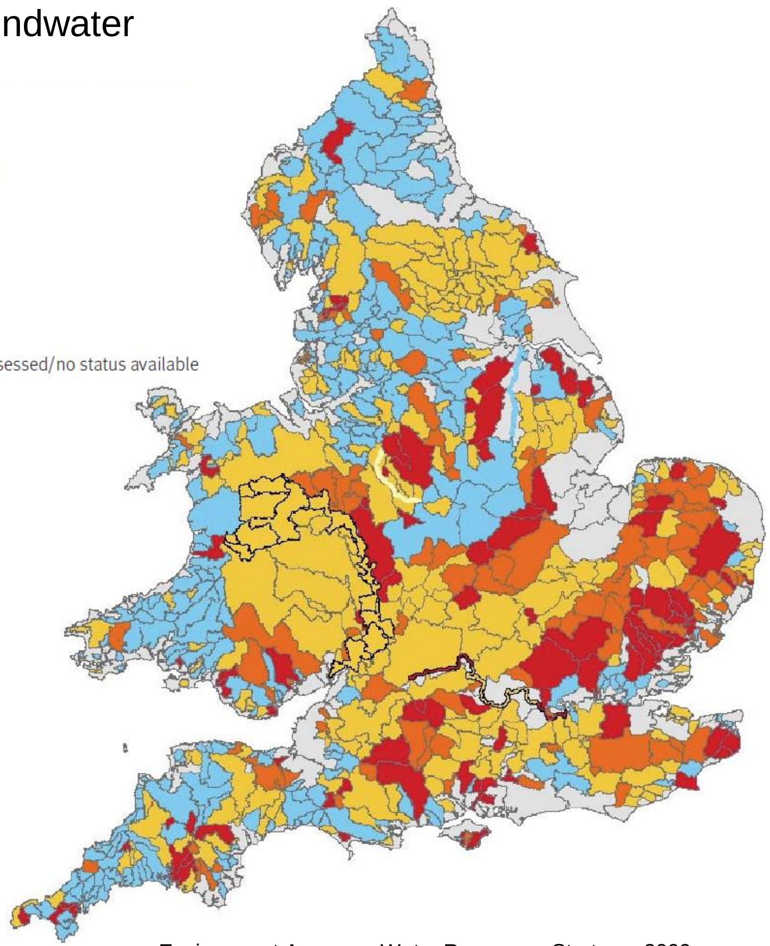
  12.2 x 10^3 million cubic metres [b]

[a] Estimate from Tyndall Centre report (2011)

[b] http://www.defra.gov.uk/statistics/environment/inland-water/

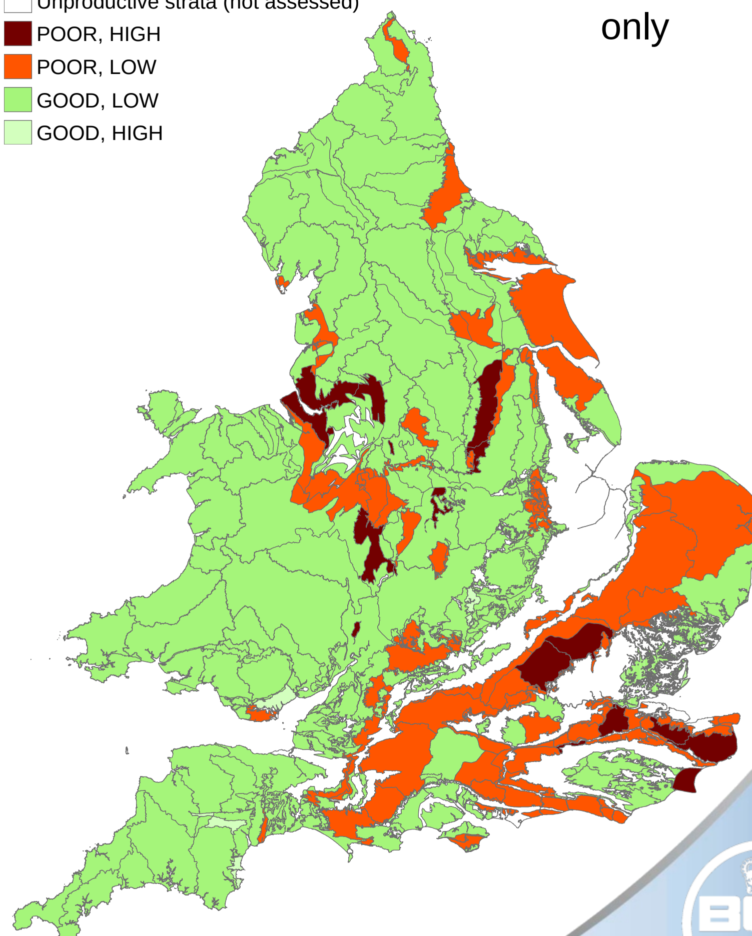
Water resource availability

Surface water and groundwater



Environment Agency – Water Resources Strategy, 2009

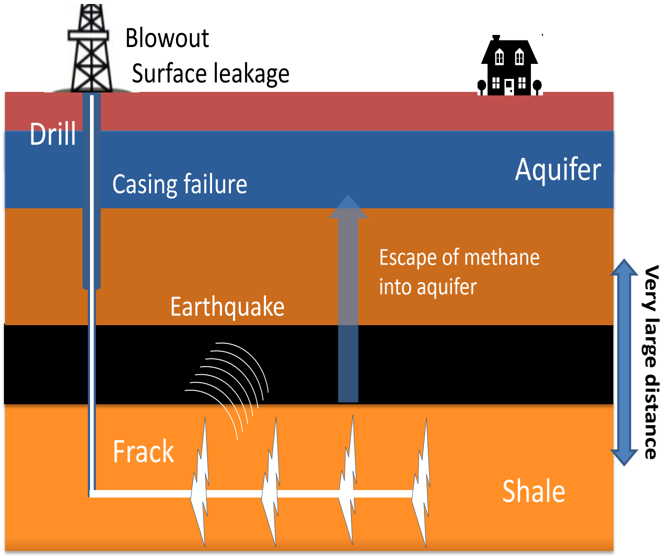
Groundwater only



Environment Agency – WFD, 2009

Contamination concerns

- Methane (shale gas)
- Fracking chemicals
- Flowback fluids and produced water



- Potential routes to groundwater (and other receptors):
  - Geological as a result of fracking
  - Well casing failure
  - Release at surface – preparation, storage, transport, disposal

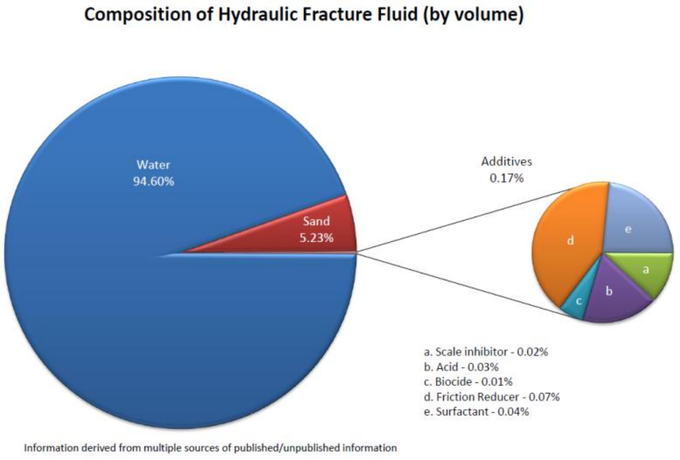
Composition of shale gas

Name	Formula	Typical content (%)
Methane	CH_4	70–90
Ethane	C_2H_6	0–20
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon dioxide	CO_2	0–8
Oxygen	O_2	0–0.2
Nitrogen	N_2	0–5
Hydrogen sulphide	H_2S	0–5
Rare gases	Ar, He, Ne, Xe	Trace
Radon	Rn^{222}	?

from Natural Gas Supply Association, 2010

- Hydrocarbons explosive – 5-10% methane in air is explosive
- Radon – radioactive gas and carcinogenic

Fracking fluid



Constituent	Composition (% by volume)	Example	Purpose
Water and sand	99.50	Sand suspension	"Proppant" sand grains hold microfractures open
Acid	0.123	Hydrochloric or muriatic acid	Dissolves minerals and initiates cracks in the rock
Friction reducer	0.088	Polyacrylamide or mineral oil	Minimizes friction between the fluid and the pipe
Surfactant	0.085	Isopropanol	Increases the viscosity of the fracture fluid
Salt	0.06	Potassium chloride	Creates a brine carrier fluid
Scale inhibitor	0.043	Ethylene glycol	Prevents scale deposits in pipes
pH-adjusting agent	0.011	Sodium or potassium carbonate	Maintains effectiveness of chemical additives
Iron control	0.004	Citric acid	Prevents precipitation of metal oxides
Corrosion inhibitor	0.002	n,n-dimethyl formamide	Prevents pipe corrosion
Biocide	0.001	Glutaraldehyde	Minimizes growth of bacteria that produce corrosive and toxic by-products
Breaker	0.01	Ammonium persulphate	Allows a delayed breakdown of gel polymer chains
Crosslinker	0.007	Borate salts	Maintains fluid viscosity as temperature increases
Gelling agent	0.056	Guar gum or hydroxyethyl cellulose	Thickens water to suspend the sand
Oxygen scavenger	-	Ammonium bisulphite	Removes oxygen from the water to prevent corrosion

after Gregory, 2011 and Ground Water Protection Council and ALL Consulting, 2009

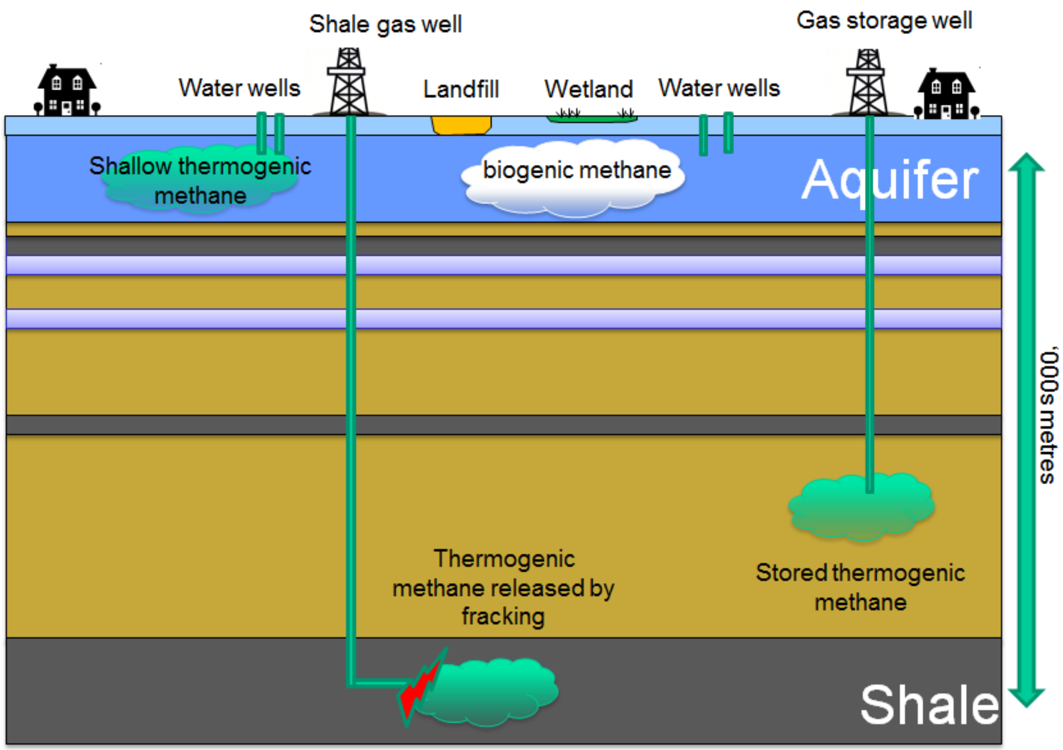
- Estimates of additives component: 0.1 – 2.0%
- Continued development
- Greater openness now in the US
- UK regulation requires authorisation

- Fate of injected fluids:
  - 20-80% returns as flowback
  - Remainder stays in formation

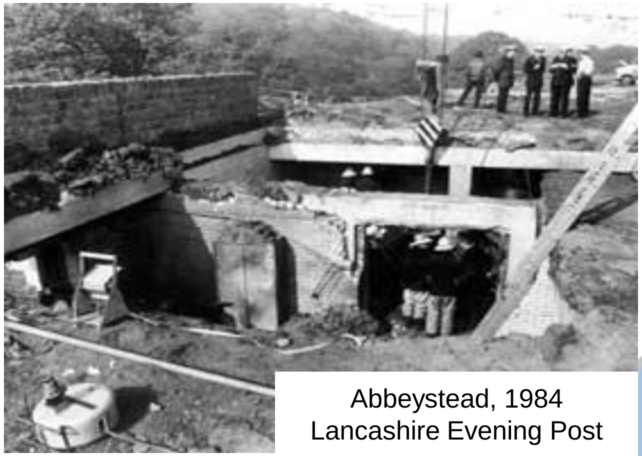
Flowback/produced water

- Flowback – reflects fracking fluid composition modified by residual material from drilling and fracking, and some formation water
- Produced water increasingly reflects formation water over time. This may include: metals (e.g. zinc, chromium, nickel), arsenic, sodium, calcium, magnesium, chloride, and NORM (U, Ra)
- Safe handling, storage and disposal of wastewaters is required by EA:
  - Small volumes – industrial wastewater treatment plants
  - Larger volumes – specialist processing for disposal and/or re-use

Sources of methane in sub-surface



Loscoe, 1986
Derby Evening Telegraph

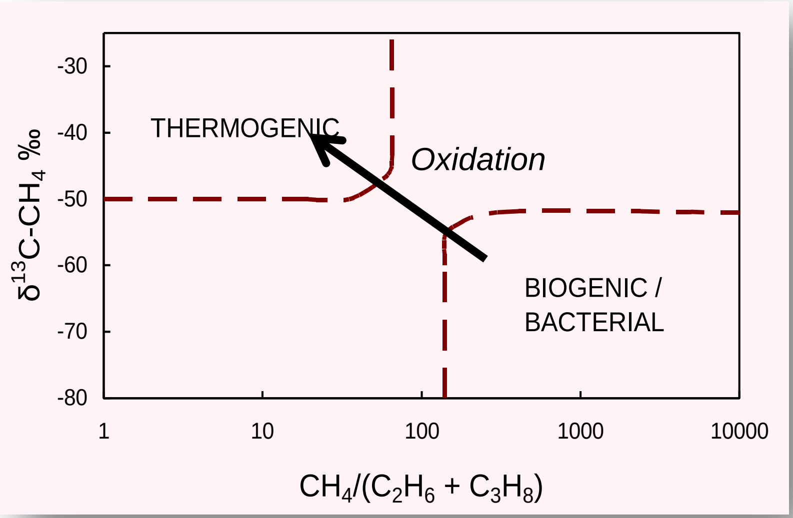


Abbeystead, 1984
Lancashire Evening Post

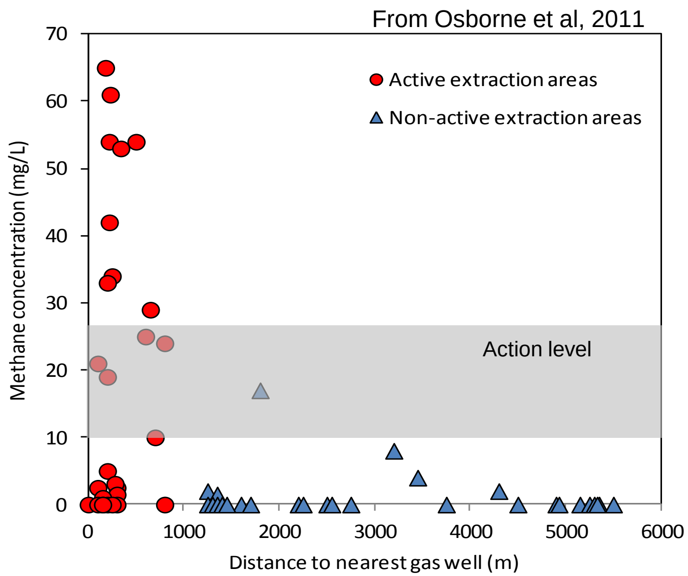
Methane – basic geochemical props

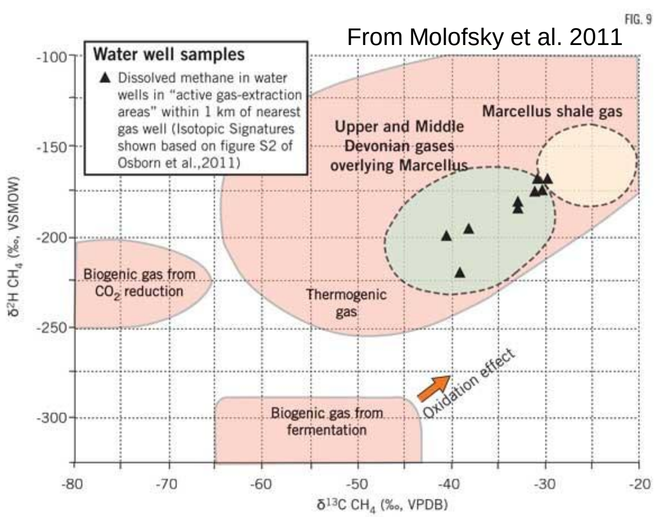
- Biogenic/bacterial (e.g. wetland, landfill):
  - high C_1/C_{2+} ratio
  - low $\delta^{13}C$ values (>-64‰) and $\delta^{2}H$ (>-175‰)
  - Measurable ^{14}C

- Thermogenic (e.g. natural gas, coalbed methane):
  - low C_1/C_{2+} ratio
  - higher (less negative) $\delta^{13}C$ (<-50‰) and $\delta^{2}H$ values (<-240‰)
  - No ^{14}C



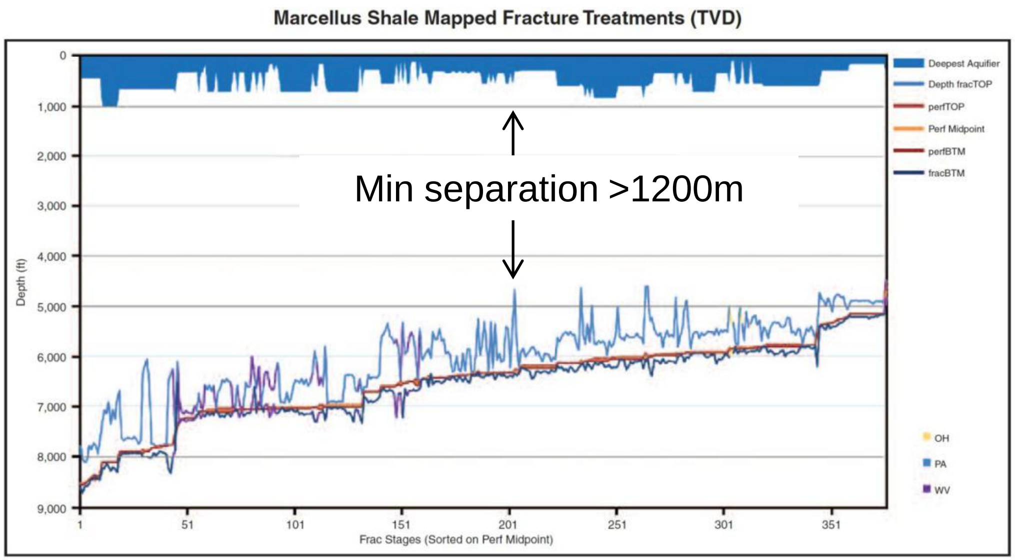
Methane in groundwater

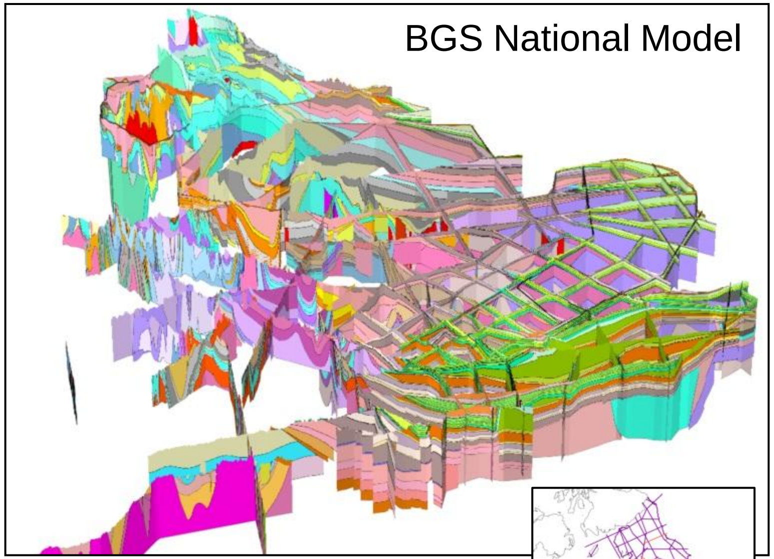


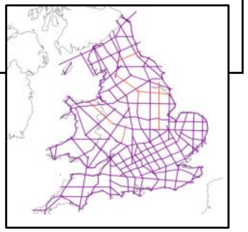


- Methane in groundwater is well known: multiple examples in literature
- Interpretation of the data should consider all possible sources and pathways
- Sub-surface provides multiple potential sources and pathways – natural and engineered
- Multiple lines of investigation/evidence needed

Pathways - geological



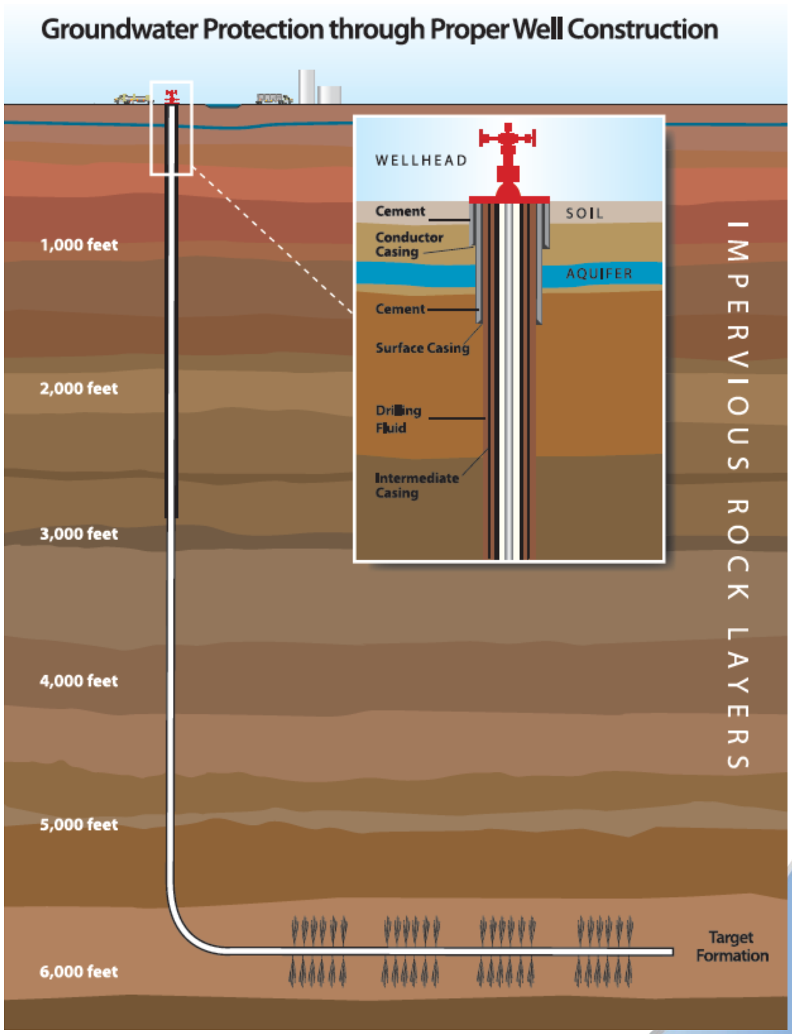




- Extent of induced fractures limited
- Distance between source and receptor ‘000s metres
- Multi-layered complex geological sequence

Well design

- Shale gas well design principals same as other oil/gas well design
- Industry standards: API, BS:ISO, HSE
- Well Integrity: material selection and well completion
- Casing: conductor/surface/ intermediate/production
- Well testing:
  - Formation integrity testing
  - Cement bond (CBL/VDL)



Pathways – poor design

- Example of Poor well location, design and construction

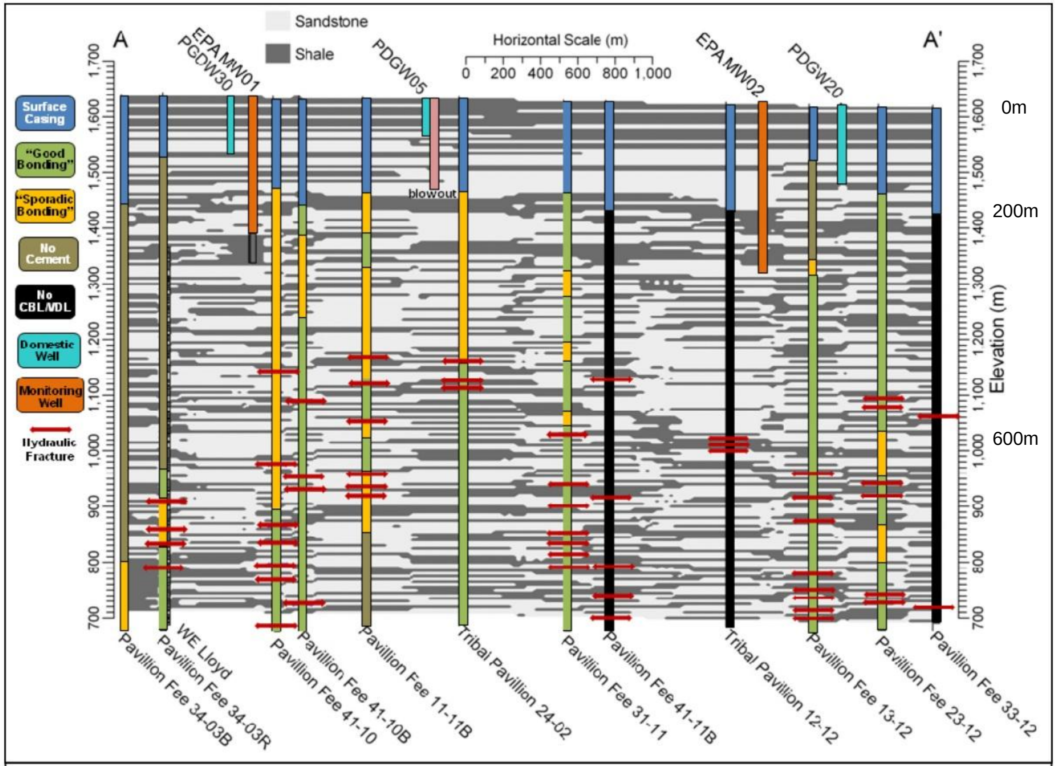
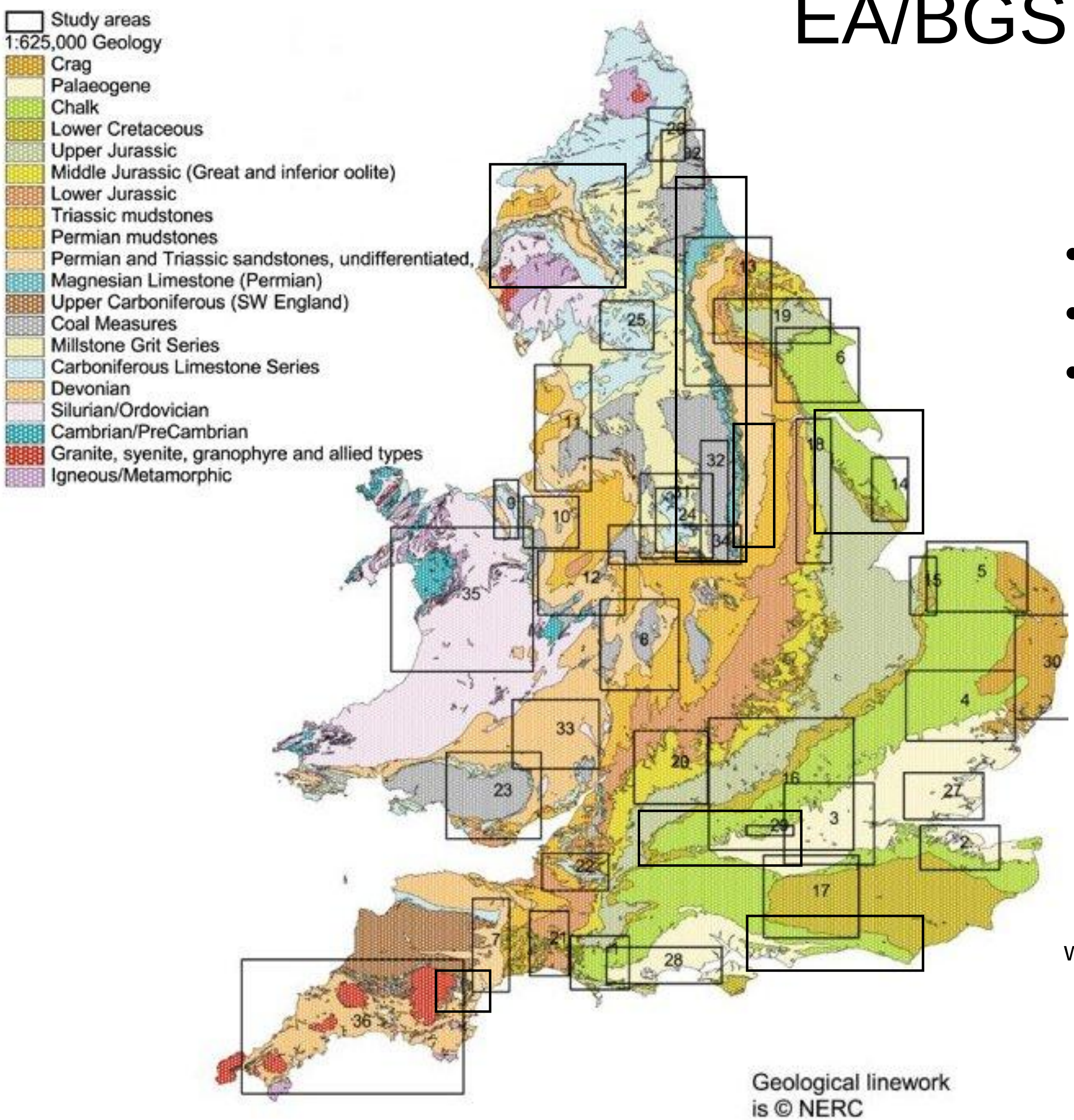


Figure 20. Lithologic cross-section along transect illustrating production wells (with evaluation of CBL/VDLs), domestic wells, and blowout location. Red arrows denote depths of hydraulic fracturing of unknown areal extent. Sandstone units are undifferentiated between fine, medium and coarse-grained units.

- Pavillion, Wyoming
- US EPA investigation into groundwater pollution from unconventional gas production
- Exploitation of gas from 372 m bgl
- Aquifer exploited to 244 m bgl
- Poor design, location, construction:
  - Storage pits
  - Surface casing too shallow
  - No or poor cement seals
- Contamination by methane and other hydrocarbons, fracking chemicals and deep formation waters

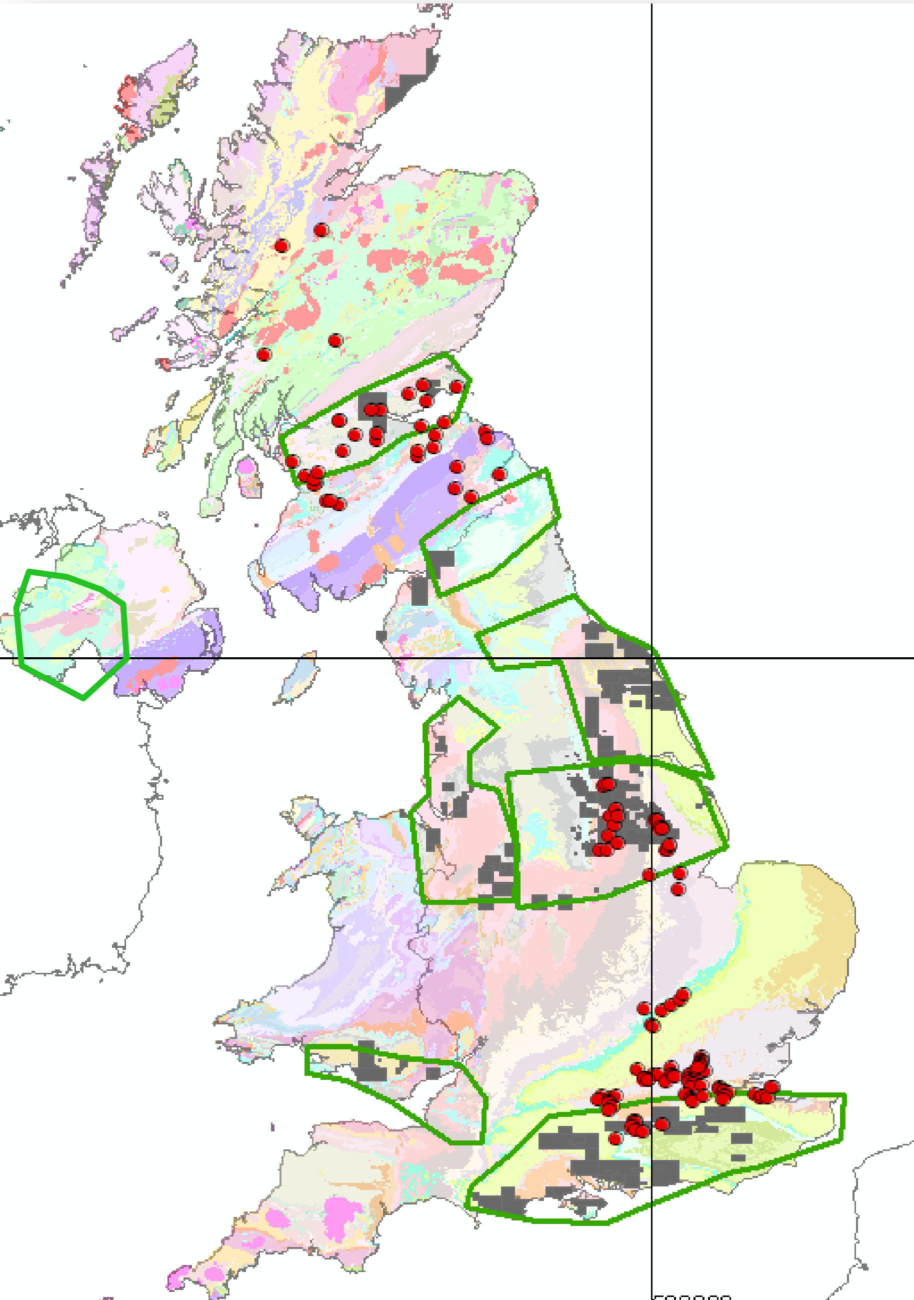
Draft report: EPA 600/R-00/000 (USEPA, 2011)

EA/BGS Baseline Project



- 29 reports
- Range of aquifer types
- Common format:
  - geology/hydrogeology
  - environmental data
  - historical/current data
  - hydrochemistry plots
  - geochemical controls
  - evolution of chemistry
  - depth profiles
  - trends

www.bgs.ac.uk/research/groundwater



BGS baseline methane survey

Priority	Area
1	West Lancashire and Cheshire basins
2	Northern Ireland
3	Stainmore Trough and Cleveland Basin
4	Wessex & Weald Basins
5	South Wales coast
6	Midlands (Edale and Widmerpool Gulf; Gainsborough Trough)
7	Northumberland Trough

1. Waters characterised using:

- Dissolved concentrations of CH_4 and CO_2 plus general water chemistry
- DOC
- C and H stable isotopes of CH_4, C-14, stable isotopes of CO_2 and DIC
- Trace organics
- Groundwater residence time indicators (CFCs, SF_6)
- Microbiological indicators

2. Collation of other data

Location of existing groundwater methane analyses (red circles), current onshore UK Petroleum Exploration and Development Licences (grey areas), and key areas of shale gas interest (green outlines)

Summary

- Some potential shale gas areas identified in the UK underlie aquifers. Groundwater protection measures exist and are effective
- Water demand for shale gas production is projected not be significant relative to other uses but local availability may be an issue
- Shale gas exploration/production uses/mobilises chemicals/substances that are potential pollutants. The risks need to be assessed and managed effectively
- Risk assessment needs to consider all potential sources of pollution, potential pathways and receptors
- Based on available literature the biggest risks appear to be from activities on the surface, followed by lack of regulation, poor well design/completion

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