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Establishing the baseline in groundwater chemistry in connection with shale-gas exploration: Vale of Pickering, UK

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Abstract

The baseline chemistry of groundwater from two aquifers in the Vale of Pickering, North Yorkshire, has been investigated ahead of a proposal to explore for shale gas, planning permission for which has recently been granted. Groundwater in a shallow aquifer including Quaternary and/or Jurassic Kimmeridge Clay deposits shows compositions distinct from a Corallian (Jurassic) Limestone aquifer, reflecting different lithologies and hydrogeological conditions. Corallian groundwaters along the margins of the vale are controlled by reaction with carbonate, with redox conditions varying according to degree of aquifer confinement. Superficial aquifer groundwaters are confined and strongly reducing, with some observed high concentrations of dissolved CH₄ (up to 37 mg/L; Feb 2016 data). This appears to be of mixed biogenic-thermogenic origin but further work is needed to determine whether the source includes a deeper hydrocarbon reservoir contributing via fractures, or a shallower source in the Quaternary or Kimmeridge sediments. The data show a shallow aquifer with a high-CH₄ baseline which pre-dates any shale-gas activity.

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1. Introduction

Significant interest exists in the development of a shale-gas industry in the UK but this is matched by significant concerns about its possible detrimental environmental impacts. Important amongst these is the potential impacts on aquifers and the quality of drinking water. Concerns include contamination by hydrocarbons, formation fluid and hydraulic fracturing fluid. Several studies in countries where shale gas is a developed industry have highlighted associations between groundwater quality and hydrocarbon extraction¹⁻³. However, establishing a causal relationship is difficult without evidence of the pre-development baseline chemical composition. This can provide a more

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robust basis for establishing whether any water-quality changes are related to exploration and development.

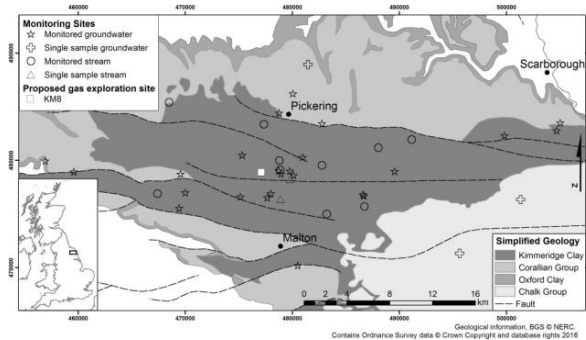


Fig. 1. Map of the solid geology of the Vale of Pickering showing locations of groundwater monitoring boreholes. Streams are also monitored and locations indicated. Jurassic clays refer to Amthill & Kimmeridge Clay. Quaternary superficial deposits overlie the bedrock and are not shown. The map indicates the location of the proposed shale-gas exploration site (KM8).

In the UK, exploration for shale gas is in its faltering infancy and assessments of the resource are not yet well-established⁴. One area of potential exploration is the Vale of Pickering, North Yorkshire (Cleveland Basin), where the hydrocarbon-bearing Bowland Shale and associated sandstone of Visean age occur at depths of some 2000 m+ below sea level⁴. A planning application has recently been granted for hydraulic fracturing to explore for hydrocarbons in a borehole at one site, Kirby Misperton (KM8) (Fig. 1).

The strata overlying the Bowland source include two aquifers. A lowermost Jurassic (Corallian) limestone aquifer crops out through structural control along the margins of the Vale of Pickering and forms an important regional source of public and private water supply. The aquifer is not exploited in the central part of the vale because of fault-induced depth (200 m+ below ground level) and possibly high salinity. A second shallow aquifer (<40 m depth) is composed of superficial Quaternary fluvio-glacial and glaciolacustrine deposits. Where these are thin or absent, shallow boreholes abstract water at least partially from permeable horizons in the underlying Upper Jurassic (Kimmeridge) clays. This mixed shallow aquifer is hereinafter termed the Superficial aquifer. As recognised aquifers, they both fall within the remit of the Regulator to protect them.

2. Geological and hydrogeological setting

The Cleveland Basin was a major depositional centre in Jurassic times. In the Vale of Pickering, a thick sequence of the Upper Jurassic strata includes the Oxford Clay, which is overlain by the Corallian Group, and in turn by the Amthill & Kimmeridge Clay. The Oxford Clay consists of 20–50 m of grey-green calcareous mudstone^{5, 6}. The overlying Corallian Group mainly comprises ooidal and micritic limestone and calcareous fine-grained sandstone but includes a variety of facies including muds, micritic limestones, silts and sands⁵. These form a 60–90 m thick sequence, deposited on a shallow marine shelf. The Amthill & Kimmeridge Clay strata are composed of some 400 m of grey mud rocks, some bituminous, with silts, calcareous clay and occasional limestone nodules⁶.

Superficial deposits include dominantly soft clays, but with occasional sand and gravel lenses. Occasional peats are also present. Superficial deposits thicken further east but are thin or absent in the vicinity of KM8. These are designated as a ‘Secondary’ aquifer and groundwater is abstracted in places for small-scale private supply.

The Corallian Group is designated as a ‘Principal’ aquifer, used for both public and private supply. Along the margins of the Vale of Pickering, it crops out as an unconfined aquifer, but confined by the Amthill & Kimmeridge Clay and superficial deposits within the vale. It is also likely hydraulically disconnected from underlying strata by the Oxford Clay. Groundwater flow in the Corallian is dominantly along fractures, which are solution-enhanced in places⁷. Discharge from the unconfined Corallian occurs via a number of springs along the margins of the Kimmeridge Clay, largely controlled by faulting. Structure also likely controls flow within the confined aquifer⁶.

3. Results

3.1. Groundwater chemistry

Samples of groundwater have been collected from both the Superficial aquifer within the vale and the Corallian aquifer along its margins. This study considers analyses from 25 groundwater sites sampled during February 2016: 14 plus 1 newly drilled borehole from the Superficial aquifer, and 10 from the Corallian. Locations of these and in relation to the proposed shale-gas exploration site (KM8) are given in Fig. 1.

Groundwater from the Superficial aquifer shows the greatest variation in major-ion compositions, with a range from Ca-HCO₃ to Na-HCO₃ types (Fig. 2a). A few samples have relatively high SO₄ and Cl as salinity increases (SEC up to 2940 µS/cm). The compositional variations suggest that they have been partially impacted by ion exchange. The Superficial aquifer groundwaters are strongly reducing with DO concentrations universally <1 mg/L, low NO₃, and variable though often low SO₄, as well as high Fe, Mn and NH₄ (Fig. 2a). The compositions suggest that conditions are sufficiently reducing in some for SO₄ reduction and methanogenesis. Concentrations of dissolved CH₄ up to 37 mg/L have been found, and exceed 1 mg/L at 8 sites (February 2016 sampled data).

The compositional variation in the groundwater from the Corallian is much smaller, all being of Ca-HCO₃ type (Fig. 2b), reflecting interaction with limestone. Redox conditions vary more as the samples include groundwater from both the unconfined and edge of the confined aquifer. DO concentrations show the full range from <0.1–10 mg/L (anoxic to fully saturated), higher concentrations of NO₃ and variable though usually lower concentrations of Fe, Mn, As, Se and Mo (Fig. 2b). Compositions of groundwater in the deep confined Corallian near KM8 will be ascertained in the coming months, but one analysis from some 3 km south of the site indicated a saline groundwater (Na 520 mg/L, Cl 460 mg/L)⁶, likely influenced by ion exchange, and suggesting limited groundwater movement and possibly long residence time.

Fig. 3 shows the distribution of CH₄ in the groundwaters of the Vale of Pickering. As shown in Fig. 2a,b, concentrations are uniformly low in the Corallian aquifer along the margins but higher in those from the Superficial aquifer. They correspond with the most reducing groundwater samples and are located in the lowest-lying section of the aquifer. Such distributions have been found in low-lying areas elsewhere⁸ and could relate to generation of the most reducing conditions in zones of slow flow/low hydraulic gradient and fine-grained organic-rich sediment.

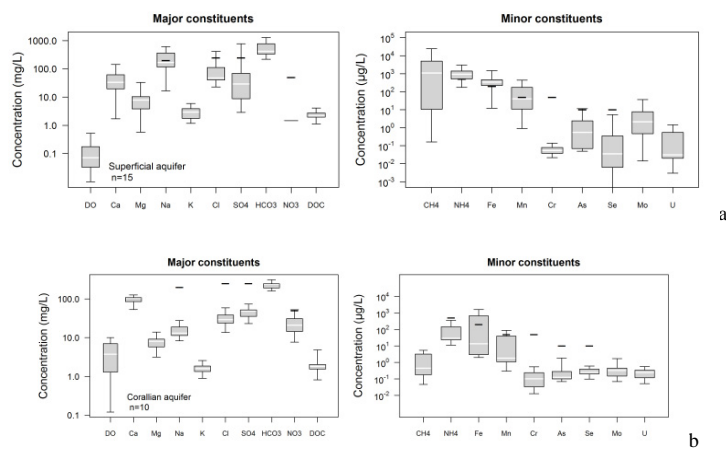


Fig. 2. Box plots of major and minor constituents in groundwater from the a. Superficial and b. Corallian aquifers showing variation in redox conditions. Horizontal lines show national drinking-water limits.

However, molar C1/C2 ratios determined so far are in almost all cases <1000, suggesting a mixed biogenic-thermogenic origin. This relationship is being investigated further but possible sources of hydrocarbons include deep reservoirs, transported via fractures or, perhaps more likely, the shallow Quaternary/Kimmeridge sedimentary rocks.

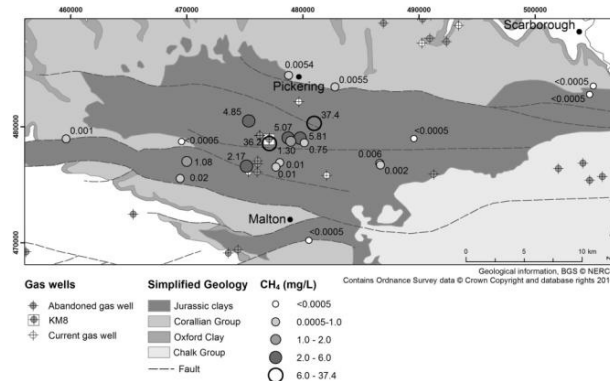


Fig. 3. Distributions of methane in the sampled groundwaters of the Vale of Pickering.

4. Conclusions

Baseline compositions of groundwater show a significant spatial variability, controlled by geology and hydrogeology. Groundwater from the Superficial aquifer close to the planned hydrocarbon exploration site is strongly reducing with some high observed concentrations of dissolved CH_4 . Preliminary investigation suggests an origin in the Quaternary/Kimmeridge Clay deposits, although deeper sources cannot be ruled out. Further investigation is needed to establish the chemistry of the deep confined Corallian aquifer. The high CH_4 values observed in Superficial groundwater form part of the natural baseline before any shale-gas development has taken place.

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