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Assessing changes in gas migration pathways at a hydraulic fracturing site: Example from Greene County, Pennsylvania, USA

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ABSTRACT

Natural gas produced from a zone of thin Upper Devonian/Lower Mississippian sands approximately 1200 m above the hydraulically fractured Middle Devonian Marcellus Shale interval was monitored for evidence of gas migration. Gas samples were collected from seven vertical Upper Devonian/Lower Mississippian gas wells and two vertical Marcellus Shale gas wells 2 months prior to-, during-, and 14 months after the hydraulic fracturing of six horizontal Marcellus Shale gas wells at the study site. The isotopic and molecular compositions of gas from the two producing zones were distinct and remained so during the entire monitoring period. Over the time of monitoring, the molecular/isotopic signatures of gas from the Upper Devonian/Lower Mississippian field did not show any evidence of contamination from deeper Marcellus Shale gas that might have migrated upward from the hydraulically fractured interval. Our results indicate no hydrologic connectivity between the fractured interval and formations 1200 m above, which means that contamination of even shallower drinking water aquifers (~2200 m above fractured interval) is unlikely at this study site. While localized consideration for geology and site development practices are extremely important, the monitoring methods used in this study are applicable when trying to understand and quantify natural gas mixing and migration trends.

1. Introduction

One of the largest shale gas plays in the US, the Marcellus Shale underlies approximately 195,000 sq. km. of the Appalachian Basin with the best development potential occurring in New York, Pennsylvania and West Virginia. The organic-rich Marcellus Shale is Middle Devonian in age and contains a total of 14.2 trillion cubic meters GIP (gas in place) (Bruner and Smosna, 2011). Currently, the most effective way to extract the gas trapped tightly in the shale is through horizontal drilling and hydraulic fracturing.

Horizontal wells typically have higher gas production rates than vertical wells because they access more of the gas-bearing strata. Though horizontal wells have higher development cost than vertical wells, the higher cost is offset by higher gas production rates over the lifetime of the well. Multiple horizontal wells are often drilled from one pad resulting in a smaller surface footprint and more efficient development of an area. Horizontal wells are becoming increasingly common as they are more economical to drill and hydraulically fracture when compared to vertical wells (Bruner and Smosna, 2011).

Hydraulic fracturing entails pumping thousands of cubic meters of "slickwater", a mixture consisting of water, sand, and chemical additives into a drilled well at high pressure. This process induces new fractures, enlarges existing fractures, and props open fracture pathways allowing gas to flow into the well. The Marcellus Shale responds well to hydraulic fracturing, which results in an increase in the volume of gas a well produces (Bruner and Smosna, 2011).

Several studies have been conducted to better understand the possible contamination of shallow drinking water aquifers by methane (stray gas), fracturing fluid, and/or formation brine migrating from depth during hydraulic fracturing (e.g. Osborn et al., 2011; Molofsky et al., 2013; Warner et al., 2012; Sharma et al., 2014). This study is unique as an actual hydraulic fracturing site was monitored over time to understand changes in gas migration pathways related to hydraulic fracturing. We monitored the geochemistry of gas produced from a gas field that is at an intermediate depth between the hydraulically fractured formation and protected shallow underground sources of drinking water (Fig. 1). The stable carbon and hydrogen isotopes of methane (ethane for select samples) and gas compositions were used to determine if gas had migrated about 1200 m upward from the

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0883-2927/

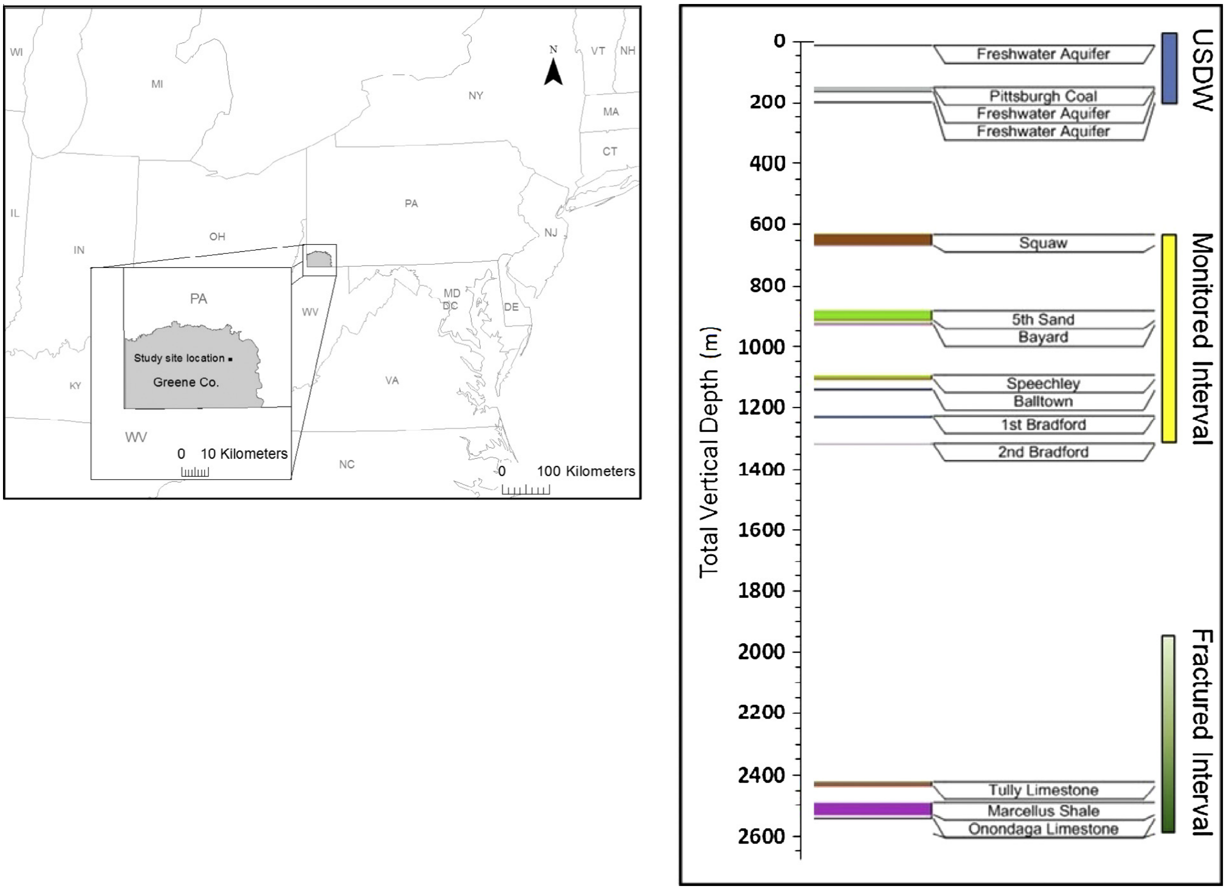

Fig. 1. Study location and stratigraphic column of the area (modified from Hammack et al., unpublished report).

hydraulically fractured zone (Marcellus Shale) to the monitored zone (Upper Devonian/Lower Mississippian gas field) before, during, or after the hydraulic fracturing of six horizontal wells in the Marcellus Shale. This method is most effective when the geochemical signatures of the waters and gases in overlying geological formations are significantly different from the unit being hydraulically fractured.

2. Study area and methodology

2.1. Study area

The study site is located in the southwestern corner of Pennsylvania in Greene County (Fig. 1), a location that has experienced significant growth in gas development in recent years. At this location, the Marcellus Shale is approximately 2470–2500 m below the surface (Fig. 1). Well infrastructure at the study site includes: (1) seven vertical wells (UD 1–7) with multiple completions in thin Upper Devonian/Lower Mississippian sands (approximately 640–1340 m below the surface), (2) two vertical Marcellus Shale wells (MW 1–2), and (3) six horizontal Marcellus Shale wells (Fig. 2). The six horizontal Marcellus Shale wells at the study site were drilled to avoid two northeast-trending reverse faults (mapped from reflective seismic) that extend vertically from below the Marcellus Shale, through the Tully Limestone, and into Upper Devonian units where they disappear. The faults do not appear to extend upward into the Upper Devonian/Lower Mississippian gas field. The three horizontal wells that extend southeastward were drilled in a section of the Marcellus Shale between the two faults. Although reflective seismic identified no fault intercepts in the three horizontal wells that extend northwestward, microseismic monitoring during the hydraulic fracturing of these wells located microseismic event clusters 300–580 m above the Marcellus Shale that may denote the location of low-offset faults (sub-seismic faults). The top of the uppermost microseismic event cluster is approximately the same height as the uppermost extent of mapped faults, or ~610 m below the lowermost producing zone in the Upper Devonian/Lower Mississippian wells (Hammack et al. unpublished report).

Gas samples were collected from two vertical Marcellus wells (MW 1–2), seven Upper Devonian/Lower Mississippian wells (UD 1–7) and two of the horizontal Marcellus wells in March of 2012 to establish baseline isotopic signatures of both Marcellus Shale gas and gas originating from the Upper Devonian/Lower Mississippian sands. Since then, isotope monitoring has continued on a monthly basis until October 2012 and a bimonthly basis thereafter. In addition to the research team at WVU, researchers from the University of Pittsburgh and the Department of Energy's National Technology Laboratory are utilizing additional tools such as microseismic, Sr isotopes, and perfluorocarbon tracers to determine the extent of fracture propagation and to monitor for evidence of fluid and gas migration.

2.2. Sample collection

Gas samples from Greene Co. are collected with high-pressure stainless steel cylinders and valves. The cylinders are attached to the gas wells at a sampling port that intercepts the production line prior to any type of processing that could affect the isotopic signature. The gas is vented at the wellhead to clear any built up mois-