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The effects of shale gas exploration and hydraulic fracturing on the quality of water resources in the United States

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Abstract

Advances in drilling technologies and production strategies such as horizontal drilling and hydraulic fracturing have significantly improved the production of natural gas by stimulating fluid flow from wells. Since 2008, these technological developments have spurred exponential growth of gas well drilling across the U.S. While the new drilling for shale gas and hydraulic fracturing technologies have dramatically changed the energy landscape in the U.S., recent scientific findings show evidence for contamination of water resources. This paper provides key observations for the potential risks of shale gas drilling and hydraulic fracturing on the quality of water resources and include: (1) stray gas contamination of shallow groundwater overlying shale gas basins; (2) pathways and hydraulic connectivity between the deep shale gas formations and the overlying shallow drinking water aquifers; and (3) inadequate disposal of produced and flowback waters associated with shale gas exploration that causes contamination of surface waters and long-term ecological effects. By using geochemical (e.g., Br/Cl) integrated with oxygen, hydrogen, strontium, radium, and boron isotopic tracers, we have characterized the geochemical fingerprints of brines from several shale gas basins in the USA, including the Utica and Marcellus brines in the Appalachian Basin and the Fayetteville brines in Arkansas. We use these geochemical fingerprints to delineate the impact of shale gas associated fluids on the environment.

Keywords: shale gas; hydraulic fracturing, stray gas; salinity; water contamination; produced water.

1. Introduction

Recent advances in drilling technologies and production strategies such as horizontal drilling and hydraulic fracturing have significantly improved the production of hydrocarbons by stimulating the flow of gas and liquids from impermeable geologic formations [1-3]. These technological improvements have increased oil and gas exploration in numerous unconventional fields across the U.S., particularly in the

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Barnett, Haynesville, Bakken, Fayetteville, Woodford, Utica, and Marcellus shale formations (Figure 1). The U.S. Department of Energy Energy Information Agency (EIA) projects that by 2035 shale gas production will increase to 340 billion cubic meters per year, about 50% of the total projected gas production in the U.S [4].

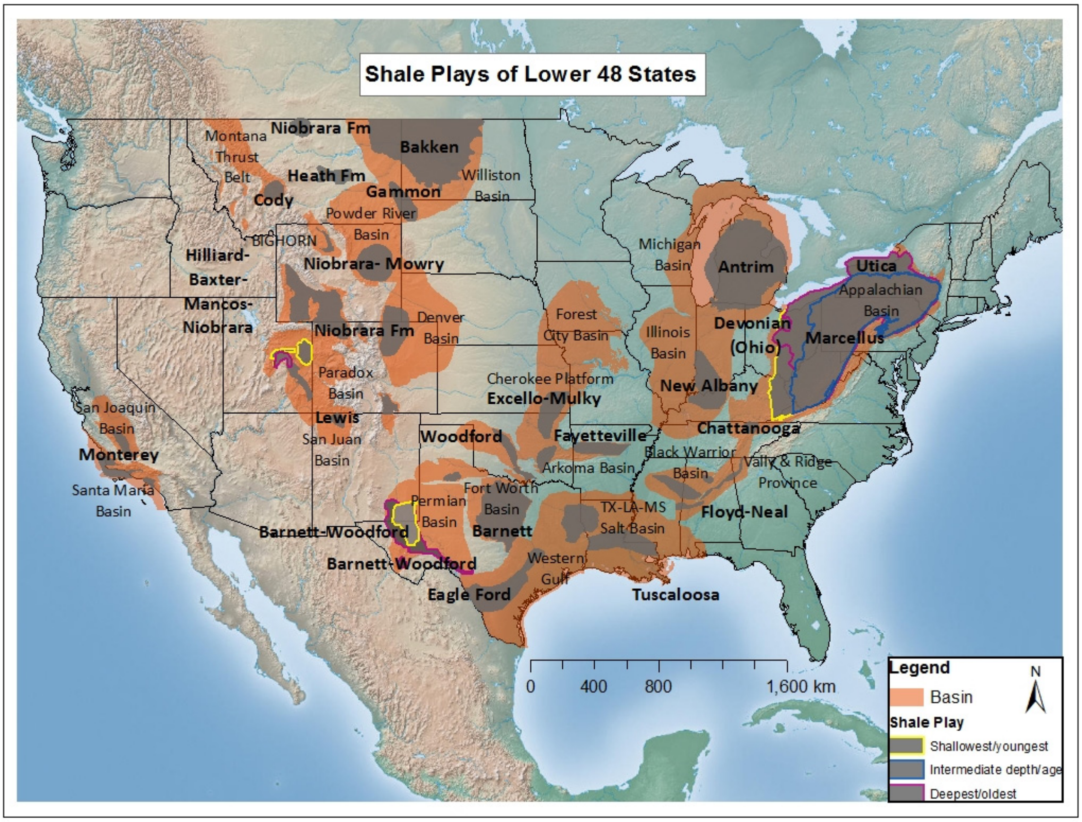

Fig. 1. Map of shale gas basins in the USA. Map was prepared by Cidney Christie (Duke University), based on data from U.S. Energy Information Administration (EIA).

The increased extraction of natural gas resources from the shale gas basins in the U.S. has increased awareness for possible environmental consequences, particularly contamination of shallower drinking water aquifers. The debate surrounding the safety of shale gas extraction and hydraulic fracturing [5] has focused on stray gas migration to shallow groundwater [6] and to the atmosphere [5], possible hydraulic connectivity between deep shale formations and shallow aquifers [7], water use [8], air quality [9]as well as the potential for contamination from hydraulic fracturing fluid and/or produced brines containing toxic substances during drilling, transport, and disposal [10-12]. As shale gas exploration is expected to become global, with new initiatives and explorations in China, Germany, Poland, Australia, and New Zealand, the results that are emerging from field-based studies in the U.S. are vital for a global assessment of the environmental risks of shale gas drilling and hydraulic fracturing. This paper provides an overview on three major possible impacts on water quality induced from shale gas exploration and hydraulic fracturing: (1) shallow groundwater contamination; (2) possible hydraulic pathways between deep and shallow formations; and (3) disposal of produced and flowback waters.

2. Shallow groundwater contamination

One of the most intensive debates on the environmental safety of shale gas exploration and hydraulic fracturing is the possible contamination of drinking water wells in areas of extensive shale gas operation. Our previous study in northeastern Pennsylvania has shown elevated levels of methane in wells located near (<1 km) shale gas drilling sites, whereas wells located away (>1 km) from these areas had much lower methane concentrations [6]. In contrast, it was argued that relatively high methane in this part of the Appalachian Basin is due to natural flux of methane and is not linked to the shale gas drilling [13]. The ability to delineate methane sources and thus the distinction between natural flux and anthropogenic contamination is based on the different isotopic ($\delta^{13}C$-CH_4; $\delta^{2}H$-CH_4) and geochemical (propane/methane ratios) compositions of thermogenic relative to biogenic methane sources. It was shown that the elevated methane in drinking water wells near the shale gas wells had a thermogenic composition (e.g., heavier ^{13}C-CH_4) than wells located 1 km away from shale gas sites with an apparent mixed thermogenic-biogenic composition. New emerging noble gas data [14] reinforce the carbon isotopes and hydrocarbon ratios data and indicate that the high levels of methane exceeding the hazard level of 10 mg/L are indeed related to stray gas contamination directly linked to shale gas operation. The most probable mechanism for stray gas contamination is leaking through inadequate cement on casing or through well annulus from intermediate formations [6, 14].

In contrast to stray gas contamination, our previous work has not shown evidence for actual contamination of dissolved constituents in shallow aquifers in northeastern Pennsylvania, even for wells with high methane contents [6,7]. New data from 236 domestic wells from Pennsylvania and New York states show no systematic difference in chloride, barium, chromium, boron, and arsenic contents in wells located in "active" zones (<1 km) and "non-active" areas (>1 km). In contrast, an EPA study reported the presence of synthetic organic compounds (e.g., diethylene glycol) as well as elevated chloride and potassium in two high-pH deep wells near extensive shale gas operation in Pavillion, Wyoming[15].

2. Hydraulic connectivity between deep and shallow formations

The fragility of shallow aquifer systems to possible contamination of fugitive gas, fracking fluids, and/or formation water depends primarily on the hydraulic connectivity between deep shale gas formations and the overlying shallow aquifers. In the Appalachian Basin, the depth of the Marcellus Shale is about one to two km, yet an intensive fracture network system provides a possible conduit for gas and fluids migration [16]. Evidence for natural pathways from deep formations to shallow aquifers in northeastern Pennsylvania is shown by the distinctive geochemical (elevated Br/Cl) and isotopic ($^{87}Sr/^{86}Sr$ ratios) compositions of saline groundwater identified in shallow aquifers [7]. The Na-Ca-Cl composition of the saline shallow groundwater mimics the composition of the Marcellus brines and different from the Ca-HCO_3 and Na-HCO_3compositions that characterize local groundwater. In addition, the $^{87}Sr/^{86}Sr$ ratios of the saline groundwater overlap the $^{87}Sr/^{86}Sr$ ratios measured in the Marcellus brines, inferring mixing between the deep Marcellus brines and shallow groundwater [7].

3. Disposal of produced and flowback waters

The high levels of salinity (TDS up to 300,000 mg/L), toxic elements (e.g., barium), and radioactivity of produced and flowback waters from the Marcellus Shale [7, 10-12, 17-18] and other shale gas basins present new challenges for handling the wastewater that is generated together with the natural gas. Our data show that disposal of the hypersaline wastewaters to waterways in western Pennsylvania, even through a brine treatment facility, generates a highly saline plume (TDS up to 100,000 mg/L) and radioactivity in both downstream surface waters and river sediments. We use the strontium isotopes to determine the source of the wastewater and to distinguish produced waters originated from shale gas from conventional oil and gas production. Alternative disposal of wastewaters through deep-well injection could induce seismic events, as shown in different sites in the U.S. [19]. Overall, one of the direct unquestioned impacts of shale gas exploration on water quality is the issue of management and disposal of wastewater associated with the gas production. The increase use of hydraulic fracturing technology for enhancement and tapping of also conventional oil and gas wells is expected to increase the volume of these types of wastewaters in the U.S.

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