LETTER

Reply to Engelder: Potential for fluid migration from the Marcellus Formation remains possible

Engelder's letter (1) argues that the sequestration of hydraulic fracturing fluids (HFFs) and brines by imbibition and capillary binding seals the Marcellus Formation and precludes the flow of fluids into overlying formations. This apparently conflicts with our study suggesting that natural connectivity exists between the Marcellus Formation and shallow aquifers in northeastern Pennsylvania (2).

First, considerable data show that the Marcellus Formation is not "dry," as Engelder suggests (1). Data from many Marcellus Formation shale-gas wells show that produced water is highly saline [total dissolved solids (TDS) exceeding 250,000 mg/L]. These concentrations are ∼10-fold the salinity of seawater and include elevated Br/Cl and Ca/Cl ratios, a combination that indicates residual evaporated seawater modified by water–rock interaction (2, 3). Data of flow-back water from hydraulically fractured shale-gas wells show that the Marcellus Formation brine constitutes a significant percentage of the return flow (2, 3) and that the brine must be present within zones intercepted by HFFs. Geochemical and isotopic data (e.g., $\delta^{18}O$) of the flow-back water (3) clearly mirror the composition of brine (2) and mainly reflect dilution of the Marcellus Formation water with HFFs. The chemical data thus suggest that formation water flows into shale-gas wells following hydraulic fracturing, apparently from permeable units within the Marcellus Formation. Further, microseismic monitoring shows the influence of hydraulic fracturing is greater in the direction of least compressive stress (i.e., upward) into overlying formations (4) rather than downward into the underlying Onondaga Formation, limiting the plausibility of a lower stratigraphic source for these fluids (1).

Second, during catagenesis of Marcellus Formation gases, brine and gas are likely expelled into the overlying Upper Devonian formations (5). These overlying sequences show evidence of joint sets similar to those observed in the Marcellus Formation (6). The apparent lack of mineralized veins and fractures in this region of Pennsylvania (6) supports the concept of a hydraulic connection between the Middle and Upper Devonian Formations. If these pathways are intercepted by fractures induced by shale-gas drilling and hydraulic fracturing (4), there is potential for the migration of stray gases and/or other fluids into the Upper Devonian sequences of the northern Appalachian Basin. Thus, modeling of imbibition* of brines or HFFs that infers lack of migration from the Marcellus Formation does not sufficiently consider the nature of the formation. Quantitative empirical work is still needed to assess that risk.

Our study did not find evidence of recent brine contribution to shallow drinking water directly associated with shale-gas development (2), and we do not expect widespread, rapid vertical movement of HFFs. However, there is evidence for natural migration of brine and subsequent dilution in shallow drinking water aquifers. The timing of emplacement and the rate of brine migration remain open and important questions in continuing efforts to determine risks. If hydraulic fracturing intercepts natural pathways (i.e., faults/fractures) that connect the Marcellus to overlying units, the migration of fluids, including gases, is possible. Such migration would likely follow similar pathways if unhealed by mineralization.

Nathaniel R. Warner[a], Robert B. Jackson[a,b], Thomas H. Darrah[a], Stephen G. Osborn[c], Adrian Down[b,d], Kaiguang Zhao[b,d], Alissa White[a], and Avner Vengosh[a,1]

[a]*Division of Earth and Ocean Sciences, Nicholas School of the Environment, Duke University, Durham, NC 27708;* [b]*Center on Global Change, Nicholas School of the Environment, Duke University, Durham, NC 27708;* [c]*Geological Sciences Department, California State Polytechnic University, Pomona, CA 91768; and* [d]*Biology Department, Duke University, Durham, NC 27708*

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[1]To whom correspondence should be addressed. E-mail: vengosh@duke.edu.

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