In situ microbial free phase gas production causes tensile fracturing: a laboratory demonstration

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Summary

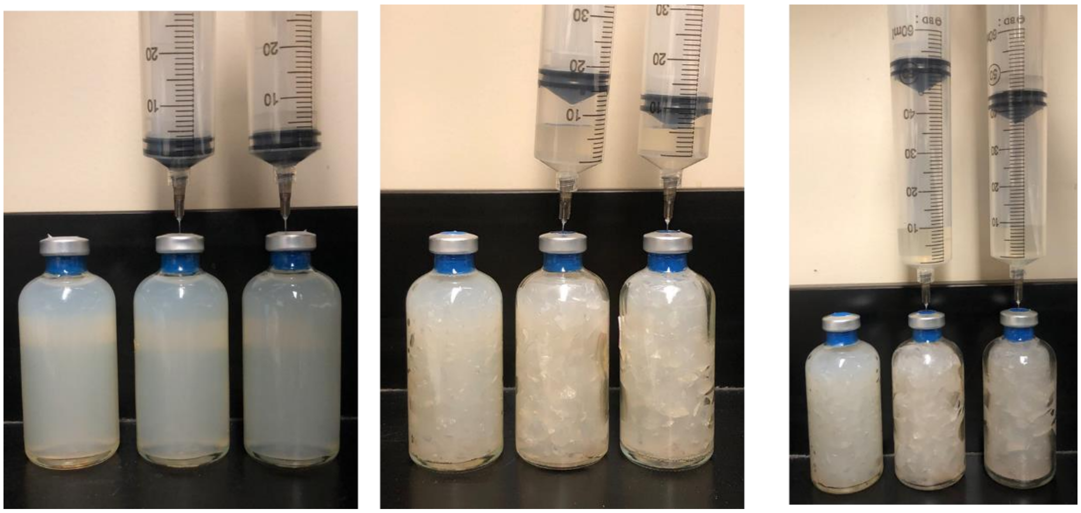
Some geological formations are over-pressurized, meaning that pore fluid pressure is greater than the hydrostatic gradient at that depth (Osborne and Swarbrick, 1997; Ramdhan and Goulty, 2011). We know that free phase gas (FPG, i.e. gas bubbles) occurs in the subsurface by the presence of dry coal bed methane (Hoch, 2005), cold-water geysers (Han et al., 2013), and menthane vents (Orphan et al., 2004). However, the role of FPG in geologic overpressuring is not well explained. FPG formation occurs when total dissolved gas pressure (P_{TDG}) exceeds bubbling pressure (P_{BUB}), which is the sum of water and capillary pressures (i.e. $P_{BUB} = P_W + P_{CAP}$). Total dissolved gas pressure (P_{TDG}) serves as proxies for continuous dissolved gas concentration data. To accurately measure P_{TDG}, pressure transducers are adapted by attaching to a sealed silicone tubing.

This research demonstrates the influence of in situ FPG production on subsurface geomechanical properties by facilitating geochemical dissolved gas production in laboratory microcosms filled with gelatin (whose linear elastic behavior is analogous to elastic rocks; Li. et al., 2020). The goal of this research is to improve our understanding of the role of FPG occurrence on geologic formation overpressuring, natural fracturing, and the subsequent formation of natural oil and gas pathways.

Method

First test was conducted in 80ml serum bottles to ensure the microbe is compatible with the agar gel and nutrient mix. Triplicate control and microbial samples were set up with 100mmol L^{-1} of nitrate and syringes on top to adjust the FPG pressure in bottle to the atmospheric pressure (Figure 1). Volume of FPG and liquid production was monitored during incubation.

The second test was conducted in four 250ml serum bottles to ensure P_{TDG} probe could be fitted in the gelatin sample with one control sample and three microbial samples. Denitrifier *Thauera* was added in the agar gel and nutrient mix to promote denitrification (Suri et al., 2017). P_{TDG} probe readings were recorded to monitor the P_{TDG} change in samples. Gas and liquid samples were collected during the incubation period to assess denitrification stages and substrate consumption rates. Silicone gel was applied on top in between the rubber top and the probe wire to create a gas seal for the serum bottles. Certain amount of gas (total of 95ml to 165ml) was released during the incubation to ensure the bottles were not significantly overpressured.



(a) (b) (c)

Figure 1 (a) Control samples showing no failure, gas or liquid production. (b) Day 3 of the microbial samples. Microbial gas was actively produced and caused dense tensile fracture networks. (c) Day 6 of microbial samples with higher FPG volume increase in syringes.

Results

In the first test, FPG formation was confirmed, with up to 75 mL collected from serum bottles. Tensile fracturing was observed and attributed to the FPG production. Based on the total NO_3^- consumed, appropriately 90ml of N_2 is produced. Experiment was ended on day 18 when there is no increasing volume of gas and liquid production.

In the second test, nitrate concentrations in the microcosms were reduced to below detection levels (<0.001 mmol L^{-1}) in all the cultures within 6 days and the reduction of nitrate to N_2 was complete by day 38 with N_2O and nitrite at non-detectable limit. The observed change in nitrogen species suggest that 240 mL of N2 gas were formed during denitrification, which would correspond to an estimated 800 kPa increase in PTDG. The measured P_{TDG} increased to a peak value of 225 kPa after 8 days, which was the point at which FPG leakage occurred through the bottle cap. Tensile fractures were observed after 2 days of incubation. This work demonstrated that biogeochemical dissolved gas production can cause tensile fractures in linear elastic material.

Future goal of this research is to i) combine aqueous and geomechanical models to reproduce hydraulic fracturing in elastic materials observed in the lab ii) apply these models to understand the role that FPG production has played in geologic fracturing and potential role in hydraulic fracturing.

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