Structural controls on fluid evolution in the Devonian Marcellus shale during deformation of the central Appalachians

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Fluid inclusion microthermometry of temporally controlled vein minerals is used to evaluate the fluid conditions of the Middle Devonian Marcellus shale during the Alleghenian orogeny. Samples from folded rocks in the Pennsylvania salient and in less deformed rocks of the Plateau province indicate that fluid pressure – temperature — composition (PTX) does not remain static during orogenesis, but varies significantly both in time and between structural settings.

Regionally, the earliest trapped fluids are in dolomite, calcite, and/or barite and consist of degraded liquid hydrocarbons, liquid hydrocarbons and condensate-type fluids. These fluids are interpreted to have been trapped during peak oil generation and migration, probably during basin filling and before folding. Fluid trapping occurred at temperatures of 60° - 118°C and at depths of less than 3.8 km.

Within the Valley & Ridge province, however, samples from folded rocks additionally contain later quartz and calcite with multiple fluid trapping events reflecting a dynamic vein opening history related to changes in fluid connectivity associated with syn-folding fracturing that allows for increased fluid mobility. The fluid trapping events are characterized by diferent fluid salinities (ranging from 10 to 25 wt. % equiv.) and CH_4:CO_2 ratios. This increased connectivity is occurring during 1) burial associated with overthrusting and/or syntectonic depositional loading and/or 2) syn-folding uplift and erosion. Importantly, the PTX history of sites in synclines is different from sites on anticlines, and reflects the different structural history of each location. The influx of fluids is indicated by the concurrent dissolution of vein calcite and precipitation of quartz, and that brine inclusions in the quartz consistently increase in T_h from early to late quartz. Interestingly, this late quartz is suprisingly methane-rich, and contains abundant, large $CH_4 \pm CO_2$ inclusions, while aqueous inclusions are exceedingly rare.

Along the boundary between the subhorizontal rocks of the Plateau province and the folded rocks of the Valley and Ridge, the PTX conditions determined for the Marcellus veins indicate a significant variation along strike. To the northeast, the lack of quartz and the presence of only liquid hydrocarbon and $CH_4 \pm$HHC inclusions in calcite and barite suggests little fluid mobility. On the other hand, to the southwest, late quartz contains more mature $CH_4 \pm CO_2$ inclusions and the presence of corroded early calcite suggests a fluid influx. The sites containing the later quartz are adjacent to an area of the Plateau with increased thermal maturation based on vitrinite relectance, suggesting that 'warm' fluids passing through the Marcellus may be responsible for the increased maturation.

Yellowstone hot spring microbial communites fed with hydrogen and bicarbonate as a metabolically active analogue for early Earth environments

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Obsidian Pool in Yellowstone National Park

Microbial ecosystems independent of sunlight and supported by hydrogenotrophic primary production have been shown in subsurface environments such as basaltic rock aquifers and volcanic rock [1,2]. The presence and activity of such ecosystems in Obsidian Pool sediments in Yellowstone National Park (YNP) was the focus of this study, as microorganisms in these environments include groups branching deeply in the phylogenetic tree of life.

Obsidian Pool is known to have diverse microbial communities of hydrogen-oxidizing bacteria and archaea [3, 4] and the water in the pool contains 46 nM H_2. The H_2 to support miro-organisms can be generated from magmatic gases [5]. Using molecular techniques, hydrogen oxidizing aerobic bacteria have been shown to be the most abundant microorganisms present at Obsidian Pool. By contrast, the sediment in Obsidian Pool is anoxic and hydrogen utilizing methanogens have been shown elsewhere in YNP [6].

Experimental

To study active hydrogenotrophic methanogens anaerobic *in situ* incubation microcosms fed with H_2 and $NaHCO_3$ were set up. Changes in H_2 and CH_4 concentrations were followed using gas chromatography. Additionally, copy number changes of a metabolic gene for methanogenesis (methyl coenzyme M reductase α-subunit; mcrA) was studied using quantitative PCR. The microbial community structure was studied with 16S rRNA gene sequence diversity via 454 pyrosequencing.

Results and conclusion

When the diversity of the 16S rRNA gene was followed using 454 pyrosequencing, Obsidian Pool was found to be dominated by Aquificales. Quantitative PCR of archaeal 16S rRNA and mcrA genes, consumption of H_2 and production of CH_4, as well as relative abundances of 16S rRNA sequences confirmed active populations of the hydrogenotrophic *Methanothermobacter* with a generation time of 6.4 h. Hydrogenotrophic organisms in turn sustained growth of heterotrophic organisms such as Thermotogales and Nitrospira. Our study supports the exsistence of a hydrogen driven subsurface ecosystems which in the 16S rRNA gene phylogeny have deeply branching microorganisms, potentially similar to the early life on Earth. This highly active and accessable early Earth analogue, will allow studies of microbial interaction in a natural environment.

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