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# Biogeochemistry of the Forest City Basin coalbed methane play

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ABSTRACT

Hydrogeochemical and microbial analyses of co-produced formation waters and gas in the Forest City Basin were coupled to determine the origin of methane in shallow coal seams and make comparisons to commercial shale and coal gas plays in the adjacent Illinois, Michigan and Cherokee basins. Forest City Basin coals contain dilute meteoric waters ($Cl^-$ < 411 mM; average $\delta^{18}O$ and $\delta D$ values = −6.9‰ and −45.6‰ VSMOW, respectively), no detectable $SO_4^{2-}$, and high alkalinity concentrations (~10 meq/L) with elevated $\delta^{13}C$ values (up to 13.1‰ VPDB). The $\delta^{13}C$ values of coalbed methane (average = −64.7‰ VPDB) are approximately 72‰ depleted relative to the potential dissolved inorganic carbon source, and the $\delta D$ values of $CH_4$ (average = −221‰ VSMOW) are approximately −175‰ depleted compared with ambient formation waters. Together, these molecular and isotopic signatures of Forest City Basin waters and gas point to a microbial origin for methane. Enrichment cultures of microbial cells inoculated from Forest City Basin coal waters confirm the presence of a microbial community of fermentative bacteria, and both $CO_2$-reducing and acetate-utilizing forms of methanogenic Archaea, similar to what has been observed in the Antrim Shale in the Michigan Basin.



## 1. Introduction

Increasing energy demands and heavy exploitation of coalbed methane and fractured shale gas plays in sedimentary basins, such as the Powder River, San Juan and Michigan basins, have sparked interest in natural gas exploration in other oil and gas provinces, such as the Forest City and Illinois basins (Fig. 1). The Upper Devonian New Albany Shale and the Pennsylvanian coal beds have been the main targets in the Illinois Basin. In the Forest City Basin, the series of relatively thin Pennsylvanian coal beds are beginning to be developed for methane extraction. In this study, we present new geochemical data of formation waters, gas, and microbial samples from the Forest City Basin emerging coalbed methane play to determine the timing and mechanisms of gas generation, and geographic distribution of biogenic versus thermogenic methane. Key comparisons are also made to Upper Devonian shales and coal beds in adjacent basins (e.g. Illinois, Michigan, and Cherokee basins) (Table 1).

### 1.1. Timing and mechanisms of $CH_4$ generation

Roughly 20% of produced methane worldwide is microbial in origin (Rice, 1992). Methane ($CH_4$) and carbon dioxide ($CO_2$) are generated by the degradation of organic matter in shales and coals by a consortium of microorganisms, primarily fermentative bacteria and $CO_2$ reducing methanogens, after which these gases are adsorbed onto the organic surfaces. Microbial $CH_4$ reservoirs are typically located at shallow depths in thermally immature (vitrinite reflectance or $R_o$ < 0.6%) shales and coals where formation waters exhibit relatively low salinities (<2 mol/L $Cl^-$) and low $SO_4^{2-}$ concentrations (<10 mmol/L) (e.g. Martini et al., 1998). Infiltration of dilute meteoric waters into these systems appears to be important for transport of nutrients and stimulation of microorganisms, as well as dilution of ambient formation waters. Microbial methane extracted from the Illinois, Michigan, Powder River, and Gulf of Mexico basins has been generated primarily since the Late Pleistocene (Martini et al., 1998; Gorody, 1999; McIntosh et al., 2002, 2007; Strapoc et al., 2007). In contrast, thermogenic gas is generated over geologic timescales in organic-rich formations that were subject to high temperatures and/or pressures. These deposits are typically located at depth in sedimentary basins, and are often associated with saline formation waters. In some cases, thermogenic hydrocarbons can then serve as biological substrates for anaerobic microorganisms, resulting in the production of secondary biogenic methane (Martini et al., 1998). Historic gas production in the Forest City and nearby Cherokee basins was focused on conventional oil and gas plays, although these resources have been in steep decline over the past several decades (Newell et al., 2002). Recent (post 1980) gas exploration has expanded to coalbed methane deposits where both thermogenic and microbial gas have been identified.

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## 2. Geological background of the Forest City Basin

The Late Paleozoic Forest City Basin extends through much of northeastern Kansas and northwestern Missouri (Fig. 2A), separated from the more deeply buried Paleozoic strata of the Cherokee Basin to the south by the Bourbon Arch (Lee, 1943). The eastern edge of the basin is bound by the Ozark uplift on the southeast, the western edge of the basin is flanked by the Nemaha uplift, and the northern margin of the basin is defined by the geographic extent of the Pennsylvanian strata (Tedesco, 1992; Bostic et al., 1993). The basin is relatively structurally undeformed with the axis near the western edge.

The Pennsylvanian–age coal beds in the Forest City basin are thin (in general, less than 71 cm thick), but laterally extensive (Newell et al., 2002). They reach a maximum depth of 488 m (1600 ft) in the central part of the basin, and have a cumulative thickness of 7 m (~22 ft) (Rice et al., 1995). Coal bearing units of the Forest City Basin are found mostly in the Middle Pennsylvanian Desmoinesian Series (Fig. 3), and the underlying Atokan Series (not shown in Fig. 3). Specific coal bearing formations within the Desmoinesian Series include the Cherokee and Marmaton Groups. There are also coal zones within the overlying Pleasanton Groups (not shown in Fig. 3). This stratigraphic sequence is dominated by alternating marine, transitional, and non-marine sediments, primarily composed of fluvial-deltaic sandstones, organic-rich shales, limestones, and coals (Bostic et al., 1993; Charpentier, 1995). More than 40 individual coal beds have been identified, and completion of multiple beds may be required for commercial gas production. Shallow coals have been mined at the surface and underground for more than 100 years, and gas explosions in underground coal mines were common in the late 1800s (Rice et al., 1995; Fig. 2A).

The Forest City Basin coals are of low thermal maturity (high-volatile C to A bituminous; $R_o$ values ~0.49 to greater than 0.68%) (Bostic et al., 1993). Coal rank increases with depth; in Kansas, shallow coal beds are high volatile C bituminous in rank, while deeper coal beds (below 290 m depth) are high volatile A bituminous in rank (Bostic et al., 1993). Coal rank also increases to the west, where coals were more deeply buried and experienced higher paleo heat flows. Maximum burial occurred in the late Paleozoic or early Mesozoic (Bostic et al., 1993).

Gas content values of desorbed coal samples from Leavenworth County, Kansas (depth interval, 231–353 m), ranged from 0.66 to 2.93 $cm^3$/g of coal, on an ash-free basis. The methane content of crushed cores ranged from 72 to 97%, and $CO_2$ content ranged from 0 to 17%. Carbon isotope values of $CH_4$ ranged from −59.7 to −46.1‰ (Bostic et al., 1993). Shallow coal burial depths and adjacent structural features to the south and west have resulted in an extensive and well-developed regional fracture system in the basin (Tedesco, 1992; Bostic et al., 1993; Newell et al., 2002).

### 2.1. Comparison to Michigan, Illinois and Cherokee basin coal beds and black shales

Several similarities can be drawn between the coals and shales of the Forest City Basin, and the fractured organic-rich shales and coal beds in the adjacent Illinois Basin (New Albany Shale and Pennsylvanian coals), Michigan Basin (Antrim Shale), and Cherokee Basin coal beds (Table 1). All of these formations are rich in total organic carbon and along basin margins have not been subjected to significant thermal maturation, as evidenced by $R_o$ values less than 0.68%. Each of these systems have also

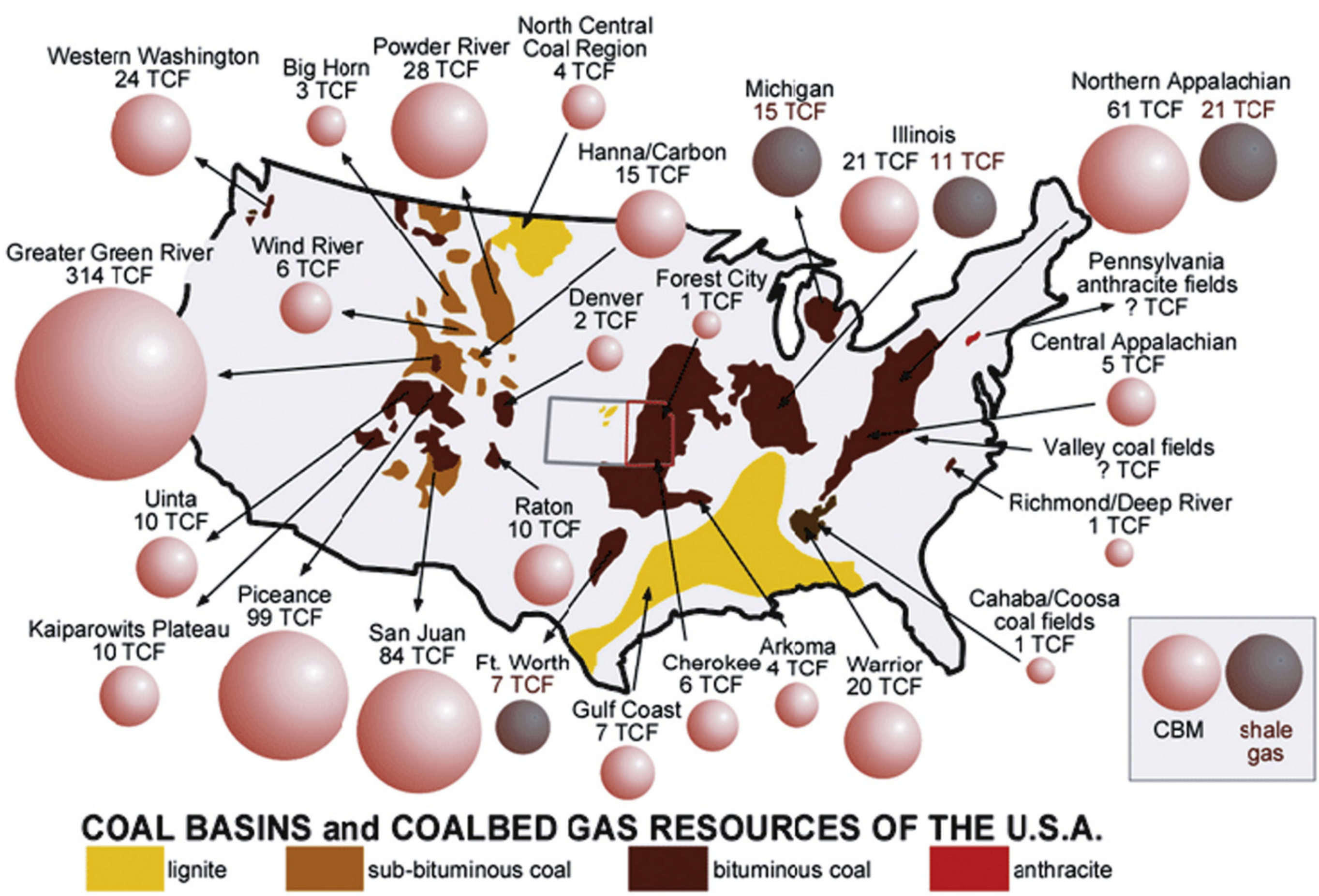


**Fig. 1.** Map of coalbed methane and fractured shale gas plays in U.S. sedimentary basins with estimates of gas-in-place (from Newell et al., 2004).