Hydrodynamic Control of Coalbed Methane Reservoir Performance in the Black Warrior Basin

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EXTENDED ABSTRACT

Coal is a continuous-type unconventional gas reservoir that is both the source rock and the reservoir rock. Adsorption is the dominant mechanism of gas storage, and gas is produced by reducing hydrostatic pressure through water production. Accordingly, coalbed methane is fundamentally a hydrologic gas play. The Black Warrior Basin of Alabama hosts one of the world's most-prolific and long-lived coalbed-methane plays, and the wealth of experience in this basin provides insight into the relationships among basin hydrology and production performance.

Coalbed methane is produced typically from 5 to 25 bituminous coal seams in the upper Pottsville Formation (Lower Pennsylvanian). Productive seams are dispersed through 600 to 1,400 m of section. Importantly, closely-spaced cleats (a miner's term for joints in coal) make coal the only rock type permeable enough to have significant reservoir properties. Pottsville strata are exposed in the eastern part of the basin and are overlain disconformably in the western coalbed-methane fields by as much as 250 m of weakly-consolidated Cretaceous strata of the Gulf of Mexico Basin. Structurally, the eastern part of the basin is an extensionally-faulted, southwest-dipping homocline. Folds in the frontal part of the Appalachian orogen are superimposed on the southwest-dipping homocline, and reservoir coal beds come to the surface along an upturned fold limb at the southeastern basin margin. This upturned basin margin is a major site of meteoric recharge that has a strong influence on the regional hydrogeology.

Recharge has resulted in the development of fresh-water plumes that extend from the southeast basin margin into the interior of the Black Warrior Basin. The plumes contain sodium-bicarbonate water, and northwest of the plumes, sodium-chloride water with low-to-moderate total-dissolved-solids content prevails. In the southwestern coalbed-methane fields, poorly-consolidated Cretaceous cover strata contain major aquifers that intercept meteoric recharge. In this area, Pottsville reservoirs can contain chloride-rich water with salinity higher than sea water.

Carbon isotopic data from produced gases and fracture-filling cements indicate that Pottsville coal contains a mixture of thermogenic gas generated during coalification and late-stage biogenic gas generated after coalification. These data suggest that late-stage bacterial methanogenesis was more active in coal than in other rock types. These data further help account for high gas saturation in many of the coalbed-methane fields because geologically-old basins that have been unroofed and cooled are typically undersaturated if only thermogenic gas was generated. Mapping isotopic data from cleat fills indicates that late-stage methanogenesis was most effective in the fresh-water plumes and less effective in saline formation waters below Cretaceous cover.

Hydrostatic pressure gradients tend to be normal as much as 20 km northwest of the upturned basin margin, suggesting support of reservoir pressure by recharge. However, deep subsurface coal mining has locally perturbed the hydrologic system, resulting

in areas of extreme underpressure. A bimodal pressure-depth plot indicates that Pottsville coalbed-methane reservoirs are compartmentalized, and the effects of compartmentalization are most readily apparent in the northwestern coalbed-methane fields, where pockets of free gas in fractures apparently facilitate natural underpressuring.

A strong relationship between hydrodynamics and production performance exists in the Black Warrior Basin. Water production values tend to be high in normally pressured areas near the southeast basin margin and below Cretaceous cover. In underpressured areas, by comparison, relatively small quantities of water are produced. Gas production values are highly variable throughout the coalbed-methane fields and tend to be low in reservoirs that are concealed below thick Cretaceous cover. Water production typically declines hyperbolically, which means that disposal of produced water is of greatest concern early in the life of most wells. The time required for wells to achieve peak gas production and to establish exponential decline is influenced primarily by gas saturation, water saturation, and increases of permeability related to shrinkage of the coal matrix as reservoir pressure is lowered and gas is produced. Accordingly, gas-undersaturated, water-wet reservoirs require patience because gas production may exhibit long-term incline while a large quantity of produced water needs to be managed. Conversely, economics tend to favor production from gas-saturated, water-depleted reservoirs because time to peak production and the amount of water to be disposed are minimal.