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Preliminary investigation of biogenic gas production in Indonesian low rank coals and implications for a renewable energy source

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ABSTRACT

Indonesia has abundant coal resources at depths suitable to contain substantial volumes of naturally occurring methane, which are currently being explored. Most Indonesian coals are thermally immature, but are composed of hydrogen-rich organic components that are presumed to make them excellent substrates for biogenic methane production. Gas isotope results from pilot wells in South Sumatra, reported in this study, are interpreted to indicate biogenic origins for the methane. Corresponding formation water samples were collected and incubated, and show the presence of indigenous microbial communities capable of producing methane from Indonesian and Australian coal. Although these results are only preliminary, they are promising and support the possibility of Indonesia developing bio renewable energy from coal seams.

1. Introduction

The depletion of oil as the main conventional source of energy in Indonesia, coupled with an increasing demand for energy, requires that the Government of Indonesia (GOI) seek an alternative energy other than oil and natural gas. Indonesia has significant coal resources and is also thought to have significant coal seam gas (CSG) resources. As such, CSG is an emerging unconventional energy resource in Indonesia, with a reported hypothetical resource of 453 Tcf (ARI, 2003; Stevens and Hadiyanto, 2004) spread over several major coal basins. Although there is no commercial exploitation to date, exploration for CSG in Indonesia has rapidly increased over the last 3 years, especially since the GOI set up new laws and regulations for CSG exploration and exploitation. The GOI has also prioritized the discovery and utilization of unconventional energy sources, including CSG.

Biogenic methane is produced by microbial degradation of the abundant organic matter in coal in the earliest stages of coalification and at low rank (Rice, 1993). As coal matures, different thermogenic gases are released starting in the lower rank subbituminous coals and peaking in the mid to low volatile rank coals. Geologically ancient biogenic methane may be retained in the coal (Rice, 1993), but recent studies (Ahmed and Smith, 2001; Faiz and Hendry, 2006; Flores et al., 2008; Kinnon et al., 2010; Klein et al., 2008) have determined that active groundwater systems have generated biogenic gas in recent geologic time (referred to as late stage biogenic gas). As coal is often a good aquifer, it provides a favorable environment for microbial activity and this late stage biogenic gas can be associated with any rank of coal (Ahmed and Smith, 2001; Faiz and Hendry, 2006; Rice, 1993; Strąpoć et al., 2011).

Coal has a complex structure and is not easily biodegraded to methane (Fakoussa and Hofrichter, 1999; Strąpoć et al., 2011). The methanogens are only able to convert simple carbon structures (Fig. 1); hence, the conversion of organic material to methane in coal involves a variety of microorganisms (a consortium) from bacteria and Archaea domains (Ferry and Kastead, 2007; Moore, 2012; Strąpoć et al., 2011). Methane in coal formation can be produced via carbon dioxide reduction (hydrogenotropic pathway), acetate fermentation (aceticlastic pathway) or via methylotrophic pathway (Ferry and Kastead, 2007; Gilcrease and Shurr, 2007; Strąpoć et al., 2011; Zinder, 1993).

Stable isotope analysis of carbon ($\delta^{13}C$) and hydrogen (δD) have been used to determine the origin of methane in coal, where compositions are expressed as ratios relative to analytical standards (Schoell, 1980; Whiticar, 1996; Whiticar et al., 1986). Methane of

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Table 1
Biogenic plays in several World Coal Basins.

Basin/area	Rank	Isotope signature ‰ (per mil)	Methanogenic pathway	Lab Proven vm/ctm	References
Bowen Basin Australia	Low volatile bituminous – High volatile bituminous (SB)	$\delta^{13}C_1$ = −23 to −78 (mixed origin) $\delta^{13}D_1$ = −207 to −215.8	CO_2 reduction	No	Faiz and Hendry (2006), Kinnon et al. (2010) and Smith and Pallasser (1996)
Surat Basin Australia	Sub bituminous – High volatile bituminous	$\delta^{13}C_1$ = −52 to −64 $\delta^{13}D_1$ = −220 to −200	CO_2 reduction, methylotrophy	vm, ctm	Draper and Boreham (2006) and Papendick et al. (2011)
Sydney Basin Australia	Low volatile bituminous – High volatile bituminous (SB)	$\delta^{13}C_1$ = −23‰ to −60‰ (mixed origin) $\delta^{13}D_1$ = −221 ± 17	CO_2 reduction	No	Faiz and Hendry (2006) and Smith and Pallasser (1996)
Gulf of Mexico USA	Sub bituminous to High volatile bituminous	$\delta^{13}C_1$ = −65.57 to −56.75 $\delta^{13}D_1$ = −220.7 to −181.6 $\delta^{13}C$–CO_2 = −29 to +18	CO_2 reduction	ctm	Jones et al. (2008) and Warwick et al. (2008)
Powder River USA	Lignite to Sub bituminous	$\delta^{13}C_1$ = −83 to −52 $\delta^{13}D_1$ = −327 to −283 $\delta^{13}C$–CO_2 = −23 to −22.4	CO_2 reduction Aceticlastic	vm, ctm	Flores et al. (2008), Green et al. (2008) and Ulrich and Bower (2008)
Southern Illinois Basin USA	Low volatile to high volatile bituminous	$\delta^{13}C_1$ = −66.5 to −56.8 $\delta^{13}D_1$ = −206 to −187 $\delta^{13}C$–CO_2 = −4.7 to +11.4	CO_2 reduction	vm	Strąpoć et al. (2007)
Forest City Basin, USA	High volatile bituminous A to C	$\delta^{13}C_1$ = −57.61 to 69.9 $\delta^{13}D_1$ = −224.2 to −217 $\delta^{13}C$–CO_2 = −1.6 to +6.8	CO_2 reduction Aceticlastic	vm	McIntosh et al. (2008)
Elk River Valley, British Columbia Canada	Lignite to sub bituminous	$\delta^{13}C_1$ = −65 to −51 $\delta^{13}D_1$ = −415 to −303	CO_2 reduction	vm, ctm	Aravena et al. (2003) and Penner et al. (2010))
Greymouth New Zealand	High volatile A bituminous	$\delta^{13}C_1$ = −59 to −63 $\delta^{13}D_1$ = −246 to −210	CO_2 reduction	No	Butland and Moore (2008)
Huntly coalfield New Zealand	Sub bituminous B to A	$\delta^{13}C_1$ = −67 to −65 $\delta^{13}D_1$ = −225 to −206	CO_2 reduction	No	Butland and Moore (2008) and Mares and Moore (2008)
Ohai coalfield New Zealand	Sub bituminous C to A	$\delta^{13}C_1$ = −58 $\delta^{13}D_1$ = −206	CO_2 reduction	No	Butland and Moore (2008)
Upper Silesian coal basin, Poland	Bituminous	$\delta^{13}C_1$ = −74 to −67 $\delta^{13}D_1$ = −202 to −170 $\delta^{13}C$–CO_2 = −27 to −13	CO_2 reduction	No	Kotarba and Pluta (2009)
Xinji, Anhui China	Bituminous	$\delta^{13}C_1$ = −61.3 to −54.7 $\delta^{13}D_1$ = −243 to −219	na	No	Tao et al. (2007)
Jharia Basin India	Sub bituminous	na	CO_2 reduction	vm, ctm	Singh et al. (2012)
South Sumatra basin	Lignite to Sub bituminous	$\delta^{13}C_1$ = −63 to −53 $\delta^{13}D_1$ = −213 to −191 $\delta^{13}C$–CO_2 = −28.4 to −5.4	CO_2 reduction, Aceticlastic	vm, ctm	Fallgren et al. (2013) and Susilawati et al. (2012)

vm = viable methanogen consortia, ctm = viable coal to methane consortia; na = data not available

biogenic origin is typically depleted in ^{13}C compared to methane of thermogenic origin (Rice et al., 1993; Whiticar, 1996). The combination of carbon ($\delta^{13}C$) and hydrogen (δD) isotopes can also be used to distinguish these methanogenic pathways as the extent of deuterium enrichment depends on the metabolic pathway involved (summarized in Golding et al. (2013) and Whiticar (1999)).

Recent isotopic and culture studies have revealed that methanogenic microbial consortia are still present in a number of biogenic CSG reservoirs (McIntosh et al., 2008; Papendick et al., 2011; Penner et al., 2010; Singh et al., 2012; Strąpoć et al., 2008), with some of them proven to have the ability to biodegrade coal and produce methane (Table 1). With appropriate growth conditions, these methanogenic consortia can be stimulated to generate significant quantities of methane over a relatively short time period (Gilcrease and Shurr, 2007; Green et al., 2008; Jones et al., 2008; Liu, 2012; Papendick et al., 2011; Scott, 1999; Singh et al., 2012). Microbial methane can even be produced from enrichment of lignite and its formation water for which there is no previous history of gas production (Fallgren et al., 2013). These authors noted that Indonesian lignite yields the highest methane production rate as well as the highest enumeration of total bacteria and methanogens compared to lignite from China and Australia. These studies support the suggestion by Susilawati et al. (2012) that microbially enhanced CSG holds great promise for the future, for generating a renewable source of natural gas across a range of coals not previously thought of as CSG reservoir targets. Ongoing research and experiments to explore the application of microbial enhancement of CSG are being conducted globally, with techniques being patented in the USA and New Zealand (IEA, 2010).

Indonesian coals are typically low rank (commonly lignite to subbituminous, but with some higher ranks), rich in moisture, and composed of hydrogen-rich organic components (liptinite and per-hydrous vitrinite) (Belkin et al., 2009; Daulay and Cook, 1988; Hutton et al., 1994; Stankiewicz et al., 1996) which is thought to make them excellent candidates for biogenic methane production. Additionally, the chemical structure of low rank coal,