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Microbial controls on the origin and evolution of coal seam gases and production waters of the Walloon Subgroup; Surat Basin, Australia

K.A. Baublys [a,*], S.K. Hamilton [a], S.D. Golding [a], S. Vink [b], J. Esterle [a]

[a] School of Earth Sciences, The University of Queensland, QLD 4072, Australia
[b] Sustainable Minerals Institute, The University of Queensland, QLD 4072, Australia

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ABSTRACT

The Walloon Subgroup coal seam gas (CSG) play in the Surat Basin, Queensland, is Australia's pre-eminent onshore gas field. Concerted multi-disciplinary research is underway investigating the distribution, origin and composition of waters and gases in this dominantly microbial CSG reservoir, to guide both continued production and potential microbially enhanced coal bed methane (MECoM) applications. However, prior to the present research, a detailed study of co-produced waters and gases from across the Surat Basin was not available in the public domain. This study tested whether co-produced water compositional and stable isotopic data show relationships with production gas stable isotope compositions, to elucidate further evidence for microbial CO_2 reduction and explore the down-dip geochemical evolution of Walloon coal bed waters and gases. A total of 41 wells were sampled with 50 water and 25 gas samples spanning the 3 major production areas of the Surat Basin. Detailed isotopic and hydrochemical analysis of these samples revealed distinct spatial trends between the different production locales. Water compositions were distinct for each of the production regions reflecting the different lithologies of adjacent recharge zones, differing fluid–rock interactions, likely different microbial consortia, and the extent of methanogenesis. On the western side of the basin near Roma, waters were the 'freshest' with the lowest median values for alkalinity (861 mg/L), and Cl^- (588 mg/L) and a $\delta^{13}C_{DIC}$ of 14.2‰. On the eastern side of the basin, the Kogan Nose waters were the most saline with the highest median values for Na^+ (1955 mg/L), Cl^- (2280 mg/L) and $\delta^{13}C_{DIC}$ (20.0‰). Also in the east, in the present gas fairway, the Undulla Nose waters had the highest median alkalinity (1841 mg/L) and were found to have a Na^+ excess (median = 1050 mg/L) and a lower than expected median $\delta^{13}C_{DIC}$ (14.0‰). Co-mingled, produced methane carbon isotope values ($\delta^{13}C$ −57.0‰ to −44.5‰) from both the upper (Juandah) and lower (Taroom) coal measures plot within the mixed 'thermogenic/microbial' genetic field. By contrast, deuterium isotopic difference [$\Delta^2H(H_2O–CH_4)$] values and cross-plots of $\delta^2H–H_2O$ and $\delta^{18}O–H_2O$ suggest that microbially mediated CO_2 reduction is the dominant methane generation process in situ. At a given depth, the Undulla Nose waters in the east are more depleted in ^2H and ^{18}O than elsewhere in the Surat Basin, which may suggest these samples have been more heavily impacted by water–rock–microbial reactions. ^{14}C values from the 3 production regions (0.115 to 1.769 pmC; age: 32,400 to >50,000 years before present (B.P.)) suggest that Walloon coals likely recharged in the last ~50,000 years (limit of radiocarbon dating). Consistent with these dates, $\delta^2H–H_2O$ and $\delta^{18}O–H_2O$ values for the Surat Basin (δ^2H −32‰ to −56‰, $\delta^{18}O$ −5.9‰ to −9.0‰) echo the stable isotopic composition of meteoric waters during the initial part of the last glacial period in southeast Queensland. Based on a strong correlation between $\delta^2H–CH_4$ and $\delta^2H–H_2O$, we suggest that methane was generated since the Late Pleistocene. PCA analysis showed a degree of positive correlation between total alkalinity and both the $\delta^{13}C_{DIC}$ (median 14.2‰) and $\delta^{13}C–CH_4$ (median −52.1‰) vectors that is consistent with finite reservoir effects. The results inform ongoing studies of gas distribution and origins and MECoM potential in the Surat Basin, and underpin a broader study examining aquifer interactions.

1. Introduction

Coal seam gas (CSG) exploration is tapering in the Surat Basin, as the production phase ramps up to meet LNG export demand. As of 2014 there are >4000 CSG wells in the Surat Basin, each needing to be dewatered before production and producing water throughout its lifetime (Geological Survey of Queensland, 2014). The Surat Basin is one of the three basins comprising the Mesozoic Great Artesian Basin (GAB) of eastern Australia (Figs. 1, 2). The GAB is the major water source for agriculture and potable supplies to townships in semi-arid, regional Queensland. Surat CSG is produced from the Middle Jurassic Walloon

* Corresponding author.
E-mail address: k.baublys@uq.edu.au (K.A. Baublys).

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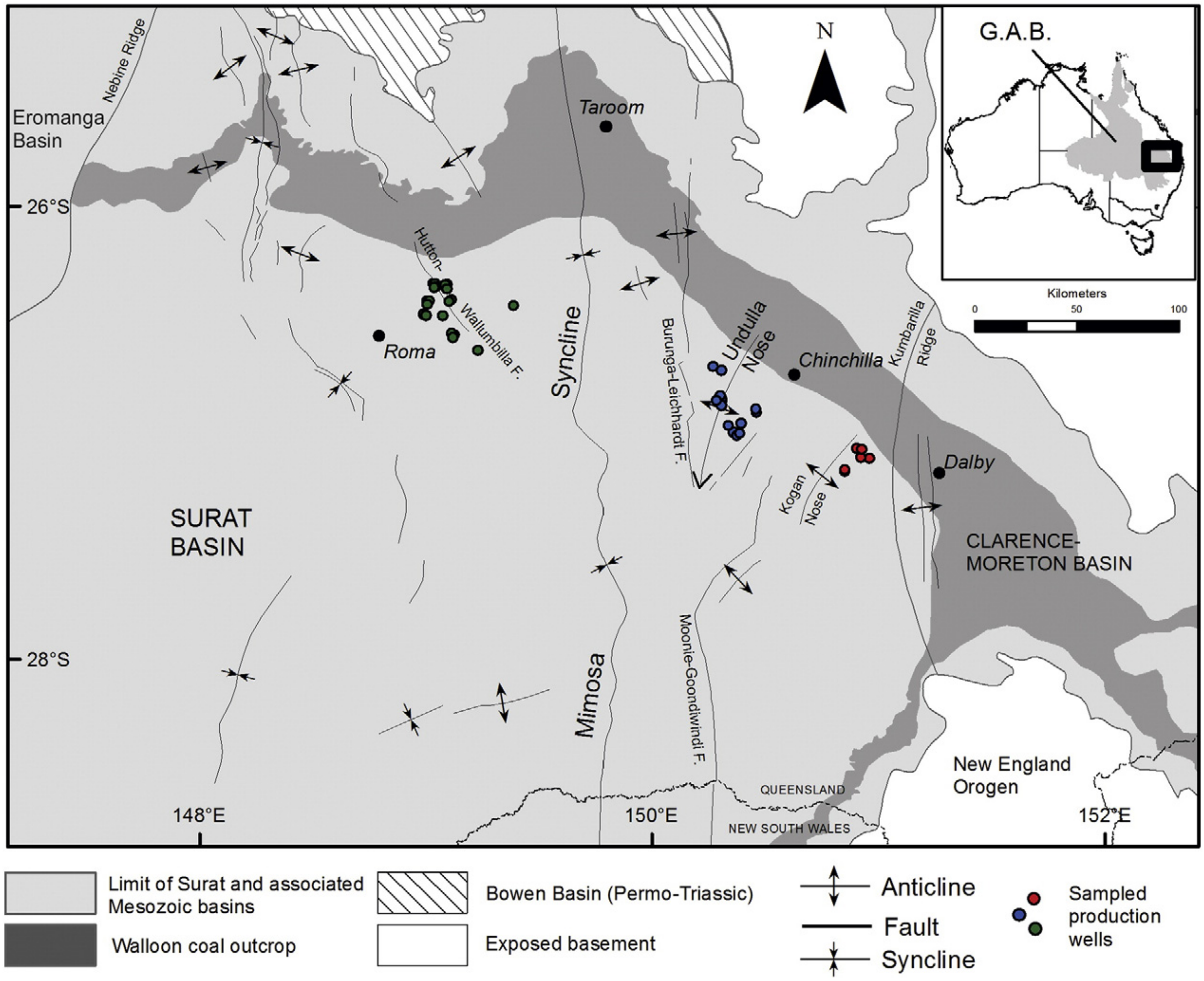

Fig. 1. (a) Structural elements map of the study area, showing the locations of co-produced Walloon water and gas samples collected for this study from CSG wells in the Surat Basin, and Walloon coal outcrop/subcrop (dark grey shading). Structure modified from Day et al. (2008) and Geological Survey of Queensland (2011). Inset: Location of the study area within Australia and the Great Artesian Basin (G.A.B.).

Subgroup, which separates two regional GAB aquifers: the underlying Hutton Sandstone (Early–Middle Jurassic) and the overlying Springbok Sandstone (Late Jurassic) (Figs. 3, 4). Detailed geochemical studies of Walloon Subgroup waters and associated coal bed gases are essential for understanding gas generation, groundwater evolution, recharge and flowpaths, inter-aquifer connectivity, and considering the effects of long-term drawdown on surrounding aquifers. Moreover, there is need for a better understanding of lateral coal bed continuity and the coherence of the aquifer system, i.e. the relative importance of local versus regional GAB hydrology in determining gas and water characteristics.

This paper presents and interprets a regional database of new geochemical and isotopic data for paired CSG production water and gas samples from the Walloon Subgroup in the Surat Basin. The aims of this paper are to: (1) investigate the geochemical evolution of Walloon coal bed waters and gases along groundwater flowpaths; (2) test whether co-produced water compositional and stable isotopic data show relationships with gas stable isotopes, to elucidate further evidence for microbial CO_2 reduction (cf. Hamilton et al., 2014a; Papendick et al., 2011); (3) combine these data with age and tracer (^{14}C and $\delta^{13}C_{DIC}$) information, to constrain the timing of microbial methane generation and assist hypothesis testing for one or more phases of gas generation; and (4) compare these findings with previous results of Walloon and major unconventional microbial gas reservoir studies elsewhere.

Isotopic and geochemical analyses were performed on a suite of paired CSG gases and waters from the 3 main gas-producing regions of the Surat Basin in Queensland: the Roma region in the west, the Undulla Nose in the east and the Kogan Nose in the southeast (Fig. 1). Stable isotopes of hydrogen, carbon and oxygen can be used to identify production water sources and evolution processes such as mixing and water–rock interaction. Carbon and hydrogen stable isotope determination of the methane and carbon dioxide components in CSG can be used to identify its biogeochemical origins (Golding et al., 2013a,b; Strąpoć et al., 2007, 2008; Whiticar, 1999). Major and trace ion water geochemistry also provide information on water–rock interaction, as well as biogeochemical reactions, recharge, flow regimes and possible water sources (e.g. Cheung et al., 2010; Stueber and Walter, 1991). In this paper, combinations of these parameters are compared with apparent groundwater ages to investigate groundwater evolution, and the timing, controls and pathways of microbial methanogenesis (e.g. Bates et al., 2011; Flores et al., 2008; Golding et al., 2013a; Schlegel et al., 2011).

1.1. Nature of groundwater and gases

1.1.1. CSG associated groundwater

CSG waters have a distinctive character with high concentrations of Na^+ and either HCO_3^- and Cl^- or both, depending on the mineralogy of the host rock as a function of the provenance and depositional