



Hydrogeological Controls on Coalbed Methane Accumulation in Eastern Surat Basin, Australia

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Abstract. The Middle Jurassic Walloon Coal Measures (CM) is a prolific, low-rank coalbed methane (CBM) resource in the Surat Basin, Australia. Depositional environment, structural background, coal quality, and hydrogeology have been identified as determining CBM accumulation. It is the basis for the evaluation and optimization of CBM favorable areas to clarify the main controlling factors of CBM accumulation. Taking the eastern Surat Basin in Australia as an example, based on clarifying the geological characteristics of CBM, the gas content versus depth profiles of 88 CBM core wells revealed the gas content changes in the eastern Surat Basin. Within individual wells, gas content either increases; increases, then decreases; or decreases with depth as the result of the variable coring intervals. The gas content maxima coincides with the Tangalooma Sandstone, regardless of depth, which is mainly controlled by the secondary biogenic recharge from above Tangalooma sandstone. It is proposed that hydrogeological conditions are the main controlling factors of gas content distribution and CBM accumulation in the eastern Surat Basin, mainly including groundwater hydrodynamic conditions and surface water system. In terms of groundwater hydrodynamics, from the eastern edge to the center of the Surat Basin, the degree of salinity gradually increased, the anion content of groundwater changed from mainly HCO_3^- to mainly Cl^- , and the hydrodynamic region was changed from strong runoff zone, medium runoff zone to a weak runoff-retention zone; the favorable water type for CBM accumulation in Walloon CM is mainly $\text{Cl}\cdot\text{HCO}_3\text{-Na}$ type, which is a weak runoff-pressured zone hydrodynamically. In terms of surface water system, the relationship between the direction of surface water runoff and the formation tendency in the eastern Surat Basin controls CBM accumulation. When the direction of runoff is consistent with the formation tendency, the formation is overpressured or hydrodynamically blocked, indicating favorable accumulation conditions, and the direction of water flow is conducive to the methanogen-producing bacteria to carry into the coal seam, thereby generating biogas and increasing the gas content. When the direction of surface water runoff is opposite to the formation tendency, the formation underpressure or hydrodynamic erosion will cause the loss of CBM, indicating unfavorable accumulation conditions, and it is not conducive to the introduction of methanogenic bacteria, thus, there is no biogas supply.

Keywords: Surat Basin · Coalbed Methane · Hydrogeology · Gas content · Accumulation

1 Introduction

CBM exploration and development practice shows that the distribution characteristics of CBM are different in different types of coal-accumulating basins, different structural units in the same basin, and even different coal-measure strata in the same structural unit [1]. The accumulation of CBM is affected by multiple factors, and directly relates to the feasibility and economical efficiency of CBM exploration and development [2, 3]. It is the basis for the evaluation and optimization of CBM favorable areas and also the key to opening the door to the commercial development of CBM to clarify the main controlling factors of CBM accumulation and the high production and accumulation law of CBM [4, 5]. The geological factors that control the gas content of coal seams can be summarized as follows: (1) Depositional environment; (2) Structural background; (3) Coal quality related to gas content, including coal rank, coal type, mineral content, moisture, volatile content, ash content and macerals; (4) Hydrogeological characteristics, including hydrochemical analysis, surface water system, gas isotope, reservoir temperature, reservoir pressure, burial and charging history, fracture development, hydraulic gradient, and sealing property of overlying strata [6–11]. Taking the eastern Surat Basin in Australia as an example, based on the analysis of the above-mentioned main controlling factors, this paper reveals the distribution trend of gas content in the eastern Surat Basin, mainly analyzes the hydrogeological conditions in the eastern Surat Basin, and discusses the control effects of groundwater type, hydrodynamic conditions, and surface water system on CBM accumulation in the research area, thereby providing a reference for similar CBM reservoirs at home and abroad.

2 Geological Characteristics

2.1 Structural Background

The main body of Bowen Basin and Surat Basin is located in Queensland, Australia, and extends south to northern New South Wales [12] (Fig. 1). Bowen Basin is the northernmost part of the Bowen-Gunnedah-Sydney Basin Group, and has a length of about 1100 km, a maximum width of 300 km, and a total area of about 15×10^4 km². Surat Basin structurally inherits the underlying Bowen Basin, and the evolution of Surat Basin began in the Early Jurassic [13]. Surat Basin, located in the southeast of Queensland and the northeast of New South Wales, is an intracratonic depression basin with an area of about 30×10^4 km². The basin is mainly composed of Jurassic and Cretaceous deposits, and the coal seams are mainly developed in the Jurassic Walloon Subgroup. The Jurassic in the Surat Basin disconformably covers the Carboniferous-Permian to Triassic in the Bowen Basin.

The structural background of a coal-bearing basin not only directly controls its nature, forming and evolution characteristics, but also determines the thickness, distribution, and coal quality of coal seams. Moreover, the subsidence or uplifting of the coal-bearing basin basement caused by tectonic activities directly controls the deposition and burial of coal measures, thermal metamorphism (coalification), and the generation, preservation and dissipation of organic matter [14]. The nature of the coal-bearing basin basement and the

location of the tectonic structure are of much significance to the forming, accumulation, exploration and development of CBM.

The Bowen-Surat Basin in Australia is adjacent to the subduction zone of the Pacific Plate in the east, and is controlled by the New England structural belt and the Thomson structural belt [15–18]. The formation of the Bowen Basin began in the Devonian and can be divided into four evolution stages: ① Basement forming period (Devonian → the early stage of Early Permian); ② Synrift period (the early stage of Early Permian → the late stage of Early Permian); ③ Early thermal subsidence period (the late stage of Early Permian); ④ Foreland filling period (Late Permian → Middle Triassic). The CM strata in the Bowen Basin were formed in the foreland filling period. The evolution of the Surat Basin began after the uplifting and denudation of the Bowen Basin in the Late Triassic and can be divided into three stages: ① Early thermal subsidence period (Early Jurassic → Late Jurassic); ② Late thermal subsidence period (the early stage of Early Cretaceous → the middle stage of Early Cretaceous); ③ Flexural deformation period (the middle stage of Early Cretaceous → the early stage of Late Cretaceous). The CM strata in the Surat Basin were developed in the middle stage of the early thermal subsidence period.

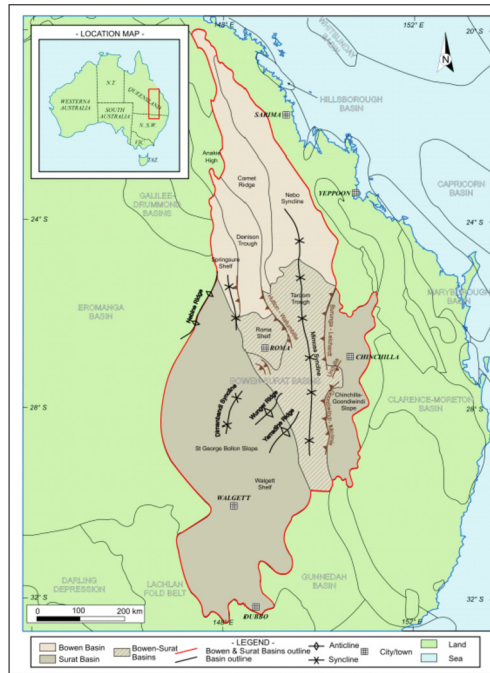


Fig. 1. Structural map of Bowen-Surat Basin (IHS, 2009).

2.2 Stratigraphic Characteristics

From the Early Permian to the Early Cretaceous, the Bowen-Surat Basin continued to deposit by up to 2500 m, and developed 5 cycles dominated by lacustrine deposits.

Due to the relatively stable structure, the structural characteristics such as gentle west and steep east have been maintained since the Early Jurassic [19, 20]. The Jurassic Walloon Subgroup has the characteristics such as gentle west and north and steep east, and outcrops on land surface in the north wing and east edge of the basin. The CBM of the Surat Basin is explored and developed mainly in its east.

The Jurassic coal in the Surat Basin was formed in the Walloon Subgroup of the Injune Creek Group of the Middle Jurassic dominated by fluvial-lacustrine deposits. The Wallon Subgroup develops Juandah CM, Tanglooma sandstone, Taroom CM and Eurmbah formation. The Juandah CM is subdivided into coal seams such as Kogan, Maclister, Wambo, Argyle, etc., and the Taroom CM is subdivided into coal seams such as Upper Taroom, Condamine, etc. The frequent migration of river channels during the deposition of coal seams in the Surat Basin led to the complex structure of the coal seams in the Walloon Subgroup, where bifurcation, pinch-out and merge of coal seams are common [21, 22].

Juandah CM. The Kogan coal seam is located at the top of the Juandah CM, usually contains 1–3 thin coal seams, gray massive to thin-bedded siltstone and gray sandstone, and has an average formation thickness of 35 m. Denudation is common in the coal seam, and it is covered with Springbok sandstone or Paleogene alluvial deposits. The Macalister coal seam usually contains 1–2 well-developed coal seams, with a high coal-to-strata ratio and multiple branches, and is subject to denudation in some areas. The Wambo coal seam is usually a thin coal seam with poor continuity, and has an average formation thickness of 55 m and a larger mudstone proportion than the overlying Macalister coal seam. The Argyle coal seam usually contains 1–2 main coal seams, and is sandwiched with thin coal and mudstone. The bottom of the Argyle coal seam is of gradual transition to Tangalooa sandstone, and the coal seam has an average formation thickness of 66 m.

Tangalooa Sandstone. The Tangalooa sandstone is widely developed in the west of the basin, and has a thickness of up to 100 m, in the west of the eastern edge of the basin. The Tangalooa sandstone in the development block has poor continuity, and mainly shows a sandstone lenticle form.

Taroom CM. The Taroom CM includes Upper Taroom and Condamine coal seams and has an average formation thickness of 121 m. Alternately thick and thin coal seams are common in the Upper Taroom coal seam, which has similar distribution law to the Argyle coal seam. The single-layer thickness of the Condamine coal seam can reach 10 m, and its distribution is stable on the eastern edge of the basin.

2.3 Basic Characteristics of Coal Reservoirs

The thickness of coal reservoirs is the material basis for determining CBM resources/reserves. Especially for low coal rank areas, thick coal seams can make up for the shortcoming of low gas content, and is conducive to the commercial development of CBM [23, 24]. The coal seams characterized by continuous planar distribution, stable thickness, and less bifurcation or pinch-out are favorable for the accumulation and development of CBM. The thickness of coal reservoirs is usually determined by logging

interpretation. The thickness of a single coal seam in the eastern Surat Basin is 2 m–4 m, and the cumulative thickness of coal seams is larger than 17 m.

The Ro of coal in the eastern Surat Basin is 0.6%, which belongs to low-rank coal. The pore structure is dominated by mesopores and macropores, and develops cleat fractures, which are in a relatively weak stress environment and effectively connect the gas in the pores, so the coal permeability is relatively high and generally 40 mD–300 mD.

The macerals of the coal in the eastern Surat Basin varies greatly, the vitrinite content is 7.7%–96.5% (averagely 42%), the exinite content is 0–42.4% (averagely 13.4%), the inertinite content is 0–21.8% (averagely 1.7%), and the content of mineral components is 3.5%–89% (averagely 42.8%).

2.4 Hydrogeological Characteristics

Groundwater System. The eastern Surat Basin contains both confined aquifers and unconfined aquifers, and the formation intervals with low permeability are usually identified as weak aquifers or aquifuges. The main aquifers are Condamine alluvial aquifer, Gubbemunda sandstone aquifer, Springbok sandstone aquifer, Walloon CM aquifer, Hutton sandstone aquifer and Precipice sandstone aquifer (Table 1).

These aquifers can be further divided into four types. ① Shallow groundwater system: Quaternary unconfined or phreatic aquifers, including Condamine alluvial aquifer; ② Middle groundwater system: confined aquifers above coal measures, including Gubbemunda sandstone aquifer and Springbok sandstone aquifer; ③ Coal seam groundwater system: CM confined aquifers, including Walloon CM aquifer, usually with low permeability and poor water quality; ④ Deep groundwater system: pore-type confined aquifers below coal measures, including Hutton sandstone aquifer and Precipice sandstone aquifer.

Affected by the aquifuge between different aquifers, the groundwater flow in the eastern Surat Basin is mainly the intralayer flow in aquifers, and interlayer flow occurs only in areas where aquifers are directly in contact or aquifuges are thin.

Table 1. Groundwater system in eastern Surat Basin.

Groundwater system	Formation	Aquifer or aquifuge	Horizontal hydraulic conductivity (m/d)	Vertical hydraulic conductivity: horizontal hydraulic conductivity	Unit water storage capacity (m^{-1})
Shallow groundwater	Condamine alluvia	Unconfined aquifer	5 (0.01–>30)	1:10	0.05 ($0.04-5 \times 10^{-6}$)
Middle groundwater system	Gubbemunda sandstone	Confined/unconfined aquifer	0.5 (0.1–5)	1:10	5×10^{-6} ($1 \times 10^{-4}-\times 10^{-7}$)

(continued)

Table 1. (continued)

Groundwater system	Formation	Aquifer or aquifuge	Horizontal hydraulic conductivity (m/d)	Vertical hydraulic conductivity: horizontal hydraulic conductivity	Unit water storage capacity (m^{-1})
	Westbourne Formation	Aquifuge	0.001	1:100	5×10^{-6}
	Springbok sandstone	Confined/ unconfined aquifer	0.5	1:10	5×10^{-6}
CM groundwater	Juandah CM	Confined aquifer	0.001 (0.0001–1)	1:100	5×10^{-6} (6×10^{-5} – 6×10^{-7})
	Tangalooma CM		0.1	1:50	5×10^{-6}
	Taroom CM		0.001 (0.0001–1)	1:100	5×10^{-6}
Deep groundwater system	Eurombah Formation	Aquifuge	0.05 (0.03–0.14)	1:50	5×10^{-6}
	Hutton sandstone	Confined aquifer	0.1 (0.05–1.25)	1:50	5×10^{-6} (3×10^{-5} – 1×10^{-6})
	Evergreen Formation	Aquifuge	0.001 (0.008)	1:100	5×10^{-6}
	Precipice sandstone	Confined aquifer	1 (0.1–4)	1:10	5×10^{-6} (5×10^{-6} – 1×10^{-7})

The water content characteristics of the Walloon CM vary greatly, the permeability is low, and the water quality in some areas is relatively poor. On the whole, the aquifers are confined aquifers, including Juandah CM aquifer, Tangalooma sandstone aquifer and Taroom coal group aquifer.

In general, the eastern Surat Basin is relatively simple in structure, each CM aquifer of the Walloon CM is a confined aquifer, and the aquifers are mutually blocked by mudstones, showing good CBM drainage and pressure reduction conditions.

Surface Water System. The current surface hydrogeological units in the eastern Surat Basin include three major river systems: ① The Dawson river system in the north, flowing to the northwest; ② The Condamine river system in the middle, flowing to the southwest; ③ The Moonie-Macintyre-Weir river system in the south, flowing to the southwest (Fig. 2) [25].

The outcrop area of the Walloon CM is distributed along the eastern Surat Basin in a NW-SE strike direction, and has a width of about 30 km. The outcrop area passes through the three major surface river systems. The flow direction of most rivers is perpendicular to the strike direction of the outcrop area, but the main channel of the Condamine River runs from Dalby to the Chinchilla drainage basin, and the flow direction of the river is parallel to the strike direction of the outcrop area of the Walloon CM.

The current surface river system in the eastern Surat Basin has a long contact distance and a large contact area with the outcrop area of the Walloon CM. Therefore, the surface river system will become an important source of surface water recharge for the Walloon CM aquifer, and is of much significance to CBM accumulation in the Walloon CM.

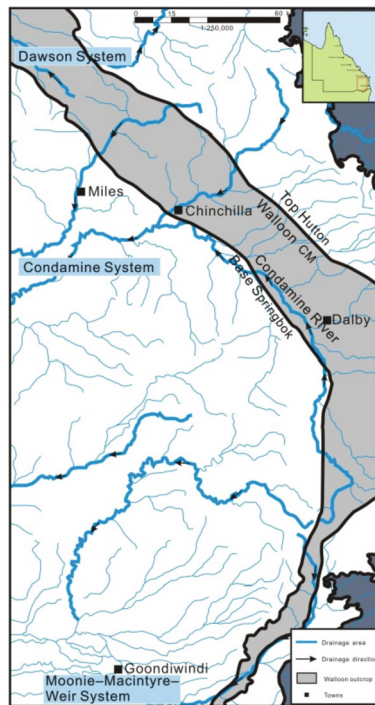


Fig. 2. Surface hydrogeological region in eastern Surat Basin [25].

3 Analysis of Gas Content Variation Trends in the Eastern Surat Basin

Within the scope of the basin, the gas content tends to increase and then decrease with the burial depth (Fig. 3). When the burial depth in the eastern Surat Basin is less than 100 m, the gas content is generally $<1 \text{ m}^3/\text{t}$; when the burial depth in the Bowen Basin is less than 100 m, the gas content is generally $<3 \text{ m}^3/\text{t}$.

The gas content analysis of 88 individual CBM wells in the eastern Surat Basin shows that the gas content versus depth trends for individual wells can be summarized into three types: trend 1: the gas content increases with the increasing depth (in line with 19 wells); trend 2: the gas content increases and then decreases with the increasing depth (in line with 61 wells); trend 3: the gas content decreases with the increasing depth (in line with 8 wells); Trend 2 predominates (Fig. 4). According to the comparison with the data of the coal seams, the depth range of the inflection point of the gas content change in trend 2 is mainly 300 m–600 m, which is basically consistent with the depth of the Tangalooma sandstone sandwiched between the two major coal measures.

The average gas content of the coal measures in the eastern Surat Basin (raw coal base, dry ash-free base) also tends to increase and then decrease with depth, and reaches the maximum near the Tangalooma sandstone (Fig. 5). The raw coal base gas content is negatively correlated with the ash content of coal seams. The Taroom CM has a high ash content (31% on average), and its average gas content is lower than that of the Condamine CM with low ash content (26% on average). There is a certain correlation between the macerals of coal and the gas content of coal seams. The dry ash-free base gas content is positively correlated with the vitrinite content and exinite content. The relationship between the vitrinite content of the Kogan coal seam and its average gas content is abnormal, which may be caused by data statistics errors (Fig. 6).

The main controlling factor for the inflection point of the gas content in the eastern Surat Basin may be the secondary biogenic recharge from above Tangalooma sandstone.

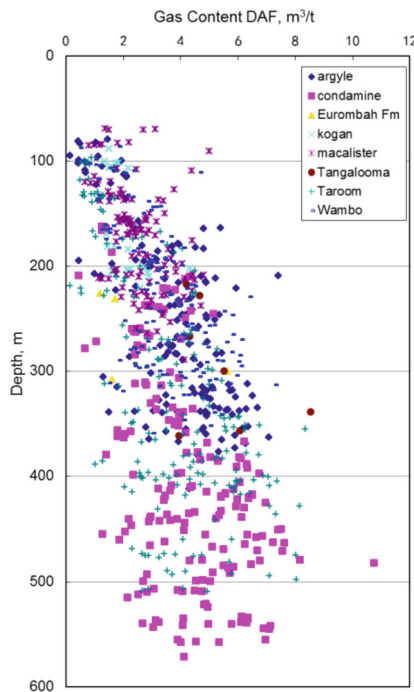


Fig. 3. Relationship between dry ash-free gas content and depth in eastern Surat Basin

The analysis shows that the wells where the gas content changes have inflection points are generally located near the outcrop area with active surface water, and are often in a weak hydrodynamic runoff zone. Coal seams with high permeability easily form a water-conducting system, which is conducive to carrying-in of methanogenic bacteria. The permeability of the Juandah CM is higher than that of the Taroom CM, so the upper coal seam is more conducive to the survival of methanogenic bacteria. The isotopic analysis of produced gas from the CBM production wells in this area has confirmed the existence of biogenic gas. The $\delta^{13}C_{CH_4}$ of the produced gas is $-57.3\text{‰} \sim -54.2\text{‰}$, showing typical biogas characteristics, which can be judged as multi-genetic gas according to δD_{CH_4} .

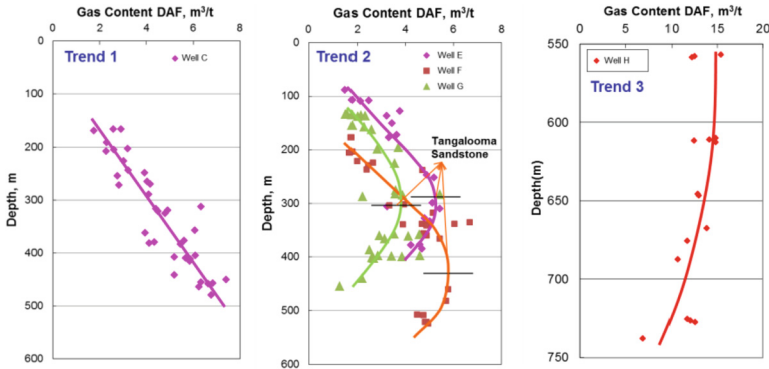


Fig. 4. Gas content versus depth trends for individual wells

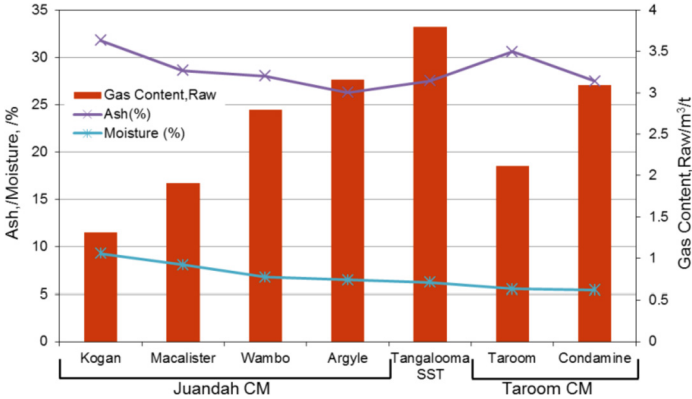


Fig. 5. Relationship between average gas content (raw base) and moisture and ash content of different coal seams in eastern Surat Basin

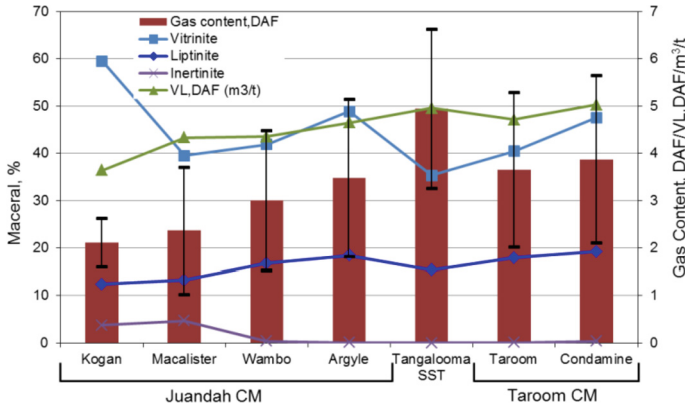


Fig. 6. Relationship between average gas content (dry ash free) and macerals of different coal seams in eastern Surat Basin

4 Hydrogeological Controls on CBM Accumulation in the Eastern Surat Basin

Hydrogeological conditions are the main controlling factors of gas content distribution and CBM accumulation in the eastern Surat Basin, mainly including groundwater hydrodynamic conditions and surface water system.

4.1 Accumulation Control Effect of Groundwater Hydrodynamic Conditions

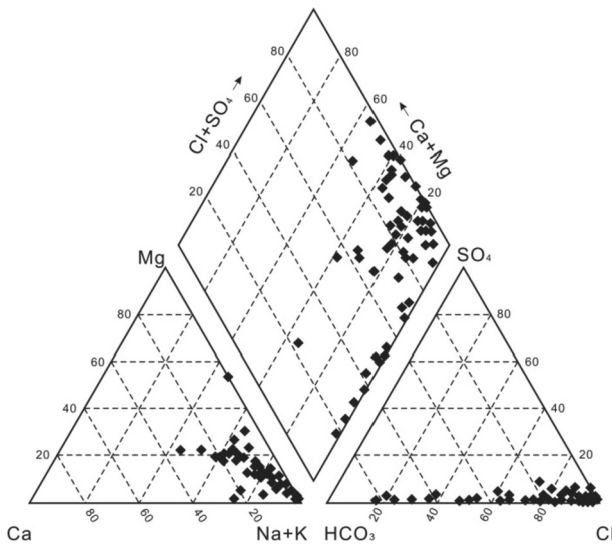
Hydrogeological conditions play a key role in the accumulation of low rank CBM. Appropriate hydrodynamic conditions easily form hydrodynamic blockage, which is conducive to the preservation of CBM. Moreover, under certain conditions of temperature, pressure and groundwater salinity, secondary biogas can be generated as a supplement to gas content. Strong hydrodynamic conditions easily lead to the loss of CBM and are unfavorable for CBM accumulation.

Based on the study of water quality in six major CBM basins in the United States, Van Voast (2003) proposed that the geochemical characteristics of formation water related to biogenic CBM mainly include extremely low sulfate concentration (less than 500 mg/L), low calcium/magnesium concentration, and high concentrations of sodium, bicarbonate and chloride [26]. The groundwater of the Walloon CM in the eastern Surat Basin has the geochemical characteristics of generating secondary biogas.

The groundwater chemical analysis data indicate that there are differences in groundwater quality in the Walloon CM in the eastern Surat Basin (Table 2, Fig. 7). The heterogeneity, chemical evolution and mineral dissolution in an aquifer, as well as the differences in the recharge amount and evaporation amount in the surface recharge areas, lead to different chemical properties of groundwater in different spatial locations of the same aquifer. The groundwater of the Walloon CM in the eastern Surat Basin mainly belongs to HCO₃—Na type and Cl—Na type, is generally weakly alkaline, and has a pH value of 7.1–11.4 in general and 8.1 on average. The conductivity of the groundwater

Table 2. Summary of groundwater quality in the Walloon CM in eastern Surat Basin

Parameter	Unit	Min.	Max.	Avg.	Statistics
pH value		7.1	11.4	8.1	63
Electric conductivity	$\mu\text{S/cm}$	830	31,000	7,223	61
Total dissolved concentration	mg/L	534	20,150	4,694	61
Ca	mg/L	4	1,160	136	67
Mg	mg/L	2	850	113	66
Na	mg/L	135	6,950	1,420	67
Cl	mg/L	65	12,770	2,280	67
HCO ₃	mg/L	5.2	1,980	561	65
SO ₄	mg/L	0	355	43	63

**Fig. 7.** Diagram of ion content of Walloon CM in eastern Surat Basin

varies greatly, and ranges from 830 to 31,000 $\mu\text{S/cm}$, indicating that the groundwater of the Walloon CM includes both fresh water and salt water (its salinity close to that of sea water). The cations are mainly Na^+ , with a concentration of 135–6950 mg/L in general and 1420 mg/L on average; the anions are mainly HCO_3^- and Cl^- , the concentration of HCO_3^- is 5.2–1980 mg/L in general and 561 mg/L on average, and the concentration of Cl^- is 65–12770 mg/L in general and 2280 mg/L on average.

The gas content of coal seams in the eastern Surat Basin is controlled by biogas recharge, and the salinity of formation water affects the generation of secondary biogas. From the eastern edge to the center of the Surat Basin, the degree of salinity gradually

increased, the anion content of groundwater changed from mainly HCO_3^- to mainly Cl^- (Fig. 8), and the hydrodynamic region was changed from strong runoff zone, medium runoff zone to a weak runoff-retention zone. The anions in the Walloon CM in the eastern basin are mainly HCO_3^- and Cl^- , and the water type is $\text{Cl}\cdot\text{HCO}_3\text{—Na}$ type, showing a weak runoff-pressured zone hydrodynamically and good CBM preservation conditions. Moreover, due to the input of methanogenic bacteria within the window of 300–500 m burial depth, a large amount of secondary biogas was generated, effectively recharging the gas content and causing the gas content to increase and then decrease with the increasing depth.

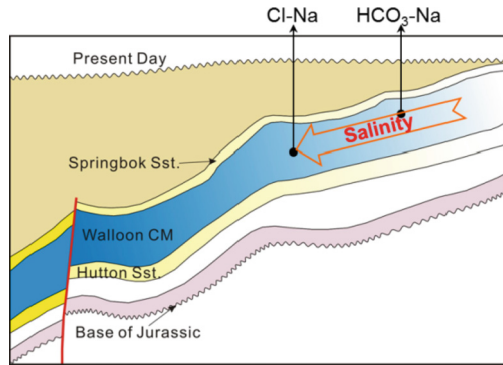


Fig. 8. Schematic diagram of the hydrodynamic profile in eastern Surat Basin

4.2 Accumulation Control Mechanism of Surface Water System

The groundwater level of the Walloon CM in the eastern Surat Basin is generally much lower than that of the river bed. Therefore, the interaction between groundwater and surface water is mainly manifested in the recharge of surface water to groundwater. Due to the seepage of the river bed in the outcrop area of aquifers, they are recharged remarkably by surface water.

The groundwater recharge area in the eastern Surat Basin is mainly located in the outcrop area in the east of the basin. This area is distributed in a continuous arc, and extends northward from the east of Goondiwindi to Dalby and Chinchilla, and then to the top of the Cape York Peninsula. In areas with high rainfall, the hydraulic gradient is large and the groundwater recharge capacity is strong; when the water recharge amount exceeds the aquifer recharge demand, recharge rejection will occur. The recharge to the shallow Condamine alluvial aquifer comes from river recharge and direct infiltration of surface rainfall.

When the direction of runoff is consistent with the formation tendency, the formation is overpressured or hydrodynamically blocked, indicating favorable accumulation conditions, and the direction of water flow is conducive to the methanogen-producing bacteria to carry into the coal seam, thereby generating biogas and increasing the gas

content (Fig. 9). For example, the Chinchilla area located in the lower part of the Condamine River system in the eastern Surat Basin has high gas content and high production. Structurally, the Chinchilla area is located in the axial part of the Undulla nose structure, and the strata are inclined southwest; the main stream of the Condamine River flows through this area from northeast to southwest, leading to active surface hydrodynamics and excellent charging conditions; The direction of surface runoff is consistent with the formation tendency, strengthening the blocking capacity of hydrodynamic force, accompanied by secondary biogenic recharge, and resulting in a large gas gradient in this area and CBM accumulation (Fig. 10).

When the direction of surface runoff is opposite to the formation tendency, the formation underpressure or hydrodynamic erosion will cause the loss of CBM, indicating unfavorable accumulation conditions, and it is not conducive to the introduction of methanogenic bacteria, thus, there is no biogas supply. For example, the northwestern area of Miles located in the lower part of the Dawson river system in the eastern Surat Basin has low gas content and unsatisfactory gas production effects.

Areas with inactive surface hydrodynamics and weak hydrodynamic plugging capacity are unfavorable for CBM accumulation. Take the southern part of the Danndan gas field as an example. Structurally, the area is located in the wing of the Kogan nose structure, and the strata are inclined southwest; from the perspective of surface configuration, this area is located in the western slope of the Great Dividing Range running north-south through eastern Australia, and has less precipitation and long-term drought; therefore, the area has inactive surface hydrodynamics and weak hydrodynamic plugging capacity and lack the input of methanogenic bacteria and gas source recharge, so that the area has a small gas gradient and CBM accumulation is difficult in the area.

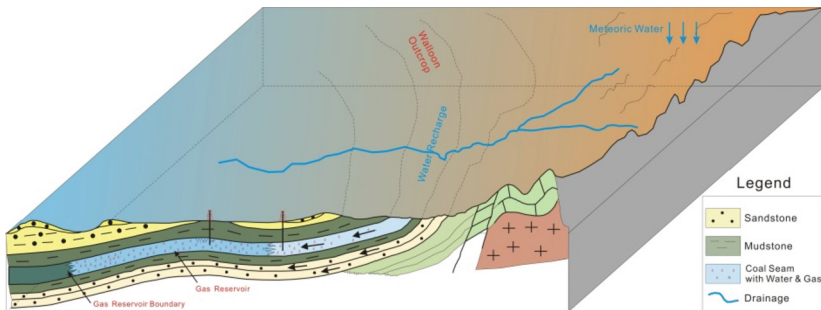


Fig. 9. Hydrodynamic model in eastern Surat Basin

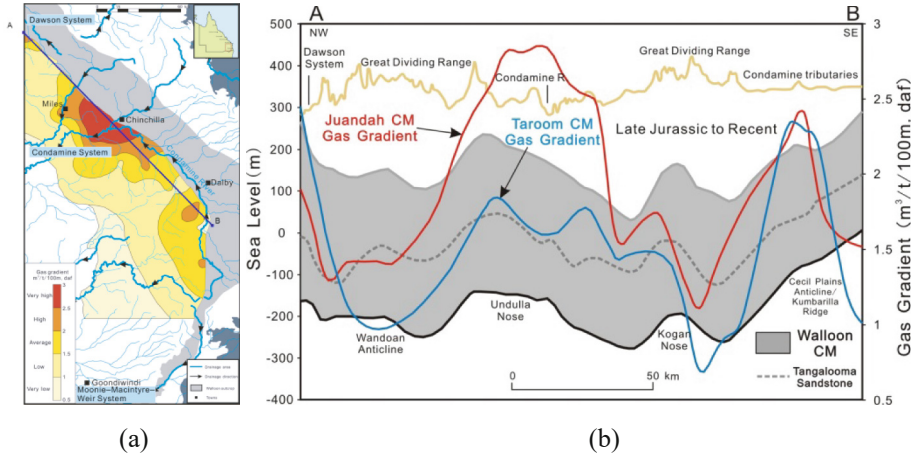


Fig. 10. Gas gradient map (a) and section (b) of the eastern Surat Basin (Modified from Hamilton, 2012) [25].

5 Conclusions

This paper has revealed that within individual wells in the eastern Surat Basin, gas content (dry ash-free base) either increases; increases, then decreases; or decreases with depth as the result of the variable coring intervals. The gas content maxima coincides with the Tangalooma Sandstone, regardless of depth. It has been proposed that the secondary biogenic recharge from above Tangalooma sandstone may be the main controlling factor for the inflection point of the gas content.

From the eastern edge to the center of the Surat Basin, the degree of salinity gradually increased, and the anion content of groundwater changed from mainly HCO_3^- to mainly Cl^- . The anions in the Walloon CM in the eastern basin are mainly HCO_3^- and Cl^- , and the water type is $\text{Cl}\cdot\text{HCO}_3\text{—Na}$ type, showing a weak runoff-pressured zone hydrodynamically. The gas gradient is large, and CBM is accumulated in the weak runoff zone near the surface water system recharge area. The watershed of the surface water system lacks hydrodynamic blocking, the gas gradient is small, and CBM is not easily accumulated.

The relationship between the direction of surface water runoff and the formation tendency in the eastern Surat Basin controls CBM accumulation. When the two are consistent, the formation is overpressured or hydrodynamically blocked, indicating favorable accumulation conditions, and the direction of water flow is conducive to the methanogen-producing bacteria to carry into the coal seam, thereby generating biogas and increasing the gas content. When the direction of surface water runoff is opposite to the formation tendency, the formation underpressure or hydrodynamic erosion will cause the loss of CBM, indicating unfavorable accumulation conditions, and it is not conducive to the introduction of methanogenic bacteria, thus, there is no biogas supply.

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