Importance of mineral sequestration during CO₂ gas migration: A case study from the Greater Gorgon area

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Abstract

High-CO₂ gas fields serve as important analogues for understanding various processes related to CO₂ injection and storage. The chemical signatures, both within the fluids and the solid phases, are especially useful for elucidating preferred gas migration pathways and also for assessing the relative importance of mineral precipitation and/or solution trapping efficiency. In this paper, we present a high resolution study focused on the Gorgon gas field and associated Rankin Trend gases on Australia’s North West Shelf. The gas data we present here display clear trends for CO₂ abundance (mole %) and δ¹³C CO₂ both areally and vertically. The strong spatial variation of CO₂ content and δ¹³C and the interrelationship between the two suggests that processes were active to alter the two in tandem. We propose that these variations were driven by the precipitation of a carbonate phase, namely siderite, which is observed as a common late stage mineral. This conclusion is based on Rayleigh distillation modeling together with bulk rock isotopic analyses of core, which indicates that the late stage carbonate cements are related to the CO₂ in the natural gases. The results suggest that a certain amount of CO₂ may be sequestered in mineral form over short migration distances of the plume.

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1. Introduction

While it is accepted that carbon capture and storage is an important method available to mitigate elevated CO₂ concentrations [1, 2], much recent scientific debate has centred on aspects related to the longer term fate of injected CO₂. In many cases, high-CO₂ natural gas fields can serve as important analogues for understanding processes...
related to longer term aspects of storage in sedimentary basins. The geochemical signatures, both within the fluids and the solid phases, are especially useful for elucidating preferred gas migration pathways and also for assessing the relative importance of mineral precipitation and solution trapping efficiency over time. In this paper, we present a high resolution study focussed mainly on the Gorgon field and associated Rankin Trend gas fields, Carnarvon Basin, Australia. These gas fields are characterized by numerous stacked reservoirs with varying CO₂ contents and provide a relevant natural laboratory for characterizing CO₂ migration, dissolution and reaction by looking at chemical characteristics of the different reservoirs. The giant gas fields of the Greater Gorgon area are also the focal point of the Chevron operated Gorgon Venture, in which 125 million tons of CO₂ will be separated from natural gas and injected into a deep saline aquifer.

2. Geologic Background

The Rankin Platform is an elongated horst block located within the northern Carnarvon Basin and is surrounded by a number of sub-basins including the Exmouth Plateau to the northwest and the Barrow and Dampier sub-basins to the southeast (Figure 1). The Rankin Platform formed due to Late Triassic rifting resulting in the formation of a number of half grabens, which exposed the Rankin block during the Jurassic and led to the intra-Jurassic unconformity. It is extensively faulted and contains the Triassic Mungaroo Formation; a stacked succession of gas-bearing reservoirs sandwiched between finer silts and muds (Figure 2). A key observation from the Rankin Trend is that CO₂ in gases display clear trends for CO₂ abundance and δ¹³C CO₂ both areally and vertically [3]. Generally, CO₂ mol % decreases and becomes depleted in δ¹³C with decreasing depth and towards the north. Furthermore when plotted against each other CO₂ abundance and δ¹³C are highly correlated, suggesting that some chemical process is responsible for their co-variation.

Figure 1 Map of the northern Carnarvon Basin, showing the Rankin Platform and the associated gas fields contained within. Dark solid lines are gas pipelines and dashed lines are proposed pipelines, including those to be developed as part of the Gorgon Venture.
3. Results

The CO2 geochemical analyses presented here are sourced both from open file well completion reports and from gas measurements conducted at Geoscience Australia over many years [3, 5, 6]. In this paper, we only present CO2 concentration data for gases that also have an accompanying measurement for δ13C. These CO2 gas analyses from natural gases of the northern Carnarvon Basin are presented in Figure 3. It is clear that gases from the Rankin Trend exhibit a systematic increase in δ13C with increasing mol% CO2, while gases from other sub-basins in the northern Carnarvon Basin do not show any correlation. The gases of the North Rankin fields have been separated from the other Rankin Trend gases, as the former are probably not related genetically and have a different source to the gases of the Greater Gorgon area. Within the Gorgon field, CO2 gases also become isotopically depleted in 13C up section as seen in several wells on Figure 2. In general, CO2 in gases of the Rankin Trend also exhibit a strong systematic spatial variability, becoming lower in CO2 content, with a depleted 13C signature towards the north.

![Cross section of the Gorgon field showing systematic spatial variations for CO2 gas chemistry (modified from [4]).](image)

Figure 2  Cross section of the Gorgon field showing systematic spatial variations for CO2 gas chemistry (modified from [4]).

4. Discussion

The spatial variation of CO2 content and δ13C CO2, combined with the inter-dependence of the two, suggests that some process was active throughout the Rankin Trend, which altered the CO2 characteristics of the natural gases. The factors that control CO2 concentration and variability in sedimentary basins have been studied for a number of years [7, 8, 9], as even small concentrations of CO2 can greatly impact the economic value of a gas field. More recently, CO2 variability in sedimentary basins has been used as an analogue to better understand migration and sequestration patterns of CO2 following CCS injection [10, 11, 12]. Based on these and other studies, there are four mechanisms that can drive systematic variations of CO2: mixing of gases with variable CO2 content, solubility trapping, mineral trapping, and biodegradation.

These four processes were modelled, and results indicate that mineral precipitation (siderite) is most likely the cause of the chemical and isotopic variation of CO2 gas. Siderite is observed as a late stage carbonate phase in most reservoir rocks of the Rankin Trend. As the CO2 migrated northward through the reservoirs and fault systems of the Mungaroo Formation, we propose that the CO2 charged fluids reacted with primary Fe-bearing minerals, resulting in siderite precipitation along the migration pathway. There are two primary sources for Fe in the Mungaroo Formation; primary Fe-bearing minerals in the reservoir units, and Fe contained within the inter-reservoir shales.
The latter was either extracted during migration through the reservoir or reacted out of shales that were smeared throughout the faults during displacement. The model we describe here for the Rankin Trend gases is similar to the

![Diagram](image)

**Figure 3** Plot of δ^{13}C vs mol % CO₂ for gases of the northern Carnarvon Basin. Gases of the Rankin Platform exhibit a strong cross-correlation, with gases becoming significantly depleted in δ^{13}C at low mol % CO₂. Although CO₂ in gases of the North Rankin fields also appear to fall on this correlation, gases are believed to have a different origin. In contrast, CO₂ from gases of the surrounding sub-basins do not exhibit any systematic trends. The variation in CO₂ content and isotopic signature within the Rankin Trend dataset is best explained by a Rayleigh distillation model, in which siderite precipitates along the migration pathway. Solubility trapping and mixing of gases from two different sources do not adequately explain the variability of the data.

migration and titration model proposed by Cathles and Schoell [13] to explain spatial variations of CO₂ content in natural gases. Furthermore, although this is not the first study to present a natural analogue exemplifying mineral sequestration of carbon, the strong and systematic effects on the residual CO₂ in gas is quite unique and important.

There is currently much uncertainty regarding the importance of mineral sequestration for the carbon storage industry. Although mineral carbonation processes are only believed to play an important role on timescales greater than about 10,000 years [2], these estimates are largely based on simplified geochemical models, which fail to account for a number of factors such as changes to reactive surface areas in a dynamic environment, and shifts in fluid composition and pH. Furthermore, it is impossible to model all carbonate phases, nor are all precipitation rates known. Chemical variations in the Greater Gorgon and Rankin Trend gases show that carbonate mineralization can be significant over a relatively short migration distance, as it was able to decrease the CO₂ content in gas by about 50% from southern Gorgon to Dionysus, a distance of about 50 km. Unfortunately, it is not possible to precisely determine the timing of the CO₂ charge nor the rate at which the CO₂ migrated north. Nevertheless, if the far-field rates of migration for injected CO₂ are anywhere similar to this natural analogue, then this work suggests that more emphasis should be placed on characterizing and quantifying mineral sequestration as an effective means of sequestering carbon.
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6. References


