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**Establishing Baselines and Predictive Geochemical Modelling of a Depleted Gas Reservoir
Carbon Storage Site, Otway Project, Australia**

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Introduction

Depleted gas reservoirs are one of the options being studied and utilized in the storage of carbon to mitigate anthropogenic greenhouse gas emissions to the atmosphere. Although numerous sites exist where carbon dioxide and other acid gases are currently being injected and stored, the Otway Project is one of the few that is being comprehensively studied to progress the science of geologic storage. Part of this program is to understand the short and long term behaviour of the storage system and to develop and evaluate monitoring and verification strategies and predictive modeling capabilities. This study focuses on the methods used to establish the geochemical baseline conditions required to monitor perturbations of the system due to the introduction of CO₂ and on the development and output of predictive geochemical models. The monitoring data and the models will then be used to interpret what the dominant physical and chemical processes taking place in the reservoir at Otway are.

Otway Project Site

The Otway Project site is in the depleted Naylor gas field in Australia. At just over 2 km depth, the target formation is the Late Cretaceous age Waarre C sandstone, a braided fluvial deposit with a marine influence approximately 20m thick (Dance et al., 2008). The area is structurally complex with numerous faults. The depleted Naylor Field is an anticlinal fault bound structure where the Waarre C reservoir dips at a shallow angle towards the southwest. The injector well (CRC-1) is located 300 m distant and 15 m downdip of the Naylor-1 observation well. The Naylor-1 well was recompleted with a downhole multilevel U-tube assembly (Freifeld et al., 2005) accessing, from 3 sample ports, the depleted methane-rich gas cap (U1 2028.8 mdd), the formation water just below the post-production gas-water contact (U2 2041.8 mdd) and the formation water at U3 2046.3 mdd.

A detailed petrologic and geochemical study of the Waarre C and the overlying Flaxmans Formation was undertaken to establish the modal mineral content and geochemical composition of the two units. The mineral content was determined using transmitted light thin section point counting and quantitative XRD. Whole rock composition was through XRF while individual mineral compositions were determined using an electron microprobe (Schacht, 2008). The petrologic, XRD and geochemical data were reconciled using the normative analysis software LPNORM (Caritat et al., 1994) to calculate a mineral content that accounts for the chemical composition.

The Waarre C is classified as sub-arkose, principally as a quartz-rich sandstone with minor feldspars dominated by potassium feldspar and trace plagioclase. Mica in the form of muscovite is common to all samples and the main authigenic mineral is kaolinite with minor illite present. Calcite is observed but is not common. The feldspars are extensively corroded with authigenic kaolinite closely associated and mica commonly has pseudomorphed kaolinite growths.

The Flaxmans Formation contains predominately quartz with minor K feldspar, muscovite and biotite as well as glauconite pellets. Authigenic minerals include kaolinite, illite and chlorite. The main cement is siderite. Mineral grains in the Flaxmans show little alteration compared to those of the Waarre C.

One of the more difficult tasks to fully parameterize geochemical models is to establish the formation water chemistry, particularly in a gas field as water is rarely produced. Several methods were used to establish the formation water composition at the Otway site. Wiewline test chamber fluid samples were collected from 6 depths after drilling CRC-1. Drill mud contamination had to be accounted for and two methods were applied. The first involved establishing and maintaining a fixed fluorescense content in the mud to allow detection and calculation of the amount of drill mud in the sample. The second involved conducting detailed analyses of the drill mud composition through time linked to drill depths then back calculating the formation water composition using the compositions of the samples and the drill mud. The fluorescense method proved unreliable while the resultant compositions from application of second method showed good consistency and ultimately closely matched formation water samples collected later. After recompletion and installation of the downhole assembly, Naylor-1 fluids were produced in an attempt to remove the kill fluid that had invaded the Waarre C. Several pre-injection samples were then collected and analyzed to try to establish the baseline conditions. The initial samples were moderately contaminated with kill fluid and later samples still had evidence of trace contamination. No water samples collected were completely free of contamination.

The composition of the gas cap was also determined in order to complete the baseline chemistry. The Naylor field gas is made up largely of methane (83-88 %) with minor amounts of higher hydrocarbons and approximately 1-2 mol % CO₂.

Geochemical Modeling

The baseline rock and fluid compositions were used to establish the in situ formation water composition at P and T using the geochemical modeling code Solmin88. Using the CO₂ fugacity set by the gas cap composition, model results indicate that the pH is buffered by the presence of calcite. Plotting the data on mineral-fluid stability diagrams indicates that muscovite-kaolinite and albite-kaolinite equilibrium has been established. Reaction path modeling suggests that the pH buffering capacity of the Waarre C is low and the potential for mineral sequestration is minimal. Long-term kinetics based reaction path modeling shows little change in the CO₂ fugacity induced by CO₂-water-rock interactions. Incorporating transport through reactive transport modeling indicates the potential for some solubility trapping which is variable depending on the hydrodynamic flow field. Overall, the storage potential of this site appears to be largely based on the integrity of the seal as there is a strong likelihood that the majority of the CO₂ injected will remain in the gas cap.

Geochemical modeling of the overlying Flaxman Formation was carried out to evaluate the potential for trapping any CO₂ leakage. The Flaxman Formation, although it contains suitable reactive minerals, is not a significant sink for carbon through carbonate mineral precipitation. The presence of considerable amounts of siderite results in pH buffering and little impact on the reactive mineral phases like chlorite. Thus the divalent cations potentially available in the chlorite are not being released into solution and new carbonate minerals are not formed.

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