Journal of Hydrology 539 (2016) 304–318

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Using environmental isotopes and dissolved methane concentrations to constrain hydrochemical processes and inter-aquifer mixing in the Galilee and Eromanga Basins, Great Artesian Basin, Australia

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ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form 20 October 2015
Accepted 6 May 2016
Available online 18 May 2016
This manuscript was handled by Laurent Charlet, Editor-in-Chief, with the assistance of Philippe Negrel, Associate Editor

Keywords:
Galilee Basin
Eromanga Basin
Environmental isotopes
Methane
Silicate dissolution
^{36}Cl/Cl ratio

SUMMARY

Groundwater recharge processes, water–rock interaction and the hydraulic connectivity between aquifers of the Galilee and Eromanga Basins in central Queensland, Australia, were investigated using stable (δ^2H, δ^{18}O, δ^{13}C and ^{87}Sr/^{86}Sr) and radiogenic (^{36}Cl) isotopes and dissolved methane concentrations, complemented by major ion chemistry. The central Eromanga and the upper sequence of the Galilee basins are both sub-basins of the Great Artesian Basin (GAB), and the coal seams of the Galilee Basin are currently explored for their potential as commercial coal seam gas deposits. In order to understand the potential influence of depressurisation of coal seams required to release the gas on adjacent aquifers, a detailed understanding of recharge processes and groundwater hydraulics of these basins prior to any development is required. Each of the different isotope systems were used in this study to provide different information on specific processes. For example, the assessment of δ^{13}C and ^{87}Sr/^{86}Sr ratios suggested that carbonate dissolution is one of the major processes controlling the water chemistry within some aquifers. In addition, the combined assessment of δ^2H, δ^{18}O and major ion chemistry indicates that transpiration is the primary process controlling the solute concentration in the GAB recharge area, whereas evaporation appears to be less significant. Groundwaters in the Galilee Basin recharge area (outside the limits of the GAB) are different to any groundwater within the GAB units. This difference is attributed to the dissolution of potassium-bearing micas, which are absent in the GAB. Groundwater age estimates based on ^{36}Cl/Cl ratios suggest that there is a steady increase along the flow paths, and this lack of anomalous age estimates from the recharge areas to the deeper parts of the basin indicates that there is no evidence for regional inter-aquifer mixing based in isotopes only. However, dissolved methane concentrations and groundwater chemistry near faults indicates the potential mix of gas and/or water from the coal seams into the GAB groundwaters, suggesting that there may be local influence of faults as gas/water conduits.

1. Introduction

Understanding hydrochemical and hydrological processes such as groundwater recharge, water–rock interaction, methanogenesis and groundwater mixing between different aquifers is an integral part of groundwater management. In heterogeneous, regional-scale aquifer or aquifer/aquitard systems, the usefulness of the simultaneous application and interpretation of hydrochemistry and stable and radiogenic isotope variations as powerful natural tracers to study groundwater evolution and resolve hydrogeological problems has been recognised during the last two decades (e.g. Woods et al., 2000; Edmunds et al., 2003; Cartwright et al., 2007, 2010; Liu et al., 2015; Raiber et al., 2015).

In this study, we have used environmental isotopes together with major ion chemistry and dissolved methane concentrations to constrain water–rock interaction, groundwater recharge processes and hydraulic connectivity between different aquifers

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http://dx.doi.org/10.1016/j.jhydrol.2016.05.016
0022-1694/

in the Galilee and Eromanga Basins, which are part of the Great Artesian Basin in central Queensland, Australia (Fig. 1).

The Galilee Basin is a Carboniferous–Triassic sedimentary basin that contains interbedded sedimentary successions of sandstones, siltstones and mudstones, with coal seams restricted to two of their stratigraphic units. It is overlain by the Eromanga Basin, a sedimentary basin that has formed during the Jurassic and Cretaceous and where no significant coal seams of commercial interest are present.

The upper sequences of the Galilee Basin and the Eromanga Basin are both part of the Great Artesian Basin (GAB), a major groundwater system in Australia which contains groundwater resources dated at more than 1 Ma in age (Bentley et al., 1986a). The coal bearing units of the Galilee Basin have been an exploration target for coal seam gas (CSG) since 2010. Gas contained within the coal-bearing units is adsorbed in the coal pore matrix and cleats, and held in place by the high hydrostatic pressure. To develop the gas, it is necessary to extract formation water (the volume depends on the hydraulic properties of the rock) to reduce the hydrostatic pressure and extract the gas, which can then flow to the surface with the water. As the Galilee Basin is overlain by the Eromanga Basin, which hosts some of the most important aquifers of the GAB, it is very important to understand whether the coal seams may be hydraulically connected with the aquifers, and to assess whether the depressurisation of the coal seam gas target units can potentially impact the quantity or quality of the groundwater resources in the GAB. At present, only pilot testing but no commercial exploitation of CSG has occurred in the Galilee Basin. While groundwater from the GAB has been extracted for more than 100 years for domestic and agricultural purposes and is therefore not in a natural equilibrium, the Galilee Basin could be used as an example to establish the pre-CSG development character of hydraulic connectivity between coal seams and aquifers. Knowledge of the pre-development baseline conditions is of importance for future management, in particular as no detailed hydrogeological studies have been carried out in the Galilee Basin. At this time, only the chemical character of the overlying Triassic units is known from limited groundwater chemistry data from bores screening these units. Several isotopic studies targeting the GAB groundwaters have also been reported (Airey et al., 1979; Calf and Habermehl, 1983).

The use of environmental isotopes confirmed the meteoric origin of groundwater. A comprehensive hydrochemical study also including $\delta^{13}C_{DIC}$ was conducted for the Lower-Cretaceous aquifer sequence of the GAB, leading to the identification of the main carbon sources, as well as the principal hydrochemical processes affecting the entire GAB (Herczeg et al., 1991). Collerson et al. (1988) studied the distribution of $^{87}Sr/^{86}Sr$ in the GAB, and identified two areas of distinct $^{87}Sr/^{86}Sr$ signatures, of which one is characterised by low radiogenic $^{87}Sr/^{86}Sr$ ratios near the recharge area, and the other with $^{87}Sr/^{86}Sr$ ratios similar to modern seawater (0.7092; Dia et al., 1992) in the central part of the basin. As groundwater is expected to be very old in some parts of the GAB, methods attempting to date old water have been applied to the GAB. The first of these methods, ^{36}Cl, was applied by Bentley et al. (1986a) on samples collected from different parts of the GAB including the study area of the current paper; these analyses indicated that the groundwater is as old as 1 million years. Later, Collon et al. (2000) used ^{81}Kr as a tool for dating very old groundwater, yielding residence times between 230 and 400 thousand years. In this study only four wells were sampled in the western part of the GAB, located far away from our study area, and in an area where different chemical and hydrodynamic conditions exist within the aquifer. Lastly, Lehmann et al. (2003) compared different methods (^{36}Cl, ^{81}Kr and ^{4}He) of dating groundwater collected from the same four wells sampled by Collon et al. (2000). The focus of the study by Lehmann et al. (2003) was on the comparison of the possibilities and limitations of using these three methods rather than on groundwater age calculation itself.

The isotopes of the carbon system (e.g. $\delta^{13}C_{DIC}$) can be used to identify hydrochemical processes and sources of carbon. They are

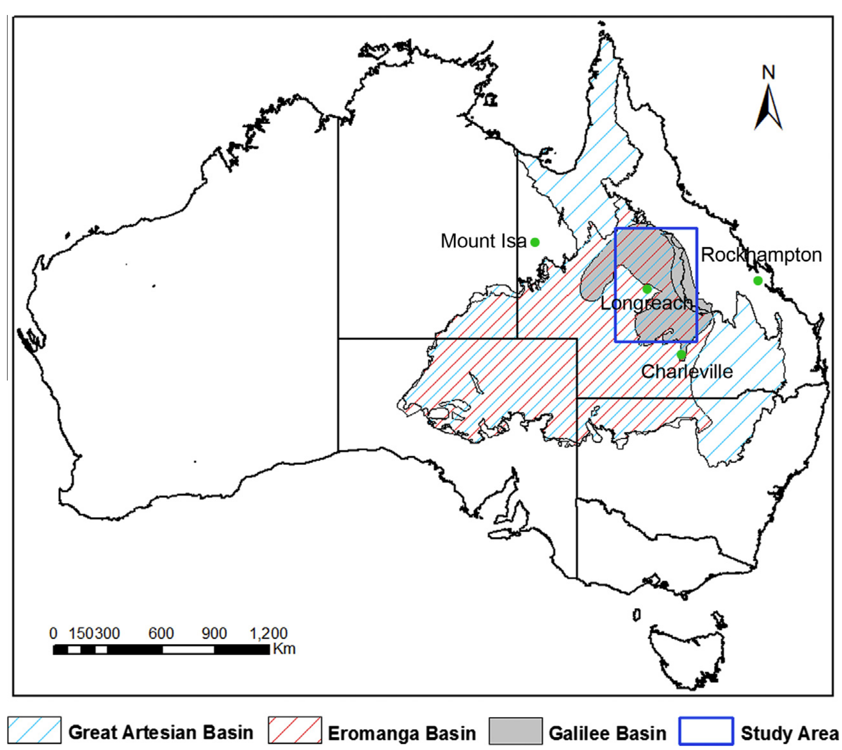

Fig. 1. Location of the study area in central Queensland. Datum GDA 1994 MGA Zone 54.