Marine and Petroleum Geology 78 (2016) 712–727

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Assessing aquitard hydraulic performance from hydrocarbon migration indicators: Surat and Bowen basins, Australia

J.R. Underschultz [a, *], P. Pasini [a], M. Grigorescu [b], T.L. de Souza [a]

[a] *The University of Queensland, Centre for Coal Seam Gas, Brisbane, QLD 4072, Australia*
[b] *The Geological Survey of Queensland, Australia*

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form
21 April 2016
Accepted 23 September 2016
Available online 25 September 2016

Keywords:
Surat Basin
Bowen Basin
Hydrocarbon systems
Hydrogeology
Fault seal

ABSTRACT

Basin hydrodynamic assessment methods are being applied to Australia's developing coal seam gas (CSG) to liquefied natural gas (LNG) export developments in the Queensland's Bowen and Surat basins. Technical challenges include the need to predict the cumulative impacts of CSG production on formation pressure in adjacent Great Artesian Basin aquifers and assess to what degree, if any, there may be fugitive methane liberated from the reservoir but not captured by production wells. Both these challenges require an understanding of the distribution of aquitard hydraulic sealing performance. We use hydrocarbon systems analysis to illuminate basin scale geological seal performance of the low permeability strata and provide baseline data on hydrocarbons in groundwater.

We collected indicators of hydrocarbons including: 1) drill stem, wireline and production test sample analysis, 2) staining, fluorescence, and streaming hydrocarbon occurrences from drill cuttings and core, and 3) mud log gas detector data. This data was allocated to stratigraphic horizons, mapped and compared to the geographic/stratigraphic location of source rocks, conventional and unconventional reservoired hydrocarbons, and aquitard/sealing strata and faults.

We found asymmetric trapping of conventional hydrocarbon reservoirs with eastern basin leakage and western basin preservation. Indications of some thermogenic gas in the Walloon Coal Measures exist yet maturity indicators are sub-thermogenic, suggesting that although much of the Walloon Coal Measures gas is biogenic, thermogenic gas may have previously migrated into the Walloon Coal Measures from elsewhere. Stratigraphically below the Walloon Coal Measures, hydrocarbon migration indicators are often clustered along lineations such as the Moonie-Goondiwindi and Burunga-Leichhardt fault systems. At the top of the Walloon Coal Measures, hydrocarbon migration indicators are clustered along the northeastern subcrop edge of the basin where the muddy strata at the top are either thin or eroded suggesting vertical leakage occurred to the overlying Springbok Sandstone aquifer. Whilst we can see where seals are either more, or less effective, at this stage we cannot make a quantitative assessment of background methane flux to surface or potential future proportional allocation of methane flux to natural vs anthropogenic causes.

1. Introduction

Basin-scale hydrodynamic systems have historically been characterised to help understand the hydraulic context of various basin resources, the conditions of their occurrence, the geological history of their formation, and how the exploitation of one resource may impact on the economic viability of another (Hitchon et al., 1990; Simmelink et al., 2003; Verweij et al., 2012; Villegas et al., 1994). These might include conventional and unconventional oil and gas, coal, mineral, geothermal, water and carbon storage resources. Sedimentary basins are increasingly being recognised as having multiple resource potential that requires purposeful management to ensure optimised "whole of life" beneficial use of the entirety of the resources (Hortle et al., 2010; Varma and Michael, 2012). To achieve this, an understanding of the distribution, continuity and heterogeneity of low permeability strata and their hydraulic performance as aquitards or "seals" becomes crucial.

In the case of the Bowen and Surat basins in Queensland (Australia), a substantial coal seam gas (CSG) resource is being

---

* Corresponding author.
E-mail address: j.underschultz@uq.edu.au (J.R. Underschultz).

http://dx.doi.org/10.1016/j.marpetgeo.2016.09.025

developed that will see on the order of 1500 PJ per year of liquefied natural gas (LNG) export, the first shipments of which began in 2015 (Department of Natural Resources and Mines (DNRM), 2015). A large portion of the CSG resource occurs within a sub-region of Australia's Great Artesian Basin (GAB) that constitutes a water resource for agricultural, industrial and municipal use. The Queensland regulator is responsible for overseeing the CSG development whilst ensuring adjacent groundwater resources remain sustainable. To achieve this, the state regulator has established an Office of Groundwater Impact Assessment (OGIA) that is mandated to monitor a large region termed the cumulative management area and predict through computer modelling any impacts of CSG development on GAB aquifers (Department of Environment and Heritage Protection (DEHP), 2012). Two categories of possible impact are: 1) declining water levels (hydraulic head) in GAB aquifers above and below the CSG reservoir, and 2) changes in hydrocarbon content (dissolved and free phase) in GAB aquifers above CSG production areas. Accurate prediction of both these potential impacts requires a good understanding of aquitard characteristics and hydraulic performance. Whilst there is extensive well based data including core analysis, petrophysical logs, drill-stem, wireline and production tests, uncertainty in aquitard characteristics remains when moving away from well control.

We propose that regional scale hydraulic performance of aquitard sealing strata can at least partially be assessed from hydrocarbon systems analysis that identifies geological timescale hydrocarbon migration pathways. These can also provide some baseline data on naturally occurring hydrocarbon content in GAB aquifers prior to CSG production that can set the context of post development fugitive hydrocarbon assessment.

2. Hydrocarbon systems analysis methodology

Historically, the first hydrocarbon discoveries in many sedimentary basins have been made by observing hydrocarbon occurrences either as surface seeps or in water wells. This is not a rare occurrence or particular to a certain sedimentary basin. For example, in the early 1900's rancher W.S. “Stewart” Herron noticed surface seeps of natural gas near Turner Valley in Western Canada. He recognised the opportunity for a local strike and validated a thermogenic source of the gas by sending samples to laboratories for analysis in California and Pennsylvania. This ultimately led to the first commercial hydrocarbon discovery in Canada in 1914 (Finch and Tippett, 2014). Dyck and Dunn (1986) describe conducting a survey of nearly 1000 water wells in the late 1970's from across an 18,000 km^2 area of Alberta analysing for CH_4, He and other constituents to determine a relationship between shallow groundwater chemistry and the occurrence of deeper petroleum accumulations. They then used this as an exploration tool to find as yet undiscovered pools. In the early days of water drilling in Queensland Australia, drillers sometimes encountered inflammable gas and small quantities of oil mixed with the water. At “Hospital Hill” near Roma in 1900, natural gas blew into a water bore from the Precipice Sandstone at 1123 m (Cadman et al., 1998) and by 1904 was flowing at 74 GJ/day (~70,000 cubic feet per day). In 1906 the township of Roma was connected to the gas for street lighting. It lasted 10 days before the flow stopped (Geological Survey of Victoria, 2015). This triggered some minor exploration activity through the 1930's and 40's but with no commercial success until the “Associated” group discovered gas in 1960 at Timbury Hills-1 near Roma. It took until 1969 before that gas flowed by pipeline to Brisbane. Meanwhile a joint venture of AOG, Union Oil and Kern County Land drilled Moonie-1 on the eastern side of the Goondiwindi-Moonie fault. The resulting Moonie oil field proved to be the first commercial hydrocarbon discovery in Australia in the early 1960's.

Over time “hydrocarbon systems analysis” methodology has developed to include an assessment of: 1) basin burial history and heat flow, 2) source rock character and hydrocarbon generation potential, 3) hydrocarbon migration fairways from basin reconstruction and hydrocarbon habitat mapping, and 4) hydrocarbon trapping and leakage potential. This desktop study takes advantage of extensive work already documented in the literature on parts 1 and 2. We concentrate our efforts on collecting and mapping public domain data from well completion reports and drilling logs on hydrocarbon indicators. These include hydrocarbon samples from drill stem, wireline and production tests that have been analysed in the laboratory, hydrocarbon shows logged from core and cuttings examination, and gas shows from mud logs. From this, we create a “hydrocarbon habitat” assessment. Finally, as a result of this analysis we discuss the implications for hydrocarbon leakage and aquitard hydraulic performance.

3. Bowen and Surat Basin hydrocarbon systems

The Permo-Triassic Bowen Basin forms the northern part of the Bowen—Gunnedah—Sydney Basin System in eastern Australia. The Bowen Basin development has been described by several authors (Baker and de Caritat, 1992; Fielding et al., 2001; Korsch and Totterdell, 2009) to be initiated by an extensional phase with deposition of Permian to Late Triassic sediments within two depocentres (Denison and Taroom troughs) separated by a basement high (the Comet Ridge) with a maximum thickness of ~10 km in the Taroom Trough (Fig. 1). There are three phases of basin formation (Fielding et al., 2001): (1) an Early Permian period of extensional subsidence with associated volcanic activity; (2) an early Late Permian passive thermal subsidence phase; and (3) a Late Permian to Middle Triassic phase of foreland thrust load-induced subsidence. The early sub-basins were filled mainly with continental alluvial sediments with the remainder of the Early Permian to early Late Permian becoming marine dominated. Late Permian saw renewed volcanism on the eastern margin that led to more restrictive marine conditions and an influx of volcano-lithic sediment. Final infilling resulted in alluvial and delta plain deposition with widespread coal formation. Alluvial sedimentation continued into the Triassic and was finally terminated by basin inversion (Uysal et al., 2001).

Late Triassic sedimentation marked the initiation of the overlying Surat Basin with sedimentation through the mid-Cretaceous. There is current debate about the cause of increased accommodation space during Surat Basin formation. One theory suggests that intracratonic sag was due to lithospheric thermal decay (Gallagher, 1990). The competing theory proposes a peri-cratonic setting in a retro-arc position where a westward dipping convergent plate margin and subduction zone resulted in dynamic tilting due to viscous corner mantle flow (Raza et al., 2009). A stratigraphic model for the Surat Basin was proposed by Exon (1976) and has subsequently been refined in several studies (Hoffmann et al., 2009; Jones and Patrick, 1981; Scott et al., 2004; Swarbrick, 1973; Yago, 1996); all describing six major fining upward cycles of Mesozoic sedimentation consisting of fluvial channelised and overbank deposits including widespread coal formation, through to fine grained lacustrine sediments. Sedimentation lasted through the mid-Cretaceous at which point renewed contraction and basin inversion resulted in upwards of 2 km erosion (Korsch et al., 2009).

Within the depositional histories of the Bowen and Surat basins, there were several periods where coals, lacustrine and marine sediments accumulated that are organic rich and have source rock potential. These are highlighted in the stratigraphic chart (Fig. 2) that shows the main stratigraphic units of the Bowen and Surat