Applied Geochemistry 37 (2013) 12–28

Contents lists available at SciVerse ScienceDirect

Applied Geochemistry

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

Geochemical modelling of petroleum well data from the Perth Basin. Implications for potential scaling during low enthalpy geothermal exploration from a hot sedimentary aquifer

Domenik Wolff-Boenisch *, Katy Evans

Applied Geology, Curtin University, GPO Box U1987, Perth, 6845 Western Australia, Australia

ARTICLE INFO

Article history:
Received 13 December 2012
Accepted 2 July 2013
Available online 13 July 2013
Editorial handling by R. Fuge

ABSTRACT

Chemical analyses derived from petroleum exploration wells are notorious for their lack of key solute data and their potential to represent mixtures of reservoir and drilling fluids rather than pristine formation compositions. These drawbacks notwithstanding, they usually pose the only access to the reservoir geochemistry. Two literature protocols were applied to a dataset of incomplete major element analyses from 148 petroleum well samples from a database compilation of the Perth Basin whose deeper aquifers may serve as potential hot sedimentary aquifers for geothermal direct heat applications. The first protocol included a set of quality control criteria that reduced the number of relatively genuine formation well samples from the raw data pool by 71%. The remaining well analyses are invariably NaCl solutions of low to medium alkalinity and an ionic strength only occasionally reaching seawater salinity. The low amount of total dissolved solids indicates the absence of extended evaporites in the North Perth Basin and the prevalence of meteoric water infiltration and circulation at depths.

The culled well samples underwent as a second protocol a forced equilibrium treatment to reconstruct *in situ* reservoir concentrations of missing elements (Si, Al, K), organic acid anions and non-carbonate alkalinity, and pH. The petroleum well samples were modelled to be in equilibrium with chalcedony (and kaolinite, albite, and paragonite) in the reservoir which yielded better convergence than using quartz instead. The derived formation temperatures correspond to geothermal gradients in the majority of cases between 25 and 35 °C, in accord with literature findings. Those wells drilled to depth <1600 m returned questionably high geothermal gradients, an indication of incomplete mineral–fluid equilibrium. The measured pH (at ambient temperature) deviated in >90% of the wells from the calculated pH, either due to degassed CO_2 or unaccounted acetate alkalinity. The wells were further modelled to be undersaturated with respect to amorphous silica and anhydrite and not likely to experience scaling of any of these two phases during geothermal production at depth <3800 m. For calcite, scaling predictions depend in how far bubbling and phase segregation can be suppressed. For the six different stratigraphies investigated here, calculated bubble points were low, indicating that pressurisation of the entire production and re-injection line seems viable. Based on a calcite growth model from the literature it is shown that, if bubble formation and concomitant carbonate flash scaling cannot be averted, the production well should be as shallow as the temperature requirements of the geothermal production allow for.

This study promotes the application of readily accessible protocols and a scaling model to deep well samples that may otherwise appear to have little geochemical value because of the way the samples were collected and handled. After data culling and treatment, insights into the geochemistry and scaling potential of deep clastic formations of the North Perth Basin that may hold the potential for geothermal exploitation as hot sedimentary aquifers can be gained.

1. Introduction

The need to find alternative energy sources has motivated widespread investigation and development of unconventional geothermal energy sources. In contrast to conventional geothermal systems, volcanic activity is absent in unconventional geothermal energy systems and the viability of thermal energy production depends on the type of heat source and permeability. Hot sedimentary aquifers (HSA) combine sufficient hot fluid volume and permeability to allow heat extraction on an economic scale for direct heat applications. They are more widespread than magma-related sources and technologically less challenging than engineered geothermal systems, such as hot dry rock sources.

---

* Corresponding author. Tel./fax: +61 8 9266 2960.
E-mail address: Domenik.Wolff-Boenisch@curtin.edu.au (D. Wolff-Boenisch).

0883-2927/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apgeochem.2013.07.004

HSA are common worldwide and exploitation of geothermal energy from these sources has become a focus of attention in recent years, in response to the need to find alternative energy sources (Lund et al., 2011).

The Perth Basin, Western Australia contains such HSA which are under scrutiny as a source for sustained geothermal heat extraction suitable for various energy intensive applications (Timms et al., 2012). Despite the relatively low temperature (~⩽100 °C at 3 km depth) of the geothermal waters permeating the sediments of the Perth Basin, there are already small-scale projects in place in the Perth metropolitan area with geothermally heated swimming pools but future plans include tapping a suitable HSA to run large-scale air conditioning systems and direct heating of water in desalination and mineral processing plants.

Geothermal heat mining involves pumping geothermal waters to the surface via a producing well, extraction of heat in heat exchanger apparatus, and, in some regulatory environments, return of the fluids via an injection well to the subsurface. Technical issues associated with the chemical consequences of cooling and pressure decreases during geothermal heat extraction can be significant. From a geochemical point of view, the most notorious of these is scaling, the precipitation of an unwanted secondary phase out of the geothermal fluid due to changes in temperature, pressure, gas content, and redox state. Scaling may reduce the efficiency of the heat exchange process, cause loss of productivity and/or injectivity and may, depending on the nature of the secondary phase, even ruin the wellbore and/or permeability of the surrounding aquifer altogether. In order to gauge the potential for scaling during geothermal activities from HSA of the Perth Basin, geochemical modelling of petroleum well data from well completion reports compiled for the Perth Basin was performed. The first step involved sifting through the available data for representative chemical analyses followed by reconstruction of the *in situ* composition of the sedimentary formation waters and final geochemical interpretation of the stability of key secondary phases, such as calcite, anhydrite and amorphous silica. Findings are presented and discussed in the context of geothermal heat extraction from the Perth Basin. The information will aid effective exploitation of geothermal energy in the Perth Basin and anticipate the most likely scaling phases that may be encountered and dealt with during future direct heat production. The paper will also contribute to a wider appreciation of the possibilities and shortcomings of using HSA as a future means for low enthalpy direct heat applications.

2. Geological background

The following brief introduction into the geologic setting and stratigraphy of the Perth Basin has been distilled from various sources (Playford, 1976; Cadman et al., 1994; Crostella, 1995; Davidson, 1995; Mory and Iasky, 1996; Crostella and Backhouse, 2000; Laker, 2000; Owad-Jones and Ellis, 2000). In this presentation, emphasis is placed on the Northern part of the Perth Basin because the culled dataset underlying this study stems, except for one sample (Gage Roads), from petroleum wells located in the Dandaragan Trough in the North Perth Basin (Fig. 1). The original dataset encompassed petroleum wells from the entire Perth Basin but it was mandatory to apply some quality control on the data, and wells from the Central and South Perth Basin were filtered out at this stage (cf. Section 3.1 on data source and treatment). The subsequent stratigraphy section describes only the six units from which all the formation waters of the petroleum wells were sourced, viz. the Irwin River Coal Measures and Carynginia Formation from the Lower Permian, the Wagina Sandstone from the Upper Permian, the Basal Triassic Sandstone from the Lower Triassic, the Cattamara Coal Measures from the Lower Jurassic, and the Gage Sandstone from the Lower Cretaceous (Fig. 2).

2.1. Basin setting

The Perth Basin is a north–south orientated elongate trough on the South Western Australian coastline (Fig. 1). It contains a succession of sediments ranging from marine to continental starting in the Silurian. The primary sediment volume was, however, deposited from the Early Permian to the Early Cretaceous (Fig. 2) in response to rifting, which concluded with the ultimate separation of India and Australia. Because of the intensive rifting over so many time periods, the Perth Basin is characterised by numerous, parallel, north–south trending (half)grabens and fault structures. Onshore sediments constitute roughly 50% of the basin surface area whereas the other half encompasses sediments offshore. The Perth Basin is flanked to the East by a north–south trending fault (Darling Fault) beyond which Precambrian granites and gneisses of the Yilgarn Craton occur. Physical weathering and erosion of these rocks provided the source for much of the sediments deposited into the subsiding (half)grabens of the Perth Basin. In the North Perth Basin, the most important sedimentary sink is the Dandaragan Trough, adjacent to the Darling Fault. This half-graben received up to 15,000 m of Silurian to Cretaceous sediments (Cadman et al., 1994) and it is here that nearly all petroleum wells which constitute the basis of this study are located (Fig. 1). To the west, the Dandaragan Trough is limited by a number of north–south trending faults whereas to the south the Cervantes Transfer fault cuts off the Dandaragan Trough from the Bermullah Trough. One sampled well was drilled into the Vlaming Sub-basin (to the south) which lies offshore on the latitude of Perth.

2.2. Basin stratigraphy

2.2.1. Irwin River Coal Measures

The Irwin River Coal Measures are an alternating sequence of sandstone, siltstone, carbonaceous shale and claystone with beds of sub-bituminous coal. The sandstones in the Irwin River Coal Measures tend to be argillaceous with low permeabilities; nevertheless, gas is produced from the Irwin River Coal Measures in the Dongara field (cf. large red–green patch in enlargement in Fig. 1).

2.2.2. Carynginia Formation

The Carynginia Formation consists predominantly of dark micaceous and carbonaceous siltstone, and fine- to coarse-grained quartz sandstone, with thin beds of fine conglomerate (Mory and Iasky, 1996). In the Carynginia Limestone facies, primary porosity was occluded by clays and sparry calcite early during diagenesis (Cadman et al., 1994). Thin, discontinuous sandstones, sealed by shales and limestones, form valid gas reservoirs within the Carynginia Formation and are exploited in the Dongara field.

2.2.3. Wagina Sandstone

The Wagina Formation sandstones predominantly comprise arenites, with quartz, K-feldspar and minor plagioclase as primary minerals and kaolinite and illite–smectite to chlorite–smectite pore fillings (Laker, 2000). Despite its limited areal distribution, the Wagina Sandstone is an important hydrocarbon reservoir in the Dongara field.

2.2.4. Basal Triassic Sandstone

The Basal Triassic Sandstone consists predominantly of bioturbated medium to coarse grained quartz-rich sandstone with interbedded limestone, carbonaceous siltstone, and minor thin pebble bands. The main diagenetic materials in the Basal Triassic