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Significance of compressional tectonic on pore pressure distribution in Perth Basin

Abualksim Ahmad *, Reza Rezaee, Vamegh Rasouli

Department of Petroleum Engineering, Curtin University, Perth, Western Australia, Australia

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ABSTRACT

The Perth Basin is one of the major tectonic structures along the western continental margin of Australia and was initially formed through the rifting and break-up of the Indian and Australian plates. The severe tectonic movements accompanied and occurred after the break-up are responsible for the most structural elements and for the distribution of pore pressure in the basin.

Investigations on the well log data from the Perth Basin have identified shale intervals which are characterised as overpressured in some parts of the basin, whereas similar shale intervals found to be normally pressured in other parts of the basin. The phenomena of overpressure have frequently been reported while drilling the same intervals. Based on this research, sections with overpressure were observed in the majority of the wells in the basal section of the Kockatea shale where there were less tectonic activities have been recorded. Normal pore pressure was observed in shallower wells in the Kockatea shales which were located within uplifted sections that were more tectonically active areas.

Based on the results of this research, the pore pressure distribution in the Kockatea Shale varied significantly from one part of the Perth Basin to another as a result of compressive tectonic stress. Compressional tectonic activities either induced fracturing in shallower localities (e.g. Beagle Ridge, Cadda Terrace and the adjacent terraces) or removed part of the Kockatea Shale as a result of faulting resulting in overpressures being released. Regions with less intensity of the tectonic activities showed an increase in pressure gradients as approaching away from the centre of uplift.

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Introduction

Several sedimentary basins around the world display some sort of abnormal pore pressure, particularly abnormal high-pressure (overpressure). The overpressure phenomenon is commonly observed in low permeability zones such as shale formations as they tend to retain overpressures compared to other kind of rock types (Osborne and Swarbrick, 1997).

No research has been done to assess pore pressure in shale formations in the Perth Basin. The primary purpose of this study is to estimate the pore pressure and evaluate its distribution in the Perth Basin using well log data. This study is part of a bigger project that evaluates shale gas potential intervals in the Perth and Canning basins. The relationship between pore pressure and the tectonically structural events was also studied in this research, and the results were analysed and presented here. This work will inform a better understanding of the overpressure and tectonics events in the Perth Basin, and in turn, a better understanding and an assessment of the shale candidate formations. Shale's pore pressure is important particularly when studied in conjunction with other shale characteristics such as thermal maturity and total organic contents (TOC) which may be used for the identification of the shale gas sweet spots.

Structure and geological setting

The Perth Basin is an elongated north–south extent in the southwest of Western Australia. The basin covers approximately 100,000 km^2 along the west coast of Australia and extends between Geraldton and Augusta. The basin contains sedimentary succession that varies from Silurian to Pleistocene (Mory, 2005). To the north, the basin is bounded by the Northampton block and the eastern margin of the basin is defined by Darling fault. Half of the basin is located onshore and extends to the west offshore to the edge of the continental shelf (Iasky and Mory, 1994).

The Basin was initially formed through the rifting and the break-up of the Indian and Australian plates as this was the major structural formation event in Perth Basin (Crostella, 1995). Following the initial rifting, subsequent deformation and deposi-

* Corresponding author. Tel.: +61 421164709.
E-mail address: b_asseni@yahoo.com (A. Ahmad).

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Nomenclature

DTCO	compressional wave transit time log (μs/ft)	ROP	drilling rate of penetration (m/h)
DTC	compressional wave transit time log (μs/ft)	ZDEN	bulk density log (g/cc)
NCT_Son	normal compaction trend from sonic log (μs/ft)	BATC	sonic transit time log (μs/ft)
PP_Son	pore pressure estimated from sonic log (psi)	SFBD	smoothed far detector only bulk density (g/cc)
ResShale	resistivity of the shale (ohm m)	g_p	estimated pore pressure gradient (psi/ft)
NCT_Res	normal compaction trend from resistivity log (ohm m)	g_{ob}	overburden pressure gradient (psi/ft)
PP_Res	pore pressure estimated from resistivity log (ohm m)	g_n	normal pore pressure gradient (psi/ft)
GR	gamma ray (API)	Δt_n	normal sonic transit time (μs/ft)
RHOB	bulk density log (g/cc)	Δt_o	observed sonic transit time (μs/ft)
PPG_Son	pore pressure gradient estimated from sonic log (psi/ft)	R_n	normal resistivity (ohm m)
Mud wt	mud weight gradient (psi/ft)	R_0	observed resistivity (ohm m)

tion occurred sequentially in the basin (Mory, 2005). Rifting and sagging occurred along the western continental margin which caused the development of a series of normal faults that dominate the Perth Basin structure (Song and Cawood, 2000).

As the drifting took place, the structure was filled by sediments which originated from the Yilgarn Craton during the late Permian through to Cretaceous periods (Iasky and Mory, 1994). The rate of sediment accumulation in the Perth Basin during this time frame was rapid and was controlled by the growth of the main regional faults which provided examples of a deformational environment which characterise the Western Australian continental margin prior to, and during the break-up (Iasky and Mory, 1994). The sediments were then lithified into sedimentary rocks which are characterised by sandstone, siltstone and shales (Crostella, 1995).

Basin-wide erosion and uplifting occurred during the break-up, which resulted in erosion and the inversion of up to thousands of meters of sediments (Figs. 2–4). The erosion and uplifting also resulted in the development of transfer faults which influenced the geometry and divided the basin into compartmentalised regions characterized as sub-basins, ridges and troughs of similar structural style reflects the present form of the geological structure (Song and Cawood, 2000).

Stratigraphy

The stratigraphic unit that is most relevant to this study, the Kockatea Shale, was developed during the tectonic evolution of the basin and deposited during the early Triassic period. The Kockatea Shale forms a major source rock and local cap rock underlying reservoirs and also thought to be potential shale gas reservoir. It consist of dark shale, siltstone, and minor sandstone and limestone beds, and the unit outcrops consist of thin, red, purple or brown colour ferruginous siltstone or fine-grained sandstone (Crostella, 1995). Kockatea Shale deposition continued over the northern Perth Basin, with active subsidence in the Dandaragan Trough where sediment thicknesses in excess of 1000 meters were deposited (Iasky and Mory, 1994).

The concepts for estimating pore pressure

The formation pore pressure can be determined by direct or indirect methods (Lesso and Burgess, 1986). Direct pressure measurements include the repeated formation tests (RFT), drill stems tests (DST) and Modular Formation Dynamics Tester (MDT). These measurements have been reported to provide promising results in permeable formations where the tools can be placed along the formation and allow sufficient time to reach pressure equilibrium. However, direct measurements cannot be used in shale formations because of their associated operational difficulties, e.g. the risk of differential pipe sticking and the high cost of rig time as the pore pressure in shale will need a very long time to reach equilibrium. Therefore, indirect methods that are based on compaction and porosity concepts (e.g. well log data) are used. In conjunction with the use of well log data to estimate pore pressure, the mud log data such as gas kicks, the drilling rate of penetration (ROP) and mud weight were also used to validate pore pressure estimation from well log data (Fertl, 1973). The most popular prediction method for pore pressure is Eaton's method and its basic concepts are the

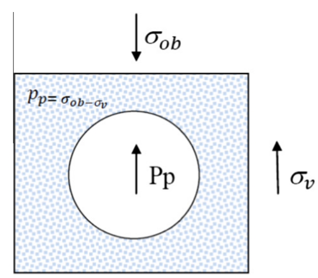

Fig. 1. A simplified diagram of state of stress underground modified from Draou and Osisanya (2000).

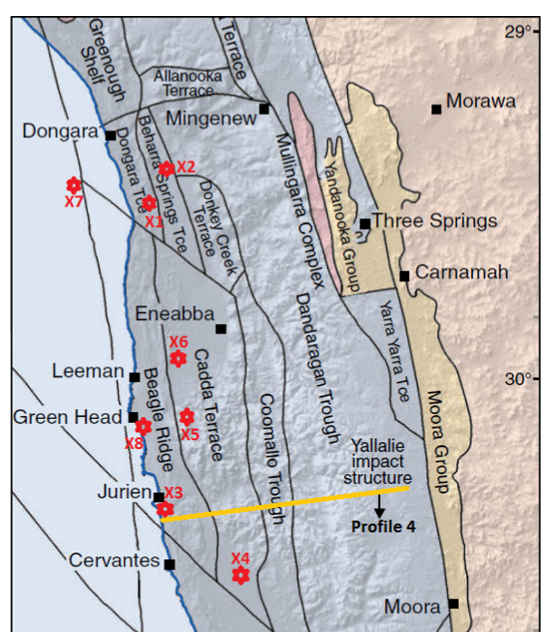

Fig. 2. Tectonic divisions & structural framework in the northern Perth Basin modified from Mory (2005).

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