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# Fluid flow through carbonate platforms as evidence for deep-seated reservoirs in Northwest Australia

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ABSTRACT

Fluid flow features in carbonate platforms of the outer Browse Basin, Northwest Australia, are investigated using 3D seismic and borehole data. During the Cenozoic, the study area evolved from a carbonate ramp to a rimmed platform with isolated carbonate build-ups; as such it played a key role in focusing fluid on their buoyant flow to the surface. Statistical analyses of direct hydrocarbon indicators show fluid flow to be focused in elevated areas i.e., the greater is the focusing of fluid, the larger is the carbonate platform or isolated build-up. Locally, karst systems created regions of enhanced permeability through the evolving carbonate stratigraphy. Karstified horizons are located on the top of carbonate build-ups and platform clinoforms as fluid buoyantly concentrates and diffuses up into topographic highs. In turn, the putative migration of gas and fluid generated hypogenic karst systems, enhancing permeability in otherwise lower permeability rock. Based on the interpreted data, we suggest a pivotal relationship between the presence of carbonate build-ups (and karsts) in the Browse Basin and hydrocarbon accumulations at depth. Areas of elevated topography focus sub-surface fluid, enhancing the permeability of carbonate successions. In turn, focused fluid flow can lead to the generation of methanogenic carbonates, promoting the growth of isolated build-ups and leading to further generation of elevated features. This grants the identification of similar features on seismic data from Northwest Australia, and other Equatorial margins in the world, as a valid proxy for the recognition of hydrocarbon accumulations below thick carbonate successions.



## 1. Introduction

Equatorial margins with water temperatures above 20 °C record high organic productivity, and the deposition of vast carbonate platforms (Testa and Bosence, 1999; Wilson 2002, 2012). On these carbonate platforms, fluid-flow features and seafloor cold seeps are often linked to the presence of underlying hydrocarbon accumulations or, instead, relate to the presence of significant volumes of methane and gas hydrates in near-surface strata (Hovland, 1985, 1994; Série et al., 2012; Prinzhofer and Deville, 2013; Wenau et al., 2015). Cold seeps may stimulate abnormal 'oases' of biological activity, leading to growth of chemosynthetic communities that accumulate authigenic carbonates on the seafloor (Hovland and Judd, 1988; Hovland et al., 1994; Løseth et al., 2009). In the Porcupine (Southwest Ireland) and Vulcan (Northern Australia) basins, Hovland et al., (1994) have shown that focused seepage of hydrocarbons through the seabed is accompanied by higher-than-normal methane concentrations around growing mounds, with some degree of fault control on the mounds' position being accompanied by migration of hydrocarbons from sub-surface units.

The Northwest Shelf is the most important hydrocarbon province in Australia, with >5 billion barrels of oil and condensate and 152 Tcf of gas discovered since exploration began six decades ago (Longley et al., 2002). Most of these hydrocarbons are sourced from the syn-rift Plover Formation (Early-Middle Jurassic), which comprises the most important reservoir interval in the region (Longley et al., 2002; Tovaglieri and George, 2014). Hydrocarbon migration through carbonate units has been observed in the nearby Yampi Shelf (O'Brien et al., 2005) and in the Petrel sub-basin (Nicholas et al., 2014), but no detailed analysis of direct hydrocarbon indicators (DHIs) has been attained for the Browse Basin (Figs. 1a and b).

Through the interpretation of a high-quality seismic volume from Northwest Australia (Browse Basin), this paper aims to assess how valid is the mapping of hydrocarbon migration and seepage on an evolving carbonate platform as a method to identify deep-seated reservoirs and active petroleum systems (Figs. 1c and 2). The Cenozoic evolution of the Browse Basin records a change from a carbonate ramp setting to a rimmed platform with isolated build-ups (Figs. 2 and 3). Resulting changes in Eocene-Holocene stratigraphy had a significant impact upon seal competence above Mesozoic reservoirs. In this work, the spatial distribution of pockmarks, gas pipes and karst features are compared with the evolution of the imaged carbonate platform to corroborate their

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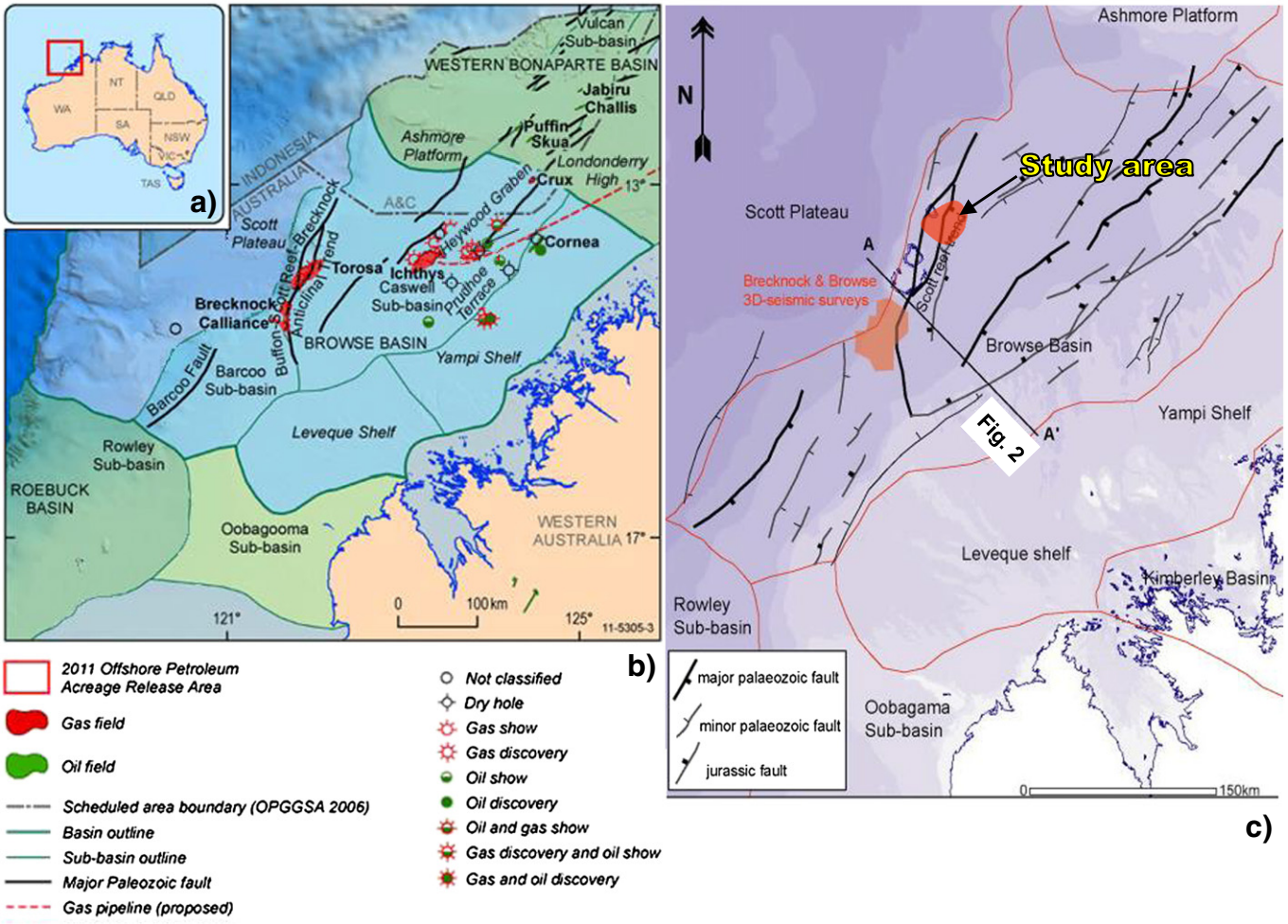


**Fig. 1.** (a) General map of Australia highlighting the location of the Browse Basin in the greater North West Shelf, Australia. (b) Tectonic elements map of the North West Shelf of Australia showing the various basins and sub-basins, hydrocarbon discoveries and the location of the study area. (c) Simplified bathymetric map of the Browse Basin showing its main structural elements. The region analysed by Rosleff-Soerensen et al. (2012) is located to the SW of the study area. Major Palaeozoic faults strike NE-SW throughout the study area (see Harrowfield and Keep 2005). The profile A-A′ is shown in Fig. 2.)

use as indicators of prolific hydrocarbon reservoirs at depth. With this in mind, this work aims to address the following research questions:

a) Is the distribution of DHIs in the Browse Basin related to the existence of deeper reservoir intervals?
b) Does fluid flow focus in specific zones of the Browse carbonate platform, following karstified areas, fault planes and platform margins?
c) Have variations in sea level, currents and wave motion within this particular area of the Browse Basin impact upon the seal competence of Miocene units?

The paper starts with a detailed description of data and methods utilised, prior to the presentation of the geological, oceanographic and stratigraphic settings of the Browse Basin. We then describe the seismic stratigraphy of the study area. Growth rates of carbonate build-ups are quantified, and the distribution of karsts and DHIs analysed statistically. At the end of the paper are discussed: a) the oceanographic and tectonic controls on carbonate platform geometry in the Browse Basin and, b) the economic and environmental significance of the fluid flow paths identified on seismic data.

## 2. Data and methods

This work uses a 2850 km$^2$ 3D seismic volume from the Browse Basin, offshore Northwest Australia, and borehole data from two industry wells (Figs. 1c and 2). Seismic-borehole ties were based on chronostratigraphic, gamma-ray, resistivity and lithological data (ConocoPhillips, 2010). The Poseidon-1 well provided gamma-ray, ROP (rate of penetration) and resistivity data from 600 m to 4000 m below the seafloor, having crossed Upper Miocene to Middle Jurassic strata. The Poseidon-2 well provided lithological constraints below 2430 m i.e., for Cretaceous and Middle Jurassic units (ConocoPhillips, 2010).

The interpreted 3D seismic volume was acquired in a direction parallel to the NW-striking continental shelf, and it is not aligned with the long axis of any studied fluid-venting structures or karst networks. Therefore, there are no spatial aliasing issues with the imaging of shallow features (Ho et al. 2012). For the intervals targeted in this study (Cenozoic), average peak-to-trough distance is 10–20 ms two-way time (TWT). Using a general velocity of 2.0 km/s, average peak-to-tough distances suggest a minimum vertical resolution of 5 m to 10 m. Interpreted horizons are relatively shallow (<2800 m), occurring at depths where data frequency and vertical resolution are remarkably preserved (Fig. 3).

Horizon mapping was performed every 20 inlines and crosslines, forming a grid of seed data for automated 3D auto-tracking, prior to converting the grid into a surface. Once computed, seismic attribute data were extracted from specific surfaces and in time-slices crossing the seismic volume. Seismic attributes used in this study include seismic trace (RMS amplitude) and seismic volume (variance) attributes. Amplitude maps display amplitude values at any given point across the