VOLCANICS: A COMMONLY UNDERESTIMATED PART OF PETROLEUM EXPLORATION

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SUMMARY

Conventionally, there has been an entrenched aversion to explore oil and gas in regions with volcanic geology. In other words, petroleum systems affected by igneous geology have not been considered with substantial oil and gas discoveries. However, the presence of volcanics is well known in many petroleum basins although not published in great details (including the North West Shelf of Australia), and there has been an increase in the number of hydrocarbon discoveries in volcanic basins worldwide.

On the other hand, there has been volcanics geology factor associated with unsuccessful exploration wells. In the NWS of Australia, explorers care about the evidences as several unsuccessful wells, widely distributed in the area, have penetrated volcanics within the Triassic-Jurassic succession, which indicates a significant exploration risk.

A primary purpose in writing this article was to illustrate that the presence of volcanics and their impacts on sedimentary rocks may lead to complex overprints for oil and gas exploration. Several 2D and 3D seismic datasets in addition to well information, from Barcoo Sub-basin of the NWS of Australia, were analysed and interpreted to demonstrate the fact that features we sometimes get with volcanics can be very misleading for hydrocarbon exploration.

Volcanic rocks within the Triassic-Jurassic succession at the NWS of Australia are not considered favourable conditions for hydrocarbon accumulation. It is therefore important to develop an approach to better understand their impact on petroleum system and derisk prospects for exploration.

Key words: igneous geology, dyke, amplitude anomaly, North West Shelf of Australia, petroleum system

INTRODUCTION

Volcanic features on seismic data can be very misleading: either they appear to be similar to carbonates or to siliciclastic rocks. A positive relief associated with volcanics on vertical seismic sections can resemble differential compaction as you would see in sediments, for example.

Many passive margin basins at the North West Shelf of Australia, including Browse Basin, are considered to be dominated by rifting and rift-related volcanism during the Late Triassic to Late Jurassic interval (Ray et al., 2008; Tovaglieri, 2013).
At Browse Basin, igneous rocks have been recognized within Plover Formation (Early to Middle Jurassic) and penetrated by several wells such as Buffon-1 which was drilled in 1980 and encountered hundreds of meters of volcanics (Holford et al., 2017). The volcanism of the Browse Basin is a product of Jurassic extensional regime, which led to rifting of microplates from the Gondwanan Supercontinent (Jablonski & Saitta, 2004; Hoffman and Hill, 2004).

Seismic and well data were used to interpret volcanics and their associated geometry in the Early Jurassic sedimentary section. This has been examined with the extensive use of 3D seismic data to determine volcanics' morphology, both on vertical sections and time slices. We have conducted an integrated seismic and well interpretation on Browse Basin focusing on identification of volcanics seismic amplitude signature.

3D seismic data can be very useful in describing the 3D geometry of geologic events and they make the morphology easier to interpret within a geological context to derisk prospects. We show some examples that revealed the morphology of volcanics (which alternatively could be misinterpreted as a differential compaction response related to sand channels for example) and how 3D data can de-risk the potential for drilling mistakenly into volcanics.

LOCATION AND GEOLOGICAL SETTINGS

The Browse Basin is located offshore at the North West Shelf of Australia (Figure 1) and covers an area of approximately 140 000 km2. It has undergone six major tectonic phases: 1- middle Carboniferous–early Permian extension, 2- Cisuralian to Late Triassic thermal subsidence, 3- Late Triassic to Early Jurassic inversion, 4- Early to Middle Jurassic extension, 5- Late Jurassic to Cenozoic thermal subsidence, and 6- Middle Miocene to Holocene inversion (Hocking et al., 1994; Baillie et al., 1994; Struckmeyer et al., 1998).

The basin contains a Paleozoic, Mesozoic and Cenozoic sedimentary succession that hosts significant hydrocarbon discoveries (Keall and Smith, 2004) and the Jurassic Plover Formation is the most prolific so far drilled. Volcaniclastic sediments are also encountered between Early Triassic to Late Jurassic deposits over the basin (Tovaglieri et al, 2013).

The central Browse Basin is divided into the Caswell and Barcoo sub-basins and the database of this study, including seismic and well data, are from Barcoo sub-basin.

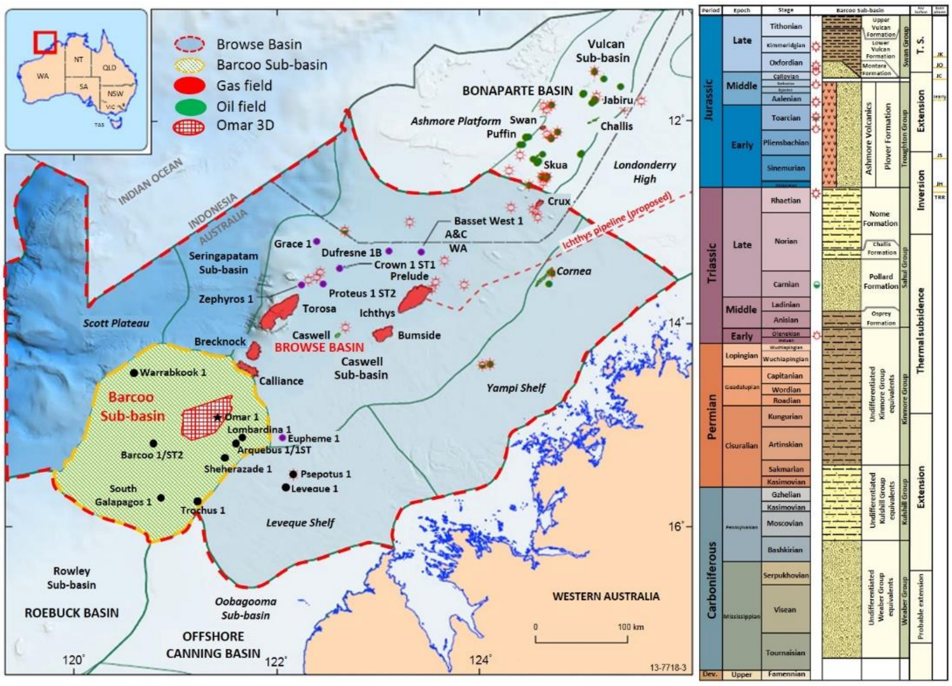

Figure 1: Location of the Browse Basin in the North West Shelf of Australia, and simplified stratigraphic column of Barcoo sub-basin (modified from AGSO Browse Basin Project Team, 1997; Nicoll et al., 2009 and Gradstein et al., 2012).

PETROLEUM SYSTEM ELEMENTS AND VOLCANICS

As of volcanics role in petroleum system, they certainly have an impact, both positive and negative. In some places, explorers want to stay away from them, in others, they want to drill them to get under or even target them as they could be hydrocarbon-bearing reservoirs.

In some cases, source rocks could be locally matured by underlying volcanic activity (Tedesco, 2017), or stratigraphic traps can form within porous fractured mafic intrusions as in the Filon example in Argentina (Ortin et al., 2005). At Serpentine Plugs of the Balcones Igneous Province in Central Texas, many successful shallow fields are influenced by volcanism with some fields producing directly from the igneous lithology. This example refers to the work of Truitt (1986). These are two examples of positive effects of volcanic geology on petroleum systems.

On the other hand, circulating hot fluids where organic rich source rocks are or where hydrocarbons are accumulated in traps, most likely lead to a negative impact on petroleum systems and consequently unsuccessful wells (Hubred, 2006). In a similar way, impermeable volcanic layers within the target interval may form a barrier to migration from mature source rock intervals to reservoir rocks (Holford et al., 2017).

Volcanic rocks may also form migration barriers, working both positive and negative: non-permeable volcanic layers can perform as a seal on top of the reservoir preventing further migration, or thick volcanic sequence can build a barrier for hydrocarbon migration from the source rock into the trap as in the Maginnis-1/ST2 example in Browse Basin (Holford et al., 2017).

Igneous rocks present a very complex history and a key geological risk in the oil and gas exploration. In the NWS, the presence of volcanics is well known and documented by several operators including Inpex and Woodside at Roebuck and Browse Basins (INPEX Dinichthys North-1 Well Completion Report, 2008; Woodside Anhalt-1 Well Completion Report, 2015). It is therefore very important to develop an approach for the identification of volcanics as the economic impact for the geology of prospects is very high.

Database

The database of this study includes high-quality seismic reflection data and well information.

Several 2D seismic lines, one 3D survey and 5 wells within or near the 3D survey were reviewed or analysed in this study (Figure 2).

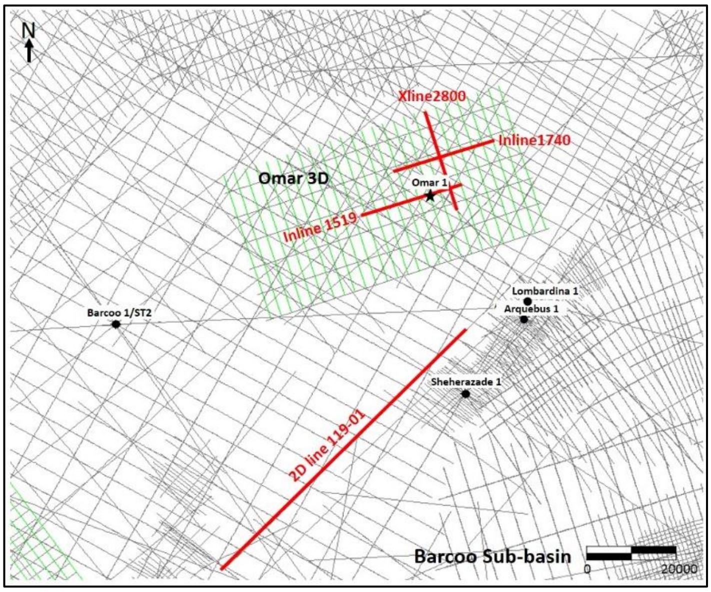

Figure 2: Map of the seismic and well data from Barcoo Sub-basin reviewed and analysed for this study. Highlighted lines in red are shown in this paper.

2D and 3D seismic data were acquired in 1998 and 2008 with recording lengths of 7s and 6s, respectively. Dataset is courtesy of Pathfinder Energy Pty Ltd and interpreted using the Kingdom Suite interpretation software.

Seismic data quality is generally moderate to high on 2D lines and regional events including faults and key surfaces can be interpreted. However, geometric configuration is recognized as a key limitation and risk in low relief structures with poor imaging. On the other hand, 3D amplitude data is relatively recent and of reasonable quality which allows delineation of differing lithological trends for identification of volcanics, specifically within the Jurassic interval.

2D seismic data have not been very successful at identifying volcanics' morphology such as ring dykes, primarily because 2D lines are spars (average 2D spacing is 6km x 10km and nothing this size or smaller can be predicted from 2D). 2D data are also limited in horizontal plane visualization, i.e. time/depth/horizon slices. Hence the 3D seismic survey was the best tool to determine the geometry of interpreted events on vertical profiles.

The 3D data is a small survey (1750 km2) and constrain mapping geologic features all over the Barcoo Sub-basin, allowing otherwise volcanics' morphology to be interpreted, that alternatively could be misunderstood on a vertical 2D seismic section.

Identification of volcanics using seismic data

Seismic data makes the geology easier to interpret for oil and gas exploration, however, the morphology of volcanics in many cases resemble features to siliciclastic facies like turbidities or fluvial delta deposits which can lead to serious pitfalls in hydrocarbon exploration, especially within the basins dominated by fluvio-deltaic sediments.

The visibility of volcanics on seismic data depends on their acoustic impedance (AI) contrast in comparison to the sedimentary layers. Layered volcanic sequences often generate strong reflections and a high amplitude anomaly. Figure 3 shows a 2D line from Browse Basin where high amplitude anomalies are interpreted as volcanic signatures.

One of the intentions of this paper is to demonstrate that 3D seismic data can be very useful in describing the geometry of volcanics allowing us to derisk prospects. A possibly unique aspect of the 3D seismic data used in this study is its high quality which permits visualizing the presence of a positive relief lithology interpreted as a ring dyke complex. The 3D geometry of this body has been examined with the extensive use of 3D seismic amplitude time slices from Omar 3D M.S.S. survey.

Figure 4 shows seismic amplitude signature with an interpreted "ring" dyke complex on 3D seismic vertical sections (at just above 3.4sec indicated with a positive relief), the corresponding amplitude time slice and similarity attribute extracted at 3.4 sec. The vertical relief is the indication that it contains harder (volcanic) rock than the surrounding sediments. Also the effect post intrusion of the volcanic is picked up with the upward deflection of seismic reflectors in the 3.1 to 3.3 sec interval. The circular' morphology on amplitude time slice is interpreted as a representation of a dyke complex intruding into the surrounding host rocks and characterized by a narrow 1.5-2 km wide disturbance of seismic reflections.

Drilling of Omar 1 has confirmed observed volcanics on seismic data in the same interval between 4338 and 4600m MDRT (Figure 5). Data from the well also indicates the rates of penetration (ROP) dropped to 3-10m/hr in this interval (Woodside Omar-1 Initial Well Completion Report, 2011) - slow and variable ROP is also an indication of a complication to drilling operations in basins with volcanics component (Millett et al., 2014).

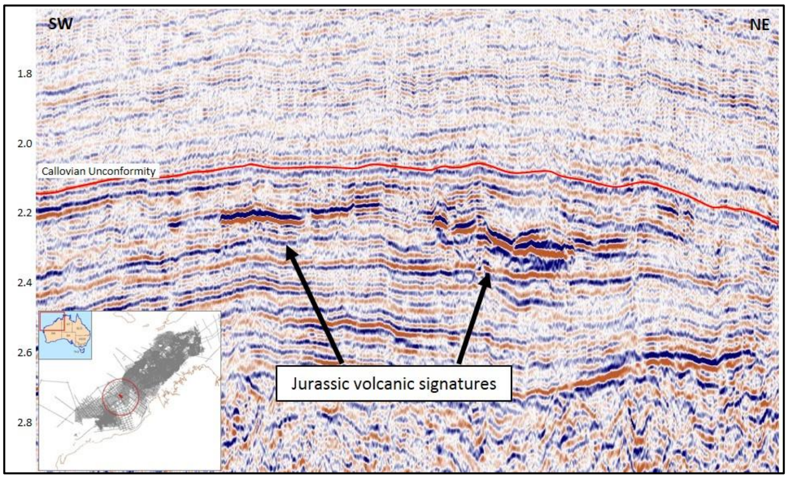

Figure 3: high amplitude anomalies between 2.2s and 2.4s are interpreted as volcanics on a 2D seismic line from Browse Basin, the NWS of Australia.

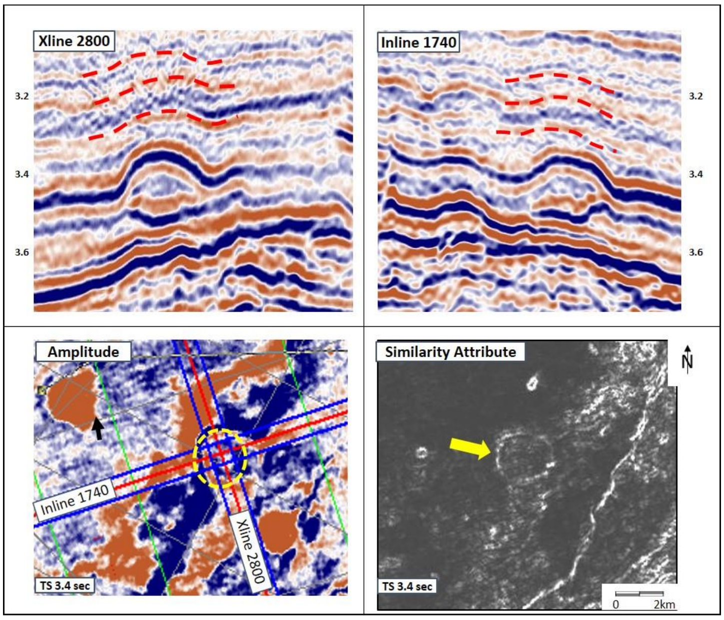

Figure 4: Positive relief associated with ring dyke recognized on vertical seismic sections and their associated time slice (Omar 3D M.S.S. survey). The upward deflection of seismic reflectors indicated with dotted red lines within 3.0 to 3.3sec time interval is considered as post intrusion effect of volcanics.

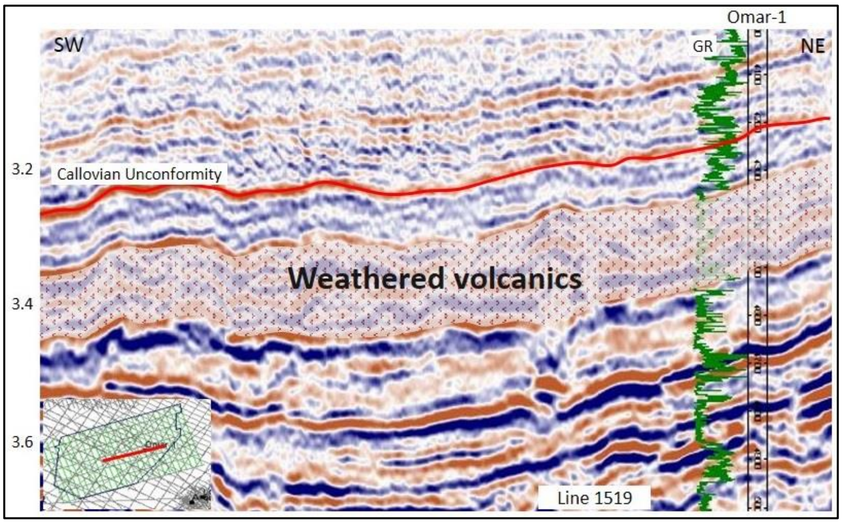

Figure 5: Omar-1 penetrated weathered volcanics between 4338-4600m MDRT (3.2s to 3.4s on seismic - within the same interval positive relief observed)

At the NWS, there are sediments deposited in a fluvial-deltaic environment with sand channels surrounded by a different lithology such as shales (Keall and Smith, 2004). Burial and overburden pressure applied to these two different lithologies, at the same depth, has different compaction responses. In other words, there are lateral changes in compaction due to the changes in lithology (sand to shale) and this results in a phenomenon known as 'differential compaction'. Like volcanics, differential compaction often appears as a positive relief on seismic data as well (Chopra and Marfurt, 2012).

As discussed above, the similarity between volcanics' morphology and differential compaction response can sometimes be very misleading; the interpreter needs to be careful differentiating between the two solely using amplitude signatures on a vertical section.

Time slices from 3D seismic data can be very useful in describing the 3D geometry of geologic events and they make the morphology easier to interpret within a geological context allowing us to derisk prospect. As demonstrated in figure 4, integrating a vertical seismic section with its associated time slice revealed the ring morphology of volcanics that alternatively could be misinterpreted as a feature related to siliciclastic facies response such as sand channels if interpreted only on a vertical 2D seismic section.

There are other useful tools to produce a more accurate picture of stratigraphic features and their spatial extension such as 3D seismic volume attributes (coherence for example can be very useful in identifying and visualizing geometry) or other attributes such as Amplitude Versus Offset (AVO) to support the lithology.

CONCLUSIONS

Two main geometries exhibited by volcanics have been recognized from 2D and 3D seismic data at Barcoo Sub-basin: Layered volcanic sequences identified as strong reflectors with high amplitude anomalies and positive relief with circular geometries associated with ring dykes.

This study demonstrates careful visualization of 3D seismic data provides a real and positive benefit to identify volcanics and hence differentiate them from siliciclastic facies or carbonates. The circular geometry associated with ring dykes identified on 3D survey is unlikely to be recognized on 2D seismic data due to their size and 2D seismic data limitation in recognizing morphology.

The observations presented in this paper have considerable implications to better understand volcanics signatures on seismic data and consequently derisk prospects in basins with igneous geology.

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