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Spatio-temporal distribution of igneous rocks and seismic facies analysis of buried volcanoes of the Prawn Platform, offshore Otway Basin

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SUMMARY

Volcanic rocks occur in different types of sedimentary basins, especially those evolving from lithospheric stretching. While volcanoes and other igneous rocks are widespread in the onshore Otway Basin, well-preserved volcanoes have not been documented in the offshore portion of the basin. Here, we analysed high-quality 2D and 3D seismic reflection datasets to investigate the spatio-temporal distribution of the igneous rocks in the Prawn Platform, offshore Otway Basin. Nineteen volcanoes, ranging from ~90–400 m in height and 1.8–6 km in diameter, occur at three stratigraphic levels: late Eocene, mid-Oligocene, and early Miocene. The igneous sills are relatively small (~0.2–11 km^2), and located immediately beneath the volcanoes, implying a synchronous intrusion activity with the volcanoes. Seismo-geomorphological analysis indicates these are shield volcanoes fed by dykes. Distinct seismic facies characterise these buried volcanoes, including the chaotic central face that represents the main volcanic eruption centre, outward-dipping moderate amplitude reflections of tuff cone, and chaotic reflections at the distal flanks representing the pyroclastic mass-wasting deposits. Interestingly, seismic facies of interbedded extrusive and sedimentary rocks are mainly observed within volcanoes over 250 m high, and are associated with gullies along their flanks, indicating these volcanoes may have been subject to subaerial erosion. The discovery of these buried volcanoes extends our understanding of magmatism in the Otway Basin, especially regarding the offshore extension of the Older Volcanics.

Key words: Buried volcanoes, seismic facies, offshore Otway Basin

INTRODUCTION

Rift and passive margin basins host various magmatic rocks (Planke et al., 2000; Holford et al., 2012). Buried volcanoes are important extrusive components of these magmatic rocks and have been encountered frequently during hydrocarbon exploration activities within sedimentary basins (Holford et al., 2012; Magee et al., 2013). These volcanoes can pose a significant risk during hydrocarbon exploration, as their external geometries are similar to that of carbonate mounds and isolated carbonate build-ups, which are commonly targeted as potential petroleum reservoirs (e.g., Watson et al., 2019). These igneous features also represent potential geo-hazards if associated with shallow gas systems (Holford et al., 2017; Sun et al., 2019). Furthermore, as a key outcome of lithospheric stretching, the occurrence and extent of volcanic rocks can provide essential insights to basin evolution, such as continental rifting and post-rift depositional processes (e.g., Planke et al., 2000).

In the onshore portion of the Otway Basin, magmatism is mainly described as remnants of shallow dykes, sills, and volcanic plugs, referred to as the Older Volcanics (Figure 1a) (~95–18 Ma). Subsequent basaltic lava fields and cones are referred to as the Newer Volcanics (~4.6 Ma to recent) (Figure 1a) (Price et al., 2003, 2014). In contrast to the existence of intensive offshore volcanism in the neighbouring Bight and Bass basins, well-developed and preserved extrusive components of this igneous system have not been documented in the offshore Otway Basin, apart from small-scale magmatic rocks that are concentrated in the inner offshore region of the basin between Portland and Cape Otway, Victoria (Holford et al., 2012).

In this study, the availability of newly released 2-D and 3-D seismic reflection datasets in the offshore Otway Basin allows us, for the first time, to characterise several buried volcanoes. Within this framework, we describe the spatio-temporal distribution of the magmatic rocks and examine the variability of internal seismic facies within the buried volcanoes. This study extends our current understanding of igneous processes

in the offshore Otway Basin and highlights facies availability within the buried volcanoes.

METHOD AND RESULTS

This study analysed 2-D and 3-D seismic reflection datasets (Figure 1b). The 3-D dataset is a high-resolution pre-stack time migrated (PSTM) seismic reflection dataset (known as the Flanagan 3-D Marine Seismic Survey). The 3-D seismic dataset covers ~974 km^2 (27 km × 42 km) in water depths of 80–150 m in the southeastern corner of the Otway Basin, ~50 km northwest of King Island and 45 km southwest of Cape Otway, Australia (Figure 1). The 3-D seismic dataset has a bin spacing of 25 m for the NE-SW oriented in-lines and 12.5 m for the NW-SE oriented crosslines. The maximum time recorded length of the data is 7 s two-way travel time (TWT). Depth-velocity curves were generated for Prawn-A1 and Whelk-1 wells to convert the height of the volcanoes from TWT (ms) to depth (m). Five main regional seismic horizons within the Cenozoic succession are interpreted, as well as the TV (top-mound horizon) and the BV (base-mound horizon) were mapped for every volcano.

Detailed seismic characterisation enabled the identification of 19 buried volcanoes, ranging from ~90–400 m in height and 1.8–6 km in diameter (Figure 1b). Relatively small (~0.2–11 km^2) igneous sills are associated with these volcanoes (Figure 1b). Based on external geometries and internal seismic architectures, we interpret these volcanoes as dyke-fed shield volcanoes. The volcanoes occur at three stratigraphic levels: late Eocene (~37 Ma), mid-Oligocene (~27–29 Ma), and early Miocene (~20 Ma), within the age of the Older Volcanics of the southern Australian margin (Niyazi et al., 2021a and 2021b).

Within the buried volcanoes, four major seismic facies (SF) are identified to analyse the internal architecture (Figure 2). SF1 is located in the centre of the volcanoes and underlain by velocity "pull-ups" and near-vertical zone disruptions (VZDs). This facies is interpreted as the main volcanic vent centre formed by magma upwelling along a vertical conduit (Figure 2). SF2 is located around SF1 and diverges away from the centre and onlaps onto the BV horizons. We interpret this facies as tuff cone, a volcanic construction unit which is commonly formed by volcanic ash falling around volcanic vents during eruptions (Figure 2). SF3 with chaotic seismic reflections at the distal part of the volcanoes, is similar to the reflections of mass transport deposits, and implies this facies is probably associated with mass-wasting depositional processes, such as pyroclastic mass-wasting flows down to the volcanic slope (Figure 2). In addition, we also identified SF4 that consists of high amplitude and continuous reflections, which are associated gullies along flanks of volcanoes over 250 m high. We interpret SF4 as interbedded extrusive and sedimentary rocks that may have been formed by subaerial erosion (Figure 2).

CONCLUSIONS

Nineteen volcanoes, ranging from ~90–400 m in height and 1.8–6 km in diameter are recognised in the Prawn Platform, offshore Otway Basin. They occur at three stratigraphic levels: late Eocene, mid-Oligocene, and early Miocene. The igneous sills are relatively small (~0.2–11 km^2), and located immediately beneath the volcanoes, implying a synchronous intrusion activity with the volcanoes. Four distinct seismic facies characterise these buried volcanoes, including the main vent centre, tuff cone, pyroclastic mass-wasting deposits and interbedded extrusive and sedimentary rocks. The discovery of large-scale, dyke fed volcanoes in the offshore Otway Basin indicates a new geographical extension of the Older Volcanics. These identified igneous rocks may have also contributed to hydrothermal circulation within the study area. Future hydrocarbon exploration programs should consider the widespread presence of igneous rocks and their impact on seismic imaging, as well as possible transmission of overpressure during drilling, in the Prawn Platform of the offshore Otway Basin.

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FIGURES

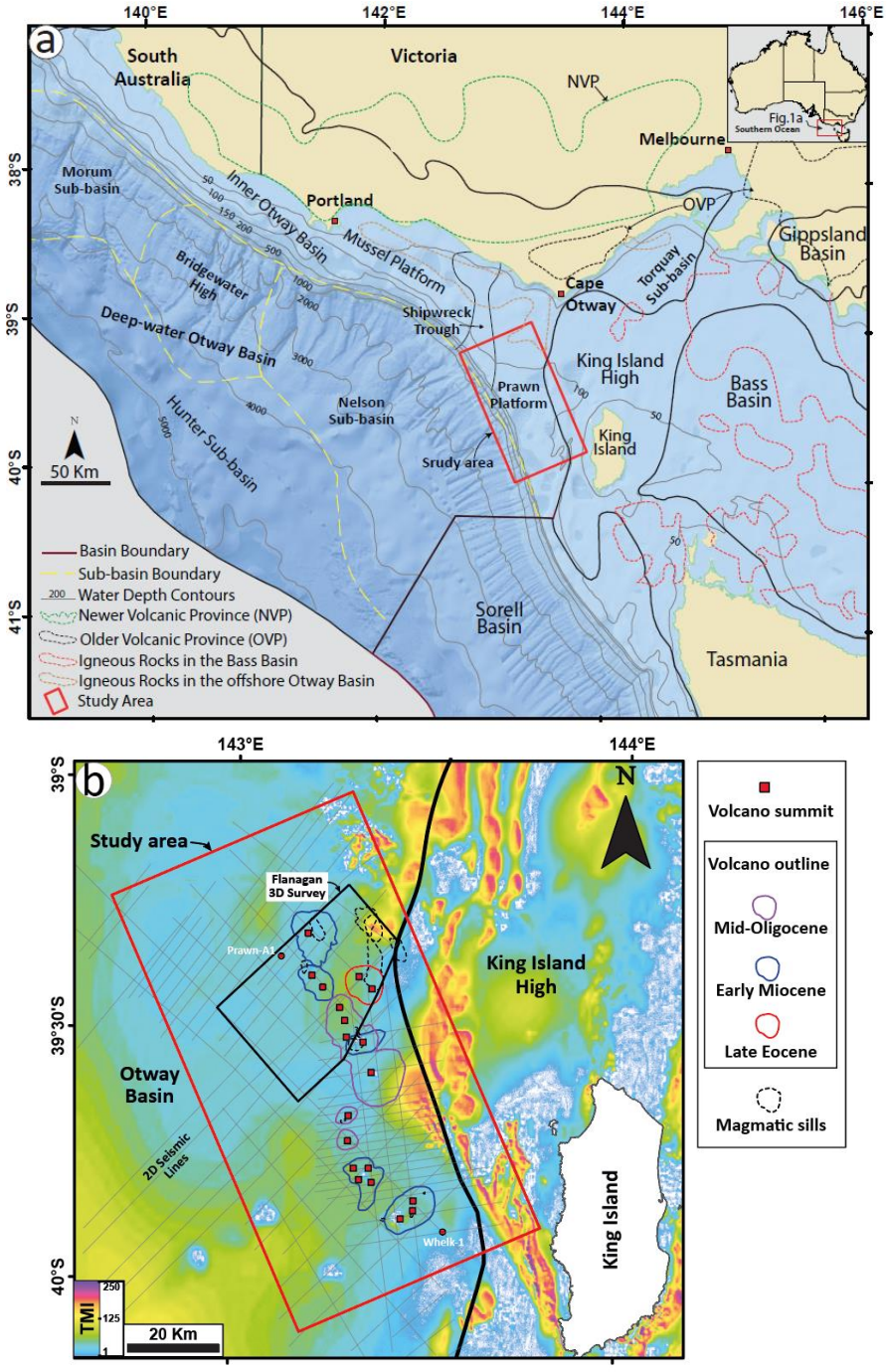

Figure 1. (a) Location of the study area (red rectangle) and surrounding structural and magmatic elements in the Otway Basin. (b) Map of the study area showing the seismic datasets identified volcanogenic mounds and magmatic sills, superimposed on the reduced to pole total magnetic intensity data.

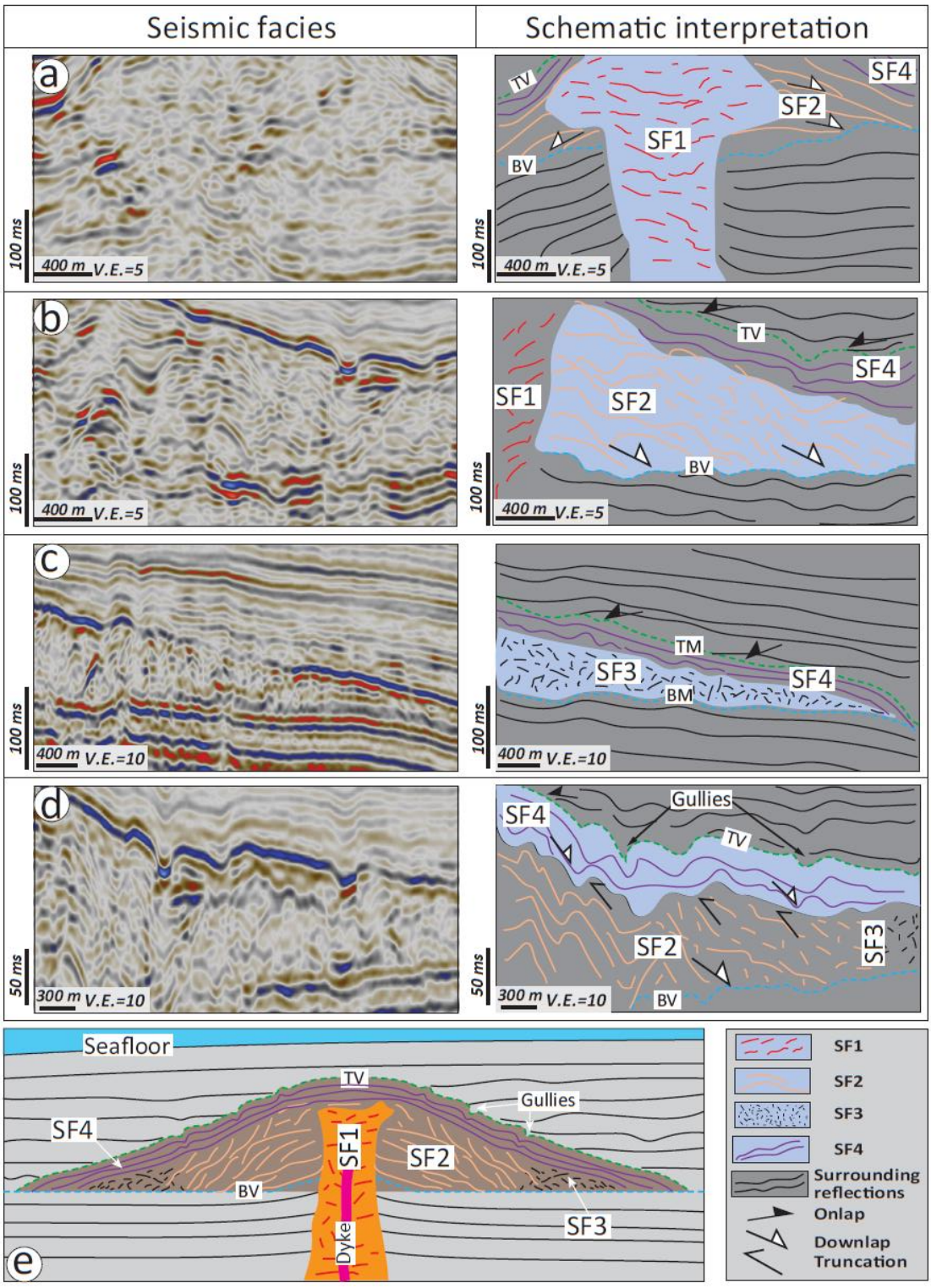

Figure 2. (a) - (d) Examples of four main seismic facies (SF1 - SF4) identified in seismic reflection dataset (left) and their schematic interpretations (right). (e) Simplified representation of the main seismic facies within a buried volcano in the Prawn Platform, offshore Otway Basin.