

MESOZOIC TO CENOZOIC DEPOSITIONAL ENVIRONMENTS & FLUID MIGRATION WITHIN THE CASWELL SUB-BASIN: KEY INSIGHTS FROM NEW INTERPRETATION & MODELLING OF THE SCHILD PHASE 2 3D

***Jarrad Grahame**

CGG Multi-Client & New Ventures

1 Ord St West Perth, WA, 6005

jarrad.grahame@cgg.com

SUMMARY

CGG Multi-Client & New Ventures have undertaken new interpretation and modelling, including stratal slicing and attribute analysis on the Schild Phase 2 3D located 170km off the north-west coast of Australia within the Caswell Sub-basin. The key objectives of the interpretation were to enhance understanding of prospectivity, paleogeographic settings and produce new insights into deeper Mesozoic – Paleozoic plays based on broadband imaging of up to 20km of sedimentary section. The following is a discussion on 2 key focus elements of the interpretation derived from the attribute analysis, comprising the identification of extensive vertical fluid / gas migration features, and fluvio-deltaic and submarine channel complexes at multiple stratigraphic levels.

Key words: Browse Basin, fluid migration, channel complexes, stratal slicing, attribute analysis

INTRODUCTION

The Schild Phase 2 3D survey is located approximately 170km off the west coast of Australia, within the Caswell sub-basin which is a major central depocenter of the Browse Basin. The survey is in close proximity to the Ichthys gas field and Cornea oil field, comprising 2,460 km² of Broadband 3D seismic data, processed to PSDM with a record length of 20km. New interpretation has been undertaken to identify and delineate depositional features and associated hydrocarbon targets within the Schild 3D. The interpretation methodology utilises stratal slicing and attribute analysis techniques, to identify and enhance visualisation of depositional features and seismic indicators of hydrocarbon migration, particularly those that approach the limit of seismic resolution and lack definition and resolution using less sophisticated interpretation techniques. Of key relevance is the presence of large-scale, localised seismic amplitude anomalies associated with vertical fluid migration, including chimney features and paleo-seafloor pockmarks. Additional depositional features, primarily submarine channel and fluvio-deltaic channel complexes were identified at multiple stratigraphic levels, hosted within Mesozoic – Cenozoic successions.

GEOLOGICAL SETTING

The Northwest Shelf of Australia formed through multiple phases of tectonic development occurring throughout the breakup of part of the continental margin of East Gondwana (Borel et al., 2002). The structural and depositional framework of the basins is characterised by cycles of tectonic deformation and clastic and carbonate sedimentation occurring from the Proterozoic when the western continental landmass of Australia was part of the supercontinent Rodinia (Li et al., 2008).

The offshore Browse Basin formed as a result of several phases of tectonic development occurring throughout the breakup of the North West continental margin of Australia. The major basin forming events which consisted of cycles of extension, inversion and thermal subsidence occurred from the Permian through to the Late Cretaceous. The basin architecture is characterised by a series of north-east trending depocenters, including the south-eastern Yampi and Leveque shelves; the central Caswell and Barcoo sub-basins; and the outboard deep water Scott Plateau. The Schild Phase 2 3D survey is located within the Caswell Sub-basin which hosts up to 20km of Paleozoic – Cenozoic sedimentary section (Blevin et al., 1997). NE trending faults constitute the dominant structural trend throughout the Schild 3D area.

Source rocks within the Caswell Sub-basin consist of Cretaceous oil prone Echuca Shoals and Jamieson Formations, and Jurassic oil and gas prone Plover and Vulcan Formations (Palu et al., 2017). The main reservoir sequences consist of Early to Middle Jurassic fluvio-deltaic Plover Formation; Cretaceous Upper Vulcan Formation, Echuca Shoals Formation and Lower and Upper Jamieson Formations which were deposited as shallow marine submarine fans and 'ponded' turbidite mounds during the post break-up phase (Geoscience Australia, 2011). The main structural trapping mechanism in this part of the basin consists of tilted fault blocks and associated anticlinal drapes as an expression of underlying structural highs, and stratigraphic pinch-outs (Geoscience Australia, 2011). The majority of wells within the Schild area intersected zones hosting residual hydrocarbons at key target levels confirming that significant volumes of hydrocarbons have been generated and migrated throughout reservoir intervals.

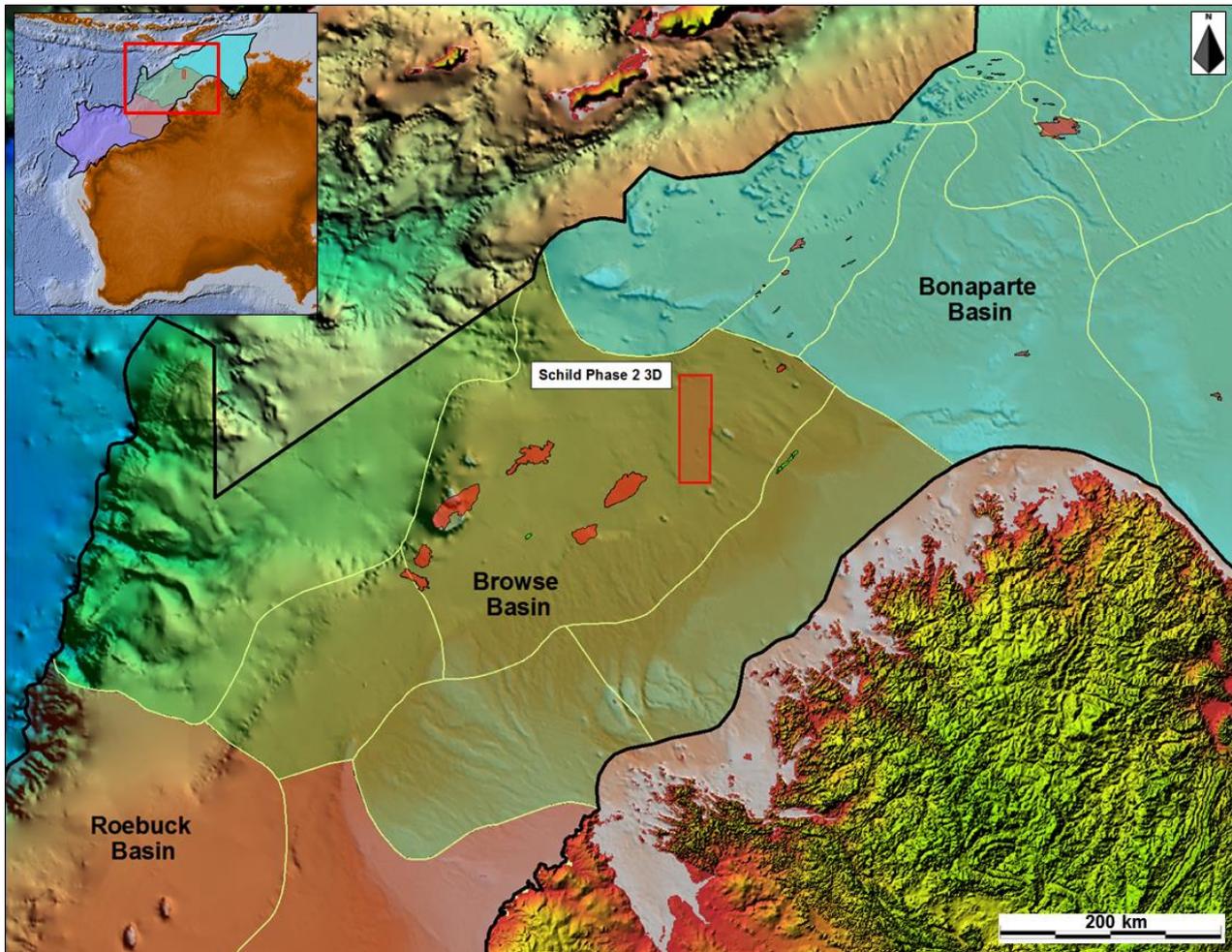


Figure 1: Schild Phase 2 3D location map within the Caswell Sub-basin.

METHODOLOGY AND RESULTS

The analysis and results discussed herein are a combination public data review and new interpretation and analysis of the Schild Phase 2 Broadband 3D seismic dataset, utilising stratal slicing and attribute analysis techniques. In addition to 3D volume based interpretation, a number of 2D lines that intersect the 3D survey area were analysed to assist in determining the spatial distribution of fluid / gas migration seismic anomalies, and depositional features.

The interpretation methodology involved a stepwise process to ultimately produce stratal slices and attributes derived from the original seismic volume using Paleoscan software. The process initially involves reconnaissance of the dataset to identify and focus on key intervals by way of time slice creation through attribute volumes, primarily Frequency Envelope and RMS Amplitude. This is followed by automated horizon picking of the entire volume to produce a suite of horizon ‘patches’, or Model Grid. Key horizon ‘patches’ are subsequently modified and infilled manually to improve the automated modelling process which can then be reiterated. Lastly, an automated 3D Geo-model from which a ‘Horizon Stack’, or suite of discrete surfaces, in the stratal domain can be created. Seismic attributes are generated during the horizon stacking process to enhance depositional features, or geo-bodies, such as channels, fans and seismic amplitude anomalies indicating the presence of migration and /or accumulation of hydrocarbons.

In addition to depositional features, primarily submarine and fluvio-deltaic channel complexes, prominent and localised vertical fluid and gas migration features were identified using the techniques outlined herein. These elements represent the key focal points for the following discussion.

Vertical fluid migration features

Large-scale, localised fluid escape features and paleo-pockmarks associated with subsurface fluid and /or gas expulsion are prevalent throughout the Caswell sub-basin and having been identified within other seismic datasets in close proximity to the Schild 3D. The features typically exhibit variable spatial properties in their vertical and lateral dimensions, and are often associated with anomalous amplitudes, velocity distortions and signal attenuation that can be pervasive throughout underlying seismic events. The seafloor expression and vertical terminations of these fluid escape features can be preserved within strata, exhibiting significant variation in scale and morphology, including km scale mounded or cratered mud volcanoes and sub-km scale pockmarks (Chen et al., 2015). The features can form abruptly, within relatively brief timescales due to sudden changes in pressure regimes often associated

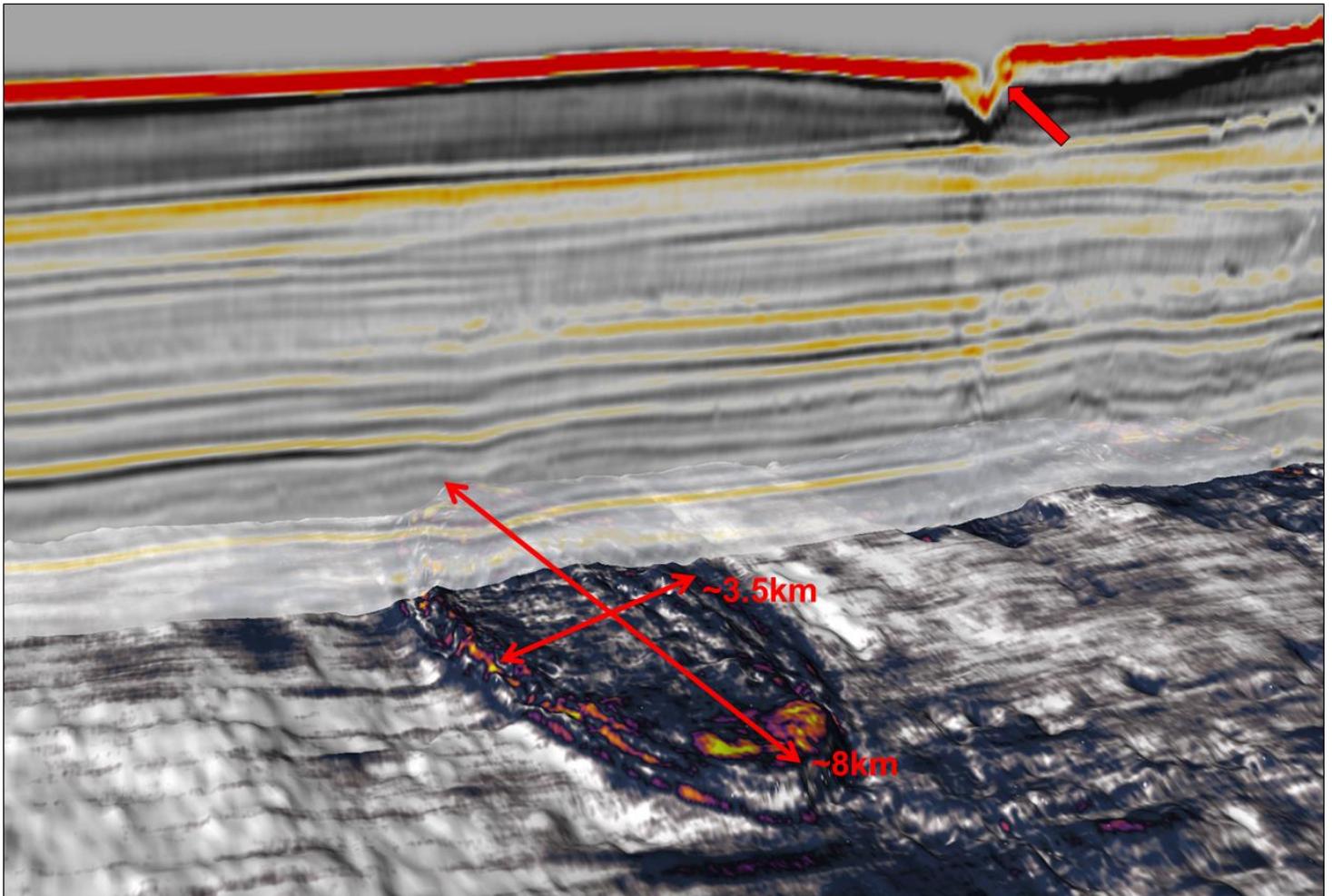


Figure 2: stratal slice with RMS amplitude attribute showing large-scale, localised, elliptical chimney feature associated with vertical fluid or gas migration.

with tectonic events, or conversely through episodic development associated with prolonged overpressure conditions and multi-phase tectonic development (Cartwright et al., 2014).

The localised fluid migration and expulsion features identified within the Schild Phase 2 3D comprise 3 main scales and morphologies. These include (primarily), km-scale circular and sub-circular mounded features, km-scale elliptical mounded features, and sub km-scale pockmarks. The features are preserved within Late Paleogene – Early Neogene successions, however the exact timeframe of development is difficult to precisely constrain given the likelihood of complex growth histories (Cartwright et al., 2014). Collision of the Australian and Eurasian plates in the Late Neogene and associated compressional fault reactivation is likely to be the dominant controlling factor in the development of the fluid expulsion features. A large number of faults intersecting Cenozoic sequences within the area propagate through to the present-day seafloor, providing conduits for fluid migration throughout the shallow subsurface. Satellite sea surface slick analysis confirms the presence of active hydrocarbon expulsion throughout this area in the present day, associated with shallow faulting.

An example of a large-scale, elliptical feature with positive paleo-seafloor relief is illustrated in Figure 2. The feature exhibits a high degree of ellipticity, likely as a function of seafloor topography and structural controls at work during development (Cartwright et al., 2014). Utilising the RMS amplitude horizon stack, or stratal slice volume, the feature can be seen to develop vertically, initiating as a cluster of discrete, small-scale expulsion features which progressively dilate and nucleate into a single mounded feature at the termination level. This type of fluid escape pipe development is one of a number of growth models that involves initial development of a complex network of feeder pipes that nucleate in later stages of growth to form a single expulsion feature, likely in the form of a mud volcano (Chen et al., 2015).

As illustrated in Figures 3a, 3b and 3c, a number of large-scale, localised circular features are present both in individual and composite clusters, highlighting the extent of fluid and / or gas migration throughout the area. Figures 1a and 1b demonstrate the interaction with pre-existing depositional features, in this case Cenozoic submarine channel complexes within the shallow subsurface. In addition to large-scale features, the RMS Amplitude results confirm the presence of sub km-scale paleo-seafloor pockmarks at the same stratigraphic level (Figure 3c), which are virtually undetectable without the application of attribute analysis techniques, as they approach the limit of seismic resolution. The presence of large-scale expulsion features in combination with small-scale paleo seafloor pockmarks establishes a complex hydrodynamic history and confirms that large volumes of fluid and gas have migrated through the area. Of key relevance to hydrocarbon prospectivity is to establish the structural controls on late-stage fluid migration due to fault reactivation, and preservation of seal integrity within deeper target intervals.

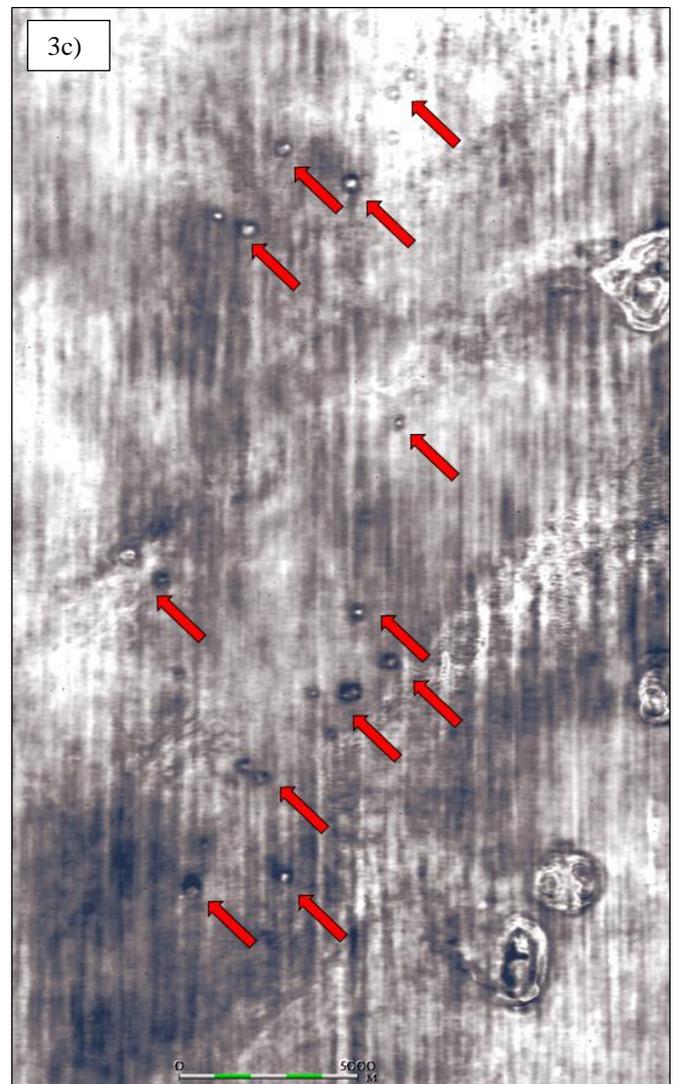
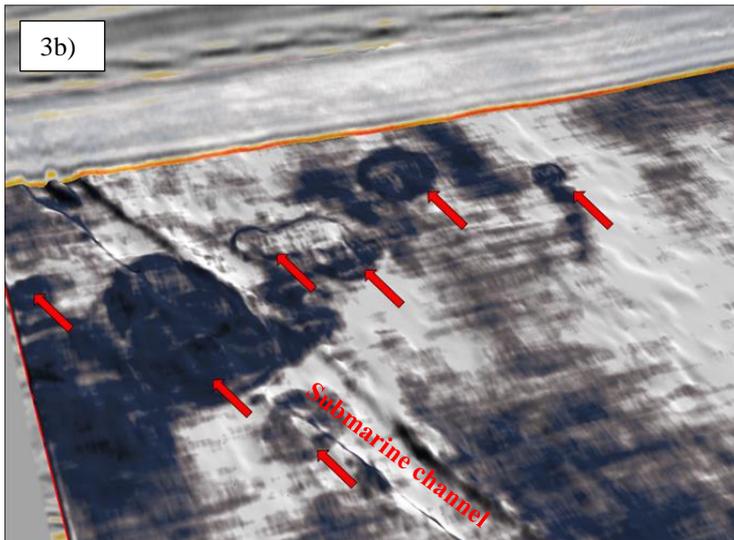
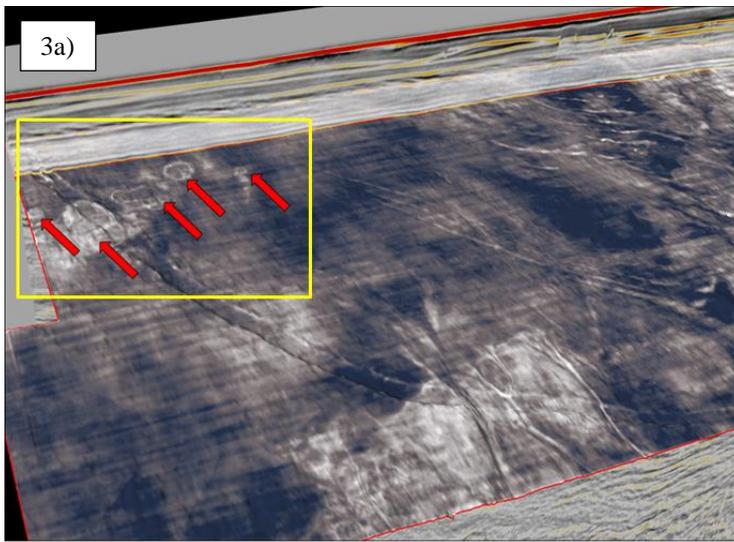


Figure 3a: stratal slice with RMS amplitude attribute showing large-scale, localised chimney features intersecting shallow submarine channel. **Figure 3b:** zoomed view of fluid escape features intersecting channel. **Figure 3c:** clusters of composite, large-scale features in combination with small-scale pockmarks

Mesozoic – Cainozoic channel complexes

In addition to the identification of paleo fluid-escape features, the stratal slicing and attribute analysis confirms the presence of a number of depositional elements, primarily sub-marine and fluvio-deltaic channel complexes at multiple stratigraphic levels. These depositional systems are of particular interest for hydrocarbon exploration, given the scarcity of well developed, coarse-grained sediments in deep-water environments. Key spatial and morphological features of the channel systems can be identified to better understand the modes of formation and depositional settings. The most critical controlling factor in channel formation can be attributed to variation in sediment supply over time as a result of sea level fluctuation and sediment supply rate (Broucke et al, 2003). Deep-water channel systems often exhibit similar geometries and features to fluvial their fluvio-deltaic counterparts, including highly variable sinuosity, avulsions, meander cut-offs and overbank deposits (Kolla et al., 2007).

The channel systems identified within the Schild 3D are hosted within multiple stratigraphic intervals of Mesozoic to Cenozoic age and exhibit variable depositional characteristics reflecting the interplay and cyclicity of depositional settings throughout the basin development. The shallowest observable channel system can be seen in Figure 1a & 1b intersecting Miocene sedimentary section. The main channel exhibits very low sinuosity which can be attributed to sediment flow parameters and bathymetric gradient at the time of deposition (Kolla et al., 2007). The main channel has an average width of approximately 1km and can be seen to be intersected by a network of distributary channels, as well as a number of vertical fluid escape features, as discussed previously.

Figure 4a highlights an extensive and complex network of Paleogene channels, exhibiting highly variable sinuosity and channel braided distribution. These parameters indicate that the channel systems likely developed within a sea level lowstand, fluvio-deltaic depositional environment. These channel networks approach the limits of seismic resolution, highlighting the benefits of amplitude attribute analysis, in this case the RMS amplitude response which provides very clear definition of the depositional system.

Lastly, preserved segments of sinuous channels can be identified within Jurassic successions, as seen in Figure 4b. These channel features likely represent the seaward progression of Plover Formation fluvio-deltaic systems which were deposited extensively throughout the greater Browse and Bonaparte basin areas. These fluvio-deltaic sediments represent a key reservoir target and highlight significant potential for reservoir sand development at the deeper Jurassic level, within the Schild 3D area.

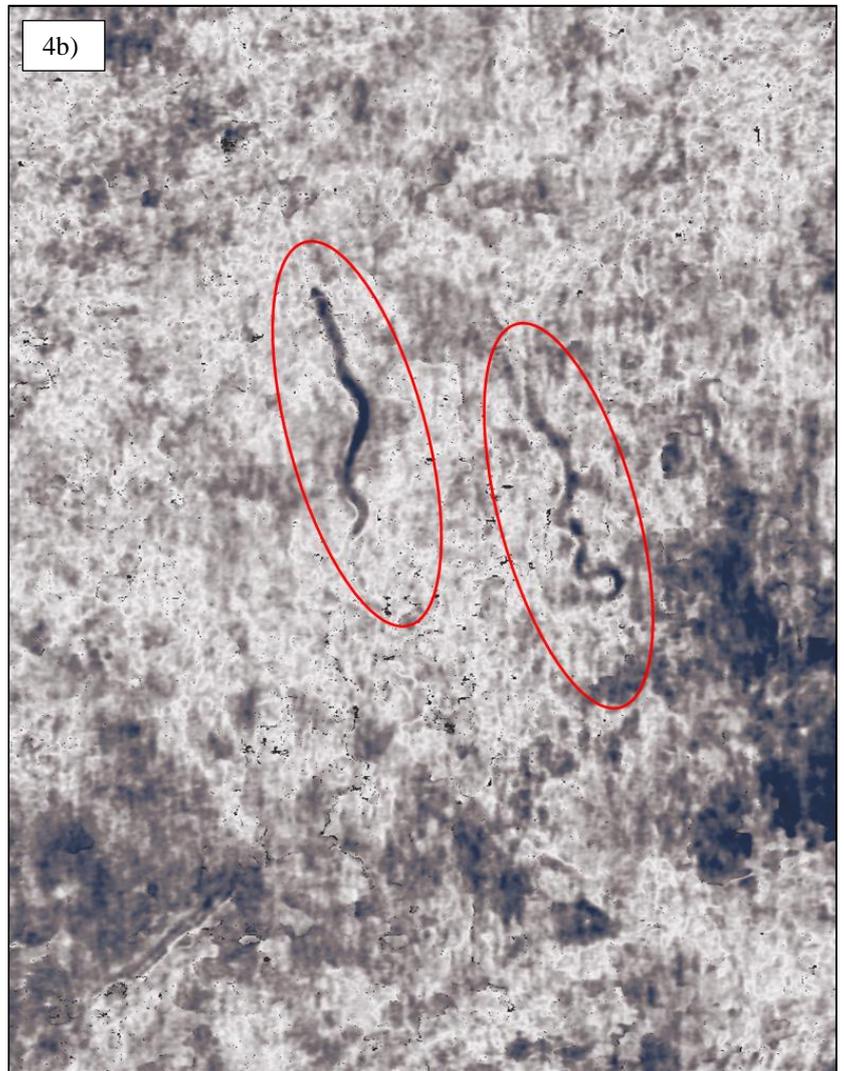
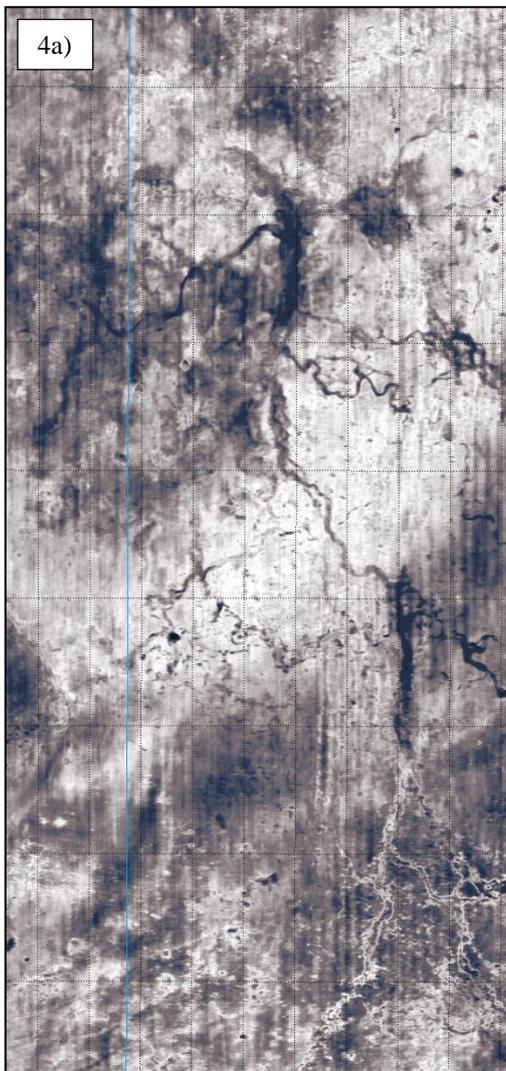


Figure 4a: stratal slice with RMS amplitude attribute highlighting extensive complex channel networks. Figure 4b: Mesozoic channels segments

CONCLUSIONS

Important features associated with recent fluid migration and paleo-depositional systems can be identified with the application of automated horizon picking and modelling, stratal slicing, and attribute volume generation. The techniques discussed herein provide significant enhancements for visualisation of features that approach the limit of seismic resolution, such as complex channel systems and paleo-fluid escape features.

A large number of fluid migration and expulsion features can be identified within Cenozoic successions, throughout the Schild 3D area. These widespread features exhibit characteristic anomalous amplitude responses and velocity distortion, typical of similar features described from published seismic analogues. The paleo-seafloor expressions of the features range in size and morphology from km-scale circular and elliptical terminations, to sub km-scale paleo-seafloor pockmarks. This recent fluid migration can largely be attributed to late-stage fault reactivation associated with the collision of the Australian and Eurasian plates, and highlights the implications for trap integrity at deeper target levels. Understanding the extent and structural controls on seal preservation is therefore of particular relevance in this area.

In addition to fluid migration features, extensive and complex channel networks have been identified at multiple stratigraphic levels within the Schild 3D. The channel systems exhibit variable depositional characteristics, including variable sinuosities, spatial profiles and distribution extents. These channel complexes represent significant depositional systems associated with transport of large volumes of sediment and are therefore an important consideration for understanding reservoir distribution, particularly at deeper Mesozoic target levels.

Further volume based, attribute analysis would be highly beneficial in modelling and enhancing understanding of deeper Paleozoic – Mesozoic successions and potential new hydrocarbon plays to enhance exploration of this highly prolific area.

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