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Abstract

Tectonic inversion reshapes sedimentary basins when later shortening overprints earlier rifting, reorganizing stresses, topography, and fluid pathways. Because its seismic expression can be subtle and overprinted, inversion is often mapped inconsistently. The Exmouth Plateau (NW Shelf of Australia) preserves a thick rift-to-passive-margin succession and high-resolution 3D seismic data that image complex fault networks. Using horizon-based 3D mapping, variance attributes, and along-strike (T-x) and depth (T-z) throw analyses, we quantify fault segmentation, linkage, and reactivation, and diagnose inversion using reverse drag and “snakehead” forced-fold geometries. The general problem is to determine where, when, and why inversion localizes within a segmented rift architecture. Here we show that inversion is selective, restricted to two discrete uplifted domains, and focused where segmented faults overlap and interact, with deeper buttressing enhancing shortening during later stress reorganization. Compared with the view that inversion primarily tracks the magnitude of far-field compression, our results show that inherited three-dimensional fault geometry strongly modulates strain partitioning. Displacement patterns show predominantly blind fault growth during rifting, followed by later reactivation and segment linkage that created mechanically favorable sites for contractional reorganization. This yields transferable seismic criteria for separating inversion *sensu stricto* from non-inversion deformation in multiphase basins. Importantly, this framework improves tectono-stratigraphic reconstructions and sharpens predictions of inversion-related traps, compartmentalization, and breach risk. More generally, it illustrates a cross-disciplinary principle: system response to new forcing is often governed by inherited architecture.

Keywords: Tectonic inversion, Fault reactivation, 3D seismic interpretation, Exmouth Plateau, Fault throw analysis

Highlights

- Inversion is selective, concentrating into two discrete uplift domains rather than broadly overprinting the rift system.
- Inversion localizes where segmented rift faults overlap and interact, linking structural inheritance to strain partitioning.
- Fault throw patterns and forced fold geometries reveal a shift from blind rift fault growth to later segment linkage and reactivation.
- A transferable 3D seismic workflow is provided to distinguish inversion *sensu stricto* from non inversion deformation and improve trap and compartmentalization prediction.

1. Tectonic inversion structures on seismic reflection data: Definitions, challenges, insights, and interpretation strategies.

Tectonic inversion, the reorganisation of rifted sedimentary basins during later shortening, sits at the crossroads of plate kinematics, lithospheric rheology, and the evolution of resource-bearing basins worldwide. Through modification of inherited extensional architecture, inversion can reshape basin topography, redirect fluid pathways, and reorganise the structural framework that governs petroleum system development (Buchanan and Buchanan, 1995; Cooper et al., 1989; Coward, 1994). Yet inversion is not a simple “fault reversal” story. Uplift and shortening may be expressed through folding, tilting, fault rotation, and localised doming, and can occur with only partial or even negligible, reactivation of the faults that first created the basin (Cooper and Williams, 1989). This diversity of outcomes makes tectonic inversion both scientifically consequential and extremely difficult to reconstruct from subsurface data.

Classically, inversion is framed as a switch from extension to compression or transpression, sometimes after long intervals of tectonic quiescence and post-rift sediment accumulation. In many basins, the most visible expression is positive inversion, where contraction partially or fully reactivates normal faults and generates uplifted fault blocks, rotated hanging walls, and fault-propagation folds (Butler and Mazzoli, 2006; Turner and Williams, 2004). These structures commonly show a depth-dependent kinematic signature where net extension at depth paired with net shortening at shallower levels, reflecting how strain is partitioned through layered stratigraphy and evolving fault strength (Morley et al., 2001; Underhill and Paterson, 1998). Negative inversion, by contrast, involves renewed extension of formerly contractional structures and is comparatively uncommon, typically restricted to the interiors of mature orogenic systems (Bally et al., 1966; Powell and Williams, 1989). While these end-members are well described, real basins often fall between them, and it is this grey zone, hybrid geometries, overprinting, and subtle deformation that remains the practical frontier for interpretation.

The central challenge is that inversion leaves signatures that are easy to define conceptually but hard to diagnose unambiguously in seismic reflection data. In multiphase tectonic settings, structural overprinting can blur the boundary between extension-related growth, later shortening, and unrelated deformation mechanisms. Inversion structures may combine extensional and contractional traits within a single fault array or fold system, with their final geometry controlled by fault dip and segmentation, the orientation of evolving stress fields, and rheological contrasts within the basin fill (Turner and Williams, 2004; Lowell, 1995). Fault scale and maturity further

influence whether reactivation is likely and how displacement is distributed across connected structures (Reilly et al., 2017). Complicating matters, folding and tilting can occur without clear fault reactivation, making it essential to separate inversion *sensu stricto* from broader, inversion-related deformation. Even widely used diagnostic markers such as “null points” i.e., positions along a fault where net slip changes sign may be absent, obscured by limited imaging, or rendered ambiguous by later strain (Turner and Williams, 2004). These interpretive difficulties are amplified where well control is sparse, deeper intervals are poorly resolved, or deformation is distributed across wide zones (Jackson et al., 2013; Shaw et al., 2005). As a result, inversion is often mapped inconsistently within and between basins, and its true spatial extent, whether local, regional, or staged through time, remains contested in many provinces (Buchanan and Buchanan, 1995).

This uncertainty is not merely academic. The ability to reconstruct inversion accurately has direct consequences for resource exploration and field development, affecting trap integrity, reservoir connectivity, and critically, the timing of trap formation relative to hydrocarbon generation and migration. Misclassifying inversion-related folds or reactivated faults can lead to overconfident trap predictions, underestimated breach risk, or flawed compartmentalisation models. At a broader scale, inversion also reflects the coupling between lithospheric deformation and surface processes, raising questions about how three-dimensional structural patterns emerge during repeated tectonic reorganisation, particularly along distal rift margins and in fold-and-thrust environments where overprinting is pervasive (Molnar and Buitert, 2023; Indrevær et al., 2017). Progress has been limited less by a lack of ideas than by a shortage of datasets capable of resolving subtle, staged deformation in three dimensions.

The Exmouth Plateau on the Northwest Shelf of Australia offers an unusual opportunity to confront these issues. Compared with the more intensively studied inboard sub-basins of the Northern Carnarvon Basin, the plateau is still underexplored despite its thick (>10 km) and relatively continuous sedimentary succession and proven hydrocarbon systems. Crucially, it preserves a multiphase tectonic history that includes Triassic–Jurassic extension, Early Cretaceous reactivation, and subtle Late Cretaceous to Neogene inversion recorded within a stratigraphic framework amenable to time-structured interpretation (Bilal and McClay, 2022). Extensive, high-resolution 3D seismic coverage enables imaging of complex fault networks and syn-tectonic architectures, including growth wedges, underfilled grabens, polygonal fault systems, and uplifted blocks, capturing how inversion overprints earlier rift fabrics. These attributes directly address long-standing interpretation bottlenecks in inversion studies: limited visibility of deeper faults, difficulty separating inversion signatures from unrelated deformation, and uneven resolution across large areas (Ha et al., 2017).

Here we use the structural complexity and data richness of the Exmouth Plateau to systematically identify and characterise phases of tectonic inversion and their tectono-stratigraphic expression. Using three-dimensional morphological mapping, structural topology, and displacement analysis, we resolve the geometry and timing of inversion-related deformation and evaluate its implications for hydrocarbon prospectivity. We focus on three linked questions: (a) what are the spatial and temporal patterns of inversion across the Exmouth Plateau; (b) which criteria most reliably separate inversion structures from non-inversion deformation in seismic reflection data; and (c) how does inversion enhance or degrade prospectivity through its effects on trap development, structural

integrity, and connectivity? Our study refines the tectonic evolution of a key segment of Australia's Northwest Shelf and advances more transferable interpretation strategies for sedimentary basins shaped by prolonged, multi-directional tectonic forcing by targeting subtle but consequential inversion signatures that conventional workflows can overlook.

2. Geological setting of the Exmouth Plateau, NW Australia.

The Exmouth Plateau is a large, subsided fragment of thinned continental crust on the North West Shelf of Australia, positioned within the Northern Carnarvon Basin (NCB) in water depths of ~0.8–4 km (Fig. 1). The plateau spans roughly 600 × 350 km and preserves a long, well-layered sedimentary record that documents progressive rifting and breakup along the western Australian margin, followed by passive-margin subsidence and later intraplate deformation. The tectono-stratigraphic framework of the NCB is ultimately tied to the breakup of Gondwana and the broader evolution of the Westralian Superbasin. Rifting processes along the margin were preceded by the Late Carboniferous separation of the Sibumasu Block from Gondwana (Metcalf, 1999), a reorganisation that set the regional boundary conditions for later basin development (Agso North West Shelf Study Group, 1994). By the Late Permian, NE-trending depocentres had developed, creating accommodation for shallow-marine clastics and carbonates and establishing the first-order architecture that later rift phases would exploit (Longley et al., 2002).

A regionally extensive marine transgression in the Early Triassic initiated deposition of predominantly marine claystone and siltstone with subordinate paralic sandstone and shelfal limestone, grouped as the Locker Shale (Bradshaw et al., 1988). This interval also includes emplacement of the Mungaroo Formation, a major mixed siliciclastic succession of sandstone and claystone with minor coal. The Mungaroo Formation prograded northwestward and spread across much of the offshore NCB (Geoscience Australia, 2022). It is central to the basin's petroleum systems, containing gas-prone source intervals that contribute to accumulations in the Dampier, Barrow and Exmouth sub-basins and across the Exmouth Plateau (Fig. 1). From the Toarcian to earliest Callovian, the basin records a shift to marine mud-dominated deposition with the Athol Formation, characterised by distinctive claystone and siltstone. In the same broad interval, regressive deltaic sandstones of the Legendre Formation accumulated, reflecting renewed sediment delivery and shoreline progradation. By the Bathonian, these systems expanded westward, driving growth of the Legendre Delta across the Dampier Sub-basin and the Rankin Platform (Geoscience Australia, 2022). Petroleum geochemistry and charge models suggest that parts of the Reindeer and Saffron–Rosemary accumulations were likely sourced from the Athol and Legendre successions (Thomas et al., 2004), underscoring the coupled stratigraphic and structural controls on charge through time.

A major plate-scale transition occurred during the Callovian–Oxfordian, when Argo Land separated from Australia and seafloor spreading initiated in the Argo Abyssal Plain (Jablonski, 1997). On the Exmouth Plateau, this episode is expressed by uplift and erosion followed by deposition of the Calypso Formation, a transgressive package of claystone and sandstone (Geoscience Australia, 2022). Importantly, this interval also saw the development of major rift-related faults along the northern margin of the plateau, imprinting a structural grain that later deformation could reactivate. Late syn-rift stratigraphy is dominated by the Barrow Delta system. Deltaic deposition began in the Exmouth Sub-basin and then prograded northward to build the lower Barrow Delta lobe

(Geoscience Australia, 2022). A younger, upper lobe developed farther east, stacking a second major sand-prone system onto the rift-margin architecture. Barrow Delta sediments commonly retain high porosity and permeability and include reservoir intervals that host giant gas accumulations such as Scarborough (Tao et al., 2013). By the Valanginian, continental breakup and sustained seafloor spreading led to widespread peneplanation and development of the Valanginian unconformity, followed by rapid subsidence and a broad transgression. A basin-wide marine succession was established, including the Birdrong Sandstone, Mardie Greensand, regionally extensive Muderong Shale, Windalia Radiolarite and Gearle Siltstone (Geoscience Australia, 2022). These units are widely associated with commercial oil accumulations, particularly in the Barrow and Dampier sub-basins, reflecting the emergence of mature source–seal–reservoir configurations during early post-breakup subsidence (Geoscience Australia, 2022).

During the mid-Santonian, tectonic stability and reduced terrigenous input promoted a decline in siliciclastic flux and set the stage for prograding shelfal carbonates along the passive margin through the Late Cretaceous and Cenozoic (Longley et al., 2002). The margin did not remain purely quiescent, however. Miocene convergence between the Australian and Eurasian plates imposed far-field stresses on the North West Shelf (Longley et al., 2002), driving local uplift, inversion and renewed faulting (Cathro and Karner, 2006; Malcolm et al., 1991). These late-stage deformation events are particularly important for this study because they reorganised trap geometries and structural closure within Cretaceous and Cenozoic successions, providing a direct link between the basin's rift inheritance and its present-day prospectivity.

3. Data and Methods

3.1 Data

The data used in this study is a high-quality, time-migrated 3-D seismic reflection volume, referred to as the Esperance 3-D volume, covering an area of 551 km² on the Exmouth Plateau in NW Australia (Fig. 1). The seismic volume has inline and crossline bin spacings of 18.75 m and 12.5 m, respectively, with a vertical sampling rate of 2 milliseconds two-way time (TWT) and a record length of approximately 6 seconds TWT. An average seismic velocity of 2000 m/s was adopted across the interval of interest, yielding a vertical resolution of approximately 10 meters, based on a dominant frequency of 50 Hz and a corresponding wavelength of 40 meters. This resolution estimate is most applicable to depths ranging from 1.2 to 3.5 seconds TWT, where frequency content is still relatively stable. Regional geological context was provided by three other 2D seismic lines and a published stratigraphic framework (Fig. 2). The 2D lines, which have a coarser sample rate of 4 milliseconds and a longer recording length of 7 seconds, were used primarily to resolve deeper structural elements, despite showing lower signal quality compared to the 3D dataset. All seismic sections were displayed using the SEG reverse polarity convention (Brown, 2004), where increases in acoustic impedance result in troughs (displayed in red or yellow) and decreases result in peaks (displayed in blue). All structural interpretations were carried out in the time domain due to the absence of a detailed velocity model; however, a constant average velocity of 2000 m/s was used to provide approximate depth conversions and resolution estimates. This approach allows consistent comparison of throw and stratigraphic geometries, while acknowledging that full depth migration is beyond the scope of this study. Uncertainty in structural interpretation arises primarily from resolution limits, signal degradation in the overburden, and oblique reflector geometries. We estimate spatial uncertainty in horizon

picking to be ± 12.5 m laterally and ± 10 m vertically, corresponding to bin spacing and vertical resolution, respectively. These uncertainties may influence the precision of fault throw estimates and segmentation analysis, particularly for faults with minor offsets or poor reflector continuity.

3.2 Seismic Interpretation technique

The seismic interpretation strategy involved the identification of fifteen horizons that mark the tops of four key megasequences: pre-extension, syn-extension, post-extension, and passive margin. Horizon interpretation was carried out using the 3D seismic volume, while the broader stratigraphic context was established using the 2D lines, incorporating data from ODP Leg 122 wells (ODP 762 and 763) and previous studies (Bilal et al., 2020; Black et al., 2017; Maidment and Djokic, 2000; Malcolm et al., 1991; Reeve et al., 2016). Horizon interpretation on the 3D seismic data was conducted at intervals tailored to the structural complexity of each region. In areas with sparse or relatively simple faulting, interpretation was performed every 10 inlines (187.5 m) and every 10 crosslines (125 m). In structurally complex regions, the interval was reduced to every 5 inlines (93.75 m) and every 5 crosslines (62.5 m). This approach allowed us to balance interpretation efficiency with sufficient resolution to capture fault-horizon interactions and subtle deformation features. The interpretation strategy aligns with best practices for reducing spatial uncertainty in fault geometry (see Andrews et al., 2024).

3.3 Fault interpretation strategy

Fault mapping was performed on perpendicular seismic sections (primarily crosslines and arbitrarily oriented lines) to maximize structural clarity and ensure accurate delineation of true fault dip, following the techniques of Mansfield and Cartwright (1996). Line spacing for fault interpretation varied between 2 and 10 lines, corresponding to spatial intervals of 25 to 125 meters, depending on the local density and clarity of fault expression. Arbitrary lines were particularly valuable in zones with oblique fault orientations, allowing improved fault continuity assessment, as recommended by Carvajal et al. (2023).

To enhance fault visibility, variance seismic attributes were employed. Time-derivative variance volumes were used to highlight trace-to-trace discontinuities indicative of structural breaks or discontinuities. Faults were identified as continuous, linear high-variance zones, and their geological credibility was confirmed through vertical seismic sections to distinguish true fault planes from noise-related or processing-induced artifacts (Omosanya et al., 2017, 2018). We adopted a minimum obliquity angle of 75 degrees between the interpreted line and local fault strike to ensure that mapped features reflect true displacement surfaces. Fault sticks were generated using a combination of manual horizon-offset tracking and variance attribute guidance. Inconsistencies in fault placement across sections were resolved through cross-verification of intersecting profiles and refinement of stick positioning in 3D space, following the methods outlined in Carvajal et al. (2024) and Bond (2015).

3.4 Fault throw characterization

Fault throw was quantified to assess patterns of fault growth, segmentation, and reactivation. This involved the generation of displacement profiles in two forms: throw versus distance along strike (T–x) and throw versus depth (T–z). The T–x plots were used to analyze fault segmentation and lateral variations in displacement, following methodologies described by Cartwright and Mansfield (1998) and Baudon and Cartwright (2008). The T–z plots were used to assess vertical displacement gradients and infer growth histories, in line with techniques proposed

by Peacock and Sanderson (1991) and Mohammedyasin et al. (2016). Throw was measured on vertical sections oriented perpendicular to the local fault strike to minimize distortion due to oblique viewing angles. Displacement values were then obtained from the vertical distance between hanging-wall and footwall cut-offs on interpreted horizons. Only discrete, discontinuous throw values were included, which means the reflector offsets had to be visible and mappable across multiple profiles. Zones with continuous folding or monocline-like geometries were excluded from quantitative throw analysis to avoid conflating fault slip with ductile strain.

For the T–x analysis, emphasis was placed on two main faults, F1 and F2, which traverse the entire seismic volume. These faults were analyzed at five stratigraphic intervals: BC, JO, JP, TR, and TRR. The JK (Top Oxfordian) horizon was excluded due to its poor preservation and truncation against faults, likely resulting from erosion or non-deposition. For the T–z plots, six representative faults (F1, F2, F5, F7, F19, and F39) were selected based on their well-defined reflection geometries and observable hanging-wall growth strata. Growth packages were identified through reflection divergence, onlap, and thickness changes across horizons, as outlined in Jackson et al. (2017). To standardize comparisons across faults, T–z plots were referenced to a zero datum at the TRR horizon, which marks the base of the post-rift megasequence. Depth below this horizon was used as the vertical axis to track displacement evolution into the syn-rift interval. Consequently, evidence of reactivation was recognized in profiles where throw increased at multiple stratigraphic levels or showed localized maxima, suggesting overprinting of deformation events. Older literature on T–x plots, including the works by Nicol and Walsh (1999, 2002), were incorporated to inform interpretations of fault linkage and the recognition of fault-tip propagation patterns.

3.5 Description of inverted faults

Inverted faults were characterized using two main structural indicators: fault drag and snakehead reflections. Fault drag was identified by the bending of seismic reflectors near fault planes, with outward-curving markers showing normal drag and inward-curving markers suggesting reverse drag, following the definitions of Grasemann et al. (2005). The identification of such geometries relied on detailed mapping of cutoff positions and reflection curvature near the faults. Snakehead reflections i.e., sinuous, antiformal structures above reactivated faults, were also seen. These features are interpreted as inversion-related forced folds, commonly found in inverted rift basins (Allmendinger, 1998; Omosanya, 2020). The combination of closely spaced horizon interpretations and attribute-guided fault mapping allowed for the robust identification of these inversion features while minimizing the likelihood of misinterpretation due to resolution limits or processing artifacts. The reliability of inversion interpretations was further enhanced by integrating observations from both T–x and T–z displacement profiles, which revealed vertical and lateral changes consistent with multiphase fault activity.

4. Results

4.1 Seismic stratigraphic setting

Mapping of 15 seismic horizons across the 3D volume defines a four-megasequence seismic-stratigraphic framework (M1–M4), with megasequence boundaries selected where reflector terminations, amplitude shifts, and regional continuity change systematically (Fig. 2). The resulting seismic stratigraphic framework consists of pre-

extension (M1; TRR–LTR), syn-extension (M2; JP–TR), post-extension (M3; VU–JO), and passive margin (M4; seabed–JM) packages (Fig. 2).

Pre-extension megasequence (M1; TRR to LTR)

M1 is bounded above by horizon TRR and below by horizon LTR (Fig. 2). TRR forms a laterally continuous, high-amplitude trough reflector throughout most of the study area (Figs. 2–5). Where TRR is truncated, truncation consistently occurs next to large, deeply seated faults (Figs. 3–5). Two internal markers, TRN and LTR, are regionally traceable within M1 (Figs. 2–5). TRN is expressed as a high-amplitude, continuous trough reflector, whereas LTR is expressed as a high-amplitude, continuous peak reflector (Figs. 3–5). Beneath TRN, reflection packages are commonly continuous to semi-continuous and exhibit moderate-to-low amplitudes, with frequent intersections by deeply seated strike-slip faults (Figs. 3–5). Below LTR, reflections become predominantly chaotic, with only sparse, discontinuous low-to-moderate amplitude events preserved (Figs. 3–5).

Syn-extension megasequence (M2; ~209.5 to ~162.5 Ma)

M2 is bounded by horizon JP at the top and horizon TR at the base (Fig. 2). JP is correlated with the Top North Rankin Beds and is traceable across the study area (Fig. 2). Near the top of M2, reflectors display low-to-moderate amplitude peak character in representative sections (Figs. 3–5). The basal marker, TR (corresponding to the Brigadier Formation), is identified by comparatively high-amplitude reflections that are locally disrupted by fault intersections (Figs. 3–5). Together, JP and TR delimit a reflection package with laterally persistent internal character, punctuated by fault-related discontinuities where the mapped structures intersect the unit (Figs. 3–5).

Post-extension megasequence (M3; ~162.5 Ma to ~137.7 Ma)

M3 overlies M2 and includes multiple regionally mapped markers, including JO and JK, as well as BC (Base Cretaceous), LB (Lower Barrow), and VU (Valanginian Unconformity equivalent) (Figs. 3–5). The interval bounded by JO (lower) and JK (upper) is characterized by continuous moderate-to-high amplitude reflection packages and abundant fault-related disruption in the mapped sections (Figs. 3–5). Both JO and JK are expressed as low-amplitude trough reflectors; JK commonly thins and locally pinches out toward the crests of fault scarps (Figs. 3–5). Horizon BC is expressed as a high-amplitude peak reflector, whereas LB and VU are expressed as high-amplitude trough reflectors (Figs. 3–5). In the eastern part of the study area, LB and VU show pronounced onlap terminations onto BC (Figs. 3–5). Both VU and BC are expressed as unconformity surfaces in the seismic data based on reflector truncation and onlap relationships (Figs. 3–5).

Passive margin megasequence (M4; ~137.7 Ma to 0 Ma)

M4 extends from horizon JM upward to the seabed reflection and includes GR, BP, and BM as additional regionally mapped markers (Fig. 2). GR (Top Gearle Formation equivalent) is a laterally continuous, high-amplitude reflector that is consistently among the most prominent events in the post-rift succession (Figs. 3–5). In several sections, GR occurs at or near the upper tips of representative faults, including faults F1 and F2 (Figs. 3–5). The remaining mapped M4 horizons (JM, BP, BM, and seabed) are regionally traceable markers used to define the passive-margin package geometry in the seismic-stratigraphic framework (Fig. 2).

4.2 Interpreted faults

Fault interpretation of the 3D seismic volume identified 45 faults, dominated by extensional normal faults with map-view orientations spanning N–S, E–W, NNE–SSW, and NE–SW trends (Figs. 6–8). On the intersecting 2D profiles, more structures with strike-slip components were recognised, particularly faults that cut through the Triassic succession and extend into the Base Cretaceous interval (Figs. 3–5). Where Triassic units are intruded by magmatic sills, positive and negative flower geometries are repeatedly seen on seismic sections (Figs. 4–5). Across the 3D dataset, the mapped faults predominantly show normal displacement expressed by stratigraphic offsets in the hanging wall, with local inversion expressed by reverse separation at discrete segments (Figs. 6–8). Fault upper tips are most buried at the Base Cretaceous level, while their lower tips typically terminate within Lower Triassic intra-Mungaroo stratigraphy (Figs. 3–6).

Two faults (F1 and F2) were selected for detailed analysis because they are the largest structures in the mapped fault population (Figs. 6–11). F1 is planar to gently listric, trends NNE–SSW, and has an average strike of 032° with an average dip of $\sim 50^\circ$ to the NW (Figs. 6–11). The mapped fault trace length varies with stratigraphic level (TRR to GR), reaching a maximum of 12.92 km; maximum mapped height is ~ 2.0 km (Figs. 6, 9–11). Where the upper tip of F1 is exposed, it coincides with a subtle scarp at the GR horizon, with relief < 10 m (Figs. 6, 9). F2 is also planar to gently listric and NNE–SSW oriented, with an average strike of 013° and a dip of ~ 38 – 42° to the NW (Figs. 6–11). F2 attains a maximum trace length of 11.9 km and a maximum height of ~ 1.9 km (Figs. 6, 9–11). Upper tip positions for F2 reach the BC and locally the GR levels, most clearly in Area 1 (Fig. 6). Additional representative faults include F5, F7, F17 and F39, which trend NNE–SSW, N–S and NE–SW (Fig. 6). These faults generally dip to the SE, except F39, which dips westward (Fig. 6). Dip angles range from 35° (F5) to $\sim 46^\circ$ (F39). Maximum trace lengths are 5.5 km (F5), 5.4 km (F7), 5.2 km (F17) and 1.2 km (F39), with maximum mapped heights of 1.85 km, 1.52 km, 1.15 km and 1.30 km, respectively (Fig. 6; Figs. 9–11).

In map view and time-slice extractions, F1 and F2 show repeated intersection geometries with neighbouring faults expressed as relay ramp structures developed along strike (Figs. 6–8). These interactions are most pronounced at -3380 to -3560 ms two-way travel time (TWTT), where both soft linkage and hard linkage relationships occur (Figs. 6–8). Within this interval, F1 forms soft and hard linkages with faults F19 and F27, while fault F26 shows persistent hard linkage with F1 from -3380 to -3520 ms TWTT (Figs. 6–8). Linkage around F2 is spatially restricted: along-strike intersections commonly involve two to three neighbouring faults (Fig. 7). F2 is expressed as three principal segments (S1–S3), defined in time slices by discrete zones of elevated variance coefficient between -3280 and -3440 ms TWTT (Figs. 7a–7c). At greater depths (-3520 to -3620 ms TWTT), only segments S1 and S2 remain mappable (Figs. 7d–7f), reflecting along-strike changes in fault trace continuity and fault-plane orientation within the mapped interval (Fig. 7).

Relay ramp development is also concentrated in the overlap zone between F1 and F2. This overlap relay is clearly expressed at the Top Mungaroo horizon (TRR) but is not preserved in overlying stratigraphy, including at the Base Oxfordian level, where the corresponding ramp surface is absent (Fig. 8). On vertical seismic sections, relay zones associated with F1 and F2 are expressed by complex graben geometries and fault-bounded depocentres (Figs. 11–14).

4.3 Lateral and vertical throw distribution plots

Lateral throw distributions ($T-x$)

Lateral throw distributions for F1 and F2 vary systematically with stratigraphic level and show multi-segment geometries across the mapped horizons (Fig. 9a–i). For F1, between 2 and 5 segments are resolved depending on horizon, whereas F2 shows between 1 and 4 segments (Fig. 9a–i). Segment boundaries coincide with local displacement minima along strike, producing C-type to hybrid C-type profiles. The highest segmentation is observed at the Base Cretaceous (BC), where both faults display the most serrated traces; deeper horizons (JP, TR and TRR) show fewer segments and simpler profiles (Fig. 9). Maximum throw values (T_{max}) decrease upward through the stratigraphy for both faults (Fig. 9). For F1, T_{max} is 304 ms TWTT at TRR, 270 ms at TR, 234 ms at JP, 173 ms at JO, and 24 ms at BC (Fig. 9). For F2, T_{max} is 266 ms TWTT at TRR, 218 ms at TR, 183 ms at JP, 93 ms at JO, and 52 ms at BC (Fig. 9). Across all horizons, throw is comparatively uniform across the central part of each fault trace and decreases toward both lateral tips (Fig. 9).

Vertical throw distributions ($T-z$)

Vertical throw distributions show contrasting depth-segmentation between F1 and F2 (Fig. 10). F1 exhibits more complex vertical segmentation than F2, with profiles that are consistently asymmetric and characterised by increasing throw downward (Fig. 10a–c). For F1, T_{max} falls between 100 and 130 ms TWTT and is located within the Mungaroo Formation (Fig. 10a–c). A distinct two-segment geometry is observed on crossline 7209, where two stacked segments (S1 and S2) are resolved (Fig. 10b). F2 shows comparatively limited segmentation with depth, while retaining the same overall asymmetry and downward increase in throw (Fig. 10d–f). For F2, T_{max} ranges from 105 to 150 ms TWTT and is likewise positioned within the Mungaroo stratigraphic interval (Fig. 10d–f).

Vertical throw characteristics of other faults

Other representative faults display a broader range of $T-z$ styles (Fig. 11). F5 and F17 each show single-segment profiles with downward-increasing throw (Fig. 11b,d). In contrast, F7 and F39 are expressed as two vertically discrete segments, with changes in throw gradient across the segment boundary (Fig. 11a,f). Notably, F39 differs from the other faults by showing a skewed C-type profile, with throw increasing upward across its two segments (Fig. 11f).

4.4 Tectonic inversion in the study area

Most interpreted faults show hanging-wall geometries consistent with extension; however, inversion-related reflector geometries are concentrated in two discrete zones (Area 1 and Area 2; Fig. 6). In both zones, uplifted stratigraphic packages are observed from TRR to JO in map view and section, defining localised uplifted panels relative to surrounding strata (Figs. 6, 12). The bounding relationships between these uplifted panels and adjacent fault blocks are expressed on seismic sections by systematic changes in reflector drag, reflector reversal, and fold development (Figs. 13–15).

In Area 1, the hanging wall of F1 shows reverse drag within the JK–JP interval on representative sections (Fig. 13). Away from the F1 plane, folded “snakehead” reflector packages and anticlinal geometries occur and extend

upward into the overlying BC interval (Fig. 13d,f). Toward the northeastern segment of F1, reflectors at the BC level in the hanging wall are locally uplifted and reversed relative to correlative reflections in the footwall (Fig. 14). At BC, reverse separation is small (<10 ms TWTT) where reversal is present (Fig. 14). Below BC, reflectors spanning JK to TRN consistently show normal drag along the hanging wall of F1, with no reversal observed in that interval (Fig. 14d,f). For F2, hanging-wall reflectors at the northeastern and southwestern fault tips display predominantly normal drag (Figs. 6, 12). Within the central part of Area 1, reflectors in the JO–TR interval show pronounced normal drag adjacent to the fault plane (Fig. 15a). Beneath TRR, reflector packages include snakehead antiform geometries, whereas above TRR the BC–GR interval is characterised by reverse drag along the fault plane and additional snakehead antiforms developed away from F2 (Fig. 15a).

In Area 2, inversion-related geometries are more pervasive above TR. Reflectors above TR are uplifted and locally reversed adjacent to faults including F20 and F45 (Fig. 15d,f). Nearby faults (including F22 and F21) are associated with monocline development above the fault traces, with fold amplitudes <15 ms TWTT (Fig. 15d,f). In map view, the cumulative expression of these uplifted and reversed packages is preserved as a subtle uplifted domain at the BC level in Area 2 (Fig. 12a).

5. Discussion

5.1 Interpretation of fault growth from displacement data

Both throw distribution plots (Figs. 9 to 11) show the complex segmentation history of faults along strike and dip, albeit with milder segmentation in the dip direction compared to the strike direction. The maximum throw recorded at the TRR (Top Mungaroo Formation) suggests fault nucleation originated there, assuming the position of T_{max} remains unaffected by segmentation, linkage, or mechanical stratigraphy. Migration of T_{max} from the fault nucleation site is common due to interactions with other faults or constraints imposed by lithological or mechanical barriers (Omosanya et al., 2015; Omosanya and Alves, 2014).

Additionally, individual segments on the T-x plots with centralized T_{max} positions or C-type profiles indicate growth through radial propagation of tips, characteristic of homogeneous incompetent materials, unlike M-types, which represent faults penetrating rigid units (Muraoka and Kamata, 1983). A skewed M-type profile suggests resistance at the tip of a propagating fault by mechanically competent rock (Muraoka and Kamata, 1983). Hence, variation in the skewness of F2 indicates the fault's complex evolution and coalescence in both vertical and lateral directions, signifying oblique slip along the fault plane (Omosanya et al., 2017). Nevertheless, variations in the positioning of T_{max} on both the T-x and T-z plots suggest post-Triassic fault formation, indicating nucleation only after the deposition of the Triassic unit.

On fault propagation mode, the predominance of M-types or downward throw increase for most faults suggests growth through blind propagation of fault tips. Specifically, faults F1 and F2 exhibit radial or blind propagation growth, unlike growth through syn-sedimentary processes (Mohammedyasin et al., 2016; Omosanya et al., 2015; Omosanya and Alves, 2014). In the study area, only Fault 39 shows evidence of syn-sedimentary growth by accumulating throw as Jurassic sediments were deposited (Fig. 11f). An added insight from the T-z plots is that the geometries of the throw plots indicate fault propagation history through isolated or coherent models (Childs

et al., 2017). Mono-segment T-z profiles are akin to fault growth through radial propagation in an isolated fault model (Mattos et al., 2016; Omosanya et al., 2017). On the other hand, T-z plots with multiple segments such as F7 and F39 have developed by linkage of fault segments.

Evidence for fault reactivation is present at shallow stratigraphic levels between BC and JO on the T-x plots (Fig. 9). The segments observed at these levels for both F1 and F2 are linked at throw minima where the faults overlap or are conjoined with other faults (Fig. 8). This is proof of reactivation along the strike direction. On the other hand, mild dip linkage, indicated by displacement minima on the T-z plot on F1 and F7, further corroborates fault reactivation, suggesting reactivation along the dip. This implies initially isolated segments were linked due to fault reactivation. The serrated nature of T-x plots for F1 and F2 at BC implies interaction of their upper tips with neighboring faults due to relay ramps and splay faults in map view at the JP-BC interval (Figs. 7 to 9, 12). These splay faults also manifest as half-graben structures in seismic sections (Figs. 13 to 15). Additionally, the serrated T-x profile at shallow levels indicates contracted strata at the upper layers of both F1 and F2.

5.2 Type and timing of tectonic inversion in the study area.

Positive tectonic inversion involves the transformation of extended strata in the hanging wall of a fault, during a compression episode, into contracted strata (Williams et al., 1989). Evidence of this reversal at the upper stratigraphic layers associated with F1 and F2, as well as some other faults, has been proven in our study area (see Figs. 3 to 15). Inverting normal faults under compression significantly influences various geological aspects and, if prolonged, can lead to the formation of plateaus (Fossen, 2016).

In our study area, evidence of prolonged positive inversion is preserved by snakehead antiforms and reverse drags (see Figs. 12 to 15). The presence of extended strata at deeper depths and contracted ones at shallower levels signifies a multi-stage tectonic history on the Exmouth Plateau, involving extension followed by compression. Hence, it is impractical to explain the observed deformation through a single extensional event, especially considering the contrasting orientations and styles of these faults along both dip and strike (Dore et al., 1999; Omosanya, 2020). A thorough investigation would necessitate an examination of the regional tectonic events that have impacted the area historically, as illustrated by the conceptual evolution model in Fig. 16.

During the Triassic to Early Jurassic extension (Fig. 16), the study area and surrounding regions experienced regional extension, contemporaneous with the opening of the Ceno-Tethys Ocean (Gartrell, 2000). This resulted in the development of large, N-S to NNE-SSW trending synthetic faults with significant segmentation, overlap zones, and throw values (Bilal and McClay, 2022). A shift in dominant tectonic forces, possibly during the Tithonian-Valanginian (162.5-144.2 Ma), led to the formation of WNW-ESE trending contractional folds. These folds, often characterized by steep inclinations and upright geometries, are the "snakehead reflections" observed in Figs. 13 to 15. Although not interpreted separately here, contracted structures are present in the Dingo and Barrow Formations and are related to Late Jurassic to Early Cretaceous Contraction linked to the breakup of the Australian and Eurasian plates (Hengesh and Whitney, 2016; King et al., 2010). Another lasting regional event is the Early Cretaceous fault reactivation (137.7-123.3 Ma), which triggered the reactivation of NNE-SSW trending faults, affecting the Muderong Shale and Windalia Radiolarite Formations (Bilal and McClay, 2022). The inverted

strata in the study area are part of the Triassic to Lower Upper Cretaceous intervals. Hence, a tectonic inversion episode is established in the Lower Cretaceous (between 162.5 to 123.3 Ma), post-deposition of these layers.

Consequently, the geometries of the basin-wide folds (Areas 1 and 2) suggest that the area could have been uplifted over a wide range of time. Although the two areas are intersected by faults F1 and F2 and their associated splays, it is not impossible that inversion of the faults started earlier, during the Oxfordian to Tithonian period when NNE-SSW contractional forces impacted the basin. During this period (as shown in Fig. 16), WNW-ESE contractional folds were created, along with the intrusion of sills and dykes into the Triassic-Jurassic interval (Bilal and McClay, 2022). This implies that the observed uplifted Areas 1 and 2 might have begun developing earlier in the Late Jurassic but evolved into profound basin-wide folds during the Turonian to Paleogene period, uplifting the younger strata up to the Gearle Formation. The compression experienced during the Turonian to Paleogene was the result of regional E-W directed stresses that affected the Exmouth Plateau (Bilal and McClay, 2022).

5.3 Tectonic Inversion on the Exmouth Plateau, Australia is a multifaceted response to shifting stress regimes.

The phenomenon of tectonic inversion, a complex geological process, critically depends on stress distribution (Byerlee, 1978; King Hubbert and Rubey, 1959), which can manifest through various mechanisms such as contractional folding, volcanism, salt diapirism, differential subsidence, and compaction (Dore et al., 1999; Omosanya et al., 2017). Typically, compressional reactivation of faults occurs under external horizontal stresses resulting from plate movements, notably in continent-continent or arc-continent collision settings, leading to compression, uplift, and the reactivation of pre-existing faults (Coward, 1994). Alternatively, basin inversion may arise during ocean-continent convergence due to alterations in subduction rates and dips (Coward, 1994; Letouzey et al., 1990). In this study, we propose that tectonic inversion was prompted by multiple geological factors. Primarily, it was driven by the compression of pre-existing normal faults, enhanced by other basin-related activities such as fault segmentation, volcanism, and uplift. Hence, we posit that the inversion in the study area can be attributed to: (a) the reversal of basinal faults or uplift of bounding faults at Triassic levels, (b) the interaction of fault segments and overlap zones and (c) buttress along deeply seated basin faults.

The Exmouth Plateau underwent initial rifting during the Late Triassic to Early Jurassic, characterized by N-S to NNE-SSW extensional faults produced by WNW-ESE-directed Mesozoic rifting (Lathrop et al., 2021; Marshall and Lang, 2013). The deposition of highly condensed Jurassic syn-rift sediment on the Exmouth Plateau, coupled with the regional Oxfordian unconformity, marked the conclusion of this rift phase (Gartrell et al., 2016; Marshall and Lang, 2013). Subsequently, evidence of pre-breakup magmatism (Karner and Driscoll, 1999) led to widespread igneous intrusions and local volcanism in the Exmouth Plateau and Exmouth Sub-Basin (Symonds et al., 1998). These magmatic features are observed within the thick Triassic Mungaroo Formation on the regional 2D lines (see Figs. 3 and 4). A later contractional event during the Late Jurassic (Cathro and Karner, 2006) reactivated these faults in the opposite sense, initiating the inversion process. Several mechanisms likely contributed to this inversion. The dominant mechanism is likely the large-scale shift from a rifting to a convergent tectonic regime, possibly linked to the collision of the Australian and Eurasian plates (Hall, 2012). This regional stress change induced a reversal of movement along pre-existing faults.

Extension persisted until the Valanginian, which marked the final separation of the Indian and Australian continents (Etheridge and O'Brien, 1994). During this rifting phase, the Gascoyne and Cuvier margins experienced a potential Tithonian mantle plume, contributing to significant uplift south of the Exmouth Plateau (Black et al., 2017; Reeve et al., 2016; Rey et al., 2008). Although the passive margin formed during the Valanginian, episodes of structural inversion occurred during the Late Cretaceous (Cathro and Karner, 2006) and the Oligo-Miocene (Keep et al., 2007). Evidence for late Cretaceous inversion in the study area is shown by uplifted sections of the Mungaroo to the Base Cretaceous formations, especially in Area 2 (see Figs. 12a and 12b). Post-Cretaceous fault activities are further linked to the continental collision between the Australian and Eurasian plates (Bilal and McClay, 2022; Hall, 2012; Hengesh and Whitney, 2016; McClay et al., 2013). Additionally, the Miocene collision between the northward-moving Australian Plate and the SE Asian microplates and Timor likely contributed to the broad folding of the Exmouth Plateau Arch (Keep et al., 2007). Thus, the primary driver of tectonic inversion in the study area is regional tectonic activity, which locally involved the intrusion of magmatic materials into the Triassic overburden.

In contrast to the faults in Area 2 that are purely contracted at their upper tips (Figs. 15d and 15f), partial or selective inversion of F1 and F2 hint at the possibility of secondary factors at play during inversion. Here, we consider structural factors such as segmentation, overlap zones and the presence of buttresses as secondary drivers of uplift in the area. Beyond the overarching stress regime, fault segmentation and the presence of structural heterogeneities can influence the localization and style of inversion. Fault segments often show variations in displacement history, rock properties, and length, concentrating stress at their overlap zones (Ben-Zion and Sammis, 2003; Childs et al., 2009; Kim et al., 2004; Wibberley et al., 2008). The segmented nature of the inverted faults (F1 and F2) observed in the Exmouth Plateau suggests that these overlap zones became preferential sites for inversion due to stress concentration (Peacock and Sanderson, 1994). Buttresses can form through a range of geological phenomena, including faulting, as evidenced by the formation of buttress folds during basin inversion scenarios (Bailey et al., 2002; Schlische, 1995; Withjack et al., 2010). Additionally, margin-parallel strike-slip faults and igneous intrusions can also create buttresses (Anderson, 2013; Beck et al., 1993). In the Exmouth Plateau, competent Paleozoic units might have acted as buttresses at depth, potentially influencing the location and style of inversion along nearby faults (Faulkner et al., 2010).

This is evident from the presence of large-scale inverted faults and strike-slip segments below the Mesozoic units in (Figs. 3 to 5). However, further data and investigations are needed to definitively establish the role of buttressing in this specific case. Another potential driver of inversion is the reversal of movement along pre-existing bounding faults or faults formed during basin subsidence. The initial rifting event likely created some of the faults that later defined the basin margins. The Late Jurassic contractional phase could have caused these faults to be reactivated in reverse, uplifting the previously downthrown blocks and contributing to the overall inversion structures observed (Keep et al., 2007).

6. Conclusions

Tectonic inversion is a key, yet unevenly expressed, driver of passive-margin architecture. Using the Exmouth Plateau as a natural laboratory, this study shows that inversion does not simply reflect the timing or magnitude of

far-field compression. It is strongly modulated by the inherited structure of the rifted margin, especially fault segmentation, fault interactions, and mechanical contrasts within the stratigraphy. We find that normal faults on the plateau record complex segmentation in both strike and dip, with displacement patterns showing nucleation at specific stratigraphic levels but frequent migration of maximum throw as faults interact, overlap, and encounter mechanical or lithological barriers. Many structures grew primarily by blind tip propagation, punctuated locally by syn-sedimentary fault growth, and later evolved through reactivation and linkage of originally isolated segments. Under later compression, these inherited geometries focused strain into discrete zones, promoting inversion where overlap regions and buttressing effects amplified shortening. Importantly, our results support a multi-stage evolution in which rift-related extension was followed by contraction from the Triassic into the Early Cretaceous, and they highlight a broader principle. The style and distribution of inversion structures are predictable only when regional stress history is evaluated alongside the mechanical and geometric inheritance of fault systems. This framework strengthens tectono-stratigraphic reconstructions and provides a transferable basis for predicting inversion-related traps and compartmentalisation in mature passive-margin basins.

Authors' Contribution

KOL: Project Administration, Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Statistical Analysis, Interpretation of Results, Figure creation and editing, Writing – Review & Editing.

OOE: Resources, Validation, Visualization, Writing – Review & Editing, Quality Assurance.

YN: Resources, Validation, Visualization, Writing – Review & Editing, Quality Assurance.

LMA: Validation, Visualization, Writing – Review & Editing, Quality Assurance.

AB: Visualization, Quality Assurance.

All authors reviewed the manuscript.

Declaration

The authors declare that this work is original and has not been published previously nor is it under consideration elsewhere. All authors have read and approved the manuscript and agree to its submission. Any necessary ethical approvals and permissions were obtained, and all sources are appropriately acknowledged.

Data Availability

The datasets used in this study were provided by Geoscience Australia and are available from Geoscience Australia under their respective access conditions. Petrel® was used under an academic license granted by Schlumberger to the University of Geneva and the University of Western Australia. No new datasets were generated during this study.

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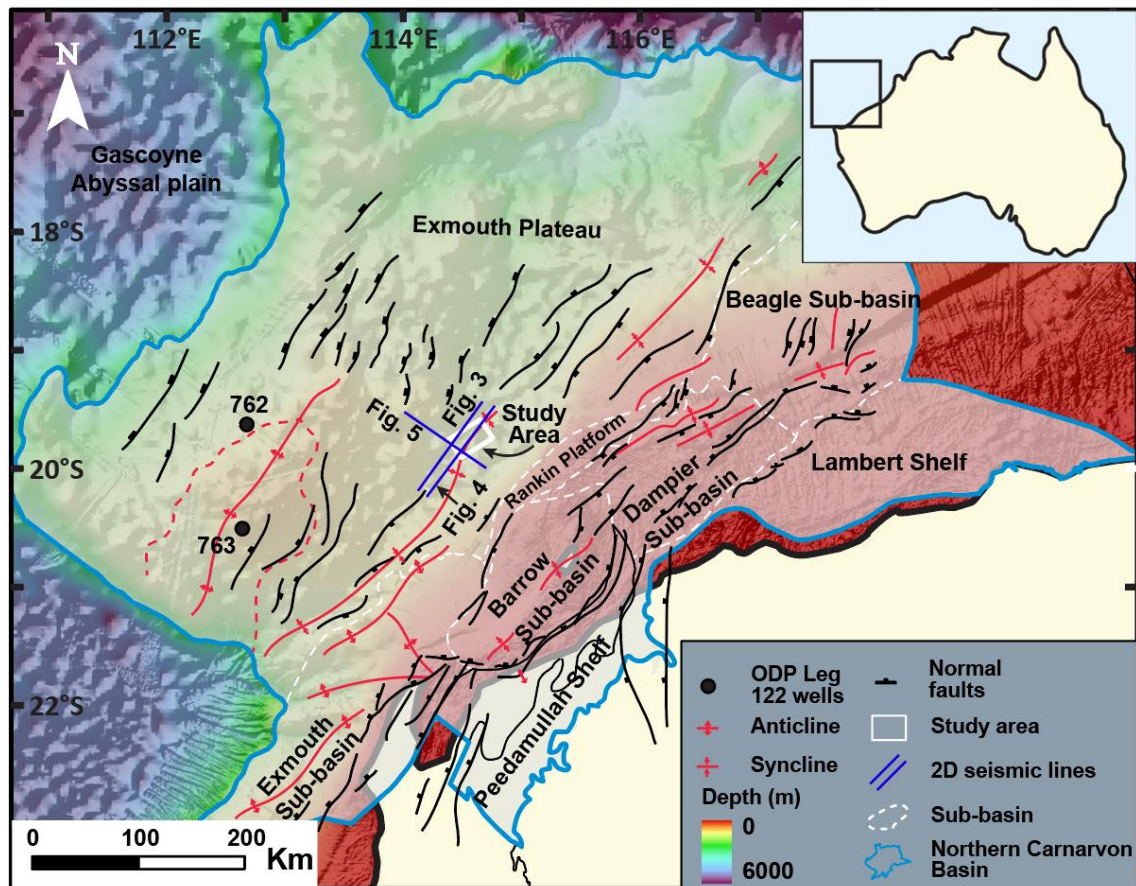


Figure 1. Location of the study area and tectonic elements of the Northern Carnarvon Basin. The structural elements are compiled from (Stagg and Colwell (1994) and (Bilal and McClay (2022)).

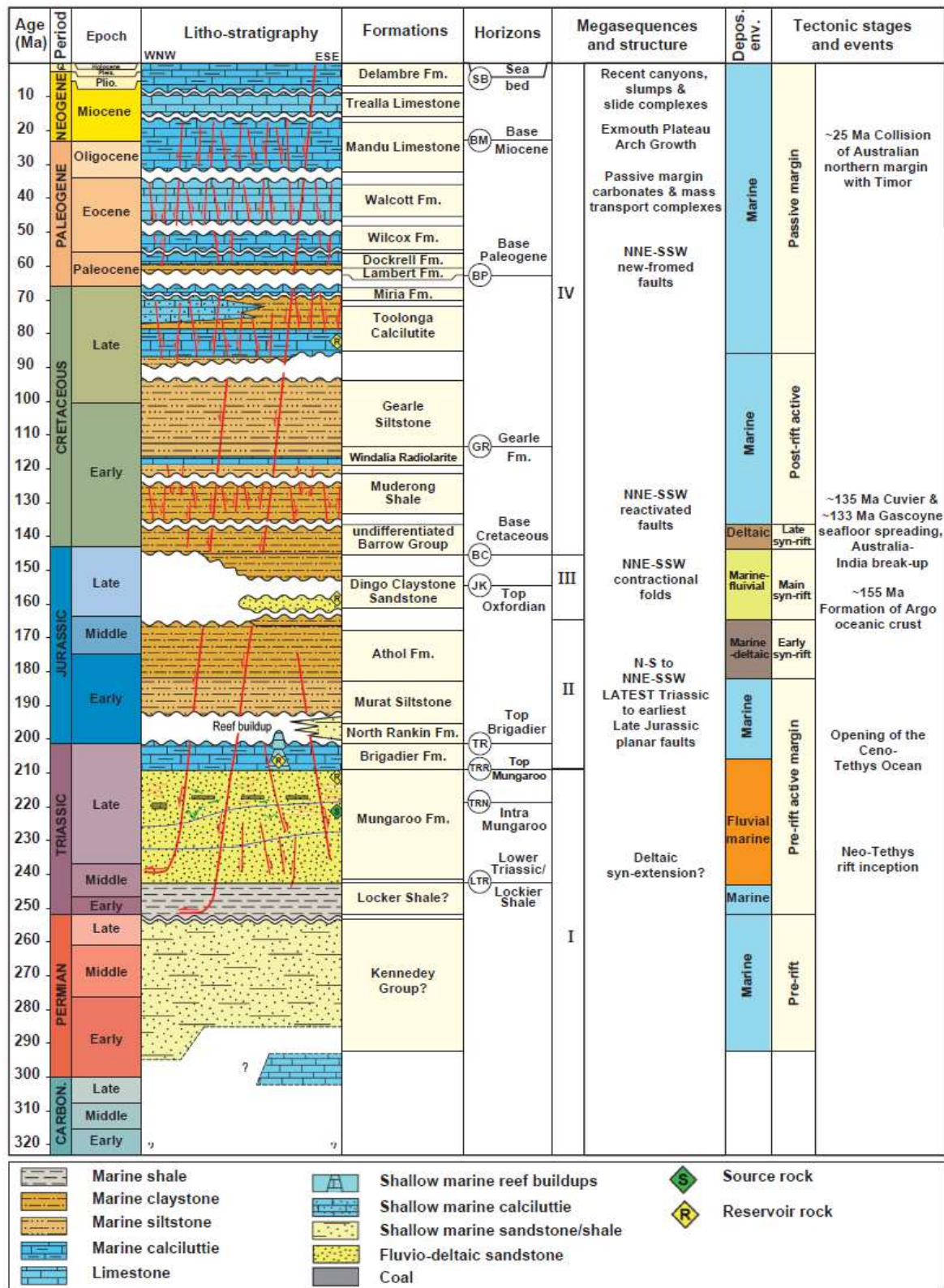


Figure 2: Tectono-stratigraphy of the central Exmouth Plateau. Litho-stratigraphic column, mega-sequences and structures are compiled from Bilal and McClay (2022). Depositional environments, tectonic stages and events are adopted from Longley et al. (2002), Gibbons et al. (2012) and Marshall and Lang (2013).

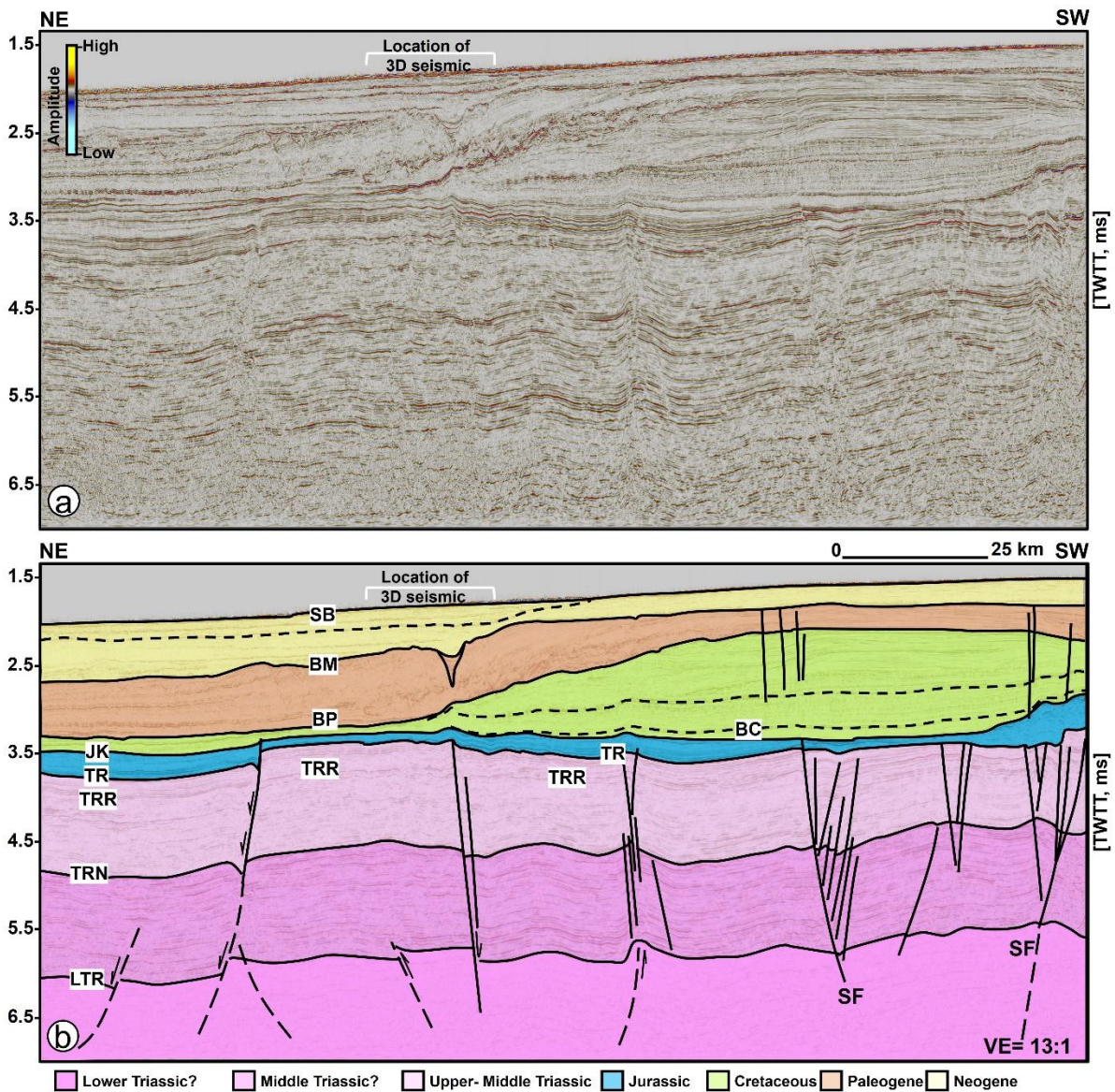


Figure 3: (a.) Uninterpreted and (b.) Interpreted NE-SW regional 2D seismic profile shows the stratigraphic and structural architecture of the study area. The Triassic intervals are affected by different types of faults, including inverted normal faults, positive and negative flower strike-slip faults. *Note: The area for the 3D seismic is marked on the Exmouth Plateau, delineating the extent of the area. SB-Seabed, BN-Base Neogene, BM- Base Miocene, BP-Base Paleogene, BC- Base Cretaceous Unconformity, JK-Top Oxfordian, TR- Top Brigadier Formation, TRR- Top Mungaroo Formation, TRN-Intra Mungaroo Formation, LTR- Lower Triassic/ Lockier Shale.*

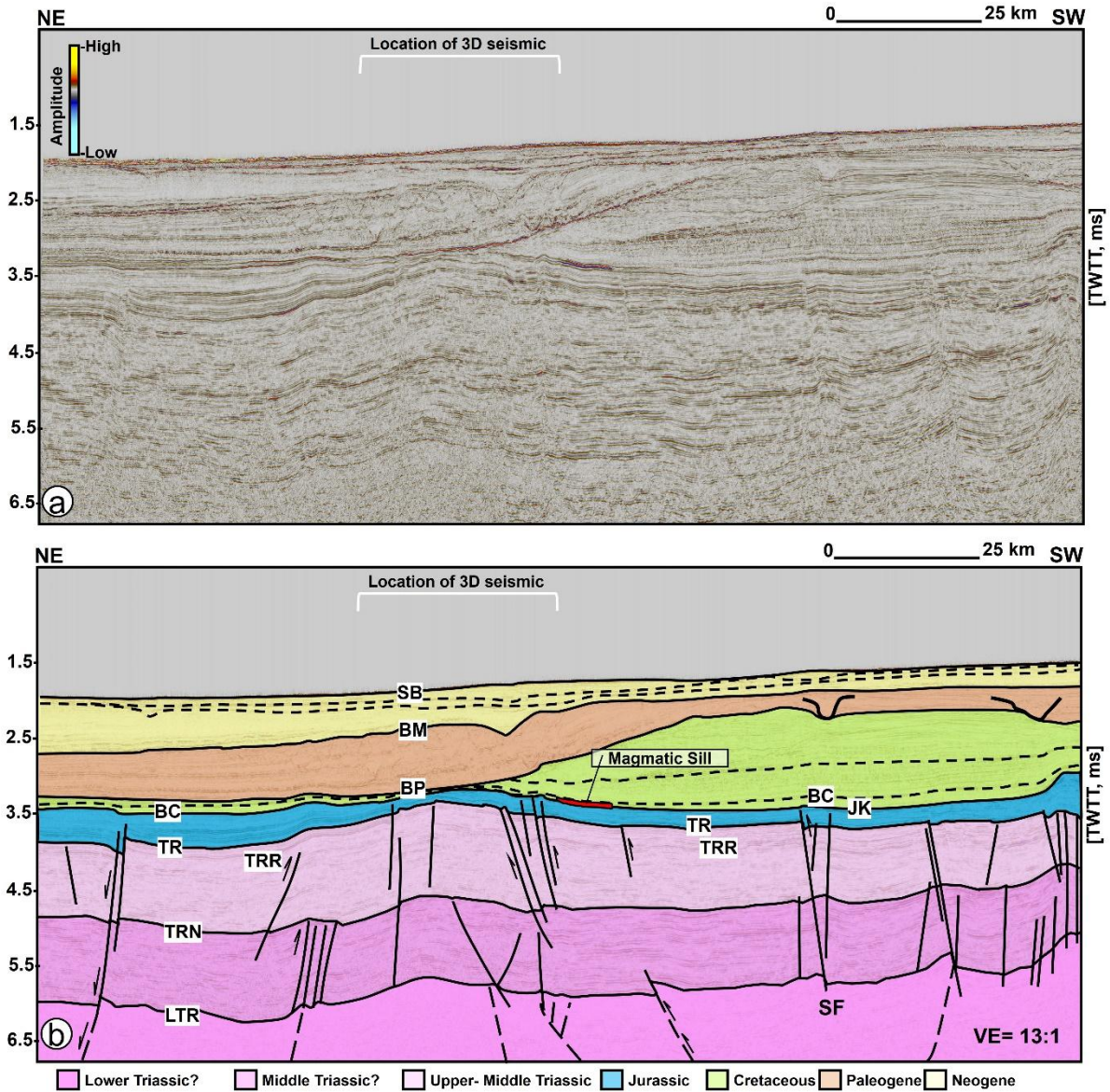


Figure 4: (a.) Uninterpreted and (b.) Interpreted NE-SW regional 2D seismic profile showing the stratigraphic and structural architecture of the study area. On this profile, most of the faults affecting the Pre-Cretaceous intervals are extensional faults except for some inverted normal faults bounding the area of the 3D seismic data. Additionally, a lateral magmatic sill is observed to be emplaced within the Upper Triassic to Jurassic units. *Note: SB-Seabed, BN-Base Neogene, BM- Base Miocene, BP-Base Paleogene, BC- Base Cretaceous Unconformity, JK-Top Oxfordian, TR- Top Brigadier Formation, TRR- Top Mungaroo Formation, TRN-Intra Mungaroo Formation, LTR- Lower Triassic/ Lockier Shale.*

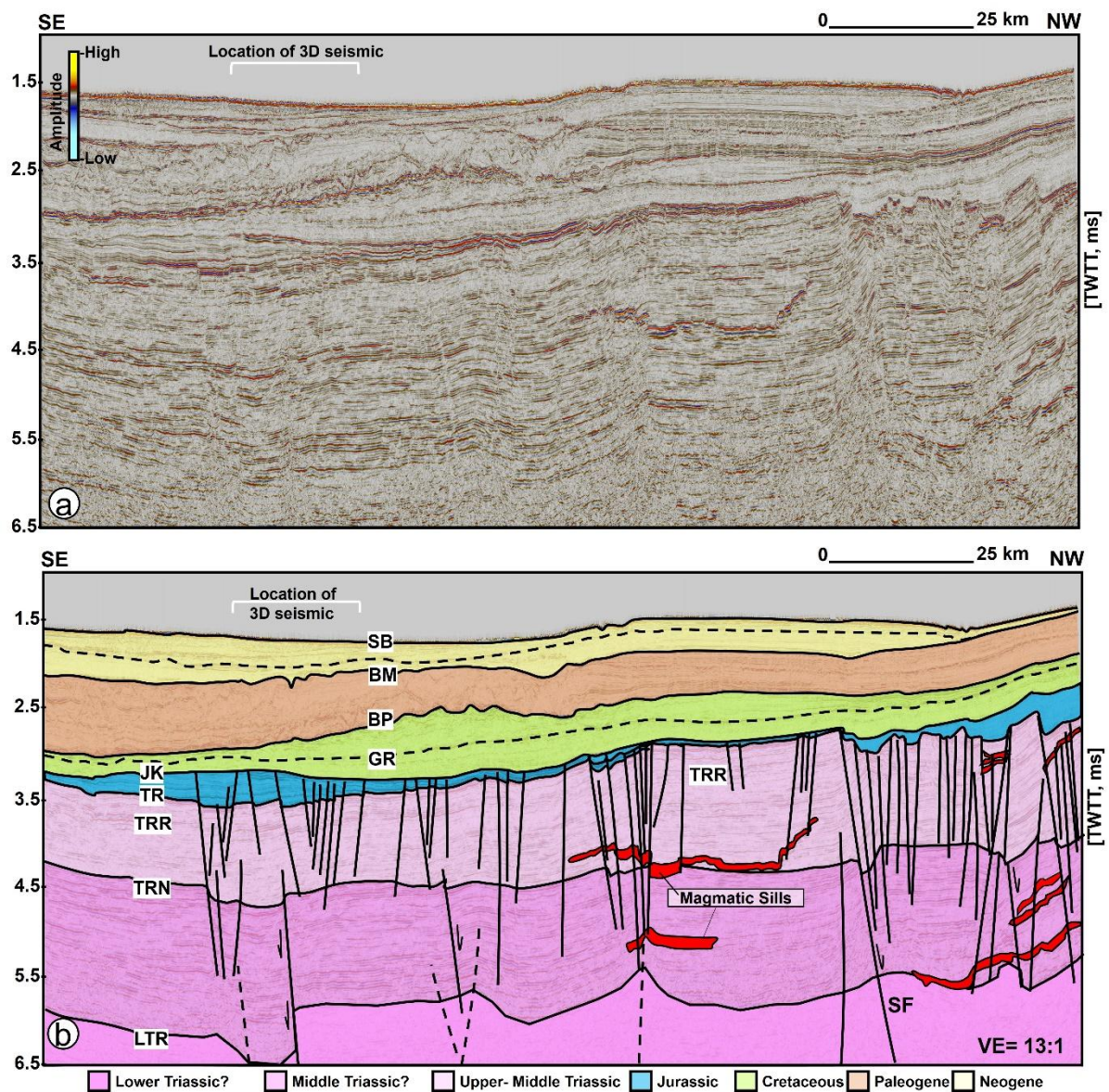


Figure 5: a. a.) Uninterpreted and (b.) Interpreted SE-NW regional 2D seismic profile shows that the Jurassic to Triassic strata of the study area are severely intersected by extensional faults and magmatic sills. Additionally, some of the faults are hard linked with basement faults, which could act as buttresses during regional tectonic interactions. *Note: SB-Seabed, BN-Base Neogene, BM- Base Miocene, BP-Base Paleogene, GR-Gearle Formation, JK-Top Oxfordian, TR- Top Brigadier Formation, TRR- Top Mungaroo Formation, TRN-Intra Mungaroo Formation, LTR- Lower Triassic/ Lockier Shale.*

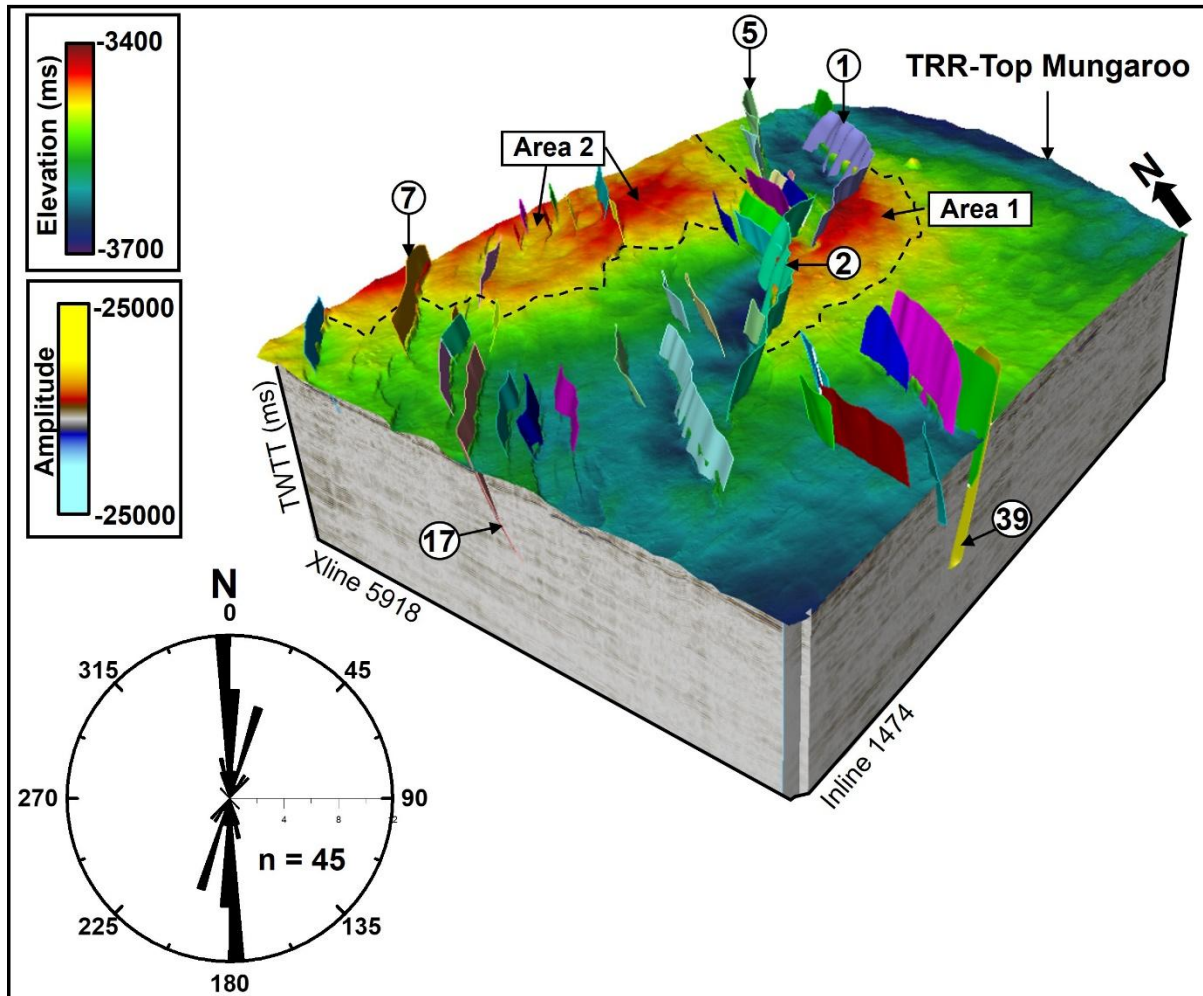


Figure 6: Structural map of the Top Mungaroo (TRR) horizon showing the interpreted faults and uplifted areas 1 and 2. The latter area was uplifted and affected by tectonic inversion linked to regional compressional events. The rose diagram for the 45 faults shows that the faults are oriented in the N-S, NNE-SSW, NE-SW, and E-W directions. In map view, many of the faults appeared extensional. However, further analysis revealed that some of them have been reactivated and inverted.

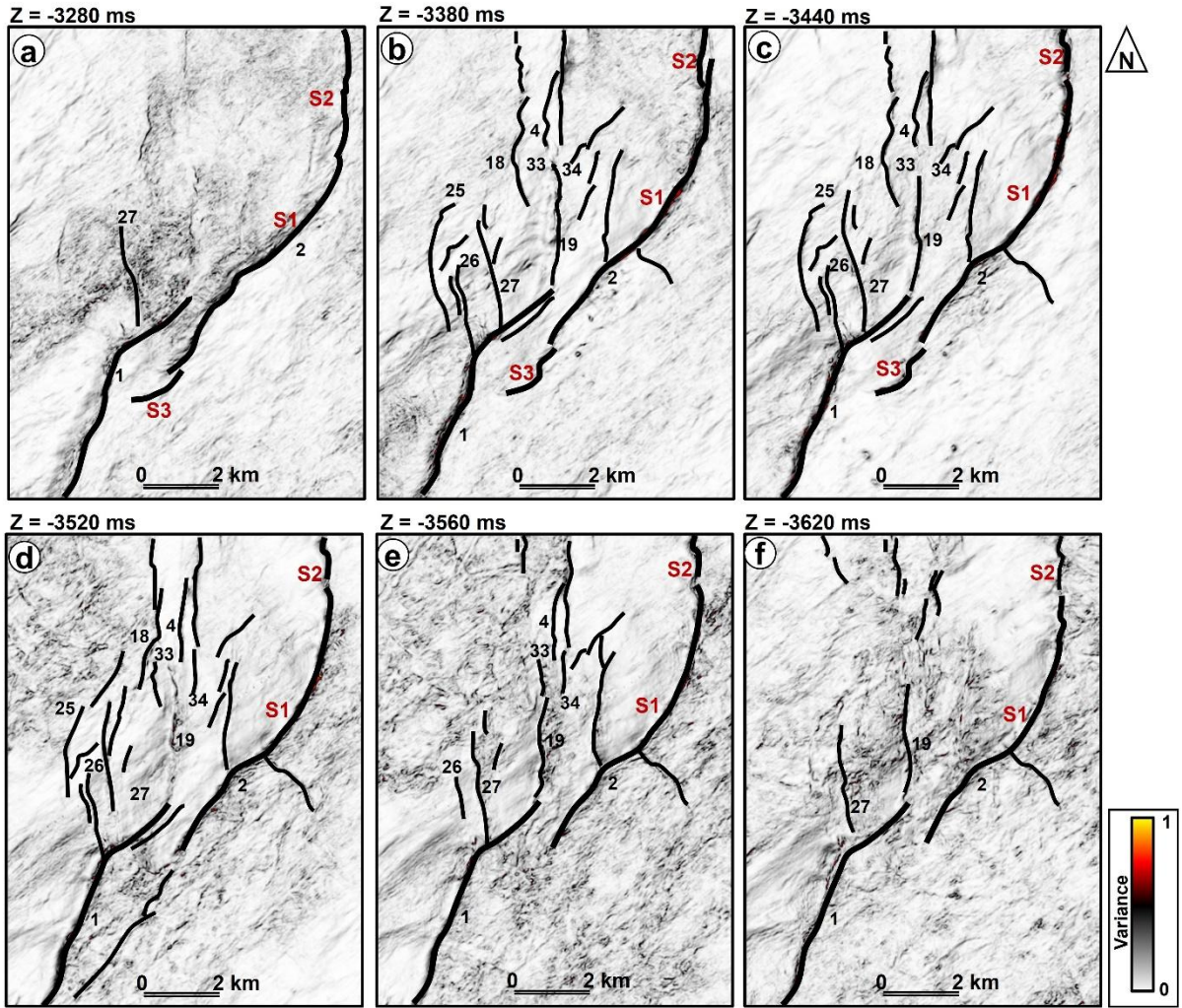


Figure 7: (a) to (f) Variance time slices from depths of -3280 ms to -3620 ms are used to validate fault interpretation and also study the interaction and segmentation of the two main faults discussed in the text. F2 was originally formed from three fault segments: S1, S2, and S3, which were kinematically and geometrically connected.

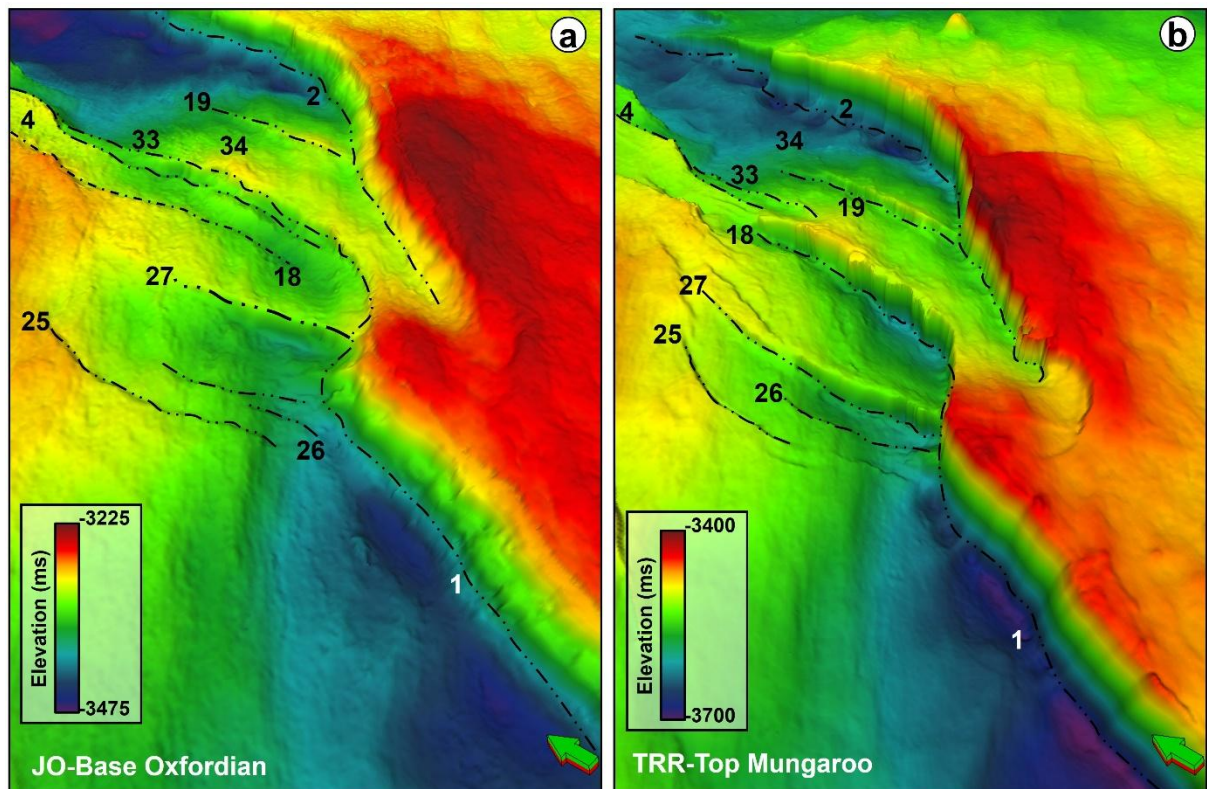


Figure 8: Structural maps of (a) JO-Base Oxfordian and (b) TRR-Top Mungaroo formations show fault segmentation patterns and the development of relay and overlap zones around the faults. The most prominent overlap zone in the study area is found between the tips of F1 and F2.

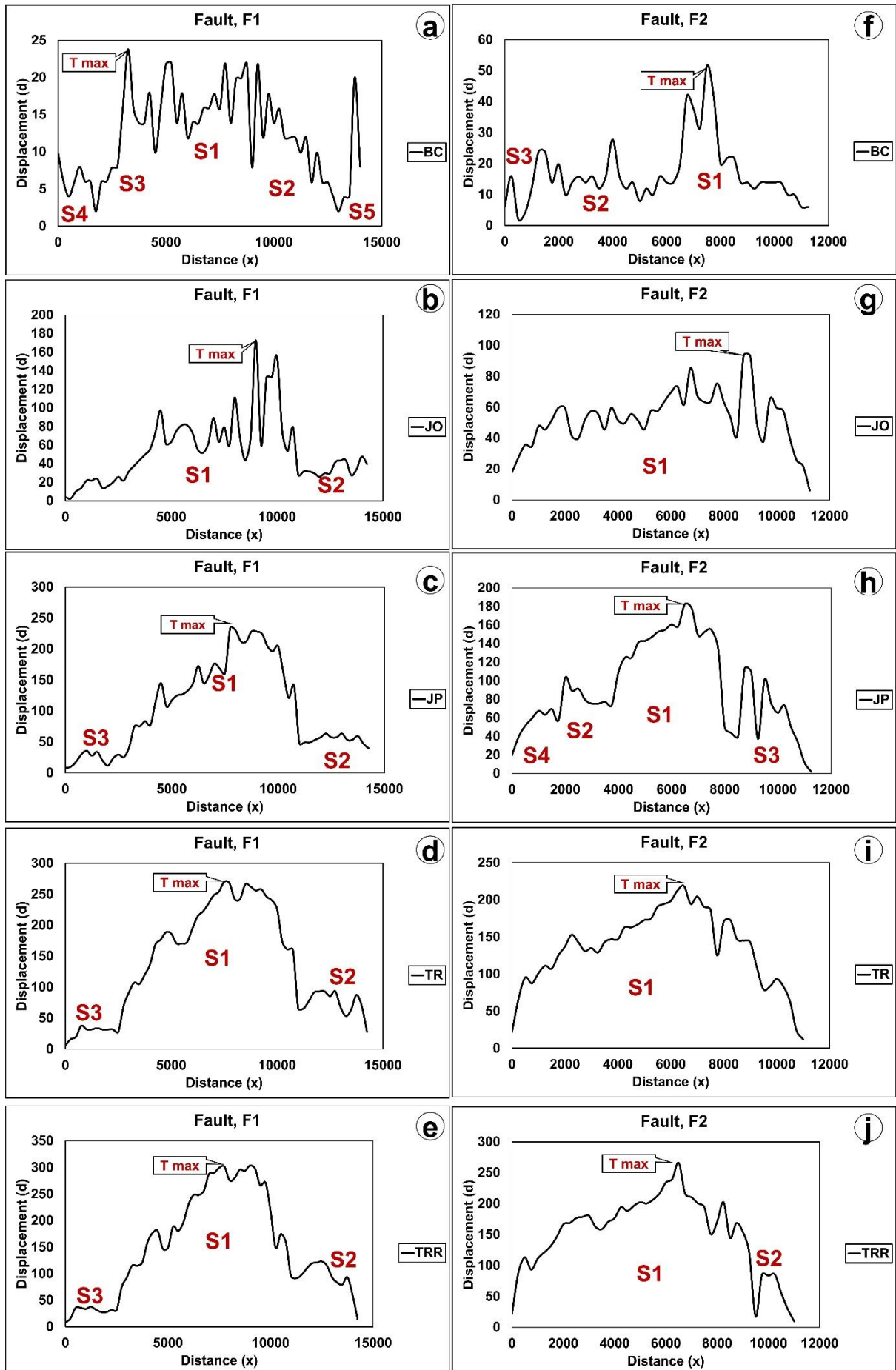


Figure 9: Displacement vs distance (T-x) plots for (a) to (e) F1 at key horizons show the along-strike throw distribution and linkage of the fault segments at the displacement minima and (g) to (j) F2 at key horizons show the linkage of the fault segments at the displacement minima. F1 exhibits multiple segment C-type profiles indicating its complex segmentation while F2 exhibits a hybrid C-type profile. At shallow levels, the serrated pattern of the T-x plots for both faults point to the presence of relay structures and inverted strata at that level.

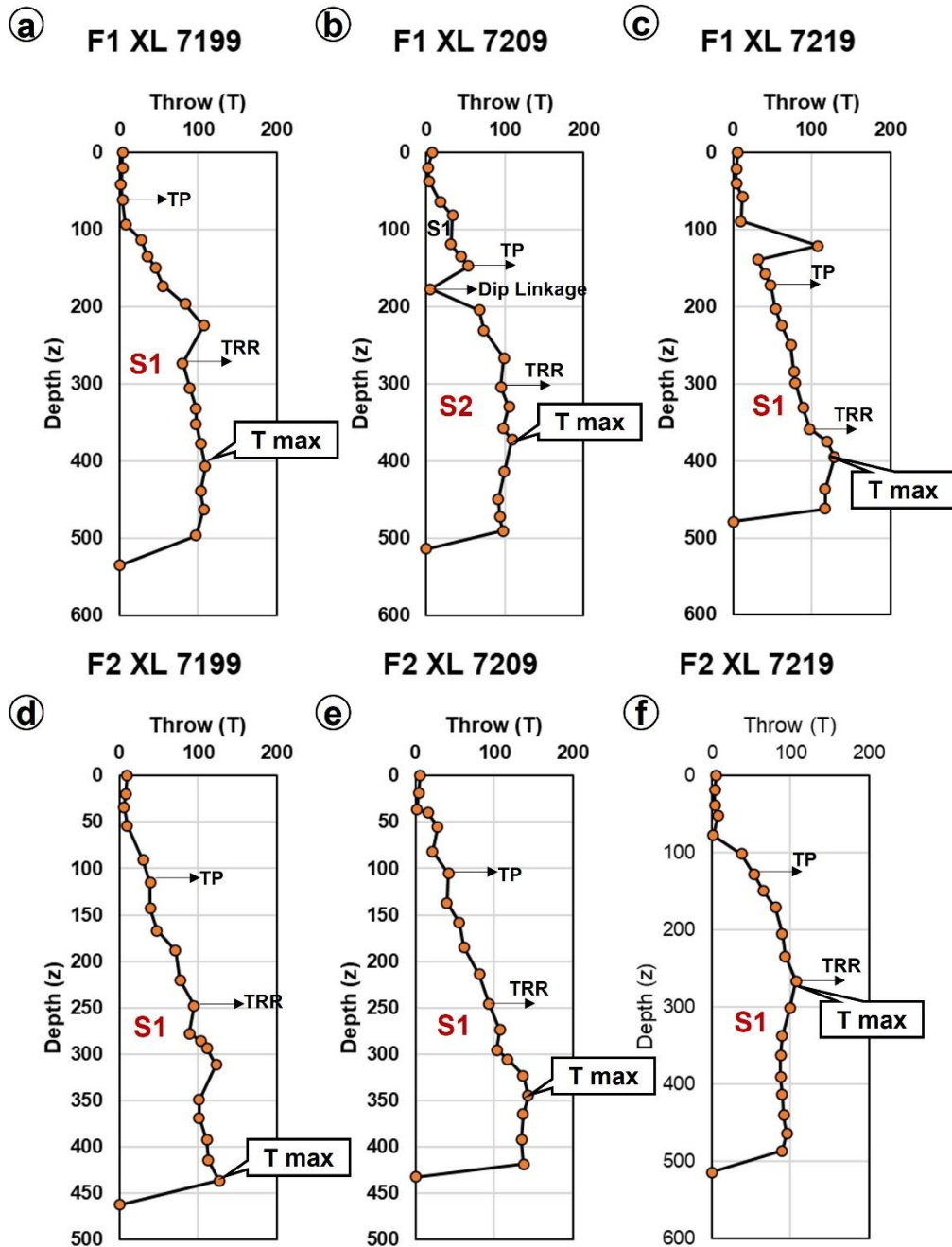


Figure 10: Displacement vs depth (T-z) plots for (a) to (c) F1 and (d) to (f) F2 at XL 7199, 7209 and 7299, respectively. The T-z plots show growth by blind propagation of faults tips. Both faults have M-Skewed profiles.

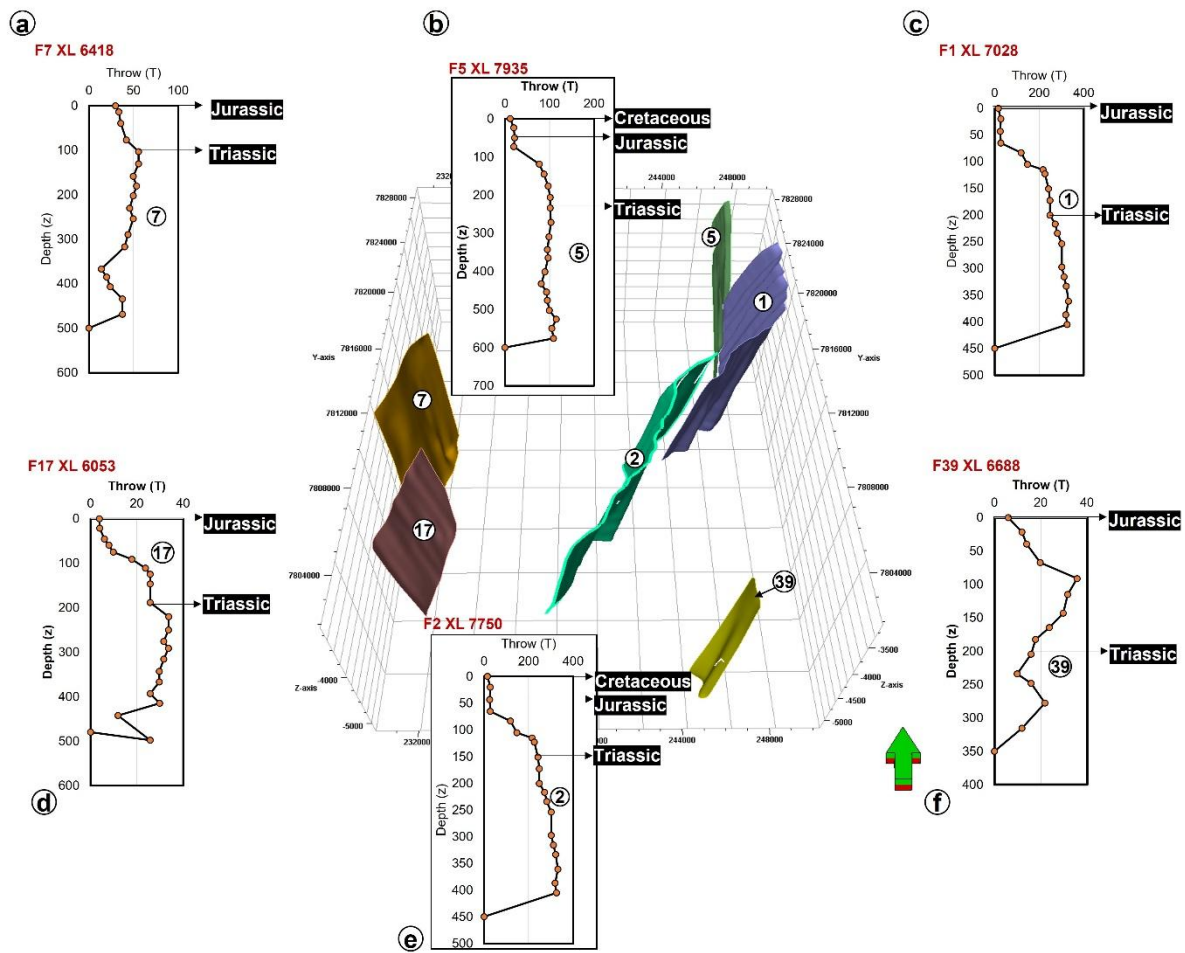


Figure 11:

Three-dimensional view of the representative faults chosen for displacement analysis. Displacement vs depth (T-z) plots (a) to (e) for the faults show their growth by blind propagation of fault tips and M-skewed profile while (f) Fault F39 has a multiple segment profile and is characterized by upward increase in fault throw akin to fault growth by syn-sedimentary activity.

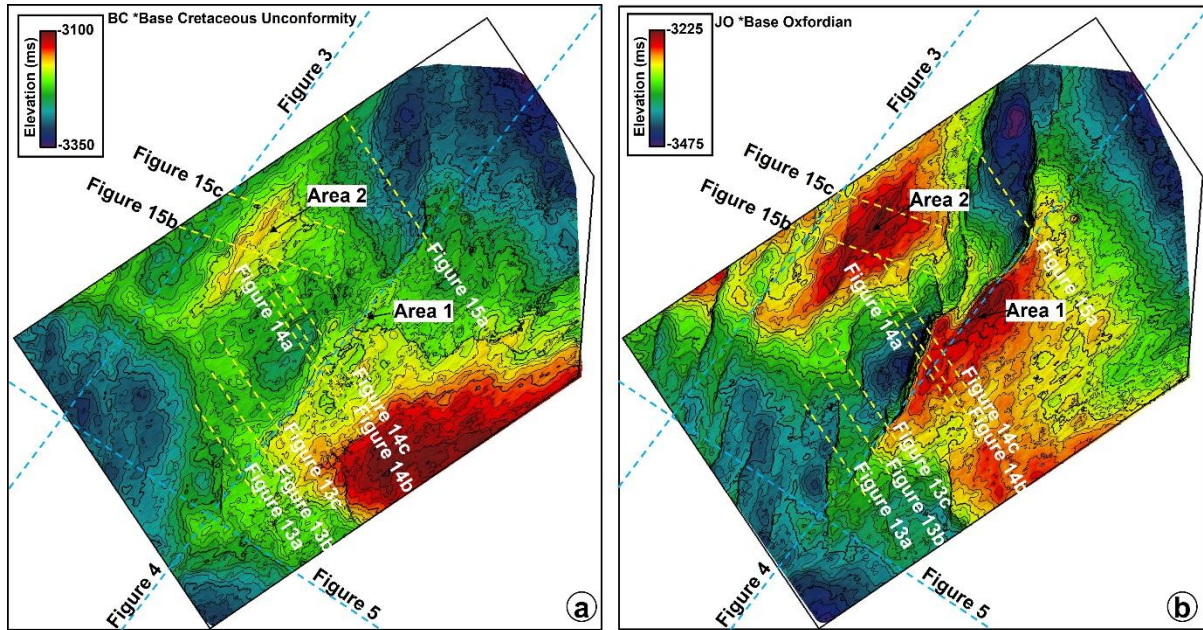


Figure 12: Map view of the (a) Base Cretaceous Unconformity and (b) Base Oxfordian showing the uplifted sections (Area 1 and 2) in the Exmouth Plateau affected by mild or selective tectonic inversion in the basin. At the Base Cretaceous level, the impact of the uplift mild and preserved as a monocline with an amplitude of >10 m.

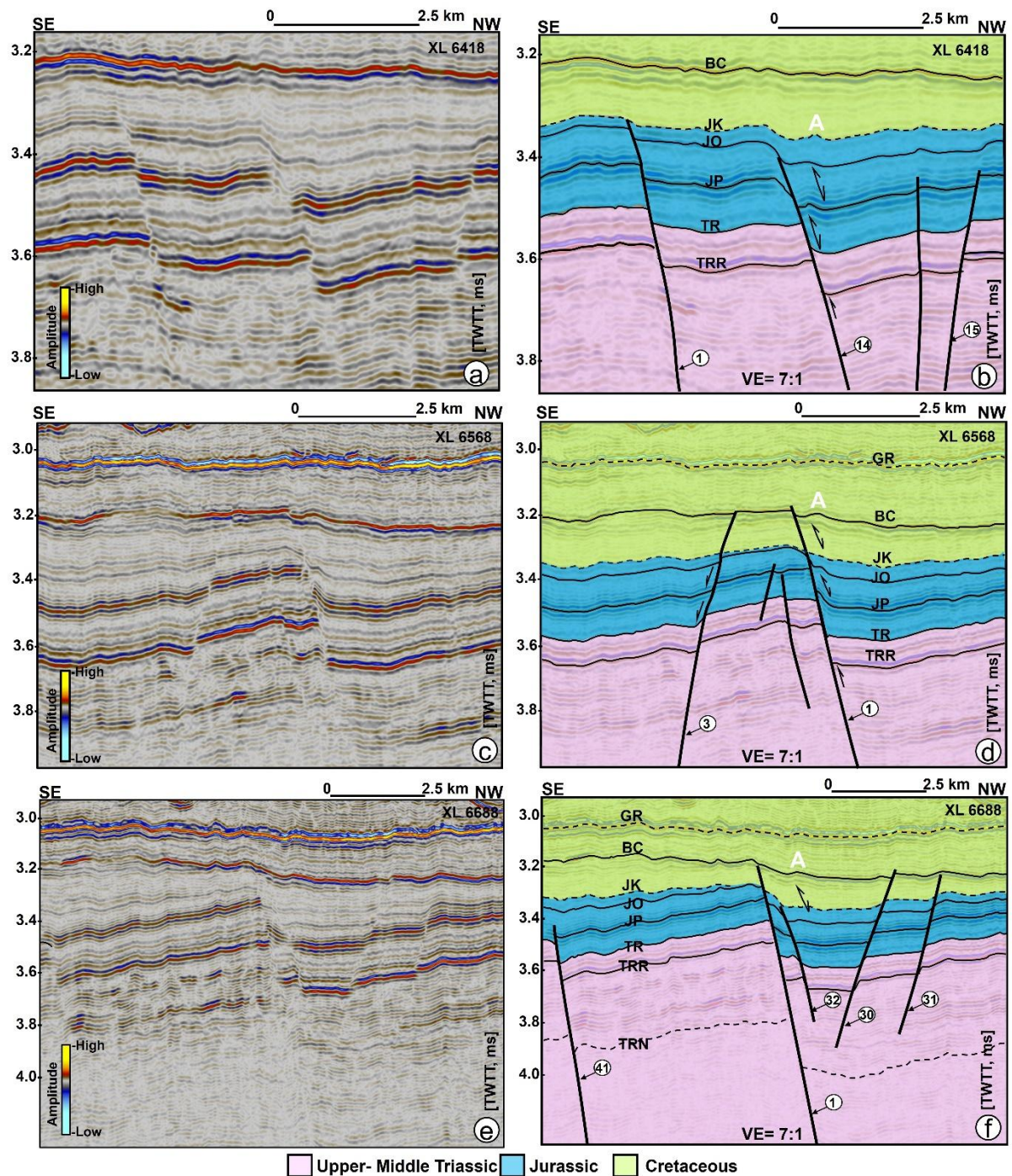


Figure 13: (a,c,e) Uninterpreted seismic sections and (b,d,f) interpreted seismic sections of the Exmouth Plateau at XL 6418, 6568 and 6688 showing the interpreted faults in the study area. The sections revealed post Triassic inversion in the study area with presence of antiforms and snakehead reflections and reverse drags along F1. Note: GR-Top Gearle, BC- Base Cretaceous Unconformity, JK-Top Oxfordian, JO-Base Oxfordian/Main unconformity, JP- Top North Rankin Beds TR- Top Brigadier Formation, TRR- Top Mungaroo Formation, TRN-Intra Mungaroo Formation. A = Snakehead Antiform.

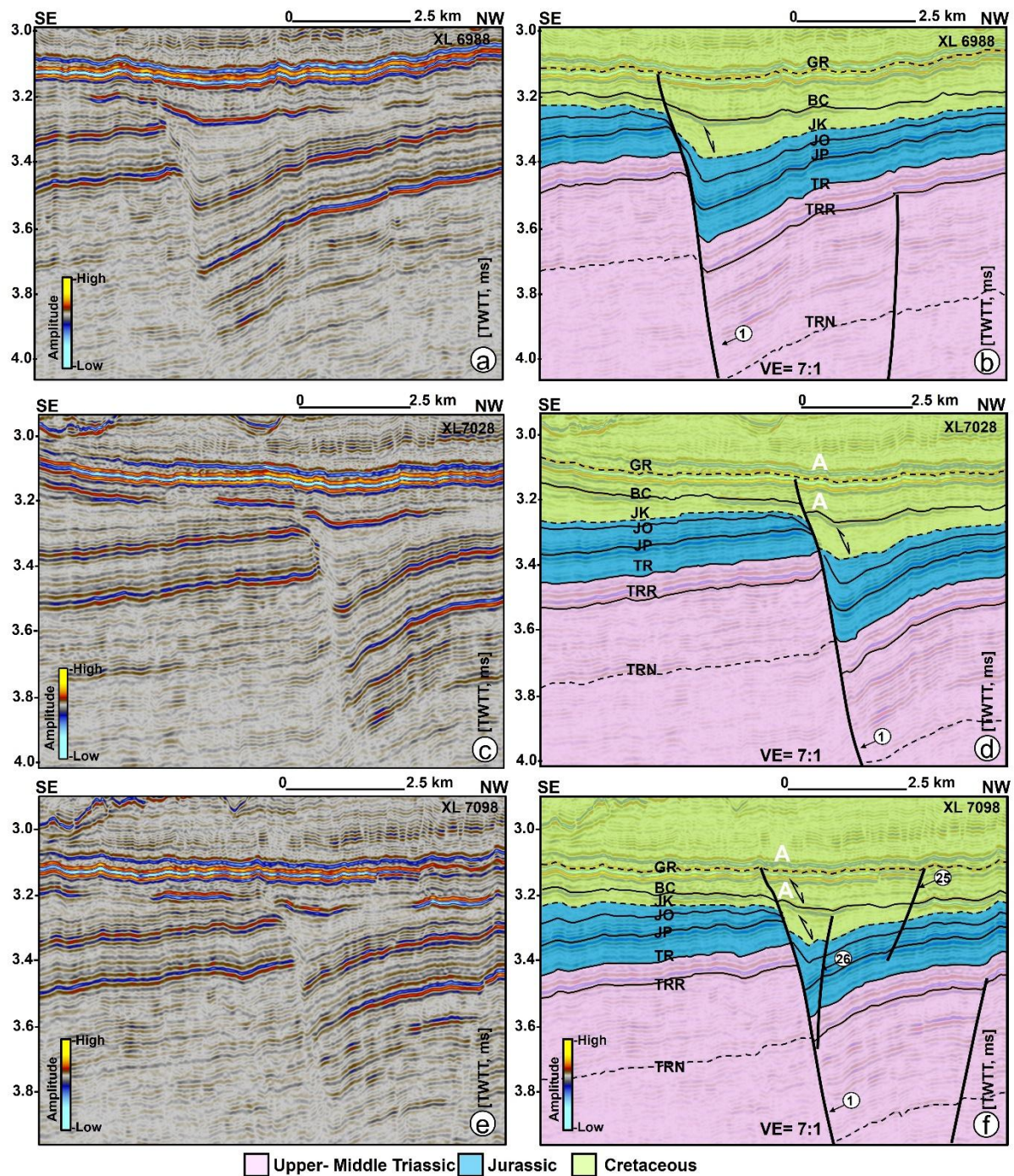


Figure 14: : (a,c,e) Uninterpreted seismic sections and (b, d, f) interpreted seismic sections of the Exmouth Plateau at XL 6988, 7028, and 7098 show the interpreted faults in the study area. The sections reveal the post-Triassic inversion in the Exmouth Plateau with evidence of snakehead reflections and reverse drags at the hanging wall of F1 towards the fault plane. The snakehead reflections are also seen at the Lower Gearle Formation. *Note: GR - Top Gearle, BC - Base Cretaceous Unconformity, JK - Top Oxfordian, JO - Base Oxfordian/Main unconformity, JP - Top North Rankin Beds, TR - Top Brigadier Formation, TRR - Top Mungaroo Formation, TRN - Intra Mungaroo Formation. A = Snakehead Antiform.*

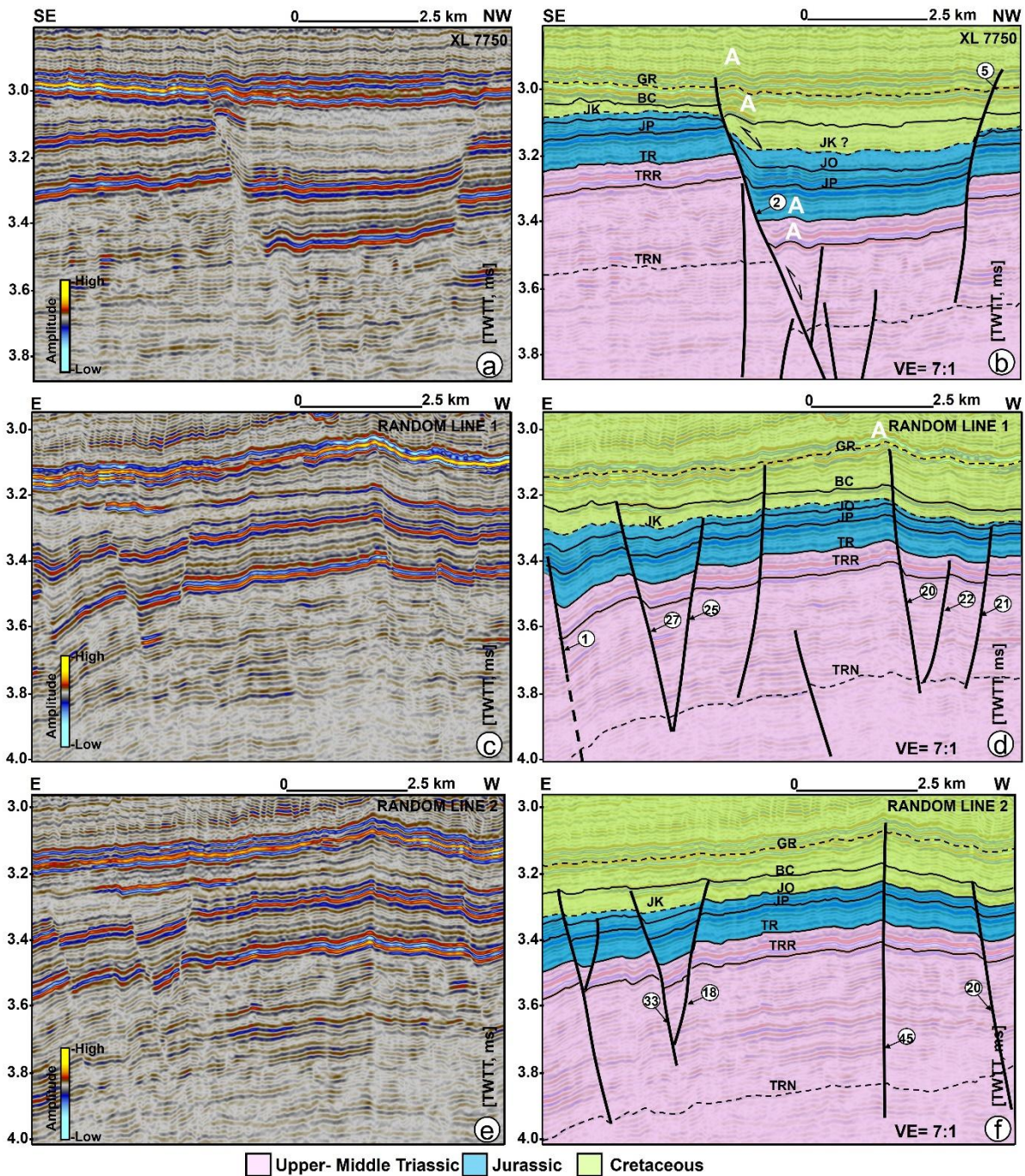


Figure 15: (a,c,e) Uninterpreted seismic sections and (b, d, f) interpreted seismic sections of the Exmouth Plateau at random lines show the interpreted faults in the study areas. The sections reveal the post-Triassic occurrence of inversion in the Exmouth Plateau with evidence of mild snakehead reflections and reverse drags shown along F2. Uplift of strata was also observed along F20 and F45 (d and f). Note: GR-Top Gearle, BC- Base Cretaceous Unconformity, JK-Top Oxfordian, JO-Base Oxfordian/Main unconformity, JP- Top North Rankin Beds TR- Top Brigadier Formation, TRR- Top Mungaroo Formation, TRN-Intra Mungaroo Formation. A = Snakehead Antiform.

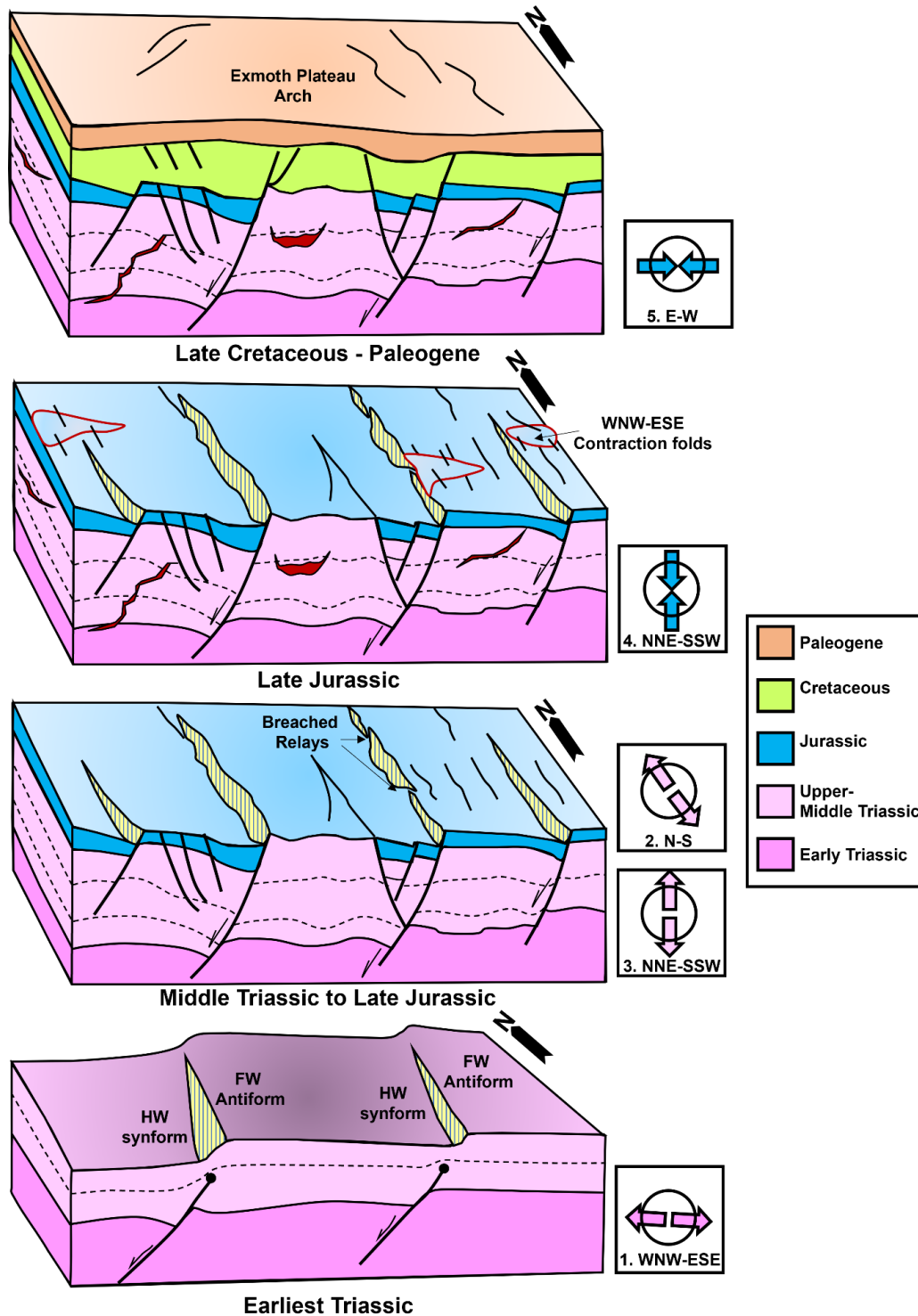


Figure 16: Conceptual models showing the development of faults in response to the tectonic phases that resulted in inversion within the Exmouth Plateau (Modified after Bilal and McClay, (2022)). The study area underwent tectonic inversion, marked by the transformation of previously extended strata into contracted formations due to compression. This inversion is attributed to diverse geological factors including fault segmentation, overlap zones, and buttressing effects, primarily triggered by regional tectonic events and changes in stress distribution over time. The observed deformation indicates a complex tectonic history involving multiple stages of extension followed by compression, with evidence suggesting tectonic inversion from Late Jurassic into the Late Cretaceous. Note: Arrows in the white boxes show the orientation of the dominant tectonic forces during the basin evolution.