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Evolution from continental rifting to passive margin in northeast Arabia; evidence from exploration wells in the United Arab Emirates

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ABSTRACT

The continental lithosphere stretches and ultimately splits during extension resulting in rifted margins that may transform into passive margins depending on their mechanical and thermal state. The heating and thinning of the continental lithosphere during the rifting process cause contemporaneous subsidence that accumulates syn-rift deposits. The lithosphere extension plays a critical role in plate dynamics as it occurs in oceans and continents. The passive margin of northeast Arabia provides a unique geodynamic system for the full development of a continental rift into a mature passive margin. Here, this margin is buried under 5-7-kilometer-thick foreland basin sequences. The basement beneath the passive margin sequences has not been imaged by seismic nor sampled by deepest exploration wells. Therefore, the evolution remains enigmatic due to the lack of resolving data and the deep burial cover. This signifies the need for a powerful innovative approach to characterize the lithospheric stretching that occurred and its ever-since evolution. Here we integrate seismic reflection profiles with compiled biostratigraphic data from 283 exploration wells to remove the sediment and water loads effect to acquire terms due to tectonic mechanisms. Seismic stratigraphy loosely identifies the top of the passive margin sequences based on the seismic reflection configurations, reflector geometry, and reflection termination. The bottom of these rifted sequences however cannot be determined. Additionally, the structural configuration of the rifting that occurred was severely obscured by the Ophiolite emplacement in the Late Cretaceous and the collision along the Zagros suture in the Miocene. As a result, the faults were negatively inverted due to the emplacement of significant orogenic loads and crustal shortening. Based on backstripping, we suggest the occurrence of at least two phases of continental rifting during the Permian-Jurassic time spanning combined age of ~147 Ma. The initial phase commenced in the Early Permian (ca. 272 Ma) and is linked to the initial Tethys opening. The final rifting phase took place in the Late Jurassic (ca. 160 Ma) and is associated with the culmination of the continental break-up of Gondwana. The anomalous tectonic subsidence coupled is related to the heating and thinning that caused the thermal contraction of the crust. A uniform depth extension model implies that the lithosphere was thinned to 88% during the initial rifting and by 1% during the final rifting based on modeled stretching factors of 1.13 to 1.27 and 1.11 to 1.17, respectively. Spatial modeling of the stretching factors yielded critical insight into the lithospheric and crustal necking that occurred in the area. The identified evolution of northeast Arabia's passive margin and its implications contributes to efforts in determining the hydrocarbon prospectivity of deep plays in the area.

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1. INTRODUCTION

The tectonic evolution of the northestern edge of the Arabian Plate and the adjacent areas (Figure 1) encompasses over 15 km thick succession of phanerozoic sediment which is hosting several prolific oil and gas fields (Alsharhan, 1989, Abdelmaksoud et al., 2022). This history results from complex rifting processes, passive margin transition, and foreland basin formation (Ali and Watts, 2009, Ali et al., 2013). Previous works (e.g., Ali et al., 2013, Abdelmaksoud et al., 2022, Jabir et., 2023) suggest that the area evolved by flexural orogenic loading of a rifted continental margin.

The rifted margin is made of Late Permian-Late Cretaceous shelf carbonates associated with minor terrigenous-evaporites deposits (Alsharhan, 1989). The accumulation of the rifted margin deposits followed the Gondwana break-up and the Tethyan Oceanic crust formation. Two foreland basins also developed in the area, the Aruma foreland basin and the Pabdeh foreland basin in response to the orogenic mass loading (i.e. Ophiolite emplacement) and the Zagros collision, respectively (Figure 2).

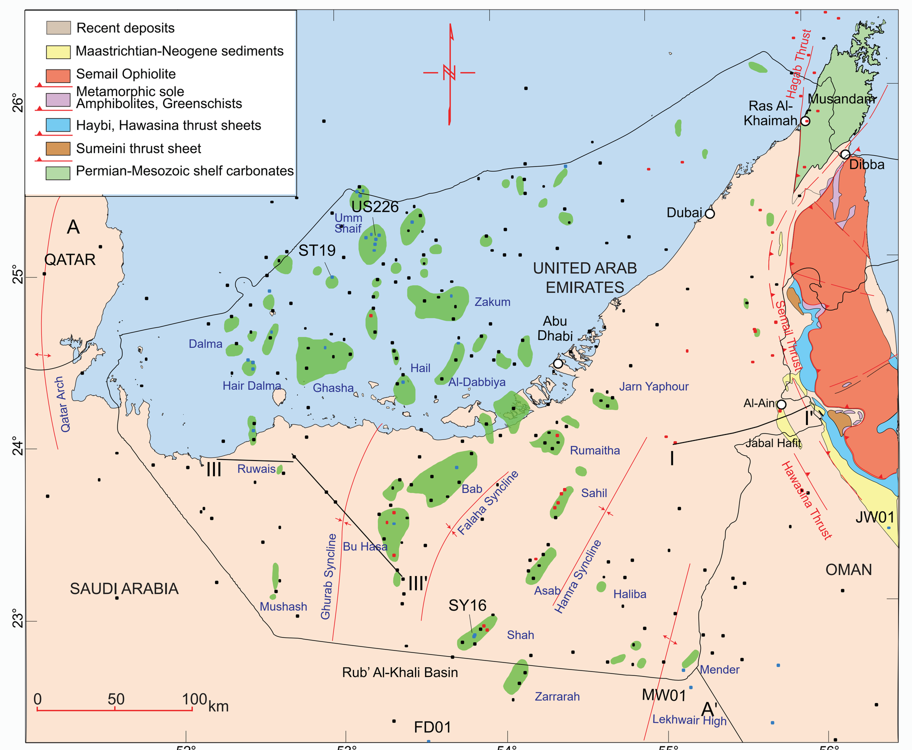

Figure 1. Simplified surface geological map of the UAE and northern Oman Mountains indicates the dataset location. The datasets include 283 wells and twp 2D seismic reflection profiles (black lines: I-I' and II-II'). The green ellipses represent the locations of the oilfields.

Here we focus on the subsidence and uplift history of an area occupied by a passive margin and overlying foreland basin sequences. It provides a unique geodynamic system for the full development of a cratonic rift into a mature passive margin and subsequent flexure under orogenic load. We first backstripp biostratigraphic data from 283 exploration wells with 1.1 to 6.2 km stratigraphic records and Pleistocene-Holocene and then determine and quantify the tectonic subsidence and uplift history of the area.

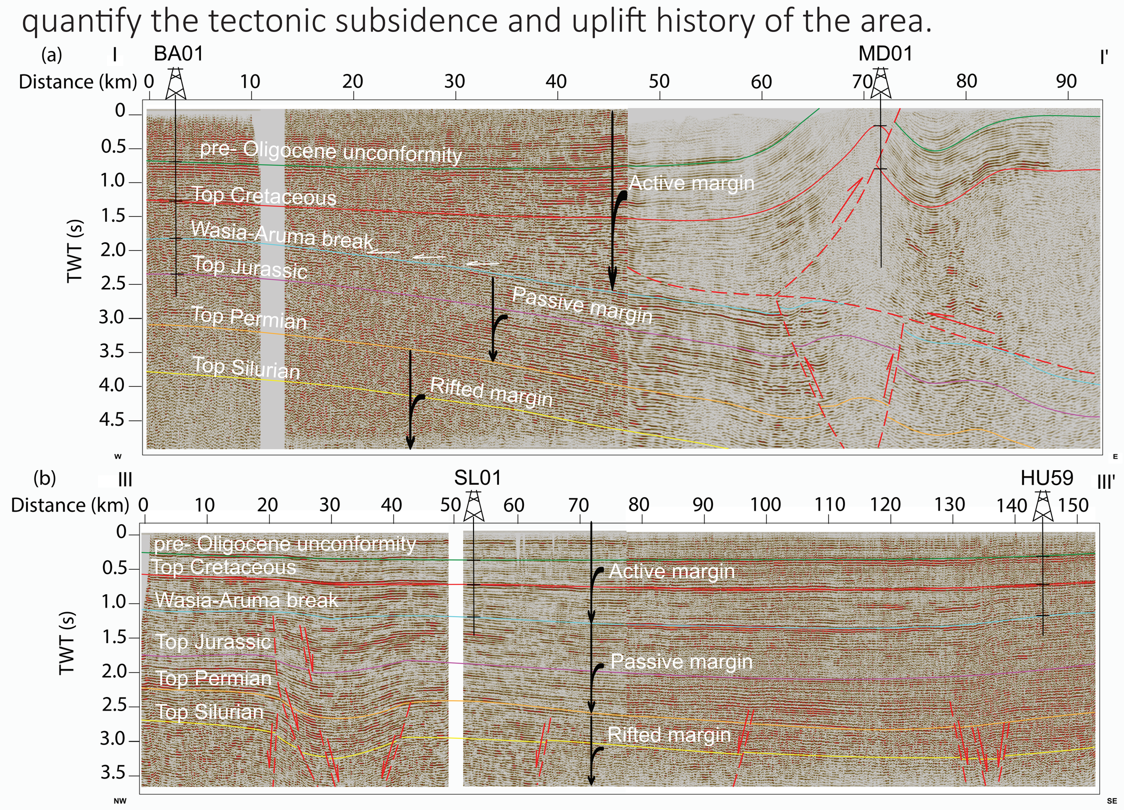

Figure 2. Two Interpreted composite seismic profiles, see Figure 1 for locations.

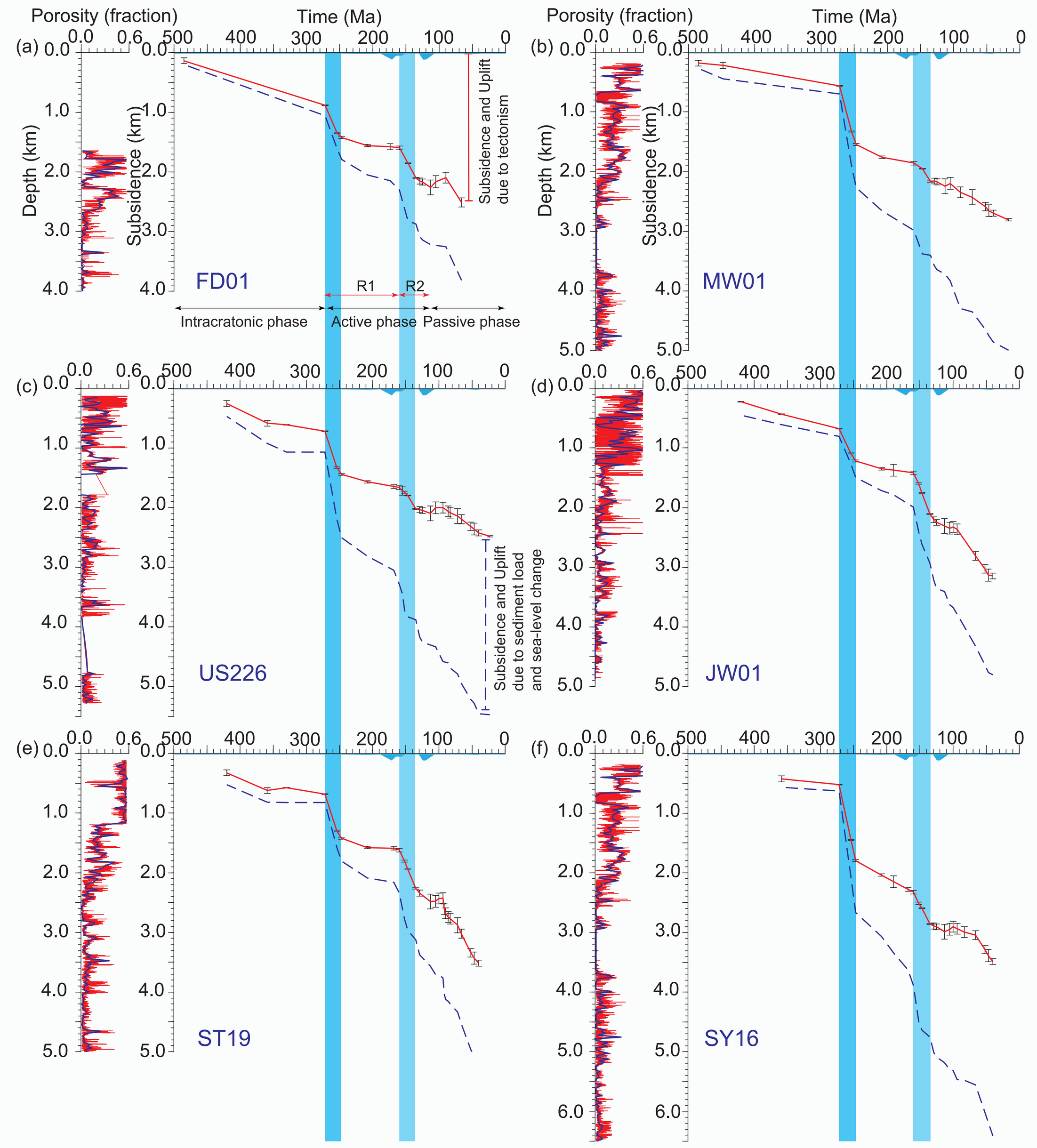

Figure 3. Simplified surface geological map of the UAE and northern Oman Mountains indicates the dataset location. The datasets include 283 wells and two 2D seismic reflection profiles (black lines: I-I' and II-II'). The green ellipses represent the locations of the oilfields.

2. RESULTS

The Airy model was assumed to account for isostasy in the lithosphere for the calculation of the tectonic subsidence and uplift. In Addition, a set of constants were used in this process, this includes densities of water, sediment grains, and mantle of 1,030, 2,670, and 3,330 kg m-3, respectively (McKenzie, 1978). Figure (3) shows the tectonic and total subsidence of representative, deepest penetrated wells. The bottom blue dashed line in Figure (3) indicates subsidence and uplift due to sediment load, sea level fluctuation, and unknown tectonic-driven subsidence. The continuous red line at the top represents the subsidence and uplift that is solely related to tectonic factors. The error bars on the later curve donate the uncertainties associated with the paleobathymetry estimations.

Two concave-up profiles occurred in the Permian-Jurassic (ca. 272-160 Ma) and Upper Jurassic-Aptian (ca. 160-120 Ma). These two internally start with an initial, short rapid drop in the tectonic curve that is typical for rift basin dynamics (McKenzie, 1978). As result, we identified two extensional episodes (i.e., rifting events, Figure(3)).

2.1 Permian- Jurassic rifting event (R1) (ca. 272-160 Ma)

The R1 commenced in the Early Permian (ca. 272 Ma) with around 20 Ma duration (Figure 3). It is characterized by a rapid initial syn-rift subsidence followed by exponential thermal post-rift subsidence. Two maps were generated for tectonic subsidence during this event indicating the syn-rift subsidence (Figure 4a) and post-rift subsidence (Figure 4b). The subsidence map of the syn-rift of R1 (ca. 247 Ma) indicates that the maximum subsidence occurred in southern Abu Dhabi and across the border to Saudi Arabia with > 1200 m.

2.2 Upper Jurassic-Aptian rifting event (R2) (ca. 160-120 Ma)

The R2 initiated at Upper Jurassic time, however, the exact initiation time varies slightly among the wells. Generally, the R2 started around 160 Ma

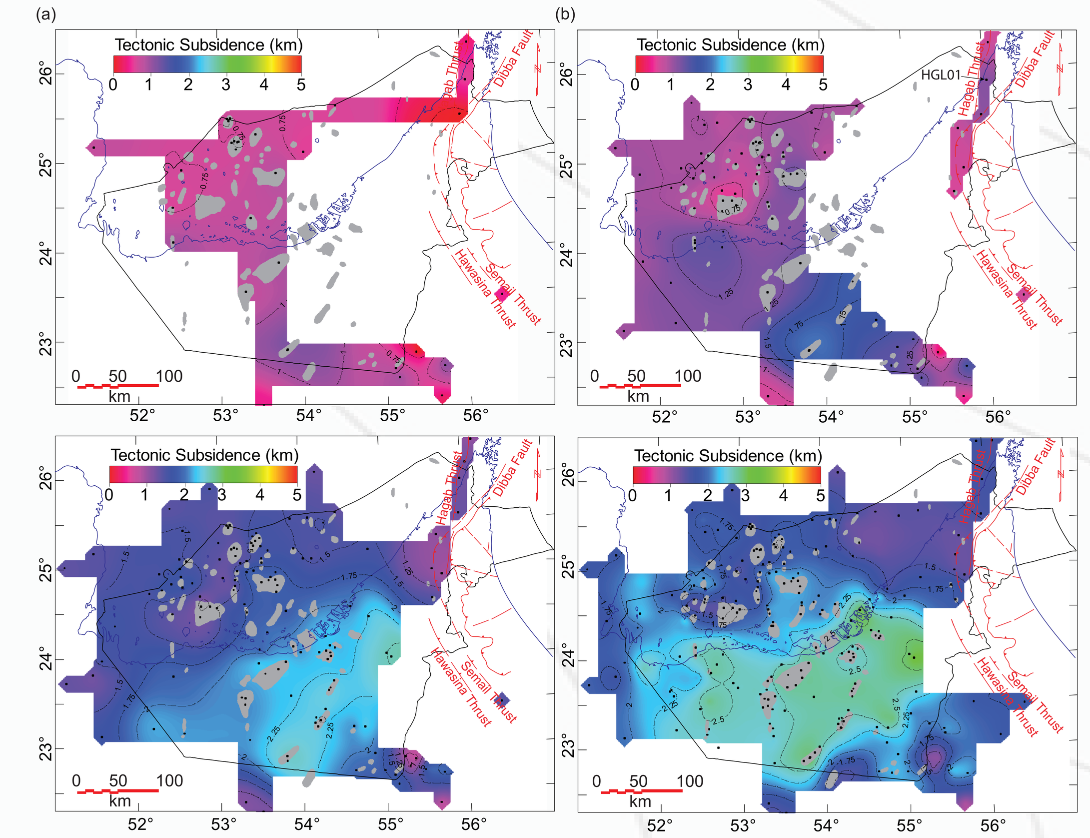

Figure 4. Subsidence maps based on the tectonically driven part of the subsidence and uplift curves. (a) mid Triassic (ca. 247 Ma). (b)) mid-Jurassic (ca. 160 Ma). (c) top Berriasian (ca. 135 Ma). (d)) top Aptian (ca. 113 Ma).

(Figure 3). The duration of the syn-rift of R2 was 25 Ma which results in an average of 520 m and 850 m tectonic and total subsidence respectively. During the syn-rift of R2, the substratum subsided with a rate of 21 m/Ma on average. However, during the post-rift of R2, the rate of tectonic subsidence was about 9 m/Ma on average.

Figure (4c-d) indicates the tectonic subsidence that occurred during the syn-rift and the post-rift phases of the R2 event respectively. Maximum tectonic subsidence occurred by the end of Aptian (ca. 113 Ma) all over onshore Abu Dhabi (> 2700 m) with a roughly northeast-southwest trend. During this time some areas in southwestern, southeastern, and offshore Abu Dhabi showed notably lower tectonic subsidence of < 2500 m.

2.3 Multi-rift uniform stretching models

The two rifting events and an initial crustal thickness (Tc) of 31.2 km (Ali et al., 2013) were assumed when comparing the tectonic subsidence and uplift curves with the thermal model prediction. Hence, we set a series of values (1.01 to 1.50) for crust and mantle extension (stretching factors, β). Also, RMS as a sensitivity analysis was used to determine the best fit β factor between observed tectonic subsidence and uplift curves and the model calculation (Figure 5). The uniform stretching models yield stretching factors of 1.09-1.3 for the Permian- Jurassic rifting event (R1) and 1.13 to 1.27 and 1.11 to 1.17 for the final rifting event (R2, Figure 5).

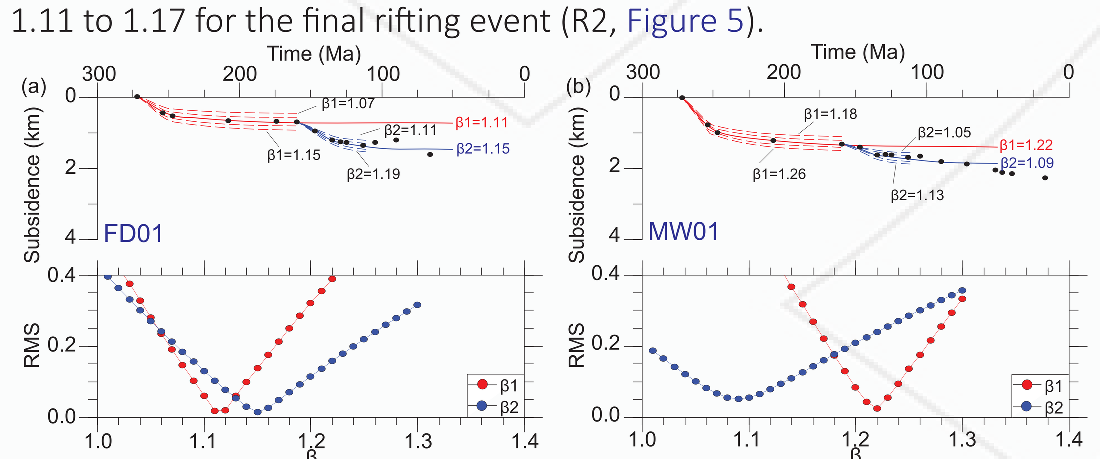

Figure 5. Example of tectonic subsidence and uplift curves compared with the thermal, uniform stretching model showing the calculated stretching factors (β) for the two rifting events (R1 and R2)

2.4 Multi-stage extension and crustal stretching

A basement depth of 18 km was previously determined based on gravity and magnetic data inversion with a Moho depth of 32-52 km (e.g., Geng et al., 2022). Figure (6a) shows the distribution of the stretching factor, β. The greatest stretching of the lithosphere occurred along the Shah oilfield's northeastern trend in southern UAE while the lowest is observed in the offshore areas of northern Abu Dhabi.

These β factors indicate that the post-Permian curst was thinned to 23.58 to 28.69 km. Figure (6c) illustrates the post-Permian crustal thickness variation. Subsequently, we assumed the resulting post-Permian crustal thickness for the uniform stretch modeling of the Upper Jurassic-Aptian rifting event (R2). A grid of the stretching factor, β, distribution (Figure 6b) shows notable trends of lower lithospheric stretching in southeastern, northeastern, north, and northwestern UAE. Figure (6d) shows the present-day crustal thickness of the western gulf, central and southern UA

We suggest a present-day crustal thickness ranging between 19 to 25 km. this implies a present depth to Moho of around 30 to 36 km assuming 11-14 km thick sedimentary cover.

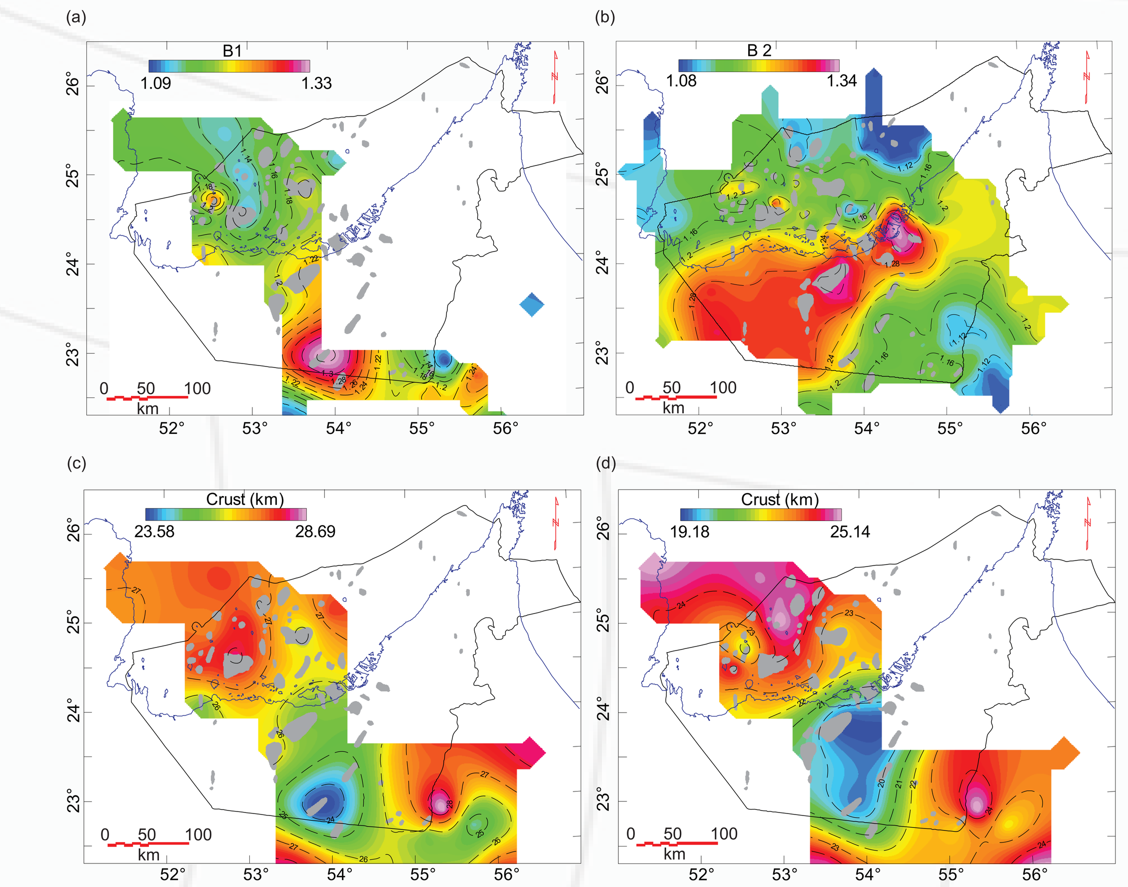

Figure 6. Grided maps of the lithospheric stretching factors, β factors, of the Permian-Jurassic rifting event (a) and the Upper Jurassic-Aptian rifting event (c). Maps in (b and d) illustrate the crustal thickness resulted after the Permian-Jurassic and the Upper Jurassic-Aptian rifting events, respectively

3. CONCLUSIONS

- Quantitative subsidence and uplift history analysis of 283 wells suggest the occurrence of multiple episodes of lithospheric extension.
- The initial rift phase started at ca. 272 Ma, with a syn-rift duration of around 20 Ma. During this initial rift phase, the lithosphere was stretched with factors between 1.09 and 1.33 (avg. 1.17).
- Upper Jurassic-Aptian rifting, commenced at ca. 160 Ma with a riffing duration of 25 causing the lithosphere to stretch with factors of 1.08 to1.34.
- The two rift phases are interpreted to be associated with the initial and final continental fragmentation of Gondwana.
- we suggest that the post-Permian curst was thinned to 23.58 to 28.69 km. Hence, suggest the present-day, post-Jurassic, crustal thickness ranging between 19 to 25 km in western, southern, central, and offshore areas of UAE.
- This implies a present depth to Moho of around 30 to 36 km assuming 11-14 km thick sedimentary cover.

REFERENCES

Abdelmaksoud, A., Ali, M., and Searle, M., 2022, Tectono-stratigraphic evolution of the foreland fold-and-thrust belt of the United Arab Emirates: Tectonics, v. 41, p. e2022TC007470.

Ali, M., and Watts, A., 2009, Subsidence history, gravity anomalies and flexure of the United Arab Emirates (UAE) foreland basin: GeoArabia, v. 14, no. 2, p. 17-44.

Ali, M., Watts, A., and Searle, M., 2013, Seismic stratigraphy and subsidence history of the United Arab Emirates (UAE) rifted margin and overlying foreland basins, Lithosphere dynamics and sedimentary basins: The Arabian plate and analogues, Springer, p. 127-143.

Alsharhan, A., 1989, Petroleum geology of the United Arab Emirates: Journal of Petroleum geology, v. 12, no. 3, p. 253-288.

Jabir, M., Ali, M., Abdelmaksoud, A., Morad, S., and Decarlis, A. (2023). Silurian-Holocene tectonostratigraphy of Abu Dhabi, United Arab Emirates: Marine and Petroleum Geology, 106279.

McKenzie, D., 1978, Some remarks on the development of sedimentary basins: Earth and Planetary science letters, v. 40, no. 1, p. 25-32.

Geng, M., Ali, M., Fairhead, J., Pilia, S., Bouzidi, Y., and Barkat, B., 2022a, Crustal structure of the United Arab Emirates and northern Oman Mountains from constrained 3D inversion of gravity and magnetic data: The Moho and basement surfaces: Journal of Asian Earth Sciences, v. 231, p. 105223.