



Geohistory Analysis of Block 14, Say'un–Masilah Basin, Yemen.

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ABSTRACT

This study presents a comprehensive geohistory analysis of Block 14 (Masila Block), Say'un–Masilah Basin, eastern Yemen, based on one-dimensional (1D) Airy backstripping of stratigraphic data from 22 wells across the Cammal, Sunah, and Tawilah fields. Eleven formations spanning approximately 161 million years (Ma), from the Middle Jurassic Kuhlan Formation (161.2 Ma) to the Paleogene Umm Er Radhuma Formation (56 Ma), were analyzed. For each formation and well, present-day and initial porosity, decompacted sediment thicknesses, total and tectonic subsidence and their rates, and sedimentation rates were quantified. Decompacted thickness consistently exceeds present-day values across all formations, with the greatest compaction effect recorded in the Shuqra Formation at Sunah-01 (~ 60 m lost to compaction). Total subsidence ranges from 28 m (Kuhlan Formation) to 943 m (Harshiyat Formation). Tectonic subsidence was lowest during pre-rift Kuhlan deposition (~ 25 m average), increased during syn-rift Naifa deposition (~ 162 m average), and peaked during Harshiyat deposition (~ 665 m; 5.33 cm/1,000 yr). The Mukalla Formation records the highest sedimentation rate (14.5 cm/1,000 yr average). Sunah-01, located in the northeastern part of the study area, records the highest cumulative total subsidence (3779 m) and tectonic subsidence (2970 m), corresponding to the thickest sedimentary succession. Tawilah-99, in the southeastern part of the study area, records the lowest cumulative values (total: 2479 m; tectonic: 1813 m), corresponding to the thinnest succession. These results provide a quantitative geohistory framework for Block 14 and a basis for future petroleum system modeling within the Say'un–Masilah Basin.

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1. INTRODUCTION

The Republic of Yemen is located at the southern margin of the Arabian Peninsula, extending between latitudes 12°40'–18°50' N and longitudes 42°50'–53°00' E. From a geological perspective, Yemen occupies the southwestern edge of the Arabian Plate, adjacent to the Afar Depression, and has experienced a complex tectonic evolution associated with the breakup of Gondwana. Redfern and Jones [1] subdivided the interior of Yemen into several major tectonic units, including basement highs, Jurassic rift basins, Cretaceous rift basins, and intergraben highs with marginal terraces. Extensional tectonics related to Late Jurassic rifting between East Africa and West India led to the formation of Mesozoic grabens

filled by thick sedimentary successions, comprising the Sabatayn, Say'un–Masilah, Balhaf, Siham-Ad-Dali', and Jiza'-Qamar basins (Fig. 1). Among these, only the Sabatayn and Say'un–Masilah basins are hydrocarbon-producing [2, 3]. The Say'un–Masilah Basin is one of the most prolific petroleum provinces in eastern Yemen [4, 5]. Block 14 (Masila Block) lies in the eastern sector of the Say'un–Masilah Basin and has been the subject of exploration and production since the late 1980s, hosting several major oilfields. The regional lithostratigraphic framework of the Say'un–Masilah Basin is presented in Fig. 2. Previous basin-analysis studies in the Masila Basin have applied 1D backstripping to investigate the subsidence history and basin evolution. Al-Matary and Ahmed inves-

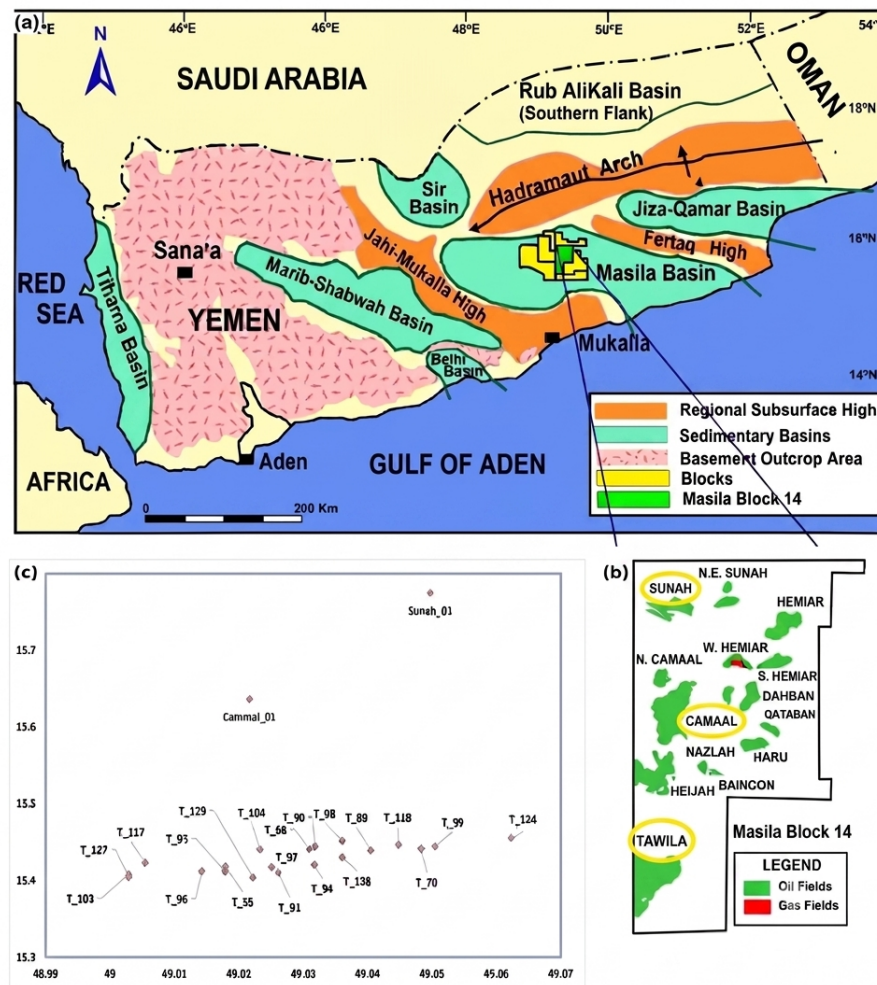


Figure 1. Main sedimentary basins of Yemen and location of the study area (modified after [9]): (a) sedimentary basins of Yemen showing regional location of the Masila Basin and Block 14; (b) study fields within Block 14; and (c) locations of the wells used in this study.

igated Block 10 in the Say'un–Masilah Basin [6], while Al-Matary and Sufian studied the geohistory of Block 7 in the Sabatayn Basin [7]. More recently, Al-Matary and Al-Tairi applied the same approach to Block 53 in the Masila Basin [8]. However, no published basin-analysis study based on 1D backstripping has specifically investigated Block 14 at the scale of the present study. Therefore, the subsidence history, decompacted sediment thicknesses, sedimentation rates, and spatial variations in total and tectonic subsidence across Block 14 remain insufficiently quantified.

Backstripping is a quantitative technique that isolates tectonic subsidence — the vertical movement of the basement driven by tectonic forces — by progressively removing the effects of sediment loading, water loading, and eustatic sea-level change from the total observed subsidence [11, 12]. This method was pioneered by Steckler and Watts [11] and Van Hinte [12] and is widely used to reconstruct basin geohistory [13–15]. In the present study, 1D Airy backstripping was applied to 22 wells distributed across the Cammal, Sunah, and Tawilah

fields. The analysis covers 11 stratigraphic formations from the Jurassic to the Paleogene and quantifies decompacted sediment thicknesses, sedimentation rates, total subsidence, and tectonic subsidence. This study aims to: (1) reconstruct the burial and geohistory of Block 14 using 1D Airy backstripping of 22 wells; (2) represent the vertical movement of stratigraphic horizons as an indicator of basement subsidence and uplift through time; and (3) provide insights into the burial history and tectonic evolution of the basin.

2. MATERIALS AND METHODS

Subsurface data from 22 boreholes drilled in Block 14, Say'un–Masilah Basin, eastern Yemen, were analyzed (Fig. 1; Tables 11 and 2). The wells are distributed across three fields: Cammal (1 well: Cammal-01), Sunah (1 well: Sunah-01), and Tawilah (20 wells: Tawilah-68, 70, 89, 90, 91, 93, 94, 95, 96, 97, 98, 99, 103, 104, 117, 118, 124, 127, 129, 138). Each well provided lithological descriptions and geophysical log data used to determine formation thicknesses and porosity profiles. Not all wells

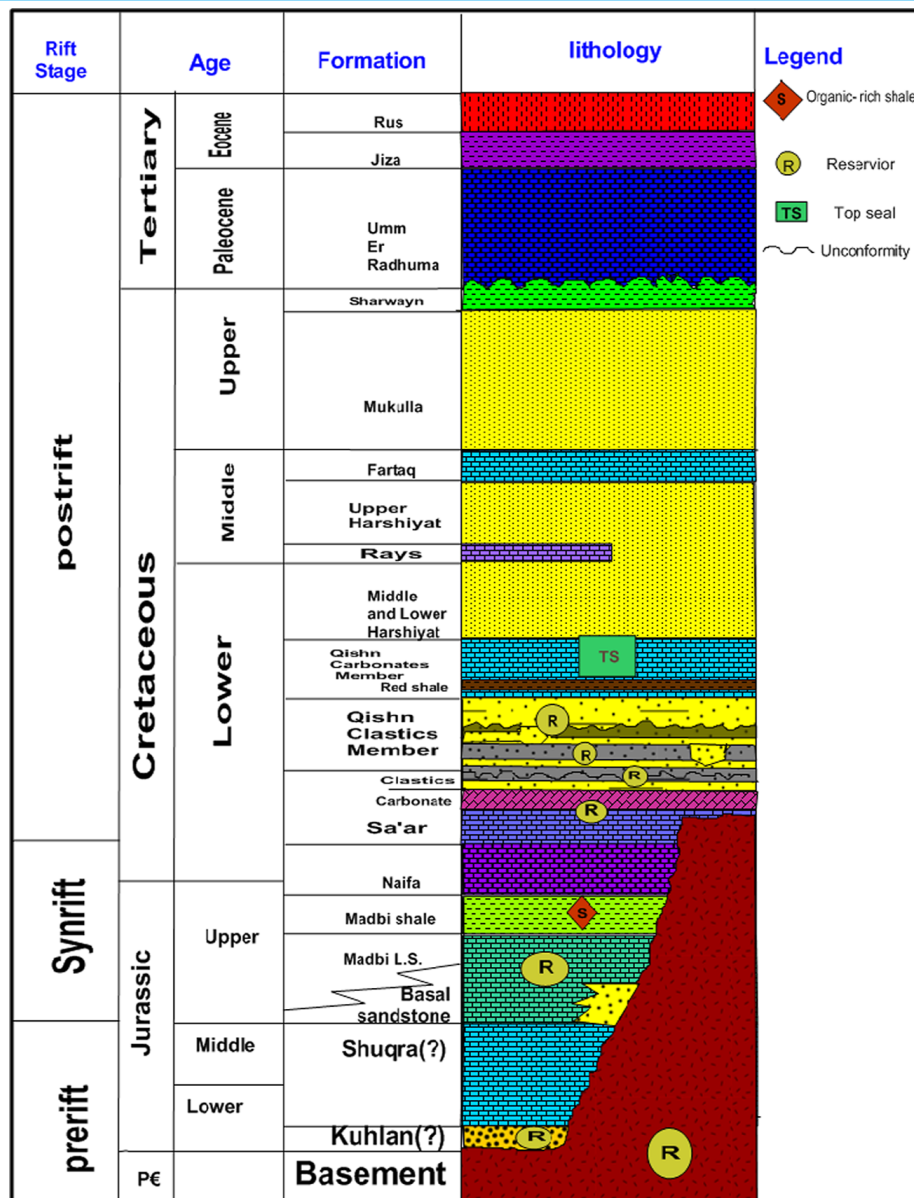


Figure 2. Lithostratigraphic section of the Say'un–Masilah Basin (after [10])

penetrated the full stratigraphic succession. The Kuhlan, Shuqra, Madbi, and Naifa formations (Jurassic) were encountered only in the Sunah-01 and Cammal-01 wells. The remaining 20 Tawilah wells penetrated formations from the Saar (basal Cretaceous) upward to the Umm Er Radhuma (Paleogene). Missing intervals in these wells were excluded from formation-level averages; regional averages stated in the text are computed only from wells that penetrated the relevant formation. Geohistory reconstruction followed the 1D Airy backstripping approach of Steckler and Watts [1] and Allen and Allen [16], in which each sedimentary layer is progressively removed from the stratigraphic column, corrected for compaction, and paleowater depth to yield the tectonic subsidence at each time step. Stratigraphic ages were assigned from the International Lexicon of Stratigraphy [17], using stage-boundary ages as listed in Table 3. Paleowater depths for common lithologies were assigned following Fluegel

[18]. Unconformities (between Saar–Qishn, ~ 7.2 Ma; Qishn–Harshiyat, ~ 8.4 Ma) were treated as instantaneous surfaces of zero thickness with no sediment contribution to the subsidence calculation. The following subsections describe the sequential computational steps applied to each formation in each well.

2.1. DETERMINATION OF SEDIMENT POROSITY

Porosity decreases exponentially with burial depth [19]. In this study, the porosity of each formation was calculated using the standard exponential porosity–depth relationship (Equation 1):

$$\phi_N = \phi_0 \cdot e^{-cz} \quad (1)$$

Table 1. names of stratigraphic units and the present-day depth to the top of these formations

Well name	Umm Er Radhuma Top (Km)	Sharwayn Top (Km)	Mukalla Top (Km)	Fartaq Top (Km)	Harshiyat Top (Km)	Qishn Top (Km)	Saar Top (Km)	Naifa Top (Km)	Madbi Top (Km)	Shuqra Top (Km)	Kuhlan Top (Km)
Cammal-01	0.04	0.46	0.04	0.77	0.37	0.19	0.19	0.03	0.03	0.02	0.01
Sunah-01	0.02	0.47	0.05	0.78	0.40	0.47	0.47	0.14	0.03	0.07	0.01
Tawilah-68	0.26	0.02	0.55	0.05	0.72	0.28	0.08	–	–	–	–
Tawilah-70	0.31	0.02	0.55	0.04	0.74	0.26	0.11	–	–	–	–
Tawilah-89	0.37	0.02	0.49	0.04	0.73	0.26	0.08	–	–	–	–
Tawilah-90	0.25	0.02	0.54	0.04	0.74	0.26	0.09	–	–	–	–
Tawilah-91	0.27	0.02	0.56	0.04	0.76	0.26	0.08	–	–	–	–
Tawilah-93	0.27	0.03	0.56	0.04	0.76	0.26	0.08	–	–	–	–
Tawilah-94	0.27	0.04	0.55	0.04	0.76	0.26	0.07	–	–	–	–
Tawilah-95	0.27	0.02	0.57	0.04	0.76	0.26	0.08	–	–	–	–
Tawilah-96	0.27	0.02	0.57	0.04	0.76	0.26	0.08	–	–	–	–
Tawilah-97	0.27	0.05	0.54	0.04	0.75	0.27	0.07	–	–	–	–
Tawilah-98	0.27	0.03	0.59	0.05	0.63	0.27	0.08	–	–	–	–
Tawilah-99	0.26	0.02	0.55	0.04	0.74	0.27	0.01	–	–	–	–
Tawilah-103	0.02	0.58	0.04	0.75	0.26	0.08	0.08	–	–	–	–
Tawilah-104	0.02	0.56	0.04	0.74	0.26	0.07	0.07	–	–	–	–
Tawilah-117	0.02	0.58	0.04	0.75	0.26	0.08	0.08	–	–	–	–
Tawilah-118	0.02	0.55	0.04	0.77	0.24	0.08	0.08	–	–	–	–
Tawilah-124	0.02	0.54	0.04	0.71	0.26	0.08	0.08	–	–	–	–
Tawilah-127	0.02	0.58	0.04	0.76	0.26	0.08	0.08	–	–	–	–
Tawilah-129	0.01	0.58	0.04	0.73	0.26	0.08	0.08	–	–	–	–
Tawilah-138	0.02	0.56	0.04	0.75	0.26	0.08	0.08	–	–	–	–

where ϕ_N is the porosity at depth Z , ϕ_0 is the initial surface porosity, and C is the lithology-specific compaction constant.

2.2. SEDIMENT DECOMPACTION

The first step in backstripping is to restore the original thickness of each sedimentary unit prior to burial-related compaction. Given the present-day thickness (T_n), present-day porosity (ϕ_n), and initial surface porosity (ϕ_0), the original (decompacted) thickness (T_0) of any unit is calculated using Equation (2):

$$T_0 = \frac{(1 - \phi_n)T_n}{1 - \phi_0} \quad (2)$$

2.3. SEDIMENT ACCUMULATION RATE

The sedimentation rate (Rf) represents the rate at which sediment accumulates during any given time interval. If the time span (A) of the interval is expressed in million years (Ma) and the original thickness (T_0) in meters, then (Rf) is calculated using Equation (3):

$$Rf = \frac{T_0}{10A} \text{ cm/1,000 yr} \quad (3)$$

2.4. TOTAL SUBSIDENCE

Total subsidence (S) represents the complete vertical displacement of the basement, incorporating contributions from sediment loading, water loading, and tectonic forces. It is calculated as the sum of the decompacted sediment thickness and paleowater depth at each time step (Equation 4):

$$S = \sum T^* + WD_i \quad (4)$$

where S is the total subsidence, T^* is the decompacted thickness of the sediment column, and WD_i is the water depth.

2.5. TECTONIC SUBSIDENCE

Tectonic subsidence (Z_i) isolates the basement movement driven purely by tectonic forces after the removal of the sediment-loading and water-loading components. It is calculated following the Airy isostasy backstripping formulation of Steckler and Watts [11] (Equations 5 and 6):

$$Z_i = T^* \frac{(\rho_a - \rho_s)}{(\rho_a - \rho_w)} + WD_i \quad (5)$$

where Z_i is the amount of tectonic subsidence at time step i ; ρ_a is the density of the asthenosphere (3,330

**Table 2.** Required Backstripping parameters used to calculate the subsidence rate

<i>parameter</i>	UmmEr Radhuma	Sharwayn	Mukalla	Fartaq	Harshiyat	Unconformity	Qishn	Unconformity	Saar	Naifa	Madbi	Shuqra	Kuhlan
Age toBase Ma	56	72.1	89.8	93.9	100.5	113	121.4	132.6	139.8	143.1	148	154.8	161.2
Initialporosity ϕ_0	0.48	0.47	0.47	0.48	0.48	0	0.48	0	0.49	0.52	0.52	0.53	0.37
CompactionConstant C	0.57	0.49	0.50	0.54	0.55	0	0.56	0	0.61	0.62	0.62	0.73	0.27
MatrixDensity	2,705	2,701	2,698	2,708	2,705	0	2,707	0	2,710	2,710	2,710	2,710	2,650
ρ km													

kg/m³); ρ_w is the density of water (1,030 kg/m³); WD_i is the paleowater depth for unit i ; and ρ_s is the bulk density of the sediment column. Following Steckler and Watts [11], ρ_s is calculated for the column after deposition of unit i using Equation (6):

$$\rho_{s_i} = \frac{\sum [\phi_i \rho_w + (1 - \phi_i) \rho_g] T_i}{S} \quad (6)$$

where ρ_g is the grain density of the unit and ϕ_i is the porosity of unit i . The values of ρ_g for each formation are listed in Table 3.

2.6. SUBSIDENCE AND SEDIMENTATION RATES

The total subsidence rate (R_s), tectonic subsidence rate (Rho), and sedimentation rate (Rf) are expressed in units of cm/1,000 yr and calculated by dividing the respective quantity by the duration of deposition (A , in Ma) (Equation 7):

$$R_s = \frac{S}{10A} \text{ cm/1,000 yr} \quad (7)$$

The same formula is applied to calculate Rho (tectonic subsidence rate) and Rf (sedimentation rate) by substituting (Z_i) and (T_0), respectively, in place of S .

2.7. SOFTWARE AND INPUT PARAMETERS

FLEX-DECOMP (Badley's Geoscience Ltd.) [20] was used to calculate the compaction constant (C), initial porosity (ϕ_0), and grain density (ρ_g) for each stratigraphic unit. The complete set of input parameters — including ϕ_0 , C , ρ_g , and formation age — for all eleven formations is listed in Table 3. The twenty-two selected wells were used to construct 1D Airy backstripping subsidence curves plotting basement subsidence against the age to the base of each formation (Figs. 3–6).

3. RESULTS AND DISCUSSION

Subsidence curves, decompacted thicknesses, and sedimentation rates for all 22 wells and 11 formations are summarized in Tables 3–5 and Figs. 3–5. The following

sections discuss each formation in stratigraphic order.

3.1. KUHLAN FORMATION (161.2 MA)

The lowermost formation in Block 14 comprises coarse- to fine-grained sandstones interbedded with non-calcareous silts and shales, resting unconformably on basement rocks. Present thickness: 11 m (Sunah-01) to 10.2 m (Cammal-01); decompacted thickness: 13.2 m and 14 m in Sunah-01 and Cammal-01 wells, respectively. Sedimentation rates: 0.73 cm/1,000 yr (Sunah-01) and 0.77 cm/1,000 yr (Cammal-01). Total subsidence: 28 m (Sunah-01) and 28.8 m (Cammal-01); total subsidence rates: 1.56 and 1.60 cm/1,000 yr, respectively. Tectonic subsidence: 25 m (Sunah-01) and 25.2 m (Cammal-01); tectonic subsidence rates: 1.38 and 1.39 cm/1,000 yr, respectively. The near-equal tectonic and total subsidence rates and low absolute values confirm deposition during the pre-rift, sediment-loading-dominated stage of basin development.

3.2. SHUQRA FORMATION (154.8 MA)

The basal formation of the Amran Group predominantly carbonates deposited in a shallow marine neritic environment [1,17]. Present thickness: 17 m (Cammal-01) to 69.5 m (Sunah-01); decompacted thickness: 31.8 m and 129.6 m in Cammal-01 and Sunah-01 wells, respectively, with the greatest compaction effect recorded in Sunah-01, where approximately 60 m of original thickness has been lost to compaction. Sedimentation rates: 0.48 cm/1,000 yr (Cammal-01) to 1.94 cm/1,000 yr (Sunah-01). Total subsidence: 82 m (Cammal-01) and 180 m (Sunah-01); total subsidence rates: 1.2 and 2.6 cm/1,000 yr, respectively. Tectonic subsidence: 81 m (Cammal-01) and 180 m (Sunah-01); tectonic subsidence rates: 1.2 and 2.7 cm/1,000 yr, respectively. The highest sedimentation rate (1.94 cm/1,000 yr) and tectonic subsidence rate (2.7 cm/1,000 yr) are both recorded in Sunah-01.

FORMATIONS	Present Porosity and Thickness Decompacted porosity and Thickness													
Umm	0.247	T												
Er Radhuma	44.74	Φ												
	0.020	0.021	T											
Sharwayn	41.44	46.78	Φ											
	0.475	0.513	0.513	T										
Mukalla	36.54	41.30	41.34	Φ										
	0.049	0.052	0.052	0.063	T									
Fartaq	31.75	35.49	35.87	47.33	Φ									
	0.778	0.810	0.811	0.926	0.928	T								
Harshaiyt	25.10	28.07	28.14	37.09	37.21	Φ								
	0.000	0.000	0.000	0.000	0.000	0.000	T							
Unconformaty	0.00	0.00	0.00	0.00	0.00	0.00	Φ							
	0.402	0.411	0.412	0.438	0.442	0.574	0.559	T						
Qishn	17.82	19.62	19.79	24.57	25.25	42.41	40.88	Φ						
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	T					
Unconformaty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Φ					
	0.466	0.473	0.474	0.494	0.497	0.578	0.574	0.681	0.675	T				
Saar	12.78	14.11	14.25	17.75	18.27	29.67	29.22	40.29	39.81	Φ				
	0.142	0.144	0.144	0.149	0.150	0.167	0.167	0.187	0.187	0.248	T			
Naifa	10.99	12.10	12.23	15.11	15.60	24.31	24.46	32.37	32.29	49.08	Φ			
	0.028	0.028	0.028	0.029	0.029	0.033	0.033	0.036	0.036	0.045	0.052	T		
Madbi	10.51	11.55	11.68	14.39	14.87	22.93	23.17	30.29	30.37	44.43	51.67	Φ		
	0.070	0.070	0.070	0.072	0.073	0.079	0.080	0.087	0.087	0.109	0.126	0.130	T	
Shuqra	7.72	8.63	8.74	11.15	11.59	19.24	19.45	26.59	26.63	41.38	48.95	50.53	Φ	
	0.010	0.010	0.010	0.011	0.011	0.011	0.011	0.012	0.012	0.012	0.013	0.013	0.013	T
Kuhlan	18.09	18.83	18.92	20.67	20.96	25.15	25.27	28.26	28.30	33.02	35.05	35.50	36.74	Φ
Σ T	2.436	2.281	2.262	1.922	1.867	1.152	1.133	0.681	0.997	0.415	0.190	0.143	0.013	

Figure 3. Backstripping and Decompacted results for Sunah-01 well in Block-14

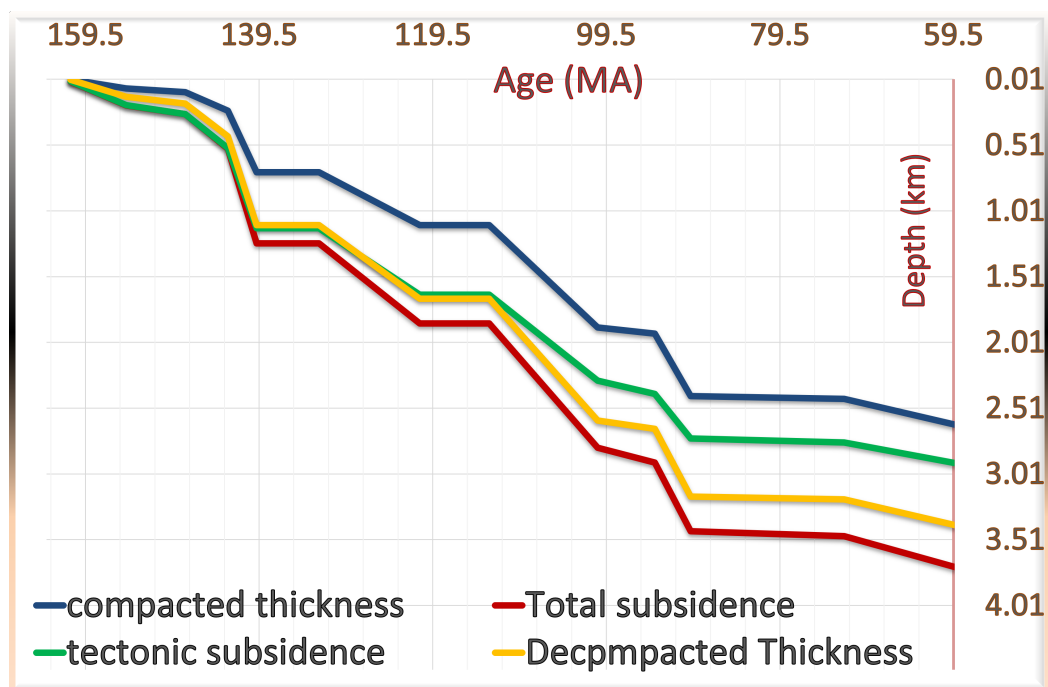


Figure 4. Subsidence curves of Sunah-01 well in Block-14

3.3. MADBI FORMATION (148 MA)

Deposited conformably above the Shuqra Formation, the Madbi is the principal source rock for hydrocarbons in both the Sabatayn and Say'un–Masilah basins [3, 17]. Present thickness: 28 m (Sunah-01) to 30.5 m (Cammal-01); decompacted thickness: 51.8 m and 54 m in Sunah-01 and Cammal-01 wells, respectively. Sedimentation rates: 0.76 cm/1,000yr (Sunah-01) to 0.8cm/1,000 yr (Cammal-01). Total subsidence: 70 m in both wells;

total subsidence rates: 0.98 and 1.02 cm/1,000 yr in Sunah-01 and Cammal-01 wells, respectively. Tectonic subsidence: 68 m (Sunah-01) and 69 m (Cammal-01); tectonic subsidence rates: ~1.0 cm/1,000 yr in both wells, consistent with deposition during the initial syn-rift stage.



FORMATIONS	Present Porosity and Thickness													
Umm	0.260	T	Decompacted porosity and Thickness											
Er Radhuma	44.57	Φ												
Sharwayn	0.036	0.040	T											
	41.01	46.59	Φ											
Mukalla	0.460	0.498	0.502	T										
	36.14	41.07	41.50	Φ										
Fartaq	0.042	0.044	0.044	0.054	T									
	31.56	35.50	36.18	47.43	Φ									
Harshiyat	0.773	0.806	0.810	0.923	0.923	T								
	25.04	28.18	28.48	37.29	37.23	Φ								
Unconformaty	0.000	0.000	0.000	0.000	0.000	0.000	T							
	0.00	0.00	0.00	0.00	0.00	0.00	Φ							
Qishn	0.373	0.381	0.383	0.407	0.410	0.534	0.521	T						
	17.96	19.88	20.19	24.94	25.55	42.79	41.33	Φ						
Unconformaty	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	T					
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Φ					
Saar	0.185	0.188	0.189	0.198	0.200	0.238	0.238	0.287	0.288	T				
	14.17	15.74	16.02	19.88	20.45	33.28	33.16	44.64	44.90	Φ				
Naifa	0.030	0.030	0.030	0.032	0.032	0.037	0.037	0.045	0.045	0.052	T			
	13.78	15.30	15.59	19.31	19.91	31.90	32.12	43.02	42.89	51.29	Φ			
Madbi	0.031	0.031	0.031	0.033	0.033	0.038	0.039	0.046	0.045	0.053	0.054	T		
	13.63	15.13	15.42	19.07	19.67	31.40	31.61	42.16	42.04	50.02	51.55	Φ		
Shuqra	0.017	0.017	0.017	0.018	0.018	0.021	0.021	0.025	0.025	0.030	0.031	0.032	T	
	10.67	12.06	12.33	15.82	16.40	28.32	28.57	39.88	39.79	48.56	50.30	52.31	Φ	
Kuhlan	0.011	0.011	0.011	0.011	0.012	0.012	0.012	0.013	0.013	0.014	0.014	0.014	0.014	T
	20.49	21.42	21.59	23.64	23.95	29.19	29.29	33.02	33.01	35.45	35.92	36.42	36.73	Φ
Σ T	2.127	1.958	1.928	1.583	1.533	0.772	0.759	0.287	0.416	0.148	0.099	0.046	0.014	

Figure 5. Backstripping and Decompacted results for Cammal-01 well in Block-14

3.4. NAIFA FORMATION (143.1 MA)

Overlies the Madbi conformably. Two facies are recognized: a restricted pelagic rift facies (porcellanites, condensed sequences, and calci-turbidites) and a more open-marine pelagic facies [1]. Present thickness: 29.5 m (Cammal-01) to 142 m (Sunah-01); decompacted thickness: 52 m and 248 m in Cammal-01 and Sunah-01 wells, respectively. Sedimentation rates: 0.86 cm/1,000 yr (Cammal-01) to 4.0 cm/1,000 yr (Sunah-01). Total subsidence: 70 m (Cammal-01) and 260 m (Sunah-01); total subsidence rates: 1.1 and 4.3 cm/1,000 yr, respectively. Tectonic subsidence: 66.8 m (Cammal-01) and 250 m (Sunah-01); tectonic subsidence rates: 1.1 and 4.2 cm/1,000 yr, respectively. The marked acceleration of tectonic subsidence in Sunah-01 relative to Cammal-01 reflects intensified Jurassic rifting recorded in the north-eastern sector of the study area.

3.5. SAAR FORMATION (139.8 MA)

Basal Cretaceous succession comprising dolomite and limestone with shale streaks. Present thickness ranges from 14 m (Tawilah-99) to 466 m (Sunah-01); decompacted thickness ranges from 23 m (Tawilah-99) to 675 m (Sunah-01). Sedimentation rates: 0.45 cm/1,000 yr (Tawilah-99) to 12.9 cm/1,000 yr (Sunah-01). Total subsidence ranges from 70 m (Tawilah-99) to 720 m (Sunah-01); total subsidence rates range from 1.32 cm/1,000 yr (Tawilah-99) to 13.85 cm/1,000 yr (Sunah-01). Tectonic subsidence ranges from 67 m (Tawilah-99) to 609 m (Sunah-01); tectonic subsidence rates range from 1.30 cm/1,000 yr (Tawilah-99) to 11.71 cm/1,000 yr (Sunah-

01). The contrast between Sunah-01 and Tawilah-99 across all parameters is the largest recorded among all formations in this study

3.6. QISHN FORMATION (121.4 MA)

The most important formation in the basin, representing the main oil reservoir [4, 5], composed of three members: Sa'af Member, Qishn Clastic Member, and Upper Qishn Carbonate Member. The present thickness ranges from 237 m (Tawilah-118) to 402 m (Sunah-01), and the decompacted thickness ranges from 335 m (Tawilah-118) to 559 m (Sunah-01). Sedimentation rates range from 3.1 cm/1,000 yr (Tawilah-118) to 4.9 cm/1,000 yr (Sunah-01). Total subsidence ranges from 395 m (Tawilah-118) to 609 m (Sunah-01), and total subsidence rates range from 3.52 to 5.4 cm/1,000 yr. Tectonic subsidence ranges from 344 m (Tawilah-118) to 505 m (Sunah-01), and tectonic subsidence rates range from 3.1 to 4.51 cm/1,000 yr. The relatively narrow range of subsidence values across all 22 wells indicates a more spatially uniform subsidence field during this interval compared to the underlying Saar Formation.

3.7. HARSHIYAT FORMATION (100.5 MA)

Rests unconformably above the Qishn Formation following a hiatus of approximately 8.4 Ma, representing a surface of non-deposition or erosion. The lithology consists of claystone interbedded with minor sandstone stringers. The present thickness ranges from 633 m (Tawilah-98) to 778 m (Sunah-01); the decompacted thickness ranges from 783 m (Tawilah-98) to 928 m (Sunah-01). Sed-

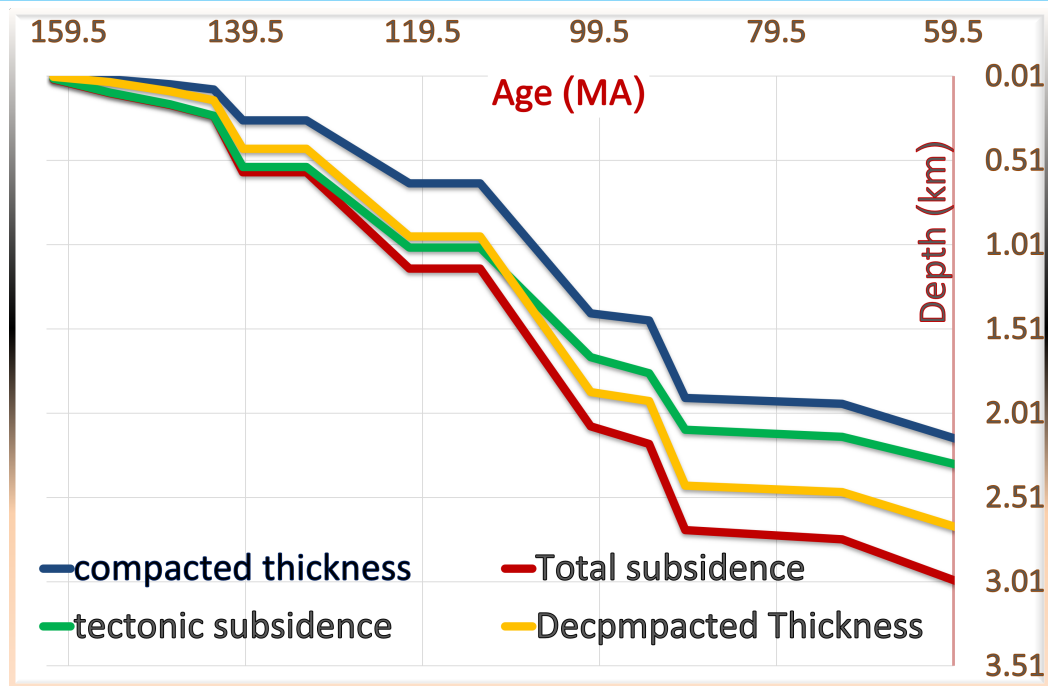


Figure 6. Subsidence curves of Cammal-01 well in Block-14

FORMATIONS			Present Porosity and Thickness							
Umm	0.264	T	Decompacted porosity and Thickness							
Er Radhuma	44.53	Φ								
Sharwayn	0.025	0.027	T							
	41.05	46.72	Φ							
Mukalla	0.551	0.596	0.597	T						
	35.46	40.40	40.49	Φ						
Fartaq	0.041	0.043	0.044	0.055	T					
	30.17	33.89	34.36	47.44	Φ					
Harshaiyt	0.738	0.768	0.770	0.898	0.895	T				
	24.15	27.15	27.31	37.69	37.50	Φ				
Unconformaty	0.000	0.000	0.000	0.000	0.000	0.000	T			
	0.00	0.00	0.00	0.00	0.00	0.00	Φ			
Qishn	0.265	0.272	0.273	0.294	0.297	0.390	0.382	T		
	18.01	19.95	20.19	26.09	26.77	44.17	43.04	Φ		
Unconformaty	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	T	
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Φ	
Saar	0.014	0.015	0.015	0.016	0.016	0.020	0.020	0.023	0.024	T
	15.47	17.22	17.47	22.80	23.56	38.44	38.58	47.71	48.66	Φ
Σ T	1.898	1.722	1.698	1.263	1.208	0.410	0.402	0.023	0.024	

Figure 7. Backstripping and Decompacted results for Tawilah-99 well in Block-14

imentation rates: 6.2 cm/1,000 yr (Tawilah-98) to 7.4 cm/1,000 yr (Sunah-01). Total subsidence ranges from 798 m (Tawilah-98) to 943 m (Sunah-01); total subsidence rates range from 6.34 to 7.54 cm/1,000 yr. Tectonic subsidence ranges from 591 m (Tawilah-98) to 670 m (Tawilah-103); tectonic subsidence rates range from 4.66 to 5.33 cm/1,000 yr. The Harshiyat records the maximum tectonic subsidence of ~ 655 m average across the study area, with a peak rate of 5.33 cm/1,000 yr in Tawilah-103.

3.8. FARTAQ FORMATION (93.9 MA)

Lies conformably above the Harshiyat Formation. Present thickness ranges from 38 m (Tawilah-91) to 50 m (Tawilah-98); decompacted thickness ranges from 51 m (Tawilah-91) to 67 m (Tawilah-98). Sedimentation rates: 0.76 cm/1,000 yr (Tawilah-91) to 1.02 cm/1,000 yr (Tawilah-98). Total subsidence ranges from 100 m (Tawilah-91) to 117 m (Tawilah-98); total subsidence rates range from 1.53 to 1.78 cm/1,000 yr. Tectonic subsidence ranges from 92 m (Tawilah-91) to 106 m

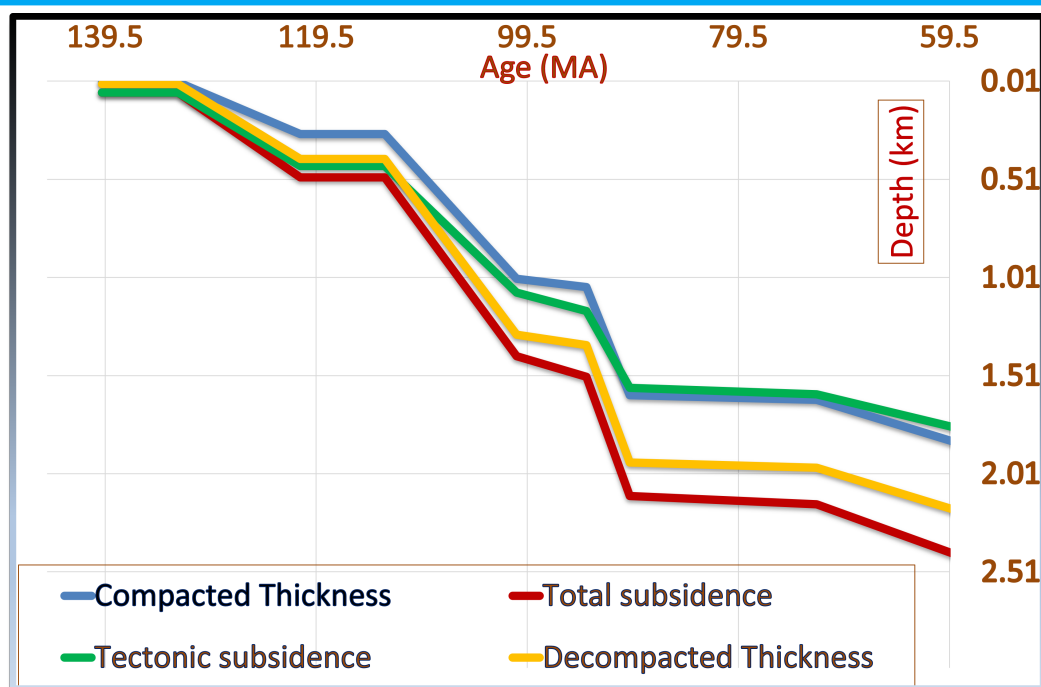


Figure 8. Subsidence curves of Tawilah-99 well in Block-14

(Tawilah-98); tectonic subsidence rates range from 1.39 to 1.60 cm/1,000 yr. The decline in tectonic subsidence rate from the Harshiyat (~5 cm/1,000 yr) to the Fartaq (~1.5 cm/1,000 yr) is the sharpest rate reduction observed between any two consecutive formations in the succession.

3.9. MUKALLA FORMATION (89.8 MA)

The largest formation in the Mahra Group, consisting mainly of sandstone with minor claystone, dolomite, and limestone. The present thickness ranges from 460 m (Cammal-01) to 585 m (Tawilah-98), and the decompacted thickness ranges from 501 m (Cammal-01) to 635 m (Tawilah-98). Mukalla records the highest sedimentation rate in the study, averaging 14.5 cm/1,000 yr. Total subsidence ranges from 512 m (Cammal-01) to 645 m (Tawilah-98), and total subsidence rates range from 12.48 to 15.73 cm/1,000 yr. Tectonic subsidence ranges from 336 m (Cammal-01) to 414 m (Tawilah-103), and tectonic subsidence rates range from 8.18 to 10.10 cm/1,000 yr. The difference between total and tectonic subsidence rates reaches up to 5.63 cm/1,000 yr across the studied wells, indicating that sediment loading contributed substantially to total subsidence during this interval.

3.10. SHARWAYN FORMATION (72.1 MA)

Deposited conformably above the Mukalla Formation, consisting of mixed carbonates and clastics. The present thickness ranges from 14 m (Tawilah-129) to 49 m (Tawilah-97), and the decompacted thickness ranges

from 17 m (Tawilah-129) to 55 m (Tawilah-97). Sedimentation rates: 0.09 cm/1,000 yr (Tawilah-129) to 0.31 cm/1,000 yr (Tawilah-97). Total subsidence ranges from 31.6 m (Tawilah-129) to 70 m (Tawilah-97); total subsidence rates range from 0.18 to 0.40 cm/1,000 yr; tectonic subsidence ranges from 26 m (Tawilah-129) to 53 m (Tawilah-97); tectonic subsidence rates range from 0.15 to 0.30 cm/1,000 yr. The marked decline in both sedimentation and tectonic subsidence rates relative to the Mukalla is consistent with a decrease in tectonic activity during this interval

3.11. UMM ER RADHUMA FORMATION (56 MA)

The uppermost formation in Block 14, representing the first formation of the Hadramaut Group, is composed mainly of limestone. Since no stratigraphic units overlie this formation within the studied succession, it has not been subjected to any overburden loading; consequently, no compaction correction was applied, and the present-day thickness is considered equal to the original depositional thickness. The present thickness ranges from 247 m (Sunah-01) to 373 m (Tawilah-89); sedimentation rates range from 1.5 cm/1,000 yr (Sunah-01) to 2.3 cm/1,000 yr (Tawilah-89). Total subsidence ranges from 297 m (Sunah-01) to 423 m (Tawilah-89); total subsidence rates range from 1.8 to 2.6 cm/1,000 yr. Tectonic subsidence ranges from 197 m (Sunah-01) to 268 m (Tawilah-89); tectonic subsidence rates range from 1.20 to 1.67 cm/1,000 yr. Sedimentation and tectonic subsidence rates are among the lowest recorded in the succession, consistent with decreased tectonic activity

**Table 3.** Calculated values of tectonic subsidence for each formation in the studied wells.

Well Name	Tectonic Subsidence (Km)												
	Umm Er Radhuma	Sharwayn	Mukalla	Fartaq	Harshiyat	Unconformity	Qishn	Unconformity	Saar	Naifa	Madbi	Shuqra	Kuhlan
Cammal-01	0.21	0.04	0.34	0.09	0.65	0.00	0.48	0.00	0.30	0.07	0.07	0.08	0.03
Sunah-01	0.20	0.03	0.34	0.10	0.65	0.00	0.51	0.00	0.61	0.26	0.07	0.18	0.03
Tawilah-68	0.21	0.03	0.39	0.10	0.64	0.00	0.39	0.00	0.16	–	–	–	–
Tawilah-70	0.23	0.03	0.40	0.09	0.65	0.00	0.37	0.00	0.20	–	–	–	–
Tawilah-89	0.27	0.03	0.37	0.10	0.65	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-90	0.20	0.03	0.38	0.09	0.64	0.00	0.37	0.00	0.17	–	–	–	–
Tawilah-91	0.21	0.03	0.40	0.09	0.66	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-93	0.21	0.04	0.40	0.09	0.66	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-94	0.21	0.05	0.39	0.09	0.66	0.00	0.37	0.00	0.15	–	–	–	–
Tawilah-95	0.21	0.03	0.40	0.10	0.66	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-96	0.21	0.03	0.40	0.09	0.66	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-97	0.21	0.05	0.39	0.09	0.65	0.00	0.38	0.00	0.15	–	–	–	–
Tawilah-98	0.21	0.04	0.41	0.11	0.58	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-99	0.21	0.03	0.39	0.09	0.64	0.00	0.37	0.00	0.07	–	–	–	–
Tawilah-103	0.23	0.03	0.41	0.09	0.67	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-104	0.21	0.03	0.39	0.10	0.65	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-117	0.21	0.03	0.41	0.10	0.66	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-118	0.20	0.03	0.39	0.09	0.66	0.00	0.34	0.00	0.17	–	–	–	–
Tawilah-124	0.21	0.03	0.38	0.09	0.62	0.00	0.37	0.00	0.17	–	–	–	–
Tawilah-127	0.21	0.03	0.41	0.09	0.66	0.00	0.37	0.00	0.17	–	–	–	–
Tawilah-129	0.21	0.03	0.41	0.09	0.65	0.00	0.37	0.00	0.16	–	–	–	–
Tawilah-138	0.21	0.03	0.40	0.09	0.66	0.00	0.37	0.00	0.17	–	–	–	–

Table 4. Calculated values of total subsidence for each formation in the studied wells.

Well Name	Total subsidence (Km)												
	Umm Er Radhuma	Sharwayn	Mukalla	Fartaq	Harshiyat	Unconformity	Qishn	Unconformity	Saar	Naifa	Madbi	Shuqra	Kuhlan
Cammal-01	0.31	0.05	0.51	0.10	0.94	0.00	0.57	0.00	0.33	0.07	0.07	0.08	0.03
Sunah-01	0.30	0.04	0.52	0.11	0.94	0.00	0.61	0.00	0.72	0.26	0.07	0.18	0.03
Tawilah-68	0.31	0.04	0.60	0.12	0.89	0.00	0.45	0.00	0.17	–	–	–	–
Tawilah-70	0.36	0.04	0.61	0.10	0.92	0.00	0.43	0.00	0.22	–	–	–	–
Tawilah-89	0.42	0.04	0.56	0.11	0.91	0.00	0.43	0.00	0.17	–	–	–	–
Tawilah-90	0.30	0.04	0.60	0.10	0.91	0.00	0.43	0.00	0.18	–	–	–	–
Tawilah-91	0.32	0.04	0.62	0.10	0.94	0.00	0.42	0.00	0.17	–	–	–	–
Tawilah-93	0.32	0.04	0.62	0.10	0.94	0.00	0.42	0.00	0.17	–	–	–	–
Tawilah-94	0.32	0.06	0.61	0.10	0.94	0.00	0.42	0.00	0.16	–	–	–	–
Tawilah-95	0.32	0.04	0.63	0.10	0.94	0.00	0.43	0.00	0.17	–	–	–	–
Tawilah-96	0.32	0.03	0.63	0.10	0.94	0.00	0.43	0.00	0.17	–	–	–	–
Tawilah-97	0.32	0.07	0.60	0.10	0.92	0.00	0.44	0.00	0.16	–	–	–	–
Tawilah-98	0.32	0.05	0.64	0.12	0.80	0.00	0.43	0.00	0.17	–	–	–	–
Tawilah-99	0.31	0.04	0.61	0.10	0.91	0.00	0.43	0.00	0.07	–	–	–	–
Tawilah-103	0.35	0.04	0.64	0.10	0.94	0.00	0.42	0.00	0.17	–	–	–	–
Tawilah-104	0.32	0.04	0.61	0.11	0.91	0.00	0.42	0.00	0.17	–	–	–	–
Tawilah-117	0.32	0.03	0.63	0.11	0.93	0.00	0.43	0.00	0.17	–	–	–	–
Tawilah-118	0.30	0.04	0.60	0.10	0.94	0.00	0.39	0.00	0.18	–	–	–	–
Tawilah-124	0.32	0.03	0.59	0.10	0.88	0.00	0.43	0.00	0.18	–	–	–	–
Tawilah-127	0.32	0.04	0.64	0.10	0.94	0.00	0.42	0.00	0.18	–	–	–	–
Tawilah-129	0.32	0.03	0.64	0.10	0.91	0.00	0.43	0.00	0.17	–	–	–	–
Tawilah-138	0.32	0.04	0.62	0.10	0.93	0.00	0.43	0.00	0.18	–	–	–	–

**Table 5.** Rate of Sedimentation for each formation in the studied wells.

Well Name	Rate of Sedimentation (cm/1000year)												
	Umm Er Radhuma	Sharwayn	Mukalla	Fartaq	Harshiyat	Unconformity	Qishn	Unconformity	Saar	Naifa	Madbi	Shuqra	Kuhlan
Cammal-01	1.61	0.22	12.23	0.82	7.38	0.00	4.65	0.00	5.54	0.86	0.80	0.48	0.77
Sunah-01	1.53	0.12	12.52	0.96	7.42	0.00	4.99	0.00	12.99	4.07	0.76	1.94	0.73
Tawilah-68	1.64	0.12	14.41	1.01	7.02	0.00	3.57	0.00	2.46	—	—	—	—
Tawilah-70	1.93	0.14	14.74	0.82	7.22	0.00	3.37	0.00	3.32	—	—	—	—
Tawilah-89	2.32	0.13	13.39	0.88	7.18	0.00	3.41	0.00	2.36	—	—	—	—
Tawilah-90	1.58	0.13	14.32	0.82	7.15	0.00	3.36	0.00	2.65	—	—	—	—
Tawilah-91	1.68	0.12	14.81	0.77	7.38	0.00	3.34	0.00	2.34	—	—	—	—
Tawilah-93	1.68	0.17	14.86	0.80	7.37	0.00	3.35	0.00	2.46	—	—	—	—
Tawilah-94	1.65	0.25	14.64	0.77	7.37	0.00	3.35	0.00	2.14	—	—	—	—
Tawilah-95	1.66	0.12	15.07	0.83	7.37	0.00	3.37	0.00	2.44	—	—	—	—
Tawilah-96	1.67	0.11	15.17	0.78	7.38	0.00	3.37	0.00	2.47	—	—	—	—
Tawilah-97	1.65	0.31	14.30	0.82	7.26	0.00	3.46	0.00	2.26	—	—	—	—
Tawilah-98	1.66	0.18	15.49	1.02	6.27	0.00	3.39	0.00	2.48	—	—	—	—
Tawilah-99	1.64	0.15	14.57	0.83	7.16	0.00	3.41	0.00	0.45	—	—	—	—
Tawilah-103	1.88	0.12	15.40	0.78	7.36	0.00	3.34	0.00	2.45	—	—	—	—
Tawilah-104	1.65	0.13	14.68	0.85	7.19	0.00	3.34	0.00	2.32	—	—	—	—
Tawilah-117	1.67	0.10	15.24	0.84	7.32	0.00	3.40	0.00	2.36	—	—	—	—
Tawilah-118	1.57	0.13	14.43	0.82	7.40	0.00	3.08	0.00	2.53	—	—	—	—
Tawilah-124	1.66	0.10	14.23	0.79	6.92	0.00	3.37	0.00	2.52	—	—	—	—
Tawilah-127	1.70	0.11	15.30	0.79	7.39	0.00	3.31	0.00	2.51	—	—	—	—
Tawilah-129	1.71	0.09	15.42	0.80	7.15	0.00	3.36	0.00	2.43	—	—	—	—
Tawilah-138	1.70	0.12	14.83	0.80	7.28	0.00	3.36	0.00	2.52	—	—	—	—

during the Paleogene.

4. CONCLUSIONS

This study presents a comprehensive geohistory analysis of Block 14, Say'un–Masilah Basin, eastern Yemen, based on 1D Airy backstripping of 22 wells. Eleven stratigraphic formations spanning ~ 161 Ma (Kuhlan to Umm Er Radhuma) were analyzed, quantifying porosity, decompacted thicknesses, total and tectonic subsidence, and their rates, and sedimentation rates. The principal findings are:

(1) Decompacted thicknesses and porosities consistently exceed present-day thicknesses and porosities across all formations, with the greatest compaction effect recorded in the Shuqra Formation at Sunah-01, where approximately 60 m of original sediment thickness was lost to compaction.

(2) The basin experienced three distinct evolutionary phases: a pre-rift phase (Kuhlan–Shuqra) characterized by slow, sediment-load-dominated subsidence; a syn-rift phase (Madbi– Naifa) marked by accelerating tectonic subsidence; and a post-rift phase (Saar–Umm Er Radhuma) during which tectonic subsidence progressively declined.

(3) Total and tectonic subsidence rates were lowest

during Kuhlan Formation deposition (total: ~ 1.56–1.60 cm/1,000 yr; tectonic: ~1.38–1.39 cm/1,000 yr), increased progressively through the Jurassic succession, and reached their maximum during Harshiyat Formation deposition, where the peak tectonic subsidence rate was 5.33 cm/1,000 yr and the peak total subsidence rate was 7.54 cm/1,000 yr. Both rates declined during Sharwayn and Umm Er Radhuma deposition, reaching minimum values of 0.15–0.30 cm/1,000 yr (tectonic) and 0.18–0.40 cm/1,000 yr (total).

(4) The Mukalla Formation records the highest sedimentation rate in the study, reaching up to 15.5 cm/1,000 yr in Tawilah-89. During this formation's deposition, the difference between total subsidence rates (~15.7 cm/1,000 yr) and tectonic subsidence rates (~10.1 cm/1,000 yr) is the largest observed in the succession, indicating that sediment loading contributed substantially to total subsidence during this interval.

(5) Sunah-01, which penetrated all eleven formations and recorded the thickest sedimentary succession in the study, has the highest cumulative total subsidence (3779 m) and tectonic subsidence (2970 m) among all studied wells. Tawilah-99, which penetrated seven formations and recorded the thinnest sedimentary succession, has the lowest cumulative total subsidence (2479 m) and



tectonic subsidence (1813 m). The difference of 1300 m in total subsidence and 1157 m in tectonic subsidence between these two wells reflects both the difference in the number of formations penetrated and the variation in sedimentary thickness across Block 14.

(6) The quantified porosity profiles, decompacted thicknesses, total and tectonic subsidence curves and rates, and sedimentation rates together constitute a comprehensive geohistory dataset for Block 14 that provides a quantitative basis for petroleum system modeling, 2D/3D subsidence studies, and basin comparison studies within the Say'un–Masilah Basin.

REFERENCES

- [1] P. Redfern and J. A. Jones, "The interior rifts of Yemen: Analysis of basin structure and stratigraphy in a regional plate tectonic context," *Basin Res.*, vol. 7, pp. 337–356, 1995.
- [2] Z. R. Beydoun and M. L. As-Saruri, "Phanerozoic depositional basins and inter-basinal highs of Yemen," *Zeitschrift für Geol. Wissenschaften*, vol. 26, no. 5-6, pp. 517–529, 1998.
- [3] D. W. Bosence, "Mesozoic rift basins of Yemen," *Mar. Petroleum Geol.*, vol. 14, no. 6, pp. 611–616, 1997.
- [4] W. A. King, B. R. Mills, G. Scoot, and A. A. Abdillah, "The masilah fields, republic of Yemen," in *Giant Oil and Gas Fields of the Decade 1990–1999*, ser. AAPG Special Publication 17, M. T. Halbouty, Ed., 2003, pp. 1–24.
- [5] D. A. Leckie and T. Rumpel, "Tide-influenced sedimentation in a rift basin—cretaceous Qishn Formation, Masila Block, Yemen: A billion-barrel oil field," *AAPG Bull.*, vol. 87, no. 6, pp. 987–1013, 2003.
- [6] A. M. Al-Matary and H. M. Ahmed, "Basin analysis study of Block 10 in the Say'un-Masilah Basin, Yemen, using a 1d backstripping method," *Arab. J. Geosci.*, vol. 5, no. 3, pp. 529–543, 2012.
- [7] A. M. Al-Matary and H. Sufian, "Geohistory analysis of the cretaceous sediments of Block 7 (Baraq Area), Sabatayn Basin, Yemen," *Fac. Sci. Bull.*, vol. 26, pp. 63–79, 2014.
- [8] A. M. Al-Matary and E. N. Al-Tairi, "Basin analysis study of Block 53 in the Masila Basin, Yemen, using a 1d-backstripping method," *Sana'a Univ. J. Appl. Sci. Technol.*, vol. 2, no. 1, pp. 65–82, 2024.
- [9] A. Al-Johia, E. Ibrahim, H. J. Al Faifi, M. M. Kinawy, N. S. Al Arifi, and A. Lashin, "Investigating deep geological reservoirs using seismic reflection and well logs, Tawila oil field, Yemen: Implications for structural setting and reservoir properties," *J. Petroleum Sci. Eng.*, vol. 176, pp. 1018–1040, 2019.
- [10] A. M. Al-Matary, M. H. Hakimi, K. A. Mustapha, A. Rahim, W. Naseem, and Z. A. Al-Shawafi, "Molecular compositions of oil-bearing sandstones and oil asphaltene from the Kharir oilfields in the Western Central Masila Basin, Yemen," *ACS Omega*, vol. 9, pp. 17 398–17 414, 2024.
- [11] M. S. Steckler and A. B. Watts, "Subsidence of the atlantic-type continental margins of New York," *Earth Planet. Sci. Lett.*, vol. 41, pp. 1–13, 1978.
- [12] J. E. Van Hinte, "Geohistory analysis—application of micropaleontology in exploration geology," *AAPG Bull.*, vol. 62, no. 2, pp. 201–222, 1978.
- [13] M. Scheck and U. Bayer, "Evolution of the northeast German Basin—inferences from a 3d structural model to subsidence analysis," *Tectonophysics*, vol. 313, pp. 145–169, 1999.
- [14] W. A. Van Sickle, M. A. Kominz, K. G. Miller, and J. V. Browning, "Late cretaceous and cenozoic sea-level estimates: Backstripping analysis of borehole data, onshore New Jersey," *Basin Res.*, vol. 16, pp. 451–465, 2004.
- [15] A. M. Roberts, N. J. Kusznir, G. Yielding, and P. Styles, "2d flexural backstripping of extensional basins: The need for a sideways glance," *Petroleum Geosci.*, vol. 4, pp. 327–338, 1998.
- [16] P. A. Allen and J. R. Allen, *Basin Analysis: Principles and Applications*, 2nd ed. Oxford: Blackwell Scientific, 2005.
- [17] Z. R. Beydoun et al., *International Lexicon of Stratigraphy, VIII, Asia, Fascicule 10b2: Republic of Yemen* (IUGS Publication 34). IUGS, 1998, pp. 1–245.
- [18] E. Flügel, *Microfacies of Carbonate Rocks: Analysis, Interpretation and Application*. Berlin: Springer, 2004.
- [19] L. F. Athy, "Density, porosity and compaction of sedimentary rocks," *AAPG Bull.*, vol. 14, pp. 1–24, 1930.
- [20] Badley Earth Sciences (Computing) Limited, *Flex-Decomp Software, v.1.0*, Badley Earth Sciences (Computing) Limited, Lincolnshire, UK, 2000.