



3D Seismic Data Interpretation and Static Reservoir Modeling of Mamuniyat Formation, I and R Oil Fields, Murzuq Basin, Libya

Mosab Abukliesh¹, Taher Mostafa ^{2,*}, M. Y. Zein El Din² and Tharwat H. Abdelhafeez ²

¹ Akakus Oil Operations, Libya

² Geology Department, Faculty of Science, Al-Azhar University, Cairo, Egypt

* Correspondence: taher_mostafa@azhar.edu.eg

Abstract

Received:
20 August 2023

Accepted:
2 March 2024

Published:
31 May 2024

The Mamuniyat Formation, located within the Murzuq Basin in western Libya, represents a hydrocarbon reservoir characterized by significant preservation quality. A 3D reservoir modeling method was used in this study to evaluate the Mamuniyat reservoir in the I and R oil fields in the Murzuq Basin. The study looked at the reservoir's structural configuration, facies distribution, and petrophysical parameters. The basic problem in those fields is the large number of dry holes. A 3D seismic survey along with geophysical well logs are the data provided to accomplish the present work. The structural model was constructed based on depth-structure maps derived from seismic data analysis, which revealed the presence of two influential faults affecting the targeted strata within the investigated area. Notably, the primary NNW-SSE-oriented normal fault assumes a critical role as a structural trap. By incorporating well logs and petrophysical parameter computations, facies and property models were established. Facies analysis identified two principal facies, namely sandstone and shale. Based on the analysis of well logs and core data, it has been determined that the Mamuniyat Formation mostly consists of sandstone, with a very small amount of shale ranging from 5 to 10%. The effective porosity values range from moderate (13%) to good (16%), whereas the oil saturation varies between 62% and 91%. Employing the three-dimensional static reservoir modeling technique facilitated the visualization of lithofacies distribution, effective porosity, and hydrocarbon saturation across the reservoir's lateral extent. Consequently, the analysis determined that the upper section of the Mamuniyat Formation predominantly comprises sandstone with a relatively limited proportion of shale. Moreover, this interval exhibits favorable petrophysical characteristics, including high porosity values and significant hydrocarbon saturation.

Keywords: Mamuniyat Formation; Murzuq Basin; 3D Seismic Interpretation; 3D Reservoir Modeling

1. Introduction

The utilization of the 3D reservoir modeling technique is crucial in the context of hydrocarbon prospect investigations due to its ability to expedite the creation of reservoir prediction models that are associated with substantial hydrocarbon reservoirs (Ugwu et al., 2022; Abdelwahhab and Raef 2020; Abdelwahhab et al., 2023). The present work used a three-dimensional reservoir modeling methodology to assess the characteristics of the Mamuniyat reservoir in Murzuq Basin, which is situated on the

southwest of Libya as shown in the location map (Fig.1a). The Murzuq Basin is classified as one of the intra-cratonic basins located on the North African Platform, with an approximate coverage area of 350,000 square kilometers. The modern boundaries of the basin are determined by multi-phase tectonic uplifts, and its present geometry bears no relation to the far larger North African sedimentary basin that was present in the early Paleozoic era. The basin exhibits multiple episodes of fault displacement over several generations; yet the resultant level of deformation is negligible. According to Davidson et al. (2000), the basin has a sedimentary deposit that attains a maximum thickness of around 4000 meters at its center. This deposit is comprised of a significant marine Paleozoic section as well as a continental Mesozoic layer. There are several concessions in the Murzuq Basin, each of which includes oil fields. The “I” and “R” (I-NC186 and R-NC115) oil fields are a part of the NC186 and NC115 Concessions, which are located on the northern Murzuq Basin, southwestern Libya. Specifically, these fields are positioned to the south of the A-NC186 Field and to the north of the N-NC115 Field. The Mamuniyat Formation's oil production is attributed to these two fields.

The I-NC186 Field was discovered in August 2005 through an exploration well conducted by Mamuniyat. In the past, two wells were excavated inside the region: B1-NC68 in 1960 and WSW21 in 2003, both of which yielded oil. The R-NC115 Field was discovered in September 2005 during the drilling of the R01-NC115 exploration well in the Mamuniyat region. Numerous scholars have conducted research on the geological setting and reservoir evaluation of the Murzuq Basin (McDougall and Martin, 2000; Davidson et al. 2000; Echikh and Sola, 2000; Fello, 2001; Hallett, 2002; El-Ghali, 2005; Le Heron et al. 2006; Ramos et al. 2006; Le Heron, 2010; Gruber et al. 2011; Cubitt et al. 2011; Castro et al. 2012; Abushalah and Serpa, 2016; Bataller et al. 2021).

The primary objective of the present study is to effectively combine geophysical seismic data and well logs to maximize the utilization of the existing data for the evaluation of the Mamuniyat reservoir. Despite achieving notable success in exploration efforts, the previous decade has witnessed the drilling of over 20 unproductive boreholes, as emphasized by Martin et al (2016), underscoring the importance of the current study.

2. Geologic Setting

Figure 1a depicts the map of Murzuq Basin. The I & R fields are located within an anticline structure situated at the base of a tilted block. This block is bounded by a significant fault trending in the northwest-southeast direction to the east, although confirmation of fault sealing has not been established. Additionally, I-03 and B1-68 wells show that reservoir property degradation constrains the field's northern-northwestern boundary. According to the data from well R03-NC115, it is evident that the I & R field structures are in the western region below the oil-water contact (OWC) at a depth of -3142 ft. TVDSS. The fields of interest and research (I & R) encompass both stratigraphic and structural traps in combination.

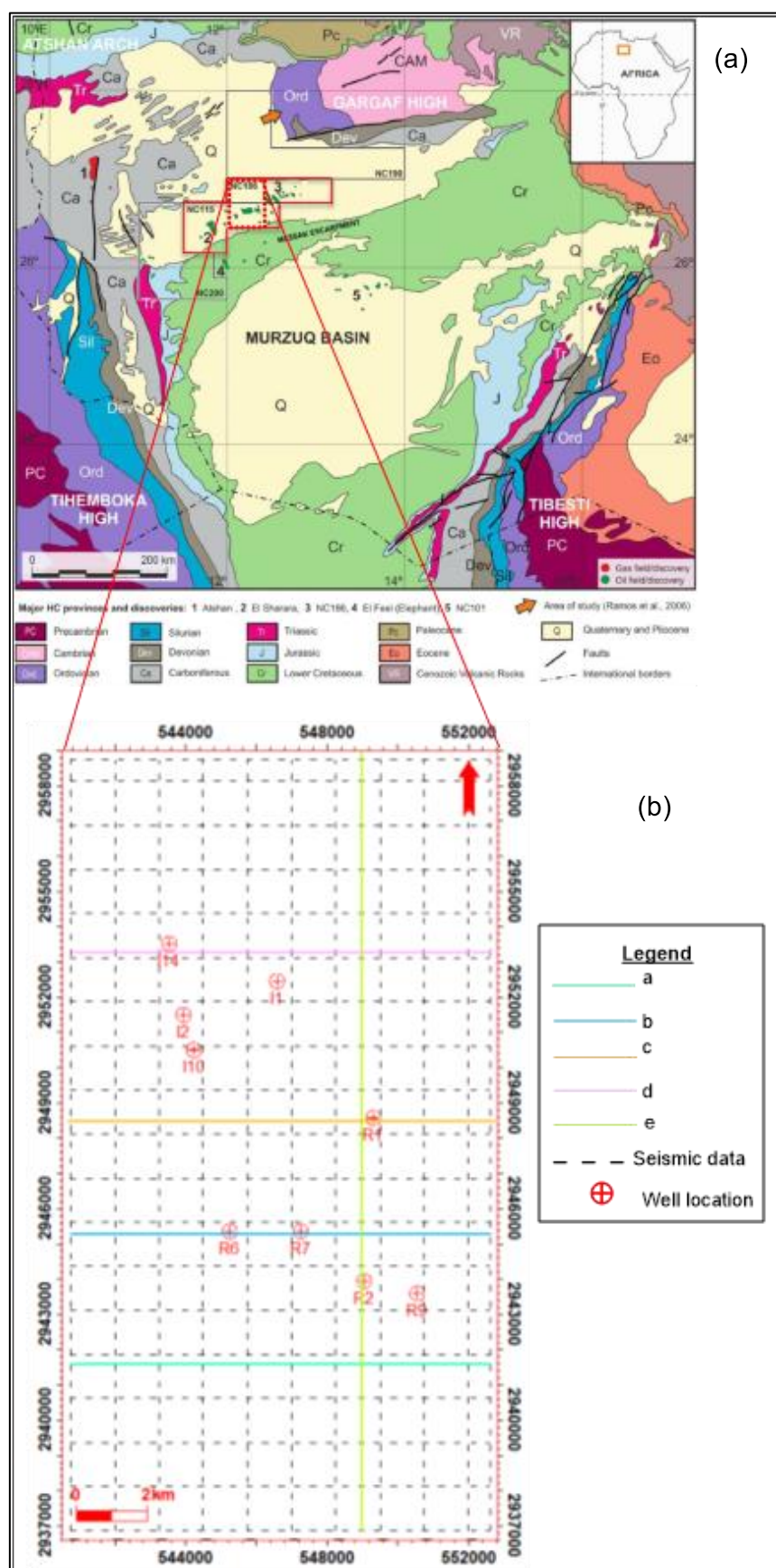


Fig. 1. (a) Location map of the Murzuq Basin, modified after (Gil-ortiz et al. 2022; Shalbak 2015) (b): a base map showing the location of the seismic survey, wells, and investigated profiles in the area

The accumulation of oil occurred within a glacial paleo valley that was previously occupied by the Mamuniyat Formation. This formation was subsequently eroded and covered by a notable Silurian marine incursion, resulting in the formation of the Taconic Unconformity. Over time, the paleo-valley underwent mild deformation during the basin's following orogenic processes (Castro et al., 2012). The predominant geological formation of the Silurian Period was the Tanezzuft Formation, characterized by its substantial thickness of shale. The predominant source rock within the region is identified as the Hot Shale member. The Upper Ordovician Mamuniyat Formation, as identified by Castro et al. (2012), serves as the producing reservoir for significant oil fields such as A, B, H, M-NC115, and B-NC186.

Using traditional sequence stratigraphy, which was made for quiet margins, makes it hard to figure out what the Mamuniyat Formation is made of because it was laid down in many different stages in a glaciotectionally active area (Fig. 2), (Fello, 2001; Mohamed and Beshr, 2022). According to McDougall and Martin (2000), the classification of Mamuniyat consists of three distinct categories: lower Mamuniyat, middle Mamuniyat, and upper Mamuniyat. In a broad sense, three discrete depositional environments have been discerned:

Lower Mamuniyat is a geological formation that is classified as a high-stand system tract. It is closely associated with the Melaz Shuqran Cycle and has similar features, such as debris flow and soft sediment deformation. The Middle Mamuniyat Formation is commonly referred to as the Lower Mamuniyat Formation. This geological unit is characterized by the presence of rippling, dewatering, and sinking heterolithic sediments. In general, sediment deposition occurred within a braid-delta system characterized by fast advancement, which was primarily driven by the melting of ice sheets. The Upper Mamuniyat exhibits exceptional reservoir features, characterized by the presence of course to highly coarse-grained deposits formed through the development of anastomosed-to-braided systems on active glacial outwash plains or sandur.

The Clean Mamuniyat Formation can be seen in the I & R fields. It is the same as the Lower Mamuniyat sequence, which can be seen in the I-NC186 Field and the eastern part of the R-NC115 Field area. The presence of Upper Mamuniyat has the potential to be observed inside the central and western regions of the R-NC115 area; nevertheless, it is imperative to verify this assertion through appropriate validation processes. The observed pattern might represent a cyclical process of excavation and deposition in which the advancement of glaciers and a subsequent slowing of sea level rise cause the basal incision. The Lower Mamuniyat series, characterized by the presence of sand-shale intercalation, exhibits a correlation with the Dirty Mamuniyat formation. Middle Mamuniyat is being worn away because thick shale and silty sandstone are mixed together. This was seen in field B-NC115, which is a highly productive reservoir in the Murzuq basin. The south-to-north well correlation (R02-NC115 to I03-NC186) shows that the quality of the reservoirs gets noticeably worse as you move toward the north and northwest of Clean Mamuniyat. The Clean Mamuniyat reservoir is not considered present at wells I03-NC186 and B1-68 due to the poor reservoir conditions observed at these locations. During the testing phase, it was seen that the I03-NC186 well did not yield any oil from the upper sand bodies. Furthermore, the traditional core analysis conducted at this particular interval indicated significantly low permeability values. According to McDougall and Martin (2000), B1-68 Well is presumptively located at the edge of the Clean Mamuniyat reservoir interval based on the data currently available.

3. Materials and Methods

The primary objective of this study is to utilize the existing 3D seismic survey and well logs in order to assess the structure of the reservoir, distribution of facies, and petrophysical parameters. In order to accomplish the objectives of this study, a seismic survey was utilized in

ERA	PERIOD/SUBPERIOD		EPOCH	AGE (My)	TECTONIC EVENT	New ROO Terminology (IRC-based)			
CENOZOIC	Quaternary or Pleistocene		Holocene	0.01	Alpine	Quaternary			
			Pleistocene	1.64		Al Mahruqah Fm.			
	Tertiary	Neogene	Pliocene	5.2		& basalts			
			Miocene	23.3		Mazul Ninah Fm.			
		Paleogene	Oligocene	35.4		Bishima Fm.			
			Eocene	56.5		Surfah Fm.			
			Paleocene	65.0		Zmam Fm.			
			MESOZOIC	Cretaceous		Late Cretaceous	97.0	Austrian	Messak Fm.
Early Cretaceous	145.6	Taouratine Fm.							
Malam	157.1	Zarzaitine Fm.							
Jurassic	Dogger			178.0					
	Lias			208.0					
	Triassic	Late		235.0	Hercynian	Tiguentourine Fm.			
Mid		241.1							
Lower		245.0							
PALAEOZOIC	Permian			Zechstein	256.1	Caledonian	Akakus Fm.		
				Rotliegendes	290.0				
	Carboniferous	Upper	Stephanian	303.0	Taconic			Tanezzuft Fm.	
			Westphalian	318.0					
		Lower	Namurian	332.9					Hot sh.mbr
			Visean	349.5					
	Devonian	Early	Tournaisian	362.5	Mamuniyat Fm.				
			Late	377.4				Tashgart / Melaz Shuqran Fm.	
			Middle	386.0					
	Silurian	Wenlock-Prid	430.4	Late Pan African	Ash Shabiyat / Hawaz Fm.				
			Liandoverian					439.0	
	Ordovician	Upper	Ashgillian	443.1	Hasawnah Fm.				
			Caradocian	463.9					
		Lower	Llave./ Lland.	476.1					
			Arenig	493.0					
Cambrian	Upper	Tremadoc	510.0	Mourizdie Fm.					
		517.0							
		Middle	536.0						
4330	INFRACAMBRIAN		Algonkian	2500.0	Pan African	Basement			
	PRECAMBRIAN		Archean	4000.0					
LEGEND Present in NC115 Not Present in NC115 Studied Formation									

Fig. 2. Stratigraphic column depicting the geological layers of the Murzuq Basin in Southwest Libya, together with the significant tectonic events that have influenced it, after (Fello, 2001; Mohamed and Beshr, 2022)

conjunction with nine boreholes (Fig. 1b). Furthermore, a comprehensive collection of geophysical well data, encompassing Gamma Ray, Deep, Shallow, and Micro Resistivity, Neutron, Sonic, and

Density logs, were provided. Four wells, specifically I-1, I-2, I-10, and I-14, were obtained from the I-NC186 Field. Furthermore, a total of five wells, specifically R-1, R-2, R-6, R-7, and R-9, were acquired from the R-NC115 Field. The current study initiated by collecting and uploading seismic data, followed by utilizing the check-shot surveys present in the area to construct the seismic-well correlation. After the tie process, the formation tops that exhibited the most significant intervals were chosen and thereafter subjected to continuous monitoring across the entire region. The analysis of seismic data subsequently revealed the presence of faults that had an impact on the region. The generation of the two-way time-structure maps was accomplished by employing the interpreted seismic horizons and carefully chosen faults. The time-depth data obtained from the provided check-shot surveys enabled the creation of a time-depth conversion method. Afterwards, the maps depicting the structure at various depths were constructed. The utilization of depth-structure maps facilitated the development of a structural framework for the formations being studied. The utilization of a structural model and the analysis of petrophysical properties have played a crucial role in the advancement of facies and property models, enabling the characterization of porosity and saturation.

4. Results and Discussion

The current study commenced with the interpretation of seismic data. The initial phase of this interpretation involved establishing a correlation between seismic data and well data through the utilization of a check-shot survey (Fig. 3). Following the conclusion of the tie, the subsequent selection process has now been feasible. Three formations, namely Tanezzuft, Mamuniyat, and Melez Shuqran formations, were chosen for comprehensive study over the region. The investigation and depiction of the structure's impact on the area were afterwards conducted and superimposed onto the seismic sections. Figure 3 displays several seismic sections that have been interpreted. The analysis of the three-dimensional seismic data led to the identification of two faults that impact the investigated strata within the designated research region. These faults included one major normal fault and one minor normal fault which have an impact on the three formations, Tanezzuft, Mamuniyat, and Melez Shuqran formations. This major fault intersected the whole study region and characterized by an NNW-SSE orientation. The primary structural trap in the region is predominantly characterized by this significant fault. Several wells have been drilled into the up-thrown side of this fault, which has the potential to serve as a reservoir. The minor normal fault is characterized by a northwest-southeast orientation and has an impact on the northwestern part of the study area. Subsequently, time-structure maps were generated for the Tanezzuft, Mamuniyat, and Melez Shuqran formations. The time-depth connection depicted in Figure 4 was subsequently employed to convert time to depth measurements. This enabled the creation of depth-structure maps for the Tanezzuft, Mamuniyat, and Melez Shuqran formations, as illustrated in Figure 5. The structure model was constructed by employing the fault polygons and depth structure maps that were generated during the seismic analysis procedures. From this model, five junctions within the research area were selected to demonstrate the impact of the structure on the area, as depicted in Figure 6. The well logs were subjected to petrophysical analysis using the Interactive Petrophysics (IP) software. The identification of the lithological composition of the Mamuniyat Formation was conducted. Estimations were conducted to determine the shale concentration, effective porosity, and hydrocarbon saturation of the Mamuniyat Formation. Based on the analysis of well logs and

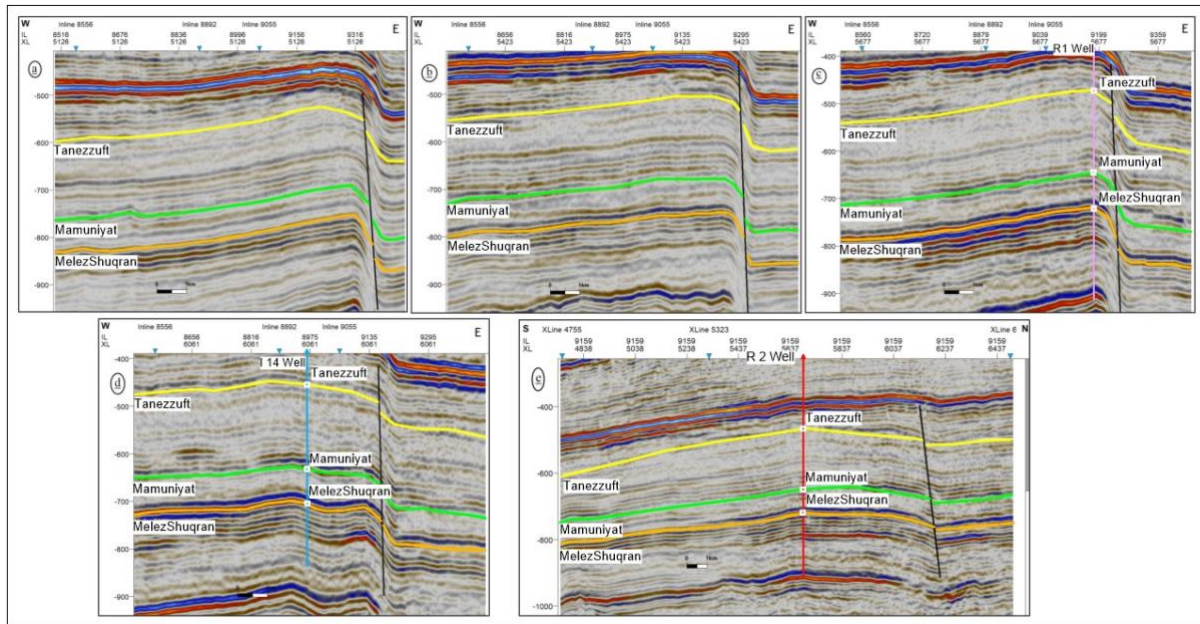


Fig. 3. The interpreted seismic sections a, b, c, d, and e (see figure 1b) show the picked horizons and faults.

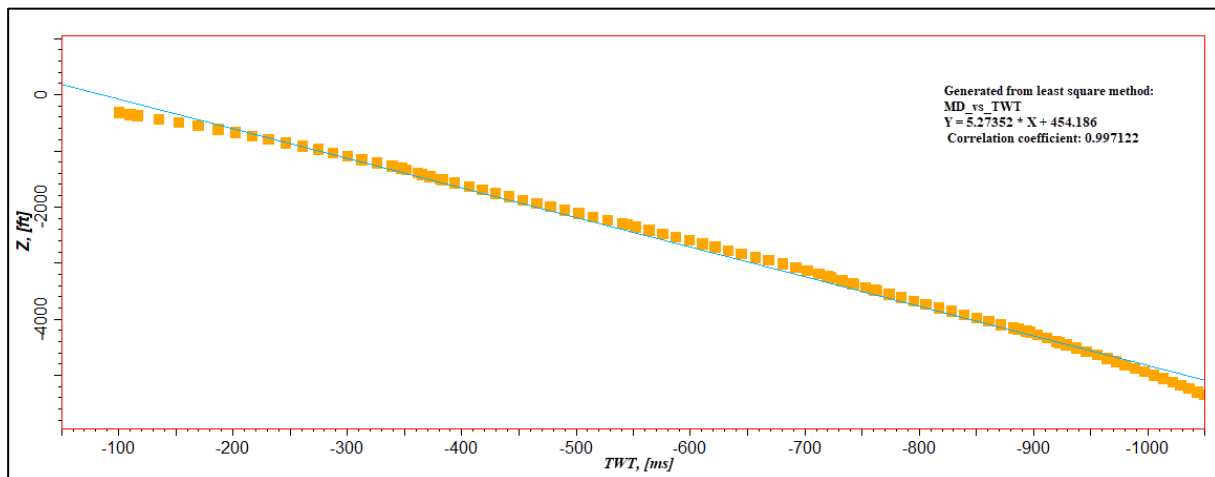


Fig. 4. The time-depth relationship used for the time-depth conversion

core data, it has been determined that the Mamuniyat Formation mostly consists of sandstone, with a very small amount of shale ranging from 5 to 10%. The effective porosity values range from moderate (13%) to good (16%), whereas the oil saturation varies between 62% and 91%. A discrete facies log was generated for all wells in the studied area based on the log data. The correlation between the analyzed wells in the area is depicted in Figure 7, showcasing the upscaled facies, porosity, and saturation logs. Subsequently, the logs were enlarged and dispersed throughout the region in order to construct the facies model. Two primary facies, namely sandstone and shale, were identified. Figure 8 displays the spatial distribution of five intersections within the facies model across the designated area. The petrophysical models were developed based on the estimated petrophysical parameters, including effective porosity and water saturation. Figure 9 illustrates the spatial distribution of the effective porosity across five cross-sectional profiles that encompass the studied region. Figure 10 depicts the spatial distribution and variability of fluid saturation across five intersections within the designated region.

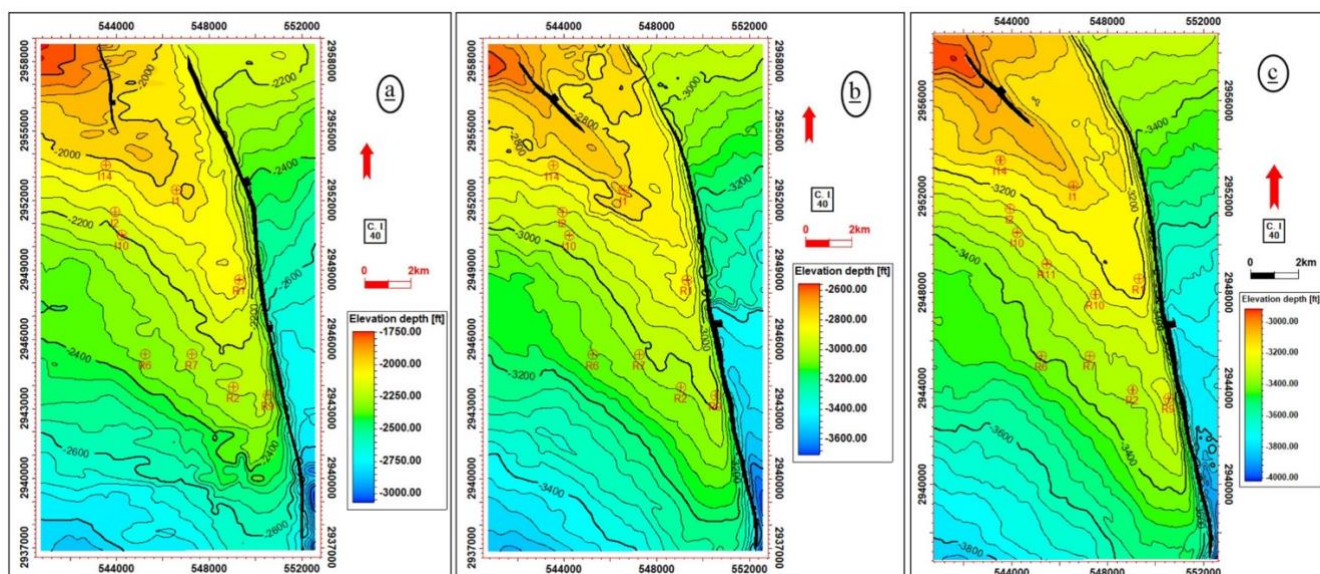


Fig. 5. The depth-structure maps of (a) Tanezzuft, (b) Mamuniyat, and (c) Melez Shuqran formations

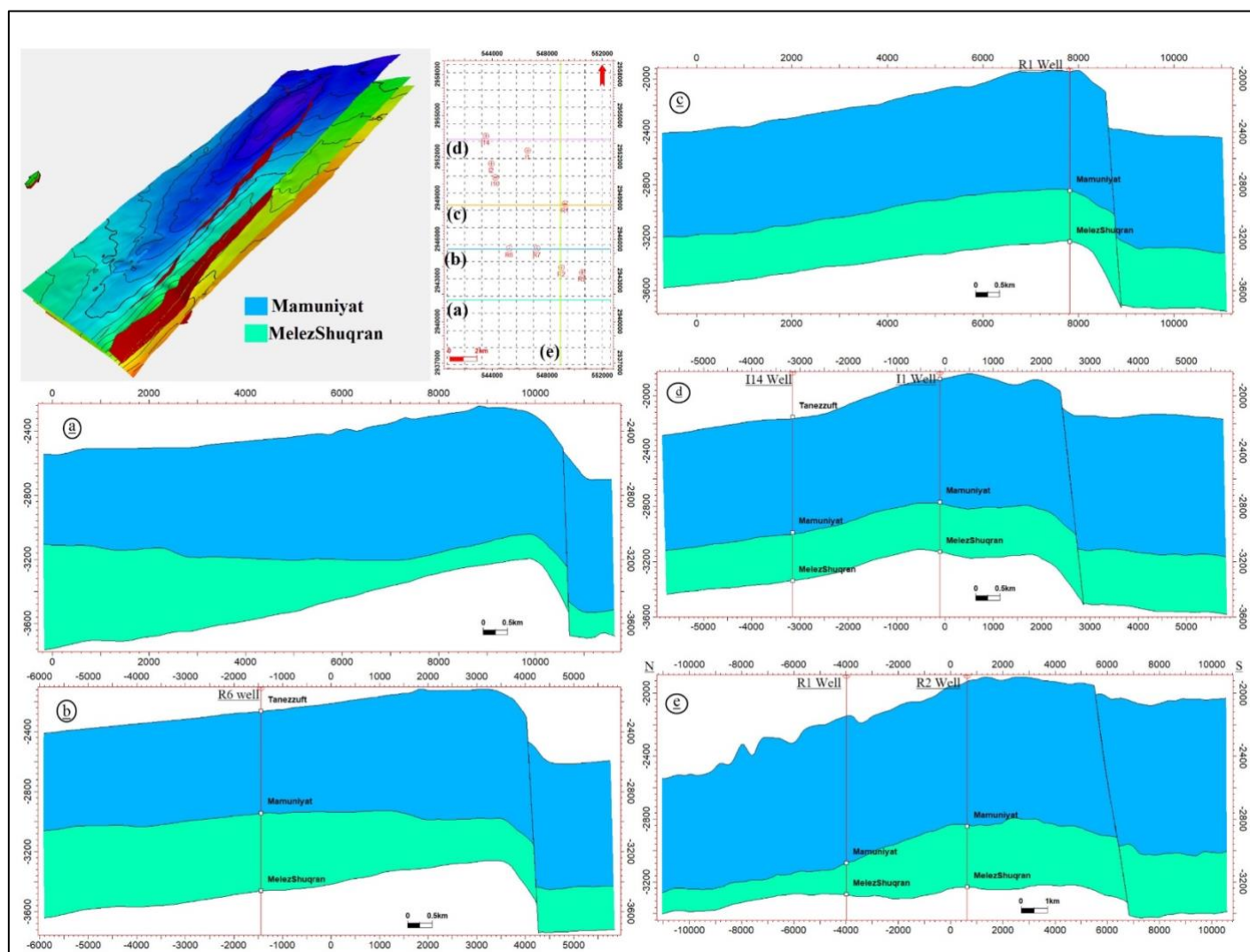


Fig. 6. Structure intersections a, b, c, d, and e through the structure model of the area

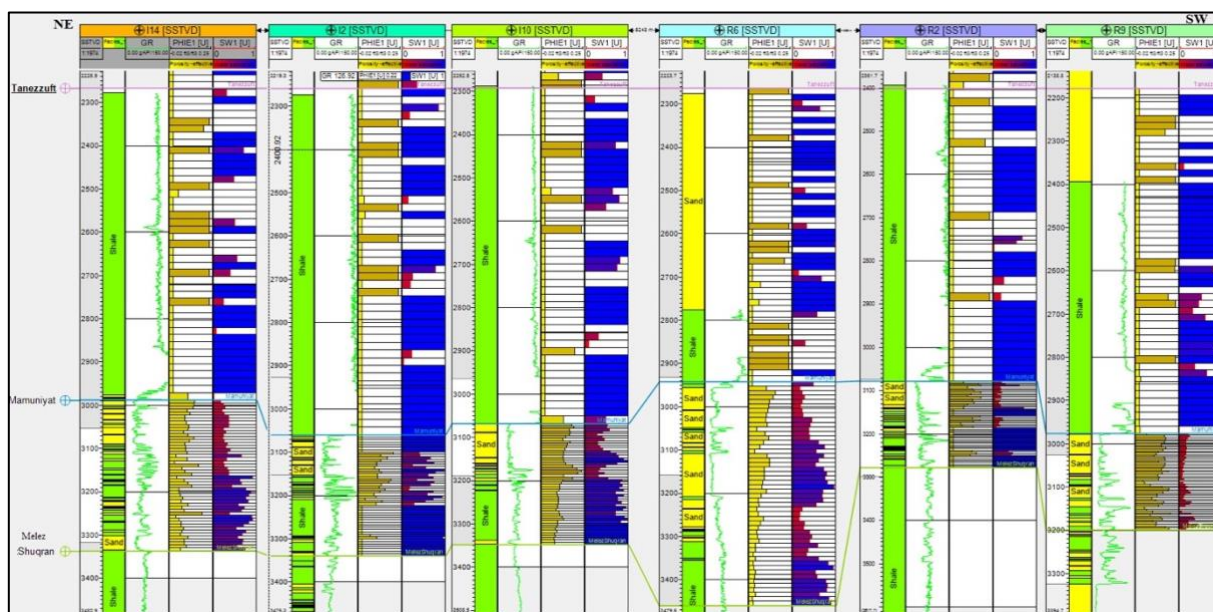


Fig. 7. The correlation between the upscaled facies, porosity, and saturation logs

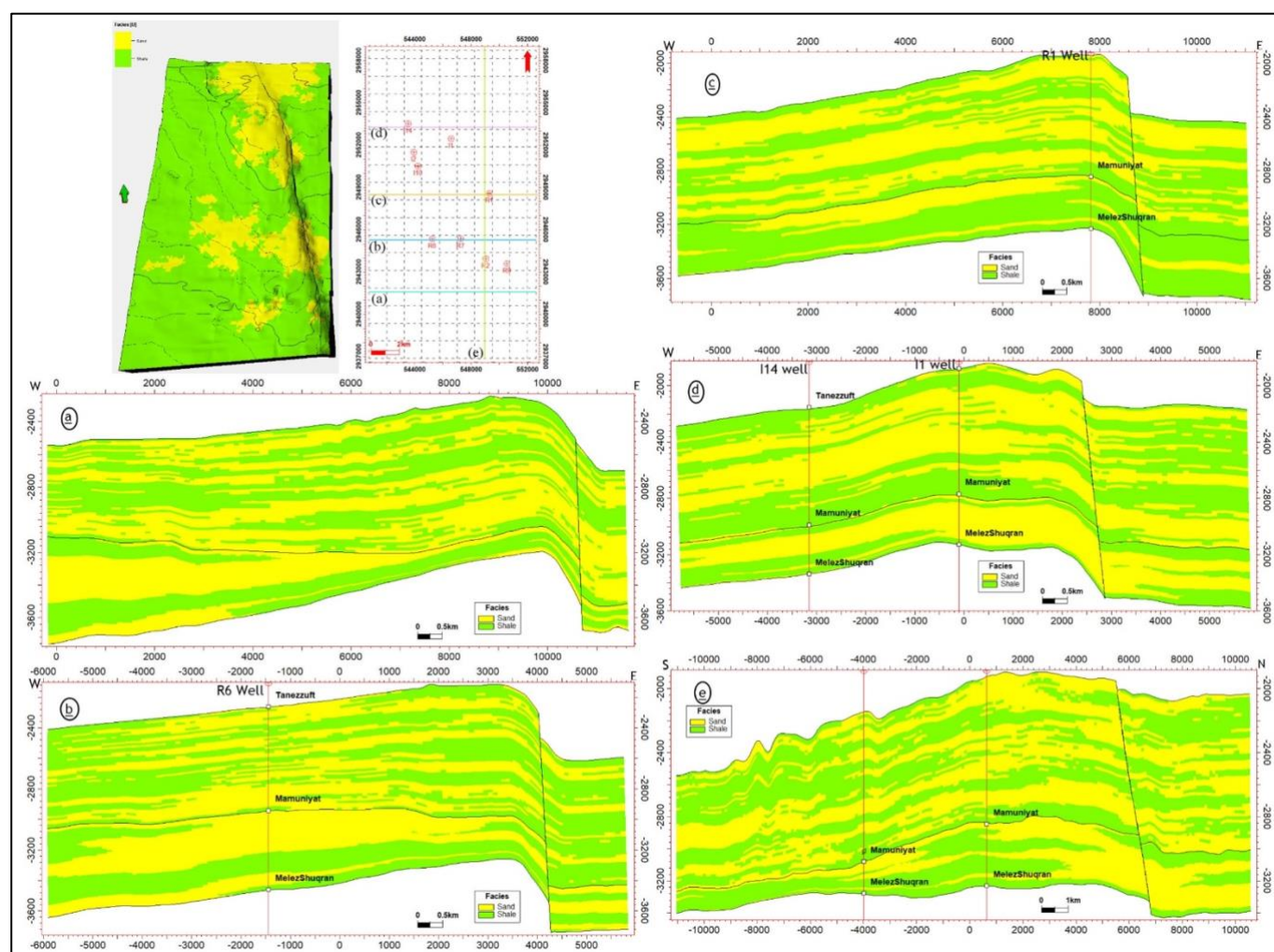


Fig. 8. Facies intersections a, b, c, d, and e through the facies model showing the facies distribution in the area

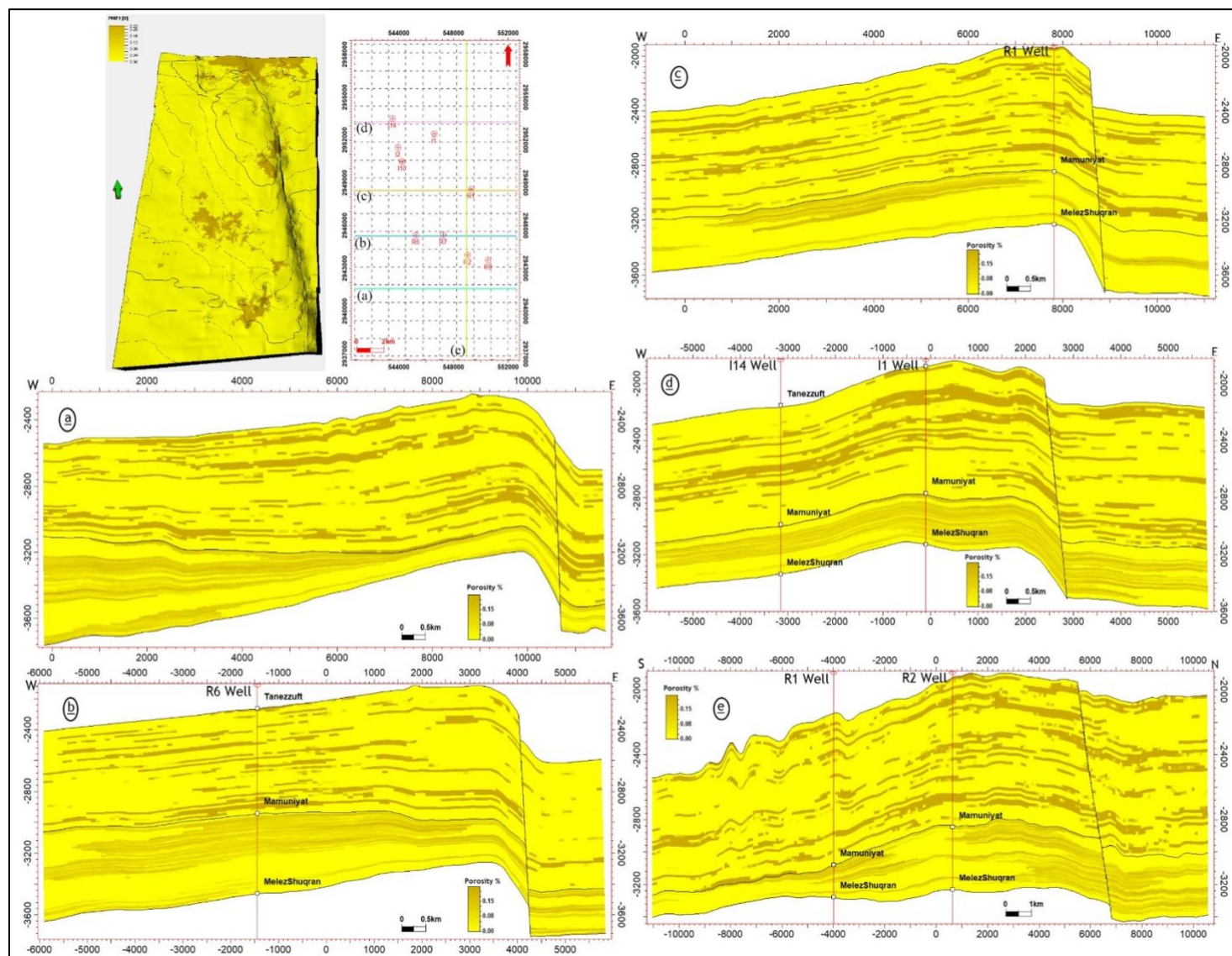


Fig. 9. Porosity intersections a, b, c, d, and e through the Porosity model showing the porosity distribution in the area

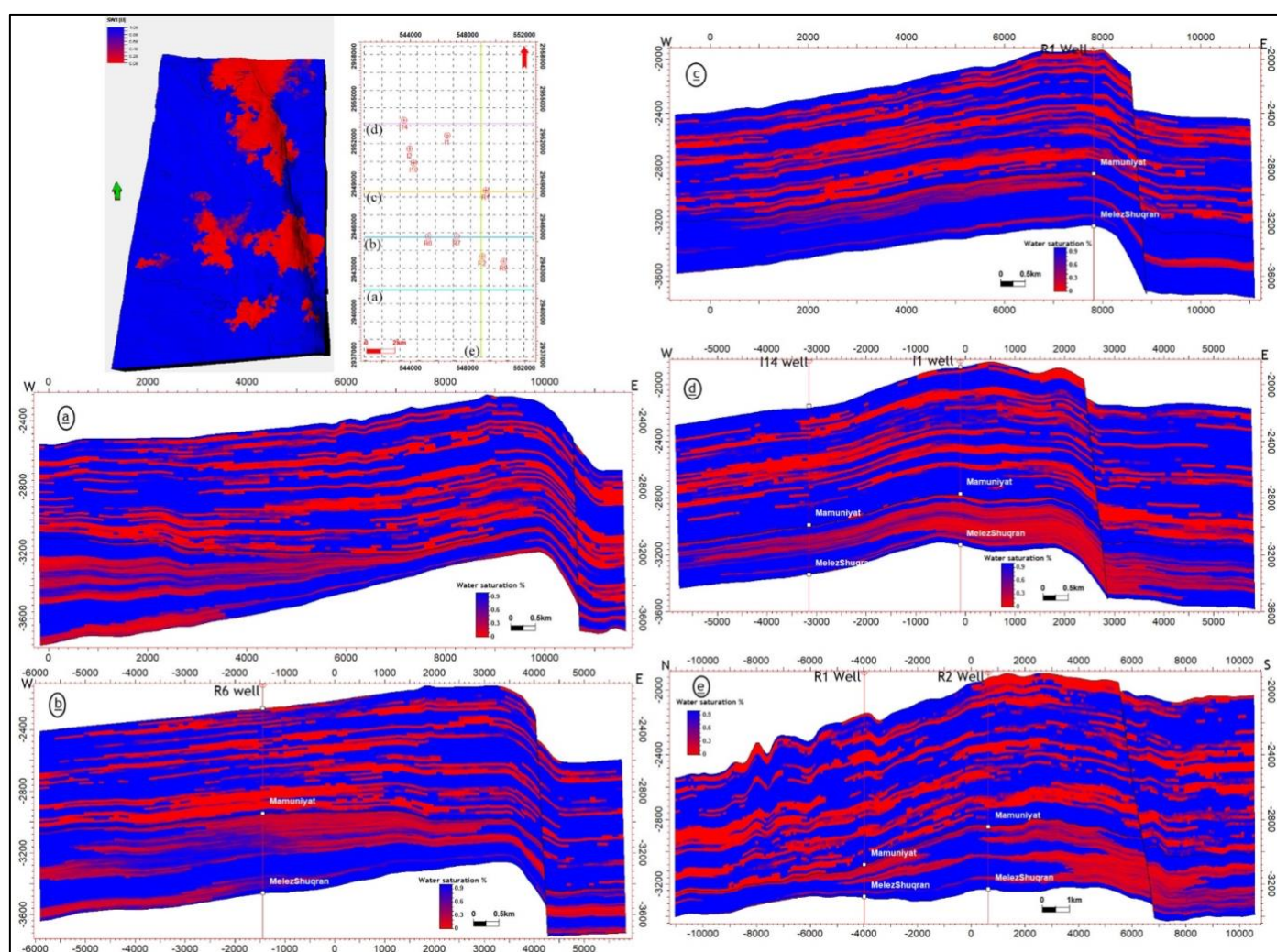


Fig. 10. Saturation intersections a, b, c, d, and e through the Water Saturation model showing the water saturation in the area

Conclusions

The current work incorporates the utilization of well logs and seismic data in order to assess the Mamuniyat Formation and construct three-dimensional static reservoir models. The Tanezzuft, Mamuniyat, and Melez Shugran formations were identified and investigated across the entire area using the 3D seismic survey. The analysis of the depth-structure maps indicates that the region is influenced by the presence of two normal faults. The primary fault exhibits significant influence in the trapping of hydrocarbons. The depth-structure maps were utilized to construct a structural model that illustrates the impact of the structure on the given region. The utilization of computed petrophysical parameters facilitated the development of static reservoir models, which effectively depict the spatial arrangement of facies, porosity, and fluid saturation within the designated region. The Mamuniyat reservoir exhibits a high degree of reservoir quality.

References

- Abdelwahhab, M. A., and Raef, A., 2020. Integrated reservoir and basin modeling in understanding the petroleum system and evaluating prospects: The Cenomanian reservoir, Bahariya Formation, at Falak Field, Shushan Basin, Western Desert, Egypt. *Journal of Petroleum Science and Engineering*, 189, 107023.
- Abdelwahhab, M. A., Abdelhafez, N. A. and Embabi, A. M., 2023. 3D-static reservoir and basin modeling of a lacustrine fan-deltaic system in the Gulf of Suez, Egypt. *Petroleum Research*, 8(1), 18–35.

- Abushalah, Y., and Serpa, L., 2016. Using instantaneous frequency and colored inversion attributes to distinguish and determine the sandstones facies of the Late Ordovician Mamuniyat reservoir, R-field in Murzuq Basin, Libya. *Interpretation*, 4(4), T507–T519.
- Bataller, F. J., McDougall, N. D., Moscariello, A., Gil-Ortiz, M., and de Paula, B. C., 2021. Late Ordovician deglaciation of the Murzuq Basin (SW Libya): a core to seismic-scale characterization of the depositional environments and sedimentary architecture. *Marine and Petroleum Geology*, 134, 105335.
- Castro, A., Laksana, S., Abdussalam, G., Allotai, O., Shaiebi, M., Alkhemri, T., Gomez Nacarino, C., Almhedwi, A., Burghig, F. and Omar, F., 2012. Integrated Reservoir Modeling on Heterogeneous Ordovician Sandstone of IR-Fields, Murzuq Basin Libya, Helps Optimizing Field Development Plan and Reduce Uncertainty. Abu Dhabi International Petroleum Conference and Exhibition, p. SPE-161197-MS.
- Cubitt, C. J., Gruber, W., Stummer, B. C., and Allotai, O., 2011. Depositional environments of the Mamuniyat Formation in the central Murzuq Basin, Libya. in 73rd EAGE Conference and Exhibition incorporating SPE EUROPEC 2011, cp-238.
- Davidson, L., Beswetherick, S., Craig, J., Eales, M., Fisher, A., Himmali, A., Jho, J., Mejrab, B. and Smart, J., 2000. Chapter 14 - The structure, stratigraphy and petroleum geology of the Murzuq Basin, Southwest Libya. in Sola, M. A. and Worsley, D. (eds) *Geological Exploration in Murzuq Basin*. Amsterdam: Elsevier Science, 295–320.
- Echikh, K. and Sola, M. A., 2000. Geology and hydrocarbon occurrences in the Murzuq Basin, SW Libya. in *Geological exploration in Murzuq Basin*. Elsevier, 175–222.
- El-Ghali, M. A. K., 2005. Depositional environments and sequence stratigraphy of paralic glacial, paraglacial and postglacial Upper Ordovician siliciclastic deposits in the Murzuq Basin, SW Libya. *Sedimentary Geology*. Elsevier, 177(3–4), 145–173.
- Fello, N. M., 2001. Depositional environments, diagenesis and reservoir modelling of Concession NC115, Murzuq Basin, SW Libya. Durham University.
- Gil-Ortiz, M., McDougall, N. D., Cabello, P., Marzo, M., and Ramos, E., 2022. Sedimentary architecture of a Middle Ordovician embayment in the Murzuq Basin (Libya). *Marine and Petroleum Geology*. Elsevier Ltd, 135, 105339.
- Gruber, W., Cubitt, C. J., Stummer, B. C., and Allotai, O., 2011. Reservoir Characterization of the Mamuniyat Formation (Murzuq Basin, Libya)-An Integrated Approach from Core to Facies. in 73rd EAGE Conference and Exhibition incorporating SPE Europec, cp-238.
- Hallett, D., 2002. *Petroleum Geology of Libya*. Netherlands.
- Le Heron, D. P., 2010. Interpretation of Late Ordovician glaciogenic reservoirs from 3-D seismic data: an example from the Murzuq Basin, Libya. *Geological Magazine*. Cambridge University Press Cambridge, UK, 147(1), 28–41.
- Le Heron, D. P., Craig, J., Sutcliffe, O. E., and Whittington, R., 2006. Late Ordovician glaciogenic reservoir heterogeneity: an example from the Murzuq Basin, Libya. *Marine and Petroleum Geology*. Elsevier, 23(6), 655–677.
- Martin, M. R., Buitrago, J., Erquiaga, M., Sarkawi, I., and Muñoz, J. G., 2016. Mature Exploration Challenges in Murzuq Basin (Libya)-Chasing Stratigraphic Traps. in 78th EAGE Conference and Exhibition 2016, 1–5.
- McDougall, N. and Martin, M., 2000. Chapter 10 - Facies models and sequence stratigraphy of Upper Ordovician outcrops in the Murzuq Basin, SW Libya. in Sola, M. A. and Worsley, D. (eds) *Geological Exploration in Murzuq Basin*. Amsterdam: Elsevier Science B.V., 223–236.
- Mohamed, Adel K, and Ahmed M Beshr. 2022. Petrophysical properties of the Mamuniyat Formation for hydrocarbon potentiality in A Oil Field, NC115 Concession of Murzuq Basin, Libya. *Arabian Journal of Geosciences*, 15 (5), 447.
- Ramos, E., Marzo, M., de Gibert, J. M., Tawengi, K. S., Khoja, A. A., and Bolatti, N. D., 2006. Stratigraphy and sedimentology of the middle Ordovician Hawaz formation (Murzuq Basin, Libya). *AAPG bulletin*. American Association of Petroleum Geologists (AAPG), 90(9), 1309–1336.
- Shalbak, F. A., 2015. Palaeozoic petroleum systems of the Murzuq Basin, Libya. *Universitat de Barcelona*.
- Ugwu, I. J., Onome, O. O., Brume, O., and Samuel, E. O., 2022. 3D Static Reservoir Modelling: A Case Study of the Izu Field, Coastal Swamp Depobelt, Niger Delta Basin. *Arabian Journal of Geosciences*, 16 (1): 42.