



Shale Oil and Shale Gas Assessment as Natural Resources In Ghadamis Basin, Libya

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تقييم نفط وغاز الطفل (الصخر الزيتي) كموارد طبيعية في حوض غدامس، ليبيا

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Received: April 26, 2026	Accepted: May 25, 2026	Published: June 30, 2026
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Abstract:

The Ghadamis basin in western Libya represents one of the country's most promising regions for unconventional hydrocarbon resources represented by shale oil and shale gas. The basin contains organic rich Paleozoic source rocks that have generated significant quantities of hydrocarbons of unconventional source. This study highlights the unconventional hydrocarbons for two rock formations are Tannezuft and Frasnian, focusing on the main evaluation parameters such as physical and reservoir that including prospective area, thickness, depth, average TOC, thermal maturity (% Ro), oil and gas concentration, and risked recoverable aiming to assessment these natural resources. However, the results of this study reflects that these resources revealed high reserves when compared with other world natural resources and good quality that can be used in future as a source of power energy generation beside the conventional hydrocarbons in Libya.

Keywords: Ghadamis Basin, Unconventional Hydrocarbon, Shale Oil, Shale Gas, Evaluation Parameters, Natural Resources.

الملخص

يُعد حوض غدامس في غرب ليبيا واحداً من أكثر مناطق البلاد واعداً فيما يتعلق بموارد الهيدروكربونات غير التقليدية، والمتمثلة في نفط وغاز الطفل (الصخر الزيتي). يحتوي الحوض على صخور مصدر غنية بالمواد العضوية تعود إلى حقبة الحياة القديمة (الباليوزوي)، وقد ولدت كميات كبيرة من الهيدروكربونات ذات المصدر غير التقليدي. تسلط هذه الدراسة الضوء على الهيدروكربونات غير التقليدية في تكوينين صخريين هما "تانيزفت" (Tannezuft) و"الفرسني" (Frasnian)، مع التركيز على معايير التقييم الرئيسية -سواء الفيزيائية أو تلك المتعلقة بخصائص المكنن- بما في ذلك المساحة المحتملة، والسُمْك، والعمق، ومتوسط محتوى الكربون العضوي الكلي (TOC)، والنضج الحراري (% Ro)، وتركيز النفط والغاز، والاحتياطيات القابلة للاستخراج (مع مراعاة عوامل المخاطرة)، وذلك بهدف تقييم هذه الموارد الطبيعية. وقد أظهرت نتائج الدراسة أن هذه الموارد تمثل احتياطيات كبيرة عند مقارنتها بموارد طبيعية أخرى حول العالم، وتتمتع بجودة جيدة تتيح استخدامها مستقبلاً كمصدر لتوليد الطاقة إلى جانب الهيدروكربونات التقليدية في ليبيا.

الكلمات المفتاحية: حوض غدامس، هيدروكربونات غير تقليدية، نفط الطفل، غاز الطفل، معايير التقييم، موارد طبيعية.

1. Introduction

Shale oil and shale gas are regarded as unconventional hydrocarbon natural resources. This is because of the nature of shale formation bearing them of low porosity and low permeability. The global energy system is undergoing a profound transformation driven by the continuous growth in energy demand, geopolitical instability, concerns over energy security, technological developments, and the increasing need to diversify sources of oil and natural gas supply. Although renewable energy technologies are expanding rapidly, hydrocarbons particularly crude oil and natural gas continue to play a major role in the global energy system. The International Energy Agency (IEA) continues to identify oil and natural gas as important components of global energy supply, while recent geopolitical developments have demonstrated the vulnerability of highly interconnected energy markets to disruptions in production, transportation, trade, and investment. In this context, unconventional hydrocarbon resources, particularly shale oil and shale gas, have acquired considerable strategic and economic importance [1].

Shale formations are fine-grained sedimentary rocks, commonly rich in organic matter, that can contain significant quantities of hydrocarbons generated during geological burial and thermal maturation. Unlike conventional petroleum reservoirs, in which hydrocarbons migrate from source rocks and accumulate in relatively permeable reservoir formations, shale reservoirs can simultaneously act as source rock, reservoir rock, and, in many cases, seal. The extremely low permeability of shale prevents hydrocarbons from flowing naturally at commercially attractive rates in most cases. Consequently, economic production generally requires the combination of horizontal drilling and hydraulic fracturing, together with sophisticated geological characterization, petrophysical evaluation, completion technologies, and reservoir-management practices [2].

Shale hydrocarbons can occur principally as shale gas, consisting predominantly of natural gas retained within organic-rich shale formations, and shale oil, referring broadly to liquid hydrocarbons produced from low-permeability, organic-rich shale and closely related tight formations. The hydrocarbons may exist as free fluids within the pore system, adsorbed onto organic matter, dissolved within organic materials, or trapped within extremely small pores and fractures. Their distribution and producibility are strongly influenced by factors such as total organic carbon (TOC), thermal maturity, kerogen type, mineral composition, pore structure, porosity, permeability, pressure, natural fractures, wettability, and geomechanical properties [3].

The development of shale resources has fundamentally changed the petroleum industry because it has expanded the amount of technically recoverable oil and natural gas beyond many traditionally exploited conventional reservoirs. The large-scale development of shale resources in the United States, particularly since the beginning of the twenty-first century, demonstrated that extensive hydrocarbon accumulations contained in low-permeability formations could be produced economically when advances in horizontal drilling, multistage hydraulic fracturing, seismic interpretation, geosteering, completion design, and reservoir stimulation were integrated effectively. The resulting growth in U.S. shale oil and shale gas production significantly altered domestic and international petroleum markets and contributed to a major increase in the role of unconventional resources in global hydrocarbon supply [2].

1.1. Shale Gas Resources

The importance of shale gas has become particularly evident in relation to natural-gas security. Natural gas is used extensively for electricity generation, industrial processes, heating, petrochemical production, and the manufacture of fertilizers and other products. Gas-fired power generation can also provide operational flexibility to electricity systems with increasing

shares of variable renewable energy. Consequently, disruptions to natural-gas supply can have effects extending beyond the gas market itself, influencing electricity prices, industrial production, fertilizer costs, and broader economic activity [3].

The strategic significance of natural gas became especially apparent following the Russia–Ukraine war, which began in February 2022. The conflict and subsequent changes in international energy trade resulted in major disruptions and restructuring of European natural-gas supply. European countries reduced their dependence on Russian pipeline gas and substantially increased imports of liquefied natural gas (LNG), while simultaneously expanding gas storage, alternative pipeline supplies, energy efficiency, and renewable-energy deployment. The episode demonstrated that energy security is not determined solely by the physical availability of resources; it is also strongly influenced by geographical concentration of production, pipeline infrastructure, LNG capacity, storage, transportation routes, geopolitical relationships, and market flexibility [4].

1.2. Shale Oil Resources

Shale oil has similarly acquired strategic significance because crude oil remains deeply integrated into the global transportation system, petrochemical industry, manufacturing sector, and numerous other economic activities. Even with the rapid expansion of electric vehicles and renewable energy, global oil demand remains substantial. The IEA's recent assessments indicate that the global energy system is changing rapidly, but oil continues to have a major role, particularly in aviation, petrochemicals, heavy transportation, and other sectors where substitution can be more difficult.

The development of shale oil resources can therefore contribute to diversification of crude-oil supply. Large-scale shale-oil production in the United States has increased the country's domestic crude-oil output and reduced its dependence on imported oil compared with previous decades. More broadly, the availability of unconventional oil resources provides additional potential sources of supply that can contribute to market flexibility when conventional production experiences disruptions or when geopolitical conditions affect international trade [5].

1.3. Shale Oil and Shale Gas Significance

The significance of shale oil and shale gas is further reinforced by the continuing increase in global energy requirements. Population growth, urbanization, industrialization, rising living standards, digitalization, and the expansion of energy-intensive technologies are contributing to continued growth in energy consumption in many parts of the world. In addition, emerging technologies such as data centers, artificial intelligence, cloud computing, electrification, hydrogen production, and advanced manufacturing are generating new demands for reliable electricity and energy infrastructure. The IEA has highlighted the rapidly increasing electricity demand associated with data centers and digital technologies, demonstrating that future energy demand will not be determined only by traditional industrial and transportation sectors [2].

This increasing demand creates a complex challenge for policymakers and energy companies. The world must simultaneously address energy security, energy affordability, environmental sustainability, and the transition toward lower-carbon energy systems. Shale hydrocarbons are relevant to this discussion because they can provide additional supplies of oil and natural gas during the energy transition, but their continued development also raises questions concerning greenhouse-gas emissions, methane leakage, water consumption, induced seismicity, land disturbance, produced-water management, and the environmental footprint associated with drilling and hydraulic fracturing [6].

1.4. Shale Oil and Shale Gas Extraction

Hydraulic fracturing is particularly important technique for extraction the unconventional hydrocarbons because the natural permeability of shale is commonly insufficient to support commercial flow rates. During hydraulic fracturing, a fluid is injected at high pressure to create or reactivate fractures within the reservoir. Proppant is then used to help maintain conductive fracture pathways after pressure is reduced. When combined with horizontal wells, hydraulic fracturing can expose a much larger reservoir volume to the wellbore than conventional vertical drilling would allow. The effectiveness of this process depends on the geological and geomechanical properties of the formation, fracture conductivity, completion design, fluid properties, stress distribution, natural fractures, and the spatial distribution of hydrocarbons [7].

The economic development of shale resources has therefore been closely associated with technological innovation. Improvements in horizontal-well length, multistage hydraulic fracturing, real-time geosteering, drilling efficiency, completion optimization, pad drilling, proppant placement, fracture diagnostics, and data analytics have contributed to improvements in productivity and reductions in development costs in mature shale plays. Continued research into enhanced shale recovery methods may further improve hydrocarbon recovery, although recovery factors remain an important challenge because a considerable proportion of the hydrocarbons initially present in shale formations can remain unrecovered.

The geopolitical dimension of shale resources is equally important. Modern energy markets are highly interconnected, meaning that a disruption in one producing region can affect prices and supply conditions in distant markets. Wars, sanctions, maritime disruptions, political instability, trade restrictions, and changes in energy policy can all influence the movement and price of hydrocarbons. The experience following Russia's invasion of Ukraine illustrated how rapidly natural-gas markets can be restructured when a major supplier becomes constrained. Similar disruptions in oil-producing regions have historically demonstrated the importance of maintaining diversified sources of supply [5].

For countries possessing potentially prospective shale formations, including several regions of the Middle East and North Africa e.g. Libya, shale resources may represent an additional petroleum opportunity. However, geological potential alone does not guarantee commercial development. Comprehensive evaluation is required to determine whether a shale play has sufficient organic richness, thermal maturity, hydrocarbon saturation, reservoir quality, pressure, thickness, lateral continuity, fracability, and economic attractiveness. Such evaluation is particularly important in regions where geological data are limited and where conventional petroleum systems have historically received greater exploration attention [4].

Therefore, the contemporary significance of shale oil and shale gas lies not simply in their ability to provide additional hydrocarbons, but in their position at the intersection of energy security, geopolitics, technological development, economics, environmental management, and the global energy transition. The wars and geopolitical tensions of recent years have demonstrated the vulnerability of energy systems to supply disruptions, while increasing energy demand has emphasized the need for reliable and diversified sources of energy. Shale resources represent one of the technological pathways through which additional oil and natural-gas supplies can potentially be developed [3].

2. How is Shale Oil and Gas Produced?

Shale oil and gas formations are “unconventional” reservoirs i.e., reservoirs of low “permeability”. Permeability refers to the capacity of a porous, sediment, soil or rock in this case to transmit a fluid. This contrasts with a “conventional” gas reservoir produced from sands and carbonates (such as limestone).

Hydraulic fracturing is a known technology and has been used for at least 60 years. It has helped produced more than 600 trillion cubic feet of natural gas and 7 billion barrels of oil. Figure 1 representation of common equipment at a natural gas hydraulic fracturing drill pad.

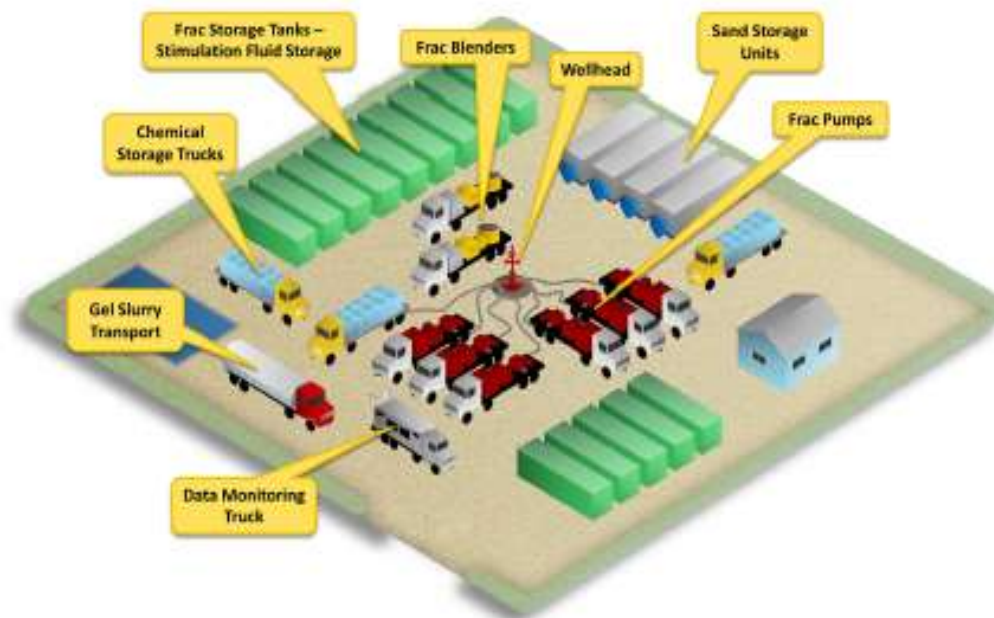


Fig. 1 Natural gas hydraulic fracturing drill pad [8]
(American Petroleum Institute, 2010)

For shale gas, hydraulic fracturing of a reservoir is the preferred stimulation method (Figure 2).

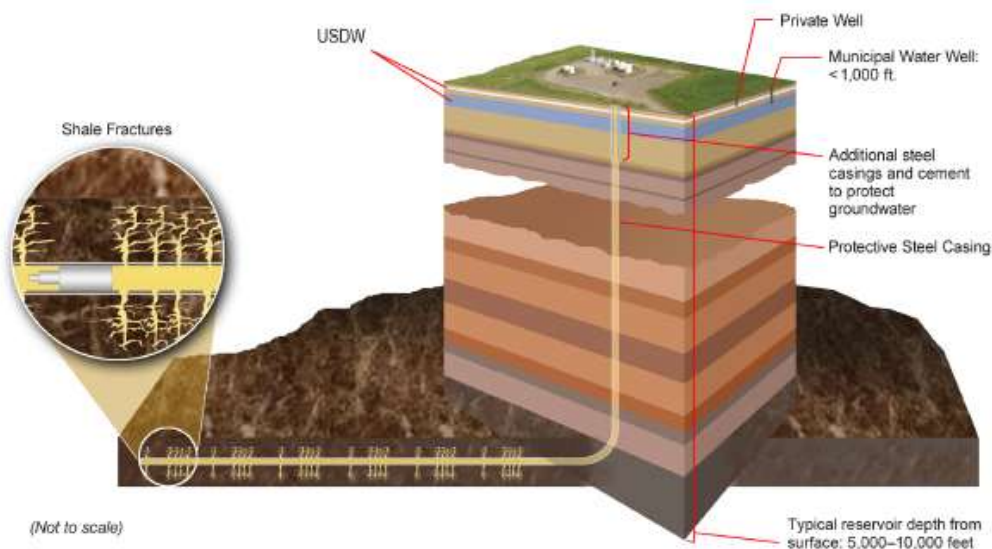


Fig. 2 Reservoir hydraulic fracturing techniques [8]

3. Location Study

Libya involved five major basins e. g. Sirte basin, Kufra basin, Murzuk basin, Ghadamis basin and Cyrenaica basin as shown in Figure 3.

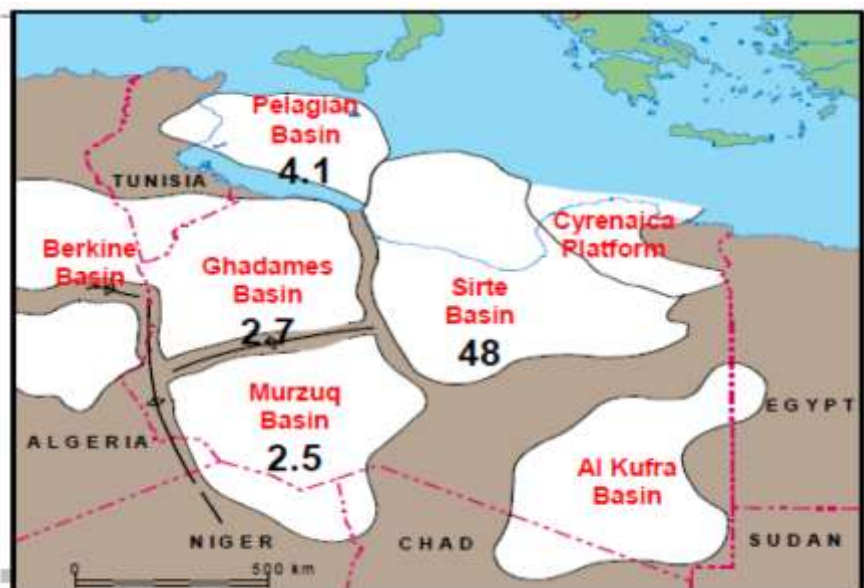


Fig 3 A map showing the location of Libyan basins reserves [9]

The shale oil and gas in Ghadamis basin occur in the basal Tanezzuft and Frasnian formations. Figure 4 a map depicts the shale formations thickness of Ghadamis basin.

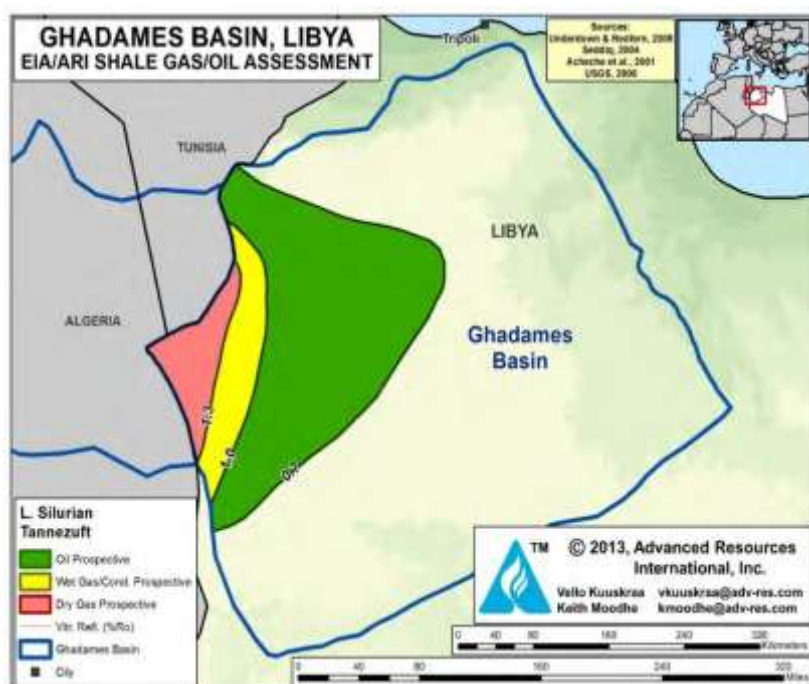


Fig. 4 Shale Gas and Shale Oil Basins of Libya [10]

4. Objectives of Study

This study try highlights the shale oil and gas in Ghadamis basins in Libyan. The main targets of this study involve:

1. To assess the shale oil and gas in Ghadamis basin.
2. To evaluation parameters have been cited as playing a role in the appraisal methods.
3. Determination the optimum parameters at which the shale oil and gas can as a natural resource.
4. Comparison between Libyan shale oils and gas with other world shale unconventional hydrocarbons.

5. Statement of Problem

Unconventional hydrocarbons such as shale oil and shale gas required a certain extraction techniques. The problems of the extraction can be suggested as:

1. Required high technology of hydraulic fracturing.
 2. Need a large amounts of water.
 3. Technical recovery may be risk.
 4. Affected negatively on the groundwater quality.
 5. Required infrastructures.
-

6. Methodology

This study based on the "Advanced Resources" methodology for assessing the in-place and recoverable shale gas and shale oil resources for the EIA/ARI "World Shale Gas and Shale Oil Resource Assessment." The methodology relies on geological information and reservoir properties assembled from the technical literature and data from publically available company reports and presentations.

The methodology for conducting the basin- and formation-level assessments of shale gas and shale oil resources includes the following five topics:

1. Conducting preliminary geologic and reservoir characterization of shale basins and formation(s).
2. Establishing the areal extent of the major shale gas and shale oil formations.
3. Defining the prospective area for each shale gas and shale oil formation.
4. Estimating the risked shale gas and shale oil in-place.
5. Calculating the technically recoverable shale gas and shale oil resource.

Each of these five shale oil and gas resource assessment steps is further discussed below:

1. Depth
 2. Thickness
 3. Maturity (Immature/oil/gas transition)
 4. Biogenic versus Thermogenic gas systems
 5. Onshore/Offshore
 6. Mineralogy including Porosity and Permeability
 7. Source rock quality (organic material type and total organic content)
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7. RESULTS AND DISCUSSION

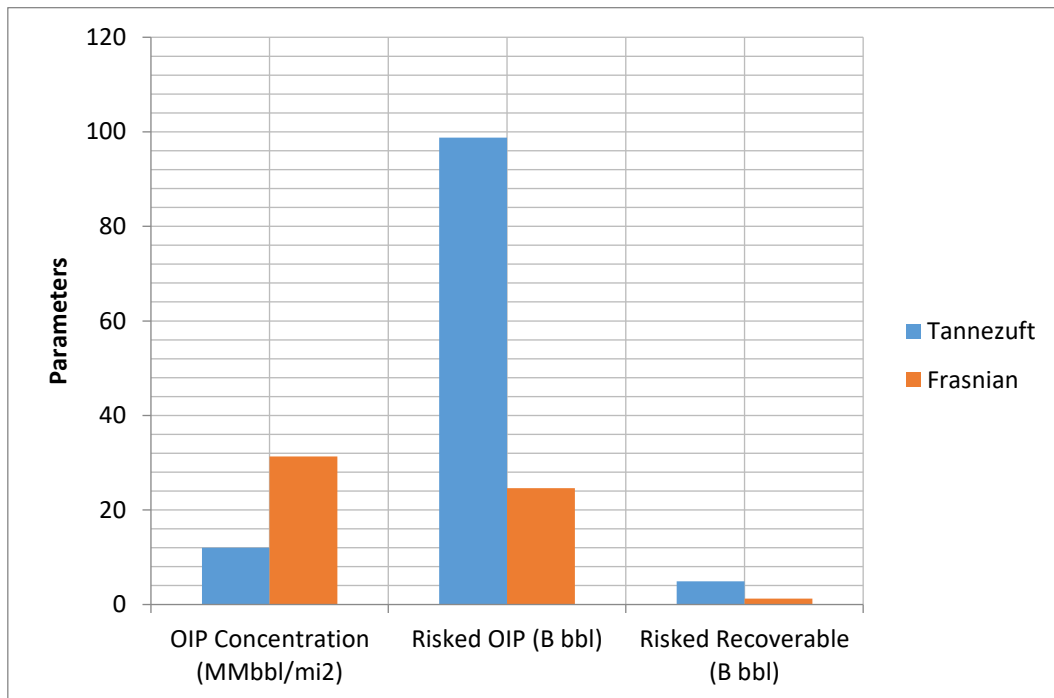
7.1. Shale Oil Assessment of Ghadamis Basin

The evaluation shale oil based on the study of EIA/ARI estimates the resources in Ghadamis basin in two shale formations Tannezuft and Frasnian as shown in Table 1. It is obviously the shale oil vary from Tannezuft formation and Frasnian formation for the various parameters of assessment.

The original oil in place (OIP) was estimated to be 12 and 31.3 MMbbl/mi², and the risked oil in place 98.8 and 24.6 B bbl for both Tannezuft and Frasnian formations respectively. Which are representing a high reserves of natural resources. The comparison of the evaluation parameters for both shale oil formations is illustrated in Figures 5 and 6.

Table 1 Shale Oil Reservoir Properties and Resources of Libya [10,11]

Basic Data	Basin/Gross Area		Ghadamis (117,000 mi ²)			
	Shale Formation		Tannezuft		Frasnian	
	Geologic Age		L. Silurian		U. Devonian	
	Depositional Environment		Marine		Marine	
Physical Extent	Prospective Area (mi ²)		16,440	3,350	1,570	370
	Thickness (ft)	Organically Rich	115	115	197	197
		Net	104	104	177	177
	Depth (ft)	Interval	10,000 - 11,000	10,500 - 11,500	8,000 - 10,000	9,000 - 10,000
		Average	10,500	11,000	8,500	9,500
Reservoir Properties	Reservoir Pressure		Mod. Overpress.	Mod. Overpress	Mod. Overpress	Mod. Overpress
	Average TOC (wt. %)		5.7%	5.7%	6.0%	6.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	0.85%	1.15%
	Clay Content		Medium	Medium	Medium	Medium
Resource	Oil Phase		Oil	Condensate	Oil	Condensate
	OIP Concentration (MMbbl/mi ²)		12.0	3.1	31.3	7.0
	Risked OIP (B bbl)		98.8	5.1	24.6	1.3
	Risked Recoverable (B bbl)		4.94	0.26	1.23	0.06

**Fig. 5** Shale oil comparison parameters for Tannezuft and Frasnian formations

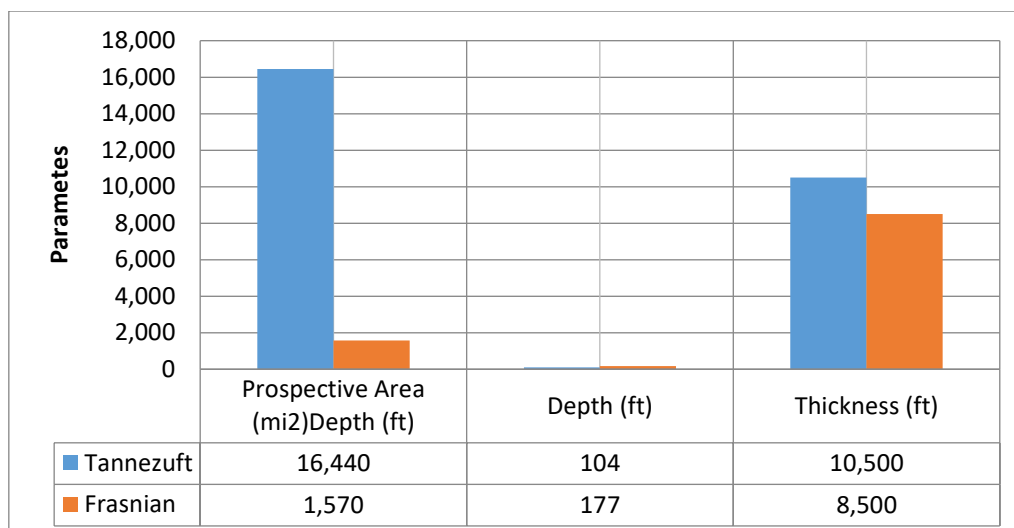


Fig. 6 Shale oil comparison parameters for Tannezuft and Frasnian formations

7.2. Shale Gas Assessment of Ghadamis Basin

This study based on some factors for shale gas in the study area of Ghadamis basin to assessment the potentiality of natural resource as alternative energy source in the future and sustainable development.

The analysis activities of the shale gas have been carried out in different parts of the world e. g. USA, EU, China, and India. These analyses discussed the shale gas reserves, development and factors affecting on activities of exploration and production (Table 2).

However, the tops of the countries containing high reserves of shale gas of technically recoverable reserve represented by France, Libya and India as shown in Figure 7.

Table 2 Comparison between shale basins in different countries and *GhadamiS* basin [10,11]

Gas shale basin		Estimated area (sq. miles)	Depth (ft)	Net thickness, (ft)	TOC (%)	TRR (tcf)
USA U.S. Department of Energy, 2009)	Barnet	5000	6500-8500	100-600	4.5	-
	Fayetteville	9000	1000-7000	20-200	4-9.8	-
	Marcellus	9500	4000-8500	50-200	3-12	-
	Woodford	11000	6000-11000	120-220	3-10	-
	Antrim	12000	600-2200	70-120	1-20	-
France (Kuuskraa, 2013)	Paris basin	61000	4000-16400	83-160	4.5-9	129.3
Netherlands (Kuuskraa, 2013)	West Netherlands basin	2750	3300-16400	90-450	2.4-6.5	25.9
Denmark Sweden (Kuuskraa, 2013)	Alum Shale	90000	3300-15000	200	7.5	41.5
UK (Kuuskraa, 2013)	North UK	10200	4000-6000	410	3.0	25.10
	South UK	3470	5000-13000	149	3.0	0.6
Eastern Europe (Kuuskraa, 2013)	Carpathian Foreland	70000	3300-16400	400	4.5	73 (Ukraine 52, Romania 21)
	Dnieper-Donets	23200	3300-16400	350	2.0	Ukraine 76
	Moesian Platform	45000	5000-16400	260-450	3.0	46 (Romania 30, Bulgaria 16)
Poland (Kuuskraa, 2013)	Baltic basin	16200	6500-16000	451	3.9	105
	Lublin basin	4980	7000-16000	228	3.0	9

	Podlasie basin	6600	6000-11500	297	3.0	9
China (Kuuskraa, 2013)	Sichuan	74500	9700-13200	250-275	-	-
	Tarim	234200	10790-16400	160-240	-	-
	Junggar	62100	5000-16400	410	-	-
	Songliao	108000	3300-8200	500	-	-
	Subei	55000	3300-16400	150-300	-	-
India (Kuuskraa, 2013)	Cambay	7900	6000-16400	500	2.6	29.5
	Krishna-Godvari	7800	4000-16400	100-390	6.0	56.9
	Cauvery	1009	7000-13000	500	2.3	4.5
	Damodar Valley	2270	3300-6600	250	3.5	5.4
Libya (Bellini et al., 2010)	Ghadamis	135,193	760-1340	20-50	15-3	80-120

TRR = Technically recoverable reserve TOC = Total organic carbon

TRR (tcf)

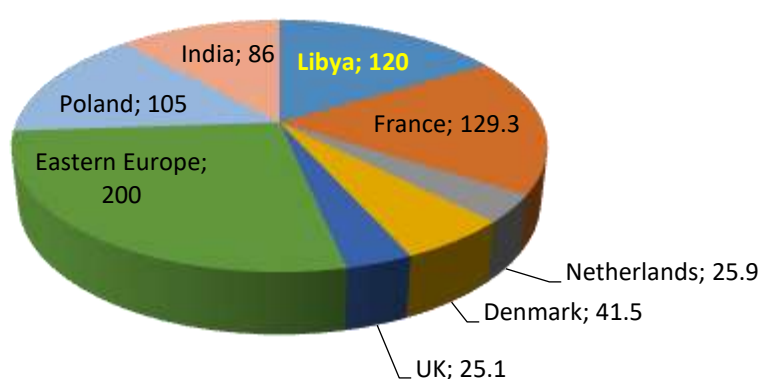


Fig. 7 Technically recoverable reserve of shale gas countries

On the other hand, the comparison between the petrophysical properties of Tanezzuft formation and the shale play in other sedimentary basins presented in Table 3.

It is obviously that the total organic carbon of Tanezzuft formation higher than the other formations, while the thermal maturity (R_o) ranging from 0.7-2.2% and the saturation by gas (%) is high 1.0-6.0%, kerogen type is II. The geologic age of Tanezzuft formation is belonging to Silurian of Plaeozoic Era, while the other formations are belonging to Middle Devonian and Middle-Late Ordovician.

Table 3 Petrophysical characterizations of some shale gas plays [12]

Formation Parameters	Tanezzuft	Wood Ford	Barnet	Fayette ville	Marcellus	Utica
Total organic carbon, TOC (%)	3-15	3-10	3-8	3-8	2.5-5.5	0.5-3.0
Thermal maturity, R_o (%)	0.7-2.2	1.1-3.0	1.2-2.0	1.2-4.0	0.6-3.0	0.3- >1.0
Quartz content, Q_z (%)	> 35	60-80	40-60	40-60	-	-
Gas saturation ratio, Φ (%)	1-6	3-6.5	3-5.5	3-5.5	-	-
Thickness (m)	20-50	30-65	60-150	15-100	-	-
Depth (m)	2500-4000	1800-3600	1800-2700	450-2000	-	-
Pressure gradient (psi/ft)	-	0.52	0.52	0.43	-	-
BCF/Section	-	40-120	50-200	55-65	-	-
Age	Silurian	-	-	-	Middle Devonian	Middle Devonian
Kerogen type	II	-	-	-	II	II

Conclusion

From the previous study of shale oil and gas the following conclusions can be drawn:

1. Shale oil and shale gas regarded as natural resources for energy nowadays.
2. Shale oil and shale gas have become important components of the modern petroleum and energy landscape
3. Shale oil and gas will be going to be a useful additional energy resource in the future for several countries particularly Libya.
4. Efficient techniques of exploration can produce a better results and will balance the energy demand with the use of shale oil and gas.
5. The assessment parameters e.g. the estimated basin area, prospective area, shale play thickness, depth and technically recoverable reserve (TRR) as well as other factors such as total organic content, thermal maturity (R_o) considered as valuable parameters.
6. In an era characterized by geopolitical conflicts, supply-chain vulnerabilities, changing international trade patterns, increasing energy demand, and an accelerating energy transition, the scientific and engineering evaluation of shale resources has become increasingly important.

List of abbreviation and acronyms

Abbreviation and acronyms	Full text	Abbreviation and acronyms	Full text
ARI	Advanced Resources Institute	OIP	Oil in place
bbl	Barrel	Tcf	Trillion cubic foot
BBO	Billion Barrels Oil	Tcm	Trillion cubic meter
EIA	Energy Information Administration	TRR	Technically recoverable resources
EUR	Estimated Ultimate Recovery	USGS	United States Geological Survey
MBOE	Thousand Barrels of Oil Equivalent	WRI	World Resources Institute

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