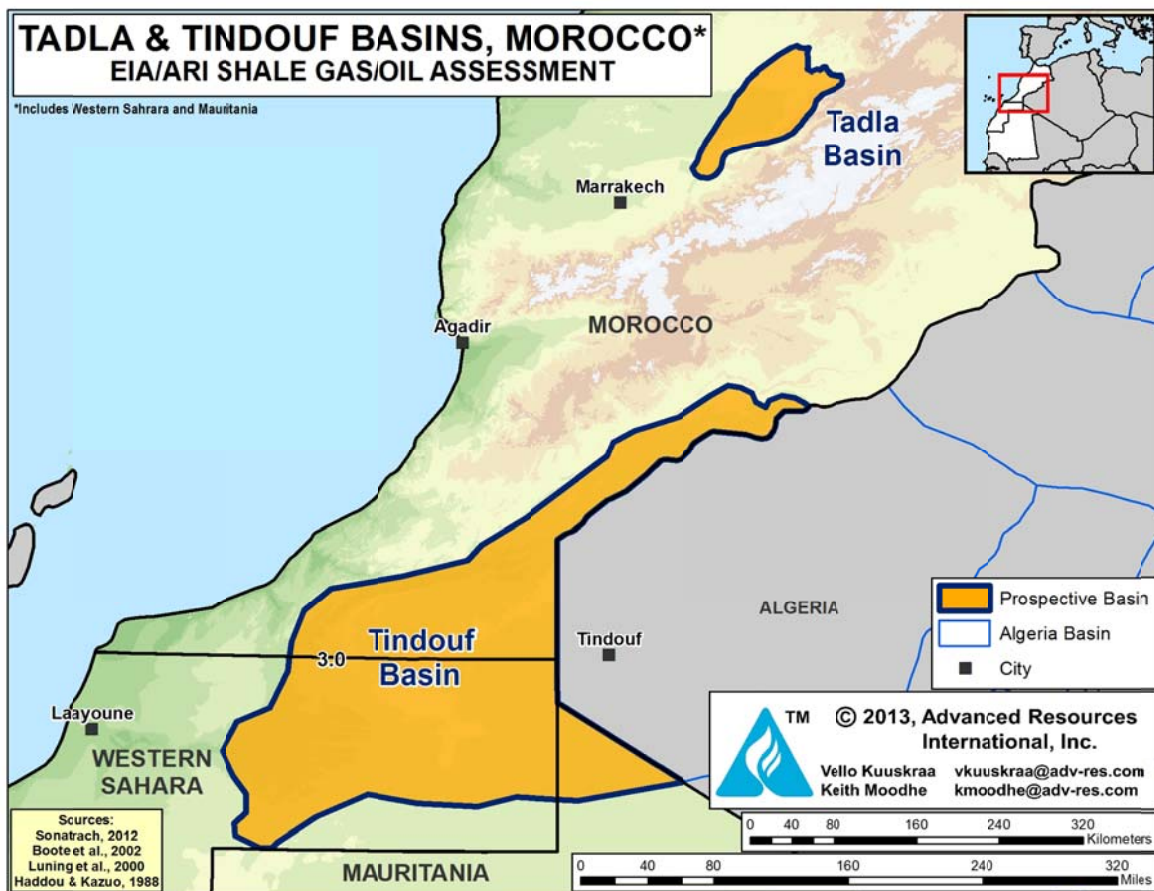


XIV. MOROCCO (INCLUDING WESTERN SAHARA AND MAURITANIA)

SUMMARY

In addition to large accumulations of Late-Cretaceous immature oil shale (kerogen) at depths suitable for surface mining¹, Morocco and its two neighboring countries, Mauritania and Western Sahara, also possess organic-rich Silurian- and Devonian-age shale gas and shale oil potential in the Tindouf and Tadla basins, Figure XIV-1. Mapping and resource characterization of these shales is challenging because regional deformation, erosion and subsidence of the shale deposits have led to their discontinuous and complex present day distribution.

Figure XIV-1. Shale Gas Basins of Morocco, Western Sahara and Mauritania



Source: ARI, 2013.

ARI estimates that the Tindouf and Tadla basins contain risked shale gas in-place of 95 Tcf, with 20 Tcf of risked, technically recoverable shale gas resources, Table XIV-1. In addition, these two basins contain risked shale oil/condensate in-place of 5 billion barrels, with 0.2 billion barrels of risked, technically recoverable shale oil/condensate resources, Table XIV-2.

Table XIV-1. Reservoir Properties and Shale Gas Resources of Morocco, Sahara Desert and Mauritania

Basic Data	Basin/Gross Area		Tindouf (77,000 mi ²)			Tadla (2,800 mi ²)
	Shale Formation		L. Silurian			L. Silurian
	Geologic Age		L. Silurian			L. Silurian
	Depositional Environment		Marine			Marine
Physical Extent	Prospective Area (mi ²)		2,020	4,670	12,380	1,670
	Thickness (ft)	Organically Rich	60	60	60	328
		Net	54	54	54	197
	Depth (ft)	Interval	6,600 - 11,000	6,600 - 13,000	6,600 - 14,000	3,280 - 9,840
Average		9,000	10,000	11,000	6,560	
Reservoir Properties	Reservoir Pressure		Mod. Overpress.	Mod. Overpress.	Mod. Overpress.	Underpress.
	Average TOC (wt. %)		4.0%	4.0%	4.0%	2.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	2.80%	2.25%
	Clay Content		Medium	Medium	Medium	Medium
Resource	Gas Phase		Assoc. Gas	Wet Gas	Dry Gas	Dry Gas
	GIP Concentration (Bcf/mi ²)		6.8	18.9	22.0	49.0
	Risked GIP (Tcf)		2.7	17.7	54.5	20.5
	Risked Recoverable (Tcf)		0.3	3.5	13.6	3.1

Table XIV-2. Reservoir Properties and Shale Oil Resources of Morocco, Sahara Desert and Mauritania

Basic Data	Basin/Gross Area		Tindouf (77,000 mi ²)	
	Shale Formation		L. Silurian	
	Geologic Age		L. Silurian	
	Depositional Environment		Marine	
Physical Extent	Prospective Area (mi ²)		2,020	4,670
	Thickness (ft)	Organically Rich	60	60
		Net	54	54
	Depth (ft)	Interval	6,600 - 11,000	6,600 - 13,000
Average		9,000	10,000	
Reservoir Properties	Reservoir Pressure		Mod. Overpress.	Mod. Overpress.
	Average TOC (wt. %)		4.0%	4.0%
	Thermal Maturity (% Ro)		0.85%	1.15%
	Clay Content		Medium	Medium
Resource	Oil Phase		Oil	Condensate
	OIP Concentration (MMbbl/mi ²)		7.9	1.7
	Risked OIP (B bbl)		3.2	1.6
	Risked Recoverable (B bbl)		0.16	0.08

INTRODUCTION

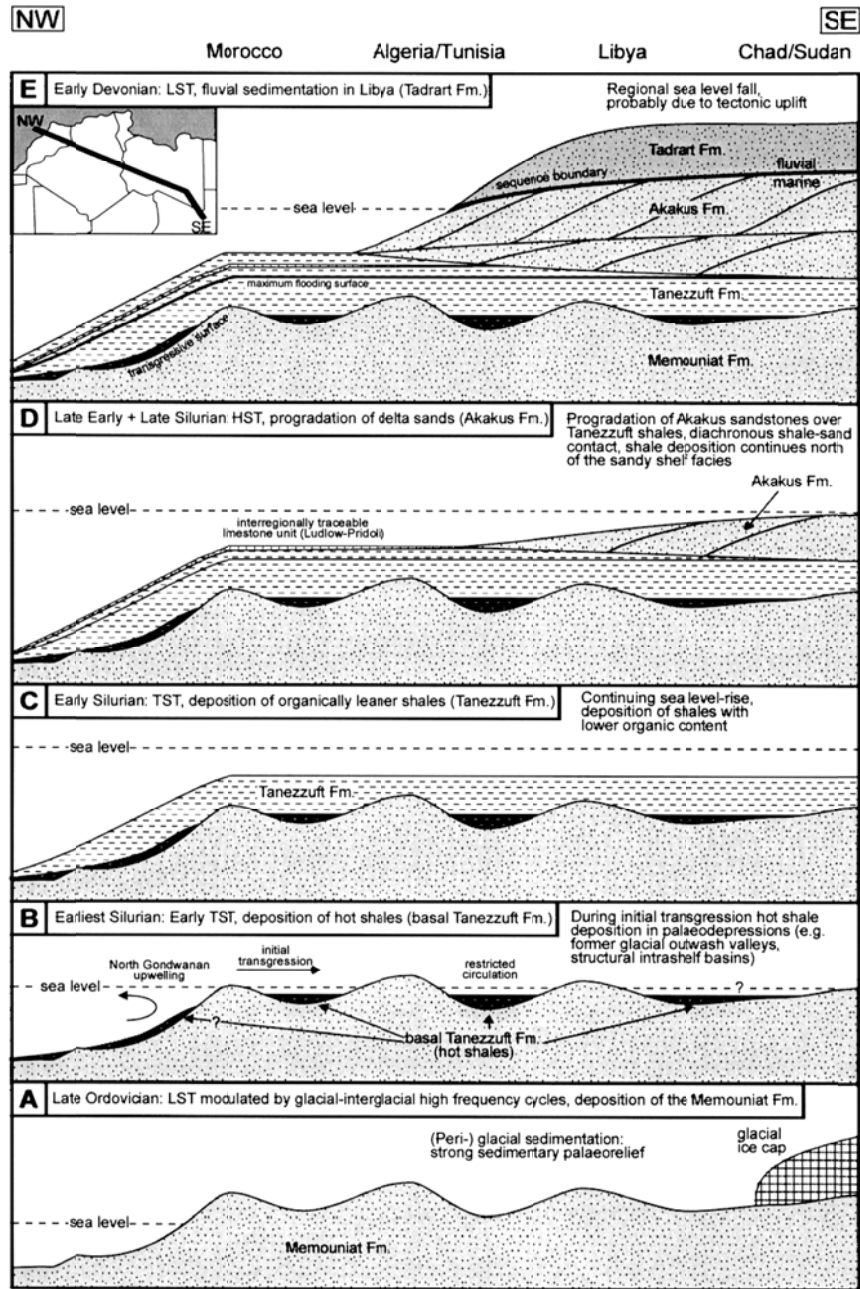
The primary shale resource on Morocco, Mauritania and Western Sahara is the lower Silurian “Hot Shale,” which consists of thin but very organic-rich layers of marine organic matter deposited during a regional anoxic event. Data from wells drilled across the country confirm the presence of organic-rich Silurian shales, although not always within the current formally established boundaries of hydrocarbon basins.

The presence of a thick Silurian section, observed in many Moroccan hydrocarbon basins, does not guarantee the presence of organic-rich shale, as areas that were regional highs during the early Silurian may not have received organic-rich sediments, Figure XIV-2.²

Accurately identifying promising shale basins and estimating their resource potential in such geologically complex areas requires significant amounts of data, which are not widely available in Morocco and its neighboring countries because of limited well drilling and data confidentiality. As this data becomes more publically available, a more rigorous shale gas and oil resource assessment of Morocco may be possible.

This report assesses the two basins which appear to have the highest potential for shale gas and oil resources based on publically available data: the Tindouf (Zag) Basin in the south of Morocco (extending into Algeria, Western Sahara, and Mauritania), and the central Moroccan Tadla Basin.

Figure XIV-2. Sedimentary Depositional Environment in Morocco, Ordovician-Devonian²



1. TINDOUF BASIN

1.1 Geologic Setting

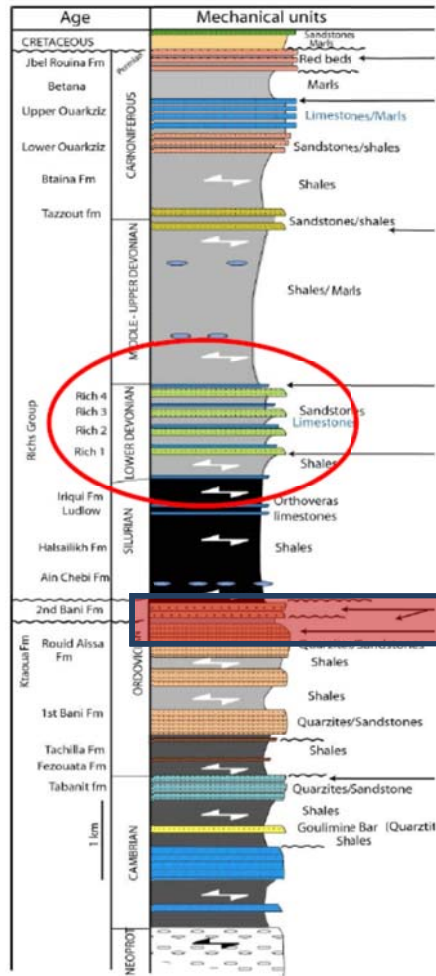
The Tindouf Basin is the westernmost of the major North African Paleozoic basins, covering a 31,660-mi² area in Morocco, Western Sahara and Mauritania. The basin is bounded by the Atlas Mountains and Ougarta Arch to the north and the Reguibate Massif in the south. Although once covered unconformably by a blanket of Mesozoic to early Tertiary sediments, the Paleozoic now crops out over much of the region. The Tindouf Basin is an asymmetric depression with a broad gentle southern flank and a steeply dipping, more structurally complex northern margin.

The Tindouf Basin was a large sediment depocenter from late Ordovician to Carboniferous time, accumulating multiple layers of organic-rich Silurian, Devonian (Frasnian) and Carboniferous (Visean) shales, Figure XIV-3.³ However, these deposits were affected by the Hercynian deformation and the prospectivity of these shale formations is uncertain. High heat flow through the basin caused the Tindouf Basin shales to reach high maturity during the Carboniferous. Uplift and erosion of these shales may have caused significant underpressuring, as the shales were not buried deep enough to replenish hydrocarbons dissipated during the Hercynian orogeny.

This report focuses on the Lower Silurian “Hot Shale,” which has greater data availability and higher confidence of remaining gas saturation in this shale interval. Through mapping of depth and thermal maturity, we have identified a 19,070-mi² prospective area in the Morocco, Mauritania and Western Sahara portion of the Tindouf Basin. The northern boundary of the prospective area is the 1,000-meter depth contour on the upthrust northern portion of the basin, Figure XIV-4.⁴ The southern boundary is the 0.7% R_o thermal maturity contour. The eastern boundary is the Algeria Border.

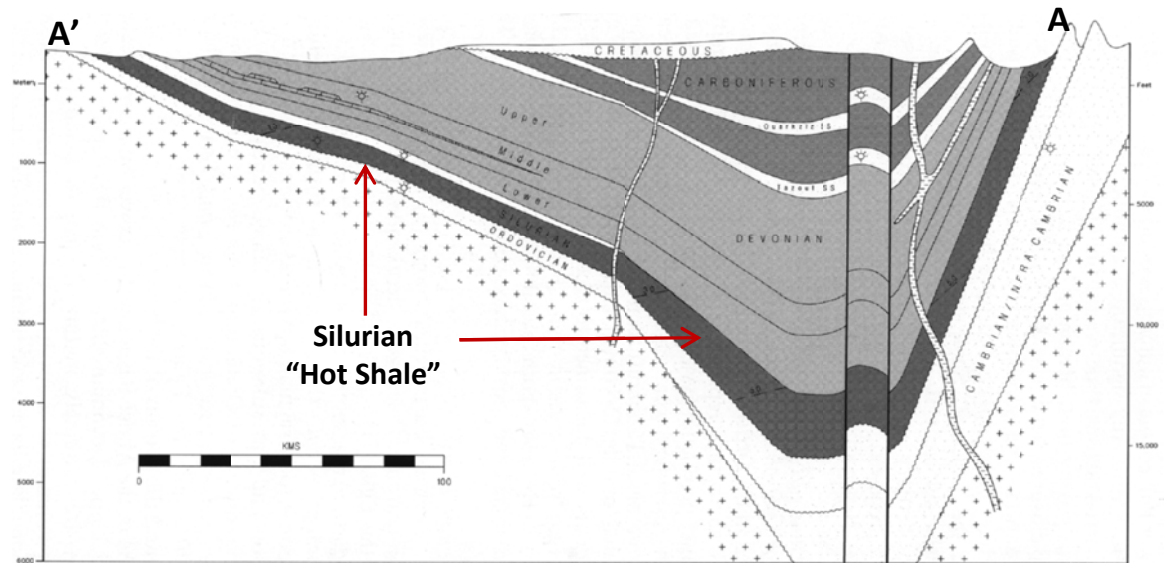
While the drilling density in the basin is extremely low, with an average of only one well per 5,000 mi², the data suggest that organic-rich, basal Silurian shales were deposited throughout the basin.² Additional well and seismic data have been collected by various international companies in partnership with Moroccan oil company, ONHYM, but these data are not yet in the public domain.

Figure XIV-3. Tindouf Basin Stratigraphic Column



Source: Longreach Petroleum Corporate Presentation, 2010

Figure XIV-4. Tindouf Basin Cross Section

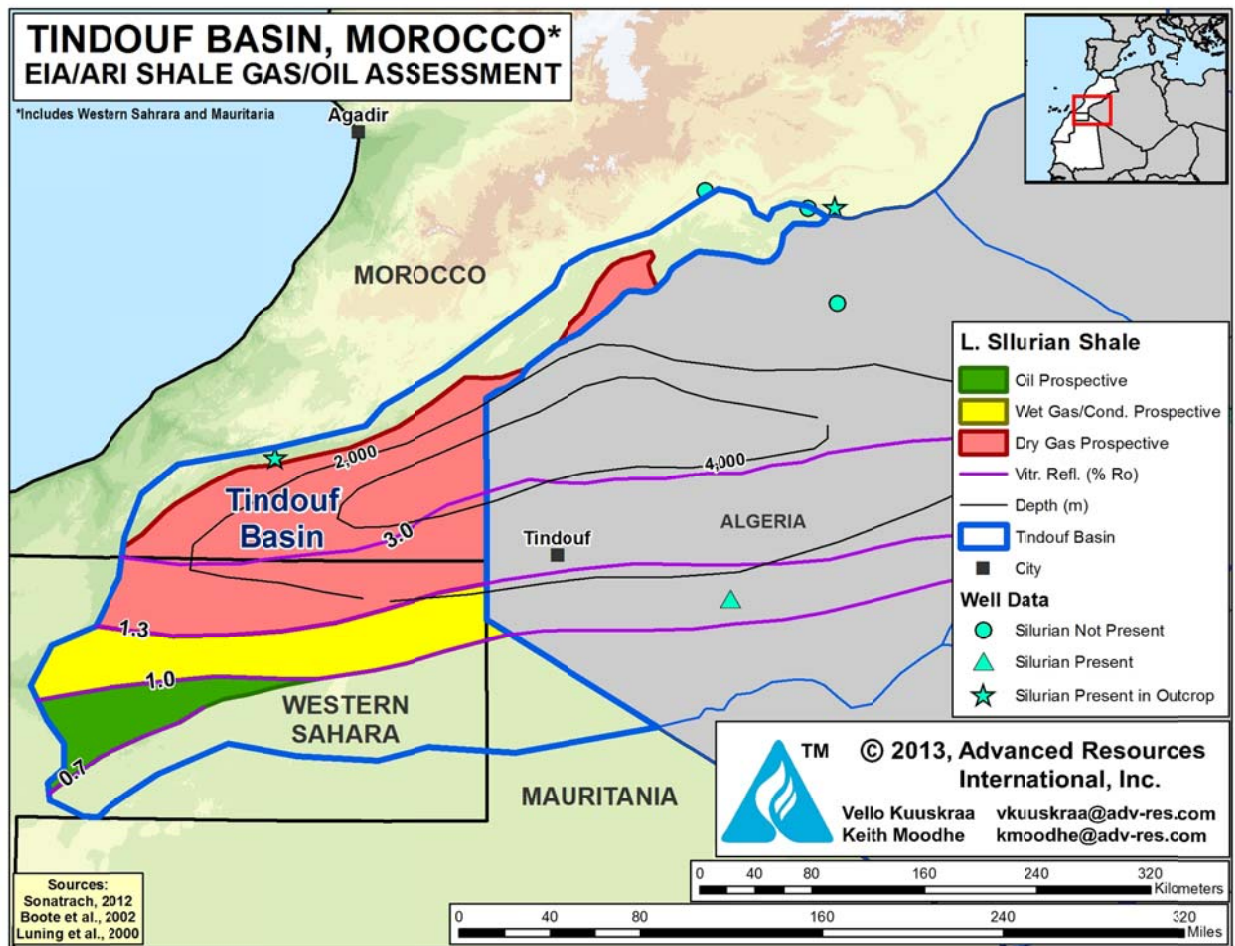


Source: Boote, 2002.

1.2 Reservoir Properties (Prospective Area)

Within the Tindouf Basin's prospective area, the depth to the Silurian "Hot Shale" ranges from 6,600 to 14,000 ft, Figure XIV-5. Present day TOC content ranges from 1% to 7%, averaging 4%. It is likely that the TOC content was higher during the time of hydrocarbon generation, due to the basin's very high thermal maturity.⁵ Thermal maturity increases to the north across the basin, ranging from 0.7% to over 3% R_o .⁴ Organic-rich net shale thickness is estimated at 54 ft, based on data from a well drilled in the southern flank of the basin.⁶

Figure XIV-5. Tindouf Basin Prospective Area, Morocco, Western Sahara and Mauritania



Source: ARI, 2013

1.3 Resource Assessment

We estimate that the wet and dry gas prospective area of the Silurian “Hot Shale” in the Morocco, Mauritania and Western Sahara portions of the Tindouf Basin has a resource concentration of 19 to 22 Bcf/mi². The oil prospective area of the Silurian “Hot Shale” has a resource concentration of 8 million barrels/mi² plus associated gas. While the shale formation is organic-rich, it is thin, limiting its resource concentration.

Within the overall 19,020-mi² prospective area, the Lower Silurian “Hot Shale” in the Tindouf Basin contains a 12,380-mi² area prospective for dry gas, a 4,670-mi² area prospective for wet shale gas and shale condensate, and a 2,020-mi² area prospective for shale oil. The risked shale gas in-place for the Tindouf Basin is estimated at 75 Tcf, with 17 Tcf as the risked, technically recoverable shale gas resource. In addition, the Tindouf Basin has an estimated 5 billion barrels of shale oil/condensate in-place, with 0.2 billion barrels as the risked, technically recoverable shale oil resource.

1.4 Recent Activity

The Moroccan national oil and gas company, ONHYM, has been evaluating the country’s shale gas potential since mid-2010. It has plans to collect seismic data followed by the drilling of a shale gas exploration well. The well is proposed to be drilled in partnership with San Leon Energy (Ireland) and Longreach Oil and Gas (Canada) on the Zag exploration license.⁷

2. TADLA BASIN

2.1 Geologic Setting

The Taldra Basin is a 2,800-mi² intra-cratonic basin located in central Morocco within the Moroccan Mesta. The basin contains nearly 16,500 feet of Paleozoic through Cenozoic sedimentary strata, Figure XIV-6. Paleozoic rocks dominate the sediments in this basin, except in areas where uplift has caused their erosion, Figure XIV-7. The Taldra Basin is bounded by the Central Massif in the north, the Atlas Mountains in the east, the Jebiliet Massif in the south, and the Rehamna Massif in the west. The Fkih Ben Salah Fault divides the basin into a southeast section, characterized by complex tectonics including heavy folding and faulting, and a northwest section, with thick carboniferous strata and minor, infrequent faulting.⁸

As in the Tindouf Basin, regional uplifting during the Hercynian and Alpine events exposed the Silurian, Devonian and Ordovician shales after they had matured and begun to generate hydrocarbons. While these shales were subsequently buried on the western edge of the basin by approximately 6,500 ft of Cretaceous and Tertiary sediments, it is unlikely that the shales generated additional hydrocarbons after reburial.⁸ As such, this basin is at high risk for underpressuring, although data are not available to confirm this assumption.

The 1,670-mi² prospective area of the Taldra Basin is bounded by the 1,000-m depth contour, various faults and the Atlas Mountain range to the east, Figure XIV-8. Little data are available in the southern portion of the basin where the prospective area is bounded by the apparent lack of organic-rich Silurian strata.

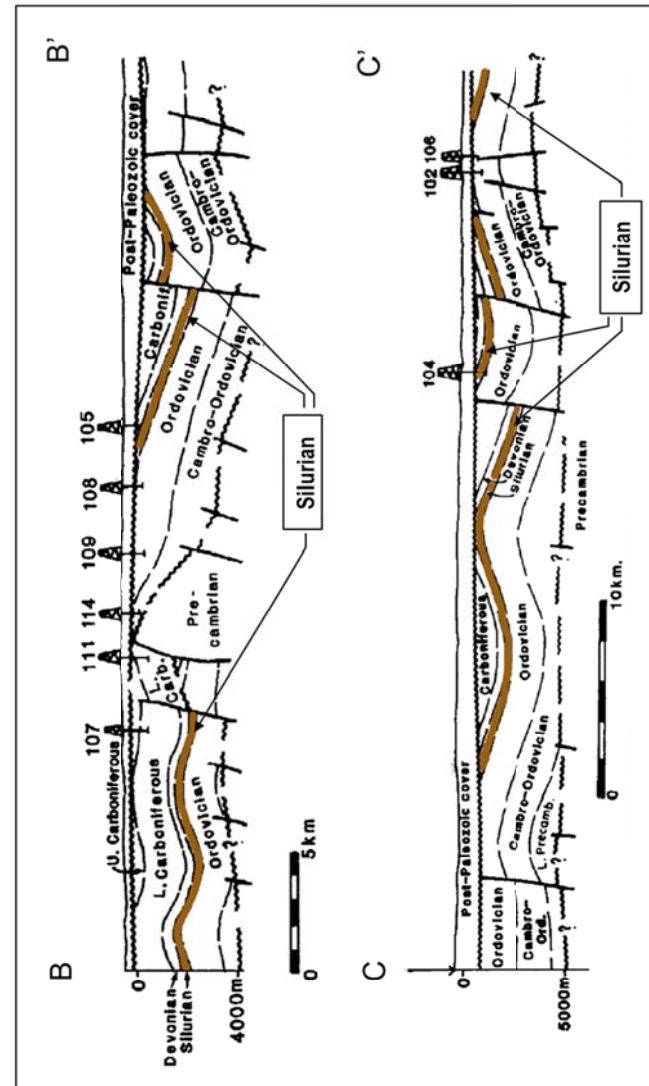
2.2 Reservoir Properties (Prospective Area)

The Lower Silurian "Hot Shale" in the Taldra Basin reaches maximum depth west of the Fkih Ben Salah Fault, ranging from 3,280 to 9,840 ft.⁸ To the east, the shale becomes shallower. Average depth in the prospective area is estimated at 6,560 ft. Where it has not been eroded, the Silurian section can reach up to 800 feet thick, with over 300 feet of organic-rich shale, of which 200 ft is net shale.⁹ TOC data from outcrops suggest that the organic content reaches 10-12%,¹⁰ but deep well data from inside the prospective area indicates TOC values closer to 2%. The Silurian shale is thermally highly mature over the prospective area; R_o values of 1.5% to 3% place the shale in the dry gas window.⁸

Figure XIV-6. Tadla Basin Stratigraphic Column⁸

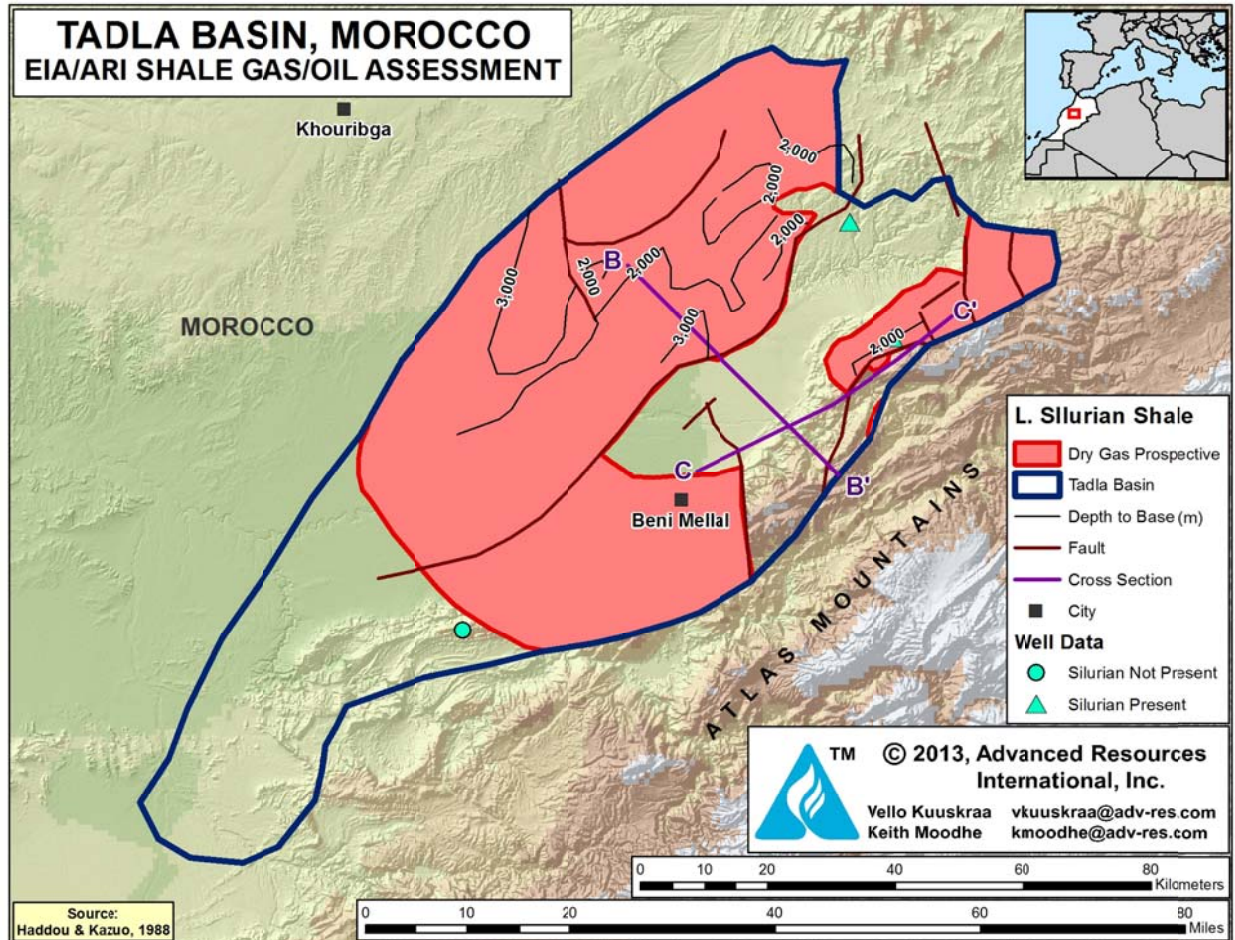
ORO-GENIC EVENTS	AGE	LITHOLOGY	LOCATION, OUTCROPS		
ALPINE	TERTIARY & QUATERNARY		Tadla plain		
	CRETACEOUS	EOCENE to MAASTRICHTIAN	"Formation phosphatée"		
		E. MAASTR. CONIACIAN TURONIAN CENOZOIC ALBIAN BERRIASIAN LIAS			
	VARISCAN	PERMO-TRIASSIC		Tanhost DRZ KMS	
		CARBONIFEROUS	STEPHANIAN WESTPHALIAN NAMURIAN	Chograne	
			L. VISEAN	Mechra B. Abbou Fourhat Ziar Mrirt Bakash	
			E. VISEAN	Conglomerate Khorifa Flysch Bouighal Ziar Uplift	
		TOURNAISIAN	Khatouet Flysch?		
		DEVONIAN	STRUNIAN FAMENNIAN FRASNIAN GIVETIAN		
			EIFFELIAN EMSIAN PRAGIAN		
LUCHKOVIAN			Akeial Syncline		
SILURIAN			Lower Silurian	Akeial Shale Mokattam Shale	
CALEDONIAN		ORDOVICIAN	ASHGILLIAN	Sidi Said Qtz Tirmah Beddous Qtz	
	CARADOCIAN		Outjet Bou Khemis		
	CAMBRIAN	LLANDEILIAN LLANVIRNIAN ARENIGIAN TREMADOCIAN	El Harcha Sst Tergou Shale		
		ACADIAN	El Hank Zguit Zaian Sst		
	PREC.	GEORGIAN	Quardane Shale Bou Acta Western Behouma		
		III	Pays Zaian (J. Hodid)		
	II	Bou Acta			

Figure XIV-7. Tadla Basin Cross Sections⁸



Source: Jabour, 1988.

Figure XIV-8. Tadla Basin Prospective Area, Morocco



Source: ARI, 2013

2.3 Resource Assessment

The Silurian “Hot Shale” in the Tadla Basin’s 1,670-mi² prospective area has a moderate 49-Bcf/mi² dry gas resource concentration. The basin contains an estimated 20 Tcf of risked shale gas in-place, with 3 Tcf as the risked, technically recoverable shale gas resource.

2.4 Recent Activity

No shale gas exploration activity has been reported in the Tadla Basin of Morocco.

3. SHALE RESOURCES BY COUNTRY

3.1 Morocco

Morocco has a 1,670-mi² dry gas prospective area in the Tadla Basin and an 8,000-mi² dry gas prospective area in the Tindouf Basin. Within these two prospective areas, Morocco has 56 Tcf of risked shale gas in-place, with 12 Tcf as the risked, technically recoverable shale gas resource.

3.2 Western Sahara

The Western Sahara portion of the Tindouf Basin has a 4,380-mi² dry gas prospective area, a 4,670-mi² wet shale gas/condensate prospective area, and a 2,020-mi² shale oil prospective area. Within these prospective areas, Western Sahara has an estimated 39 Tcf of risked dry, wet and associated shale gas in-place, with 8 Tcf as the risked, technically recoverable shale gas resource. In addition, Western Sahara has 5 billion barrels of risked shale oil/condensate in-place, with 0.2 billion barrels as the risked, technically recoverable shale oil resource.

3.3 Mauritania

Mauritania has a small 50-mi² wet shale gas/condensate prospective area in the Tindouf Basin containing only minor shale gas and oil resources.

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⁸ Jabour, H. and Nakayama, K., 1988. "Basin Modeling of Tadla Basin, Morocco, for Hydrocarbon Potential." American Association of Petroleum Geologists, vol. 72, no. 9, p. 1059-1073.

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¹⁰ Tadla-Haouz Basin. Opportunities for Hydrocarbon E & P in Morocco. ONHYM, 2010.<http://www.onhym.com/HYDROCARBURES/Prospectivite%20des%20Bassins/ExplorationR%20regionale/Onshore/HaouzTadlaBasin/tabid/347/language/en-US/Default.aspx?Cat=27>.