Chapter 3

Silurian Gas-Rich "Hot Shale" from Akkas Gas Field, Western Iraq: Geological Importance and Updated Hydrocarbon Potential and Reservoir Development Estimations of the Field

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77246

Abstract

The Silurian hot shale is encountered in the Akkas field, which is regarded as one of the largest gas fields in Iraq. It contains 5.68 tscf of initial gas in place of which 4.55 tscf is estimated to be recoverable. There is also the potential of condensate and other prospects in deeper formations. The well test confirmed the presence of natural gas with a flow rate of 6–8 MMscfd. Silurian shale contains two organic-rich black hot shale beds that are fissile with high-gamma uranium radiation. Silurian hot shales are geologically important from different sides. Stratigraphically, Silurian graptolites are used to delineate the time transgressive depositional advance of marine clastics across the Arabian Peninsula after the melting of Ordovician glaciers. For assessment of the hydrocarbon generation in the Paleozoic of Iraq, the hot shales of the Akkas Formation are low-sulfur, high-gravity oil, condensate, and gas and are considered as an important gas-rich formation in the region. From petrological and mineralogical view, the presence of distinctive minerals and some elements are important to interpret the depositional and climatic situation at Silurian time. This chapter also sets out assumptions about Akkas gas field development.

Keywords: gas-rich shale, hydrocarbon potential, importance, reservoir estimation, Akkas field, western Iraq

1. Introduction

The lower Silurian shales especially the characteristics "hot shale" are a major source rock on the Arabian Peninsula [1–3]. They are regarded as the source of the non-associated gas in the North Field of Qatar and of the oil in central Saudi Arabia and western Iraq [4, 5]. They are also the origin of 80–90% of Paleozoic-sourced hydrocarbons in North Africa [1]. This prolific basal Silurian source level not only occurs over wide areas of Arabia and North Africa, but source rocks are also present at a similar level in the interior basins of the US, the Amazon and on the Russian platform [6, 7]. Silurian organic-rich shales account for the generation of 9% of the world's petroleum [6, 1].

The Silurian Akkas Formation does not crop out in Iraq and it has been penetrated in several boreholes in the western desert of Iraq (**Figure 1**). The Akkas Formation overlies the Ordovician

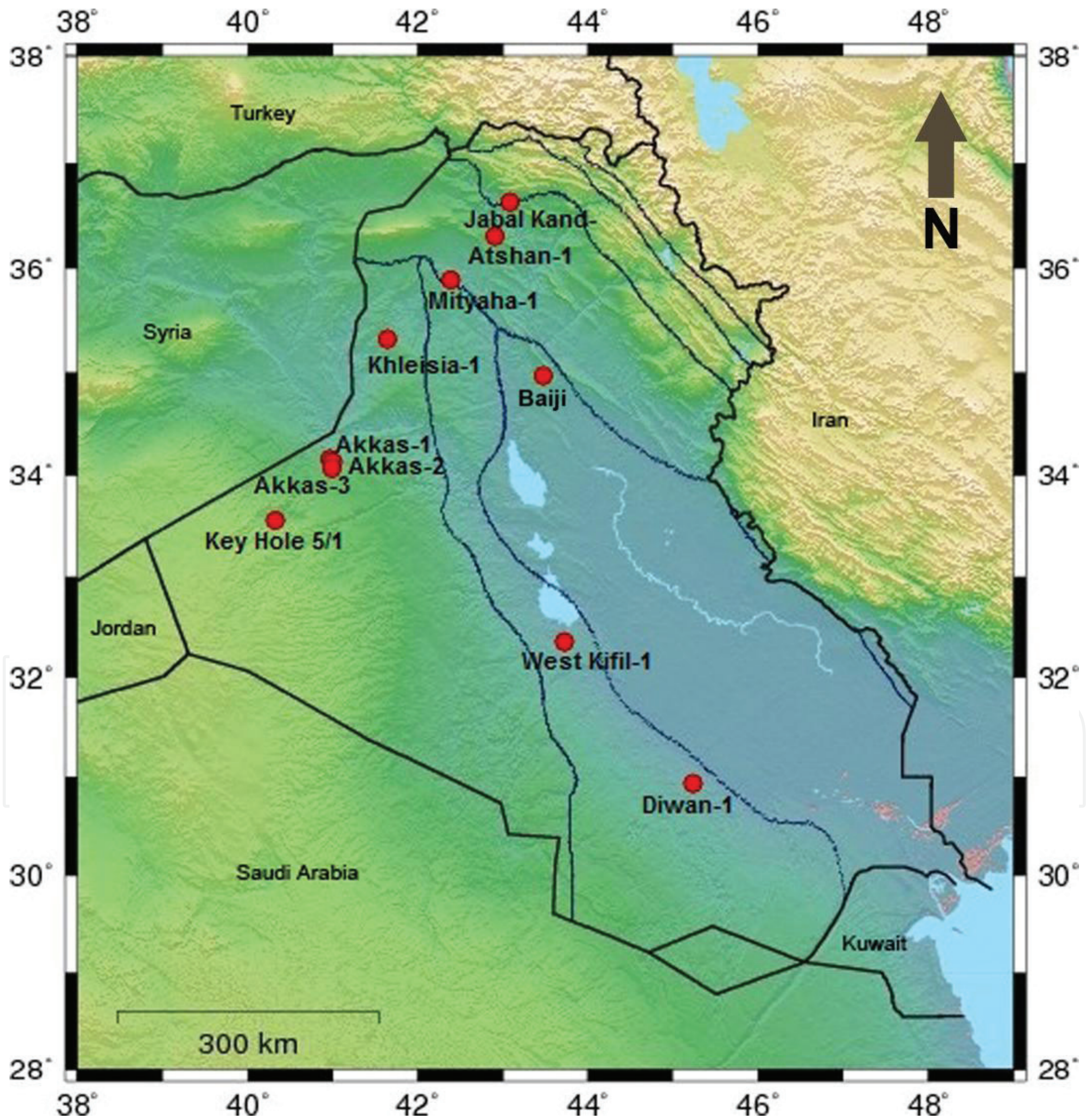

Figure 1. Map of Iraq showing the locations of wells that penetrate the Paleozoic rocks of Iraq including the wells of the current study, Akkas 1-3 (SA 1-3), Khleisia and key hole KH5/1 (source Abd Alwahab 2013, [8]).

Khabour Formation and underlies the Devonian Pirispiki Red Beds Formation in surface outcrops in extreme northern Iraq or Kaista Formation in other locations [5]. It consists of black fissile shale with sandstone and siltstone intercalations. It is divided into lower Hoseiba and upper Qaim members. The Hoseiba Member consists of black, gray to dark gray shale, fissile,

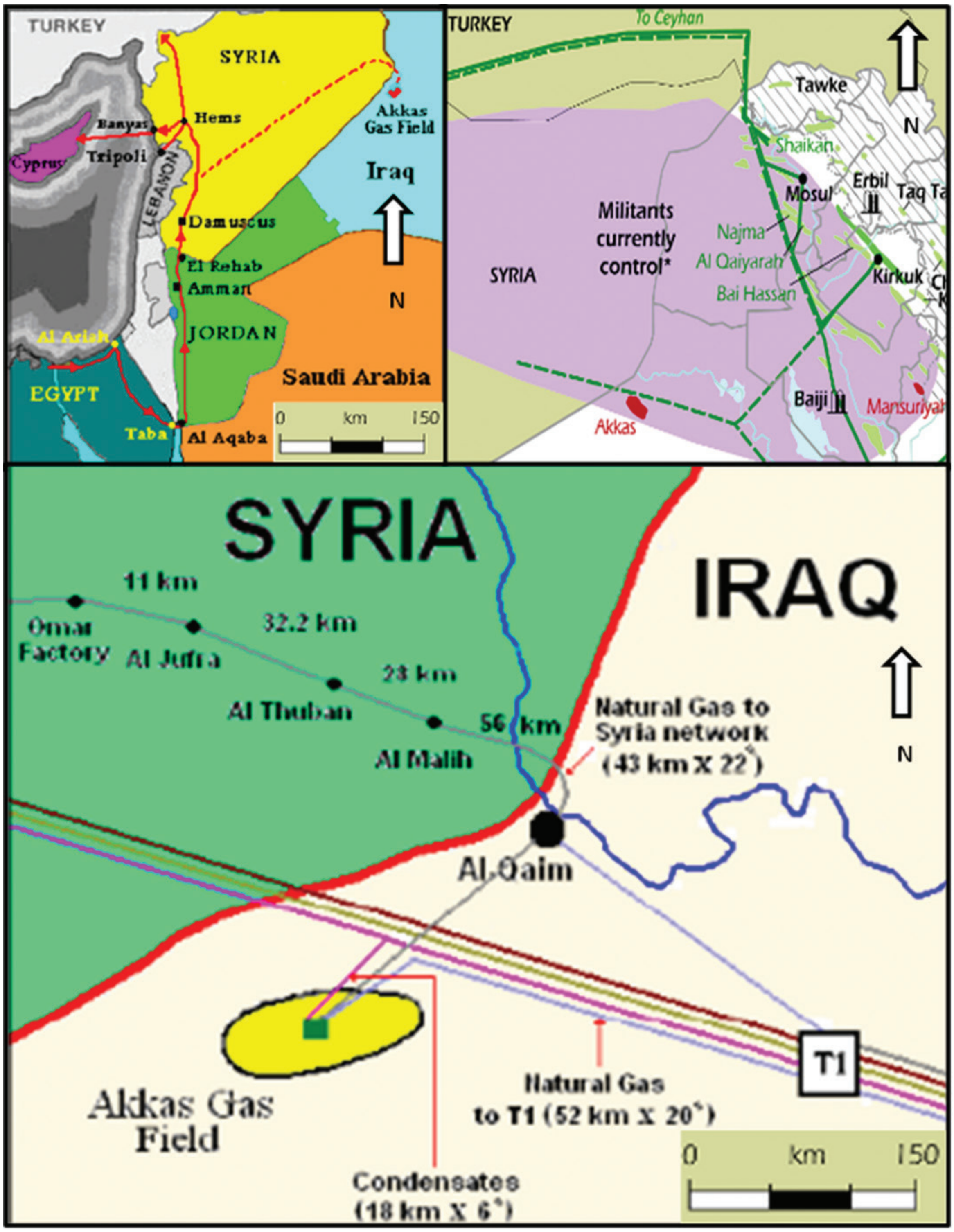

Figure 2. Location of the Akkas field and pipelines connection (source AlShalchi 2008 [9]).

micaceous, non-calcareous, pyritic and silty, with graptolite and brachiopods. It contains two organic-rich black hot shale beds that are fissile with high-gamma uranium radiation. These hot shales also existed in the early Silurian after the melting of the Gondwana polar glaciers.

The study area is located in the Akkas field of western Iraq (**Figure 2**). It is 52 km from the T1 pump station and 285 km from the K3 pump station. The distance between this field and Baji town, where the entire Iraqi gas grid passes, is around 300 km. The nearest industrial complex to the field is the Al-Qaim. Industrial Complex that consists of a fertilizer plant and cement plant is less than 40 km away. The first exploration well in Akkas region took place in August 1992. The drilling program target was to reach a depth of 5000 m, but this did not succeed due to technical difficulties. The drilling reached a depth of 4238 m, and the well test confirmed the presence of natural gas with a flow rate of 6–8 MMscfd.

Akkas is one of the largest gas fields in Iraq. It contains 5.68 tscf of initial gas in place, of which 4.55 tscf is estimated to be recoverable. There is also the potential of condensate and other prospects in deeper formations. In 2001, the development of Akkas-Saladin gas field was referred to the Syrian Petroleum Co. The commitment was to drill five horizontal wells and redrill the Akkas-1 (SA-1) discovery well horizontally. An average well test for another five wells demonstrates more than 9 MMscfd on the largest choke.

The present chapter aims to illustrate the importance of the gas-rich shale from Akkas field of western Iraq in terms of geological and hydrocarbon potential clues and with the available limited information to calculate the probable reserves and design the plan of development for the field.

2. Geological setting

The Akkas Field is a part of the Widyan basin and Interior Platform Province of western Iraq and northern Saudi Arabia [10]. The gas fields of the Widyan basin-interior platform in western Iraq are mainly Lower Paleozoic petroleum systems such as gas in the Ordovician Khabour and lower Silurian Akkas formations. Their main source could be the Khabour Formation and the oil shale of the Akkas Formation. Structural framework of folding and faulting as well as stratigraphic facies changes could form the main traps in these regions. The lower Paleozoic Qusaiba/Akkas petroleum system of Saudi Arabia and western Iraq which consists of one assessment unit “the horst/graben-related oil and gas assessment unit” is characterized by high-gravity, low-sulfur crude oil, as well as natural gas, occurs in horst/graben-related traps that formed prior to, during, and after Hercynian (Carboniferous) deformation [10].

Silurian rocks are not exposed in Iraq. They are absent from outcrops in northern Iraq due to erosion at the late Devonian unconformity (Van Bellen et al. [11]). However, they have been penetrated in several boreholes in the Western Desert of Iraq. The Silurian (Llandovery and Wenlock) succession consists of shales with a basal hot shale unit encountered in the wells Akkas-1 and Khleisia-1 (**Figure 1**). The thickness of the basal hot shale is 19 m and occurs about 60 m above the top of the basal Silurian hot shale unit. The basal Silurian hot shale is believed to be the main Paleozoic source rock in the western and southwestern deserts of Iraq and to be the source rock of the light oil and sweet gas discovered in the Akkas field. In Akkas-1, the total organic carbon (TOC) ranges between 0.96% and 16.62%, and in Khlesia-1 it ranges from 1.0% and 9.94%, with a hydrocarbon potential of about 49 kg HC/tonne [12].

The maturation distribution is complicated by an intense Hercynian-age horst-graben relief; therefore, Silurian hot shales could be over-mature in deeper areas of the region while they are immature in shallower areas [12].

The Paleozoic hydrocarbons of the Western Desert of Iraq are almost free of H_2S and composed of up to 85% methane and ethane. Silurian shale was deposited under dysoxic to anoxic conditions in an intra-shelf basin located north of the Central Arabian Arch.

3. Methodology

Graptolite chitinozoan identification is conducted on a dark gray, indurated graptolitic shale from Silurian shale from a depth between 2213 m and 2221 m, from the Akkas-1 well, drilled in 1993 by the Iraqi Oil Exploration Company in the western desert of Iraq (**Figures 3**, **4A**). The graptolites were measured with an eyepiece graticule. For chitinozoan extraction, the standard HCl-HF-HCl processing method was employed, which was done at School of Earth and Environmental Sciences, University of Portsmouth, UK.

Samples were prepared and analyzed for the type organic matters at laboratories of Wollongong University, Australia, according to the procedures of Falcon and Snyman [13]. Five black shale samples are chosen for this part of study. Selected types of organic matters are illustrated in (**Figure 4B**, **C**).

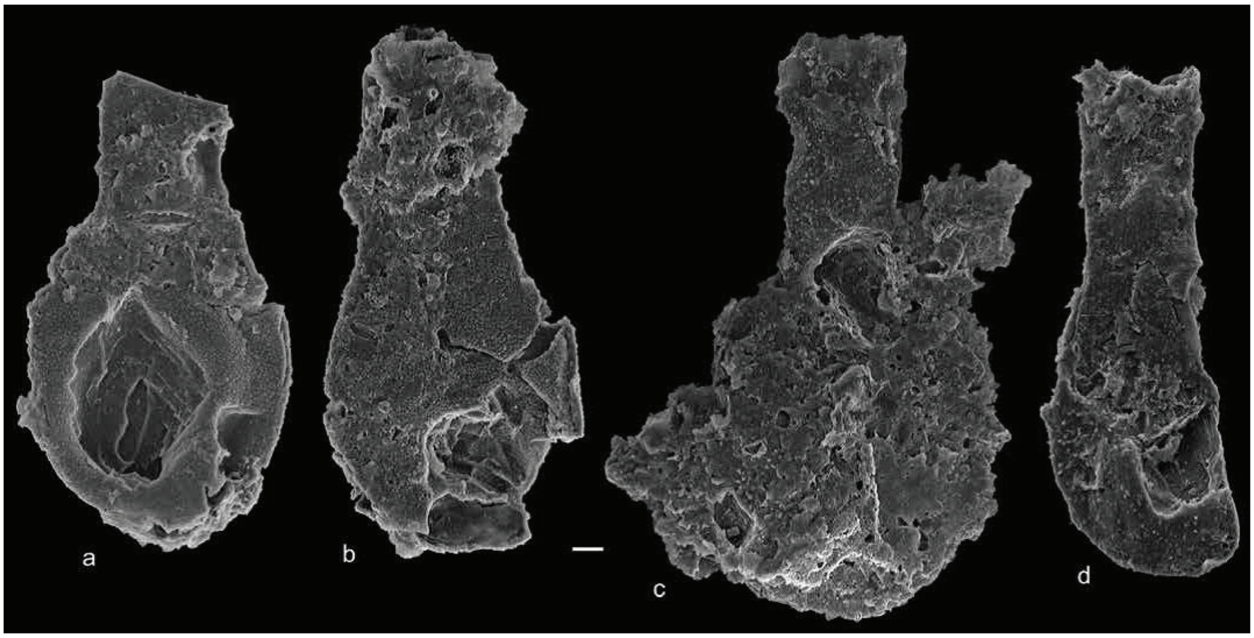

Figure 3. Chitinozoans from Silurian shale in Akkas-1 well, western Iraq; a–c: *Sphaerochitina sphaerocephala* (Eisenack [16]), d: Angochitina sp., scale bar (10 μm), after Loydell et al. [3].

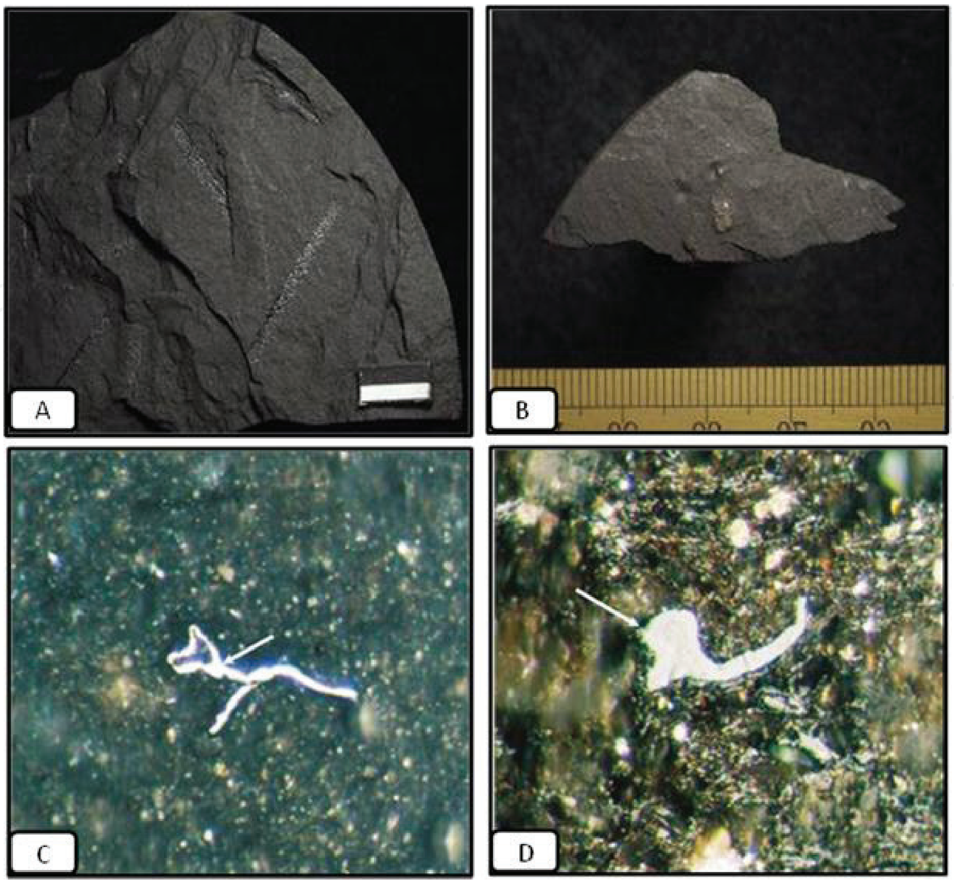

Figure 4. A: Graptolites in hand specimen of black fissile hot shale. B: Pyrite crystal in the hot shale. Both samples are from the Silurian Akkas formation, C: Tasmanite in Silurian hot shale, X50, D: Vitrinite (arrow) common with a lot of organic matter in Silurian shale, x50, Akkas formation, Akkas-1 well western Iraq.

A representative portion of each sample was manually ground to a fine powder using a ceramic mortar and pestle. The powder was packed into a recessed plastic holder and preferred orientation was minimized. The samples were analyzed using a Philips X-ray diffractometer (PW3710) scanning from 4 to 60° 2θ. Ten samples from both hot and cold shales are selected and representative diffractograms are shown in (**Figure 5**). The generator was controlled using Philips PC-APD software. Peak identification was enabled using PDF/ICCD database and quantification using Rietveld analysis using commercial program Siroquant (Sietronics, Australia). Analysis was done at laboratories of the department of Earth Sciences, Royal Holloway University of London.

A scanning electron microscope (SEM) helps identification and description of the mineral phases. The SEM also reveals their morphology, textural relationship and growth habits. SEM analyses were carried out with magnifications between 100X and 12,000X with gold-coated samples. The coater is a EDWARDS RV3, using a quartz crystal thickness monitor. Analysis was carried out at the scanning microscope unit of MTA Ankara, Turkey, using FEI QUANTA 400 scanning electron microscope from JKMRC Technical Company. Several clay and non-clay minerals were recognized in the studied Silurian shales from the same above-mentioned ten samples analyzed for XRD analysis (see **Figure 6**). TOC (total organic carbon) values (wt%) were obtained using a Leco instrument by combustion in oxygen. Samples were analyzed by Geomark Research Ltd. (Houston, Texas, USA).

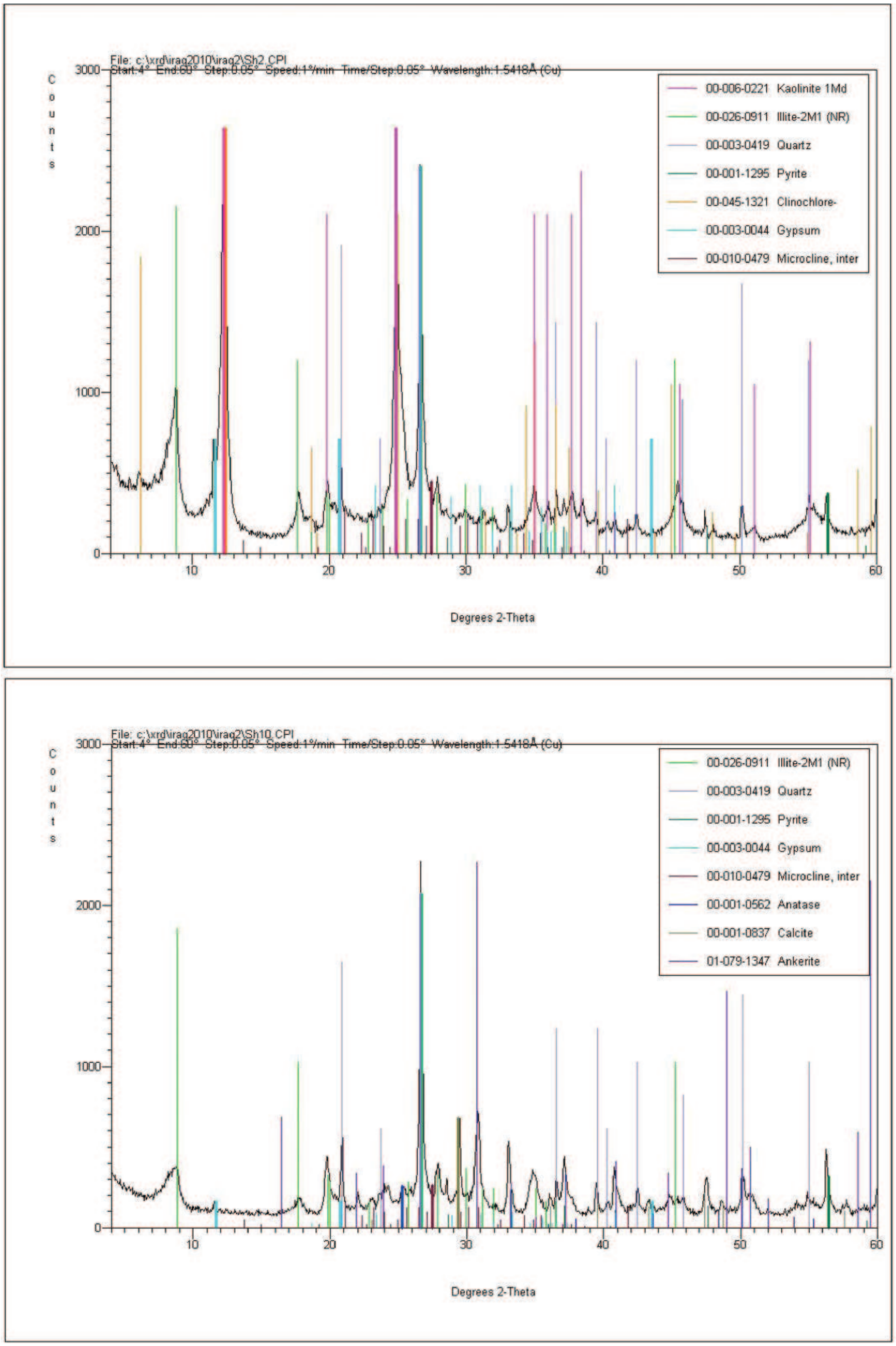

Figure 5. X-ray diffractograms for bulk hot shale sample in the well Akkas-1 (SA-1), illustrating the main clay and non-clay components. Samples represent the cold shale (upper) and hot shale (lower).

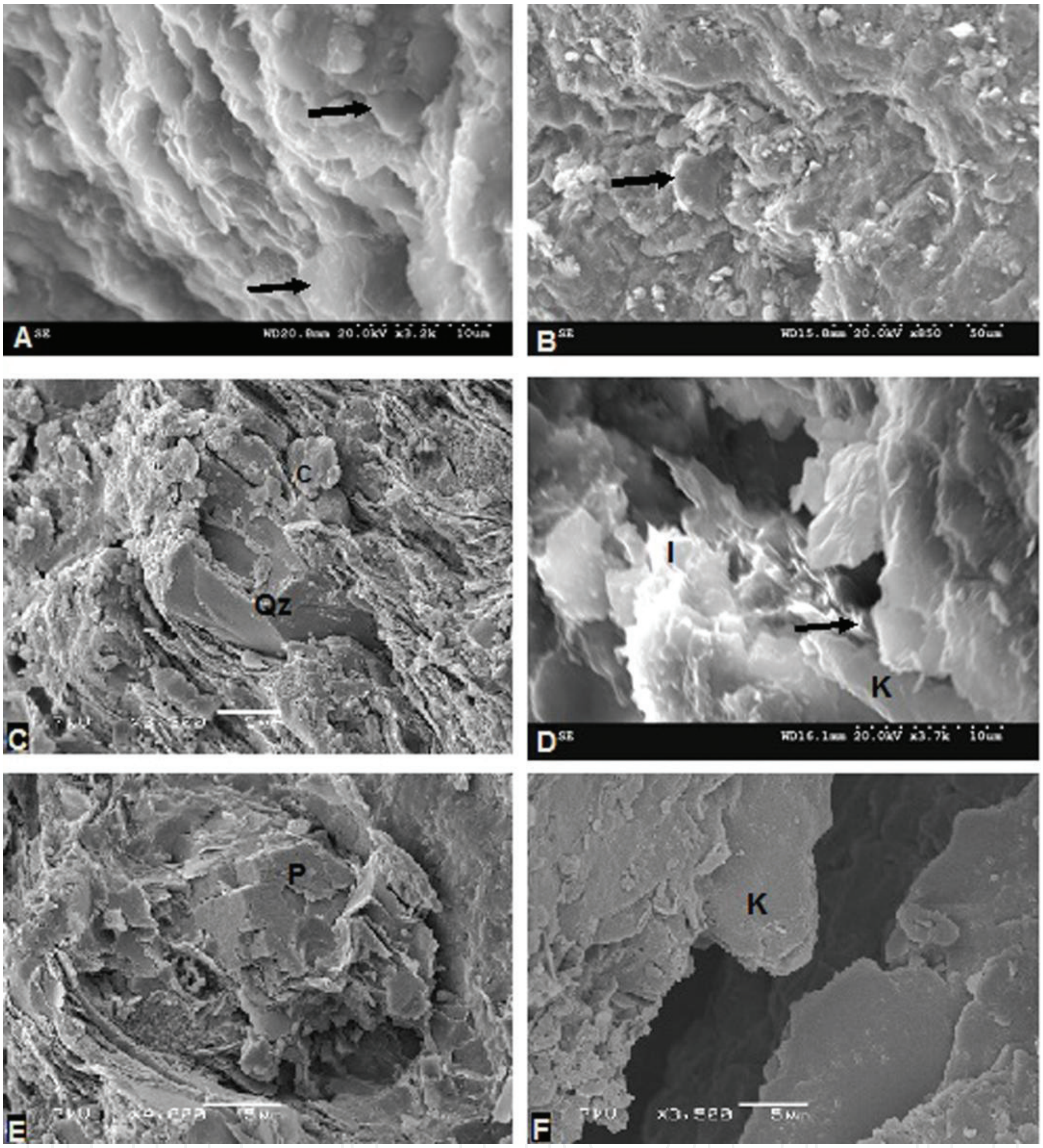

Figure 6. Scanning Electron Microscopic Images (SEM) from the hot shale, A- kaolinite hexagonal plates some are degraded (black arrows), B- illitization of kaolinite, C- Authigenic quartz (Qz) and carbonates (C), D- fine illite fibers (I and arrow) and kaolinite booklets (K). E- Cubes of pyrite (P), F- common kaolinite booklets mostly are degraded (K).

4. Significance of Silurian shale in Iraq

4.1. Stratigraphic importance

Graptolites are important index fossils for dating Paleozoic (Silurian) rocks and are used to delineate the time transgressive depositional advance of marine clastics across the Arabian Peninsula after the melting of Ordovician glaciers. After the peak of the late Ordovician glaciations during the Hirnantian [14], ice melting led to a rapid eustatic sea-level rise and a far-reaching southward transgression which commenced during the latest Ordovician persculptus graptolite Zone. This must have been a very rapid transgression (or sediment-starved) because shallow-marine sand waves, strandlines and rippled sandstones, resulting from littoral reworking, were preserved during the transgression and were subsequently buried beneath graptolitic shales [15].

Graptolites from 'hot' shale from western Iraq demonstrate that it is of early Wenlock Monograptus riccartonensis Zone age, somewhat younger than the Llandovery age previously ascribed to it [2]. A post-Llandovery age also is indicated from chitinozoan study from western Iraq [3], (**Figure 3**).

During these short periods, a favorable combination of factors in parts of North Gondwana led to the deposition of exceptionally organic-rich shales. The Silurian post-Rhuddanian shales are, in general, organically lean and do not make a significant contribution to petroleum generation.

The restriction of the hot shales to the Rhuddanian Stage implies that palaeohighs, which during the latest Ordovician-early Silurian transgression were flooded only during post-Rhuddanian times, are likely to be devoid of the Silurian hot shales. The palaeorelief, therefore, controlled not only the timing of the onset of shale deposition but also the presence or absence and probably the thickness of the hot shales.

The environment of deposition was anoxic before, during and after deposition of the 'hot' shale, except for some very brief incursions of more oxygenated water that enabled the development of a very limited burrowing benthos and graptolite preservation as three-dimensional pyrite internal molds [3].

4.2. Petrology and mineralogy

The Silurian shale of the Akkas Formation contains common graptolites Monograptus convolutes (**Figure 4A**). A lot of organic matter is also present in addition to abundant vitrinite and pyrite (**Figure 4B**). Large fragments of vitrinite and some grainy organic matter of marine algae (Tasmanites) are also observed (**Figure 4C–D**).

The mineralogical composition of the studied shale units in western desert of Iraq is studied using X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. The main clay minerals observed are illite and kaolinite, while the non-clay minerals include quartz, feldspars (microcline), pyrite, apatite, anatase, carbonates (calcite and rare dolomite) and ankerite (**Figure 5**).

SEM analysis shows that kaolinite is commonly present as hexagonal plates mostly are degraded (**Figure 6A**, **D**, **F**). Illite grew from precursor kaolinite (illitization of kaolinite, see **Figure 6B**), this characteristically occurs during burial diagenesis. Illite also is commonly present as fibers and fine white flakes (**Figure 6D**). Quartz is the next most common non-clay mineral observed in the studied shales. Detrital quartz grains and few diagenetic quartz overgrowths were observed using the SEM (**Figure 6C**). SEM analysis shows that the carbonates

Sample number	L. Depth (m)	Leco TOC (WT%)	S1 mg/g	S2 mg/g	S3	HI	OI	S1/S1 + S2	TMAX C	% Carbonate
Sh1	1750	0.58	0.22	0.21	0.25	36	43	0.51	385	3.7
Sh3	1895	0.33	0.15	0.51	0.24	155	73	0.23	431	6.2
Sh5	2030	0.63	0.23	0.31	0..28	49	44	0.43	401	7.2
Sh8	**2222**	**9.59**	**6.27**	**24.91**	**0.48**	**260**	**5**	**0.20**	**438**	**16.7**

Table 1. Organic geochemical results for the analyzed shale samples.

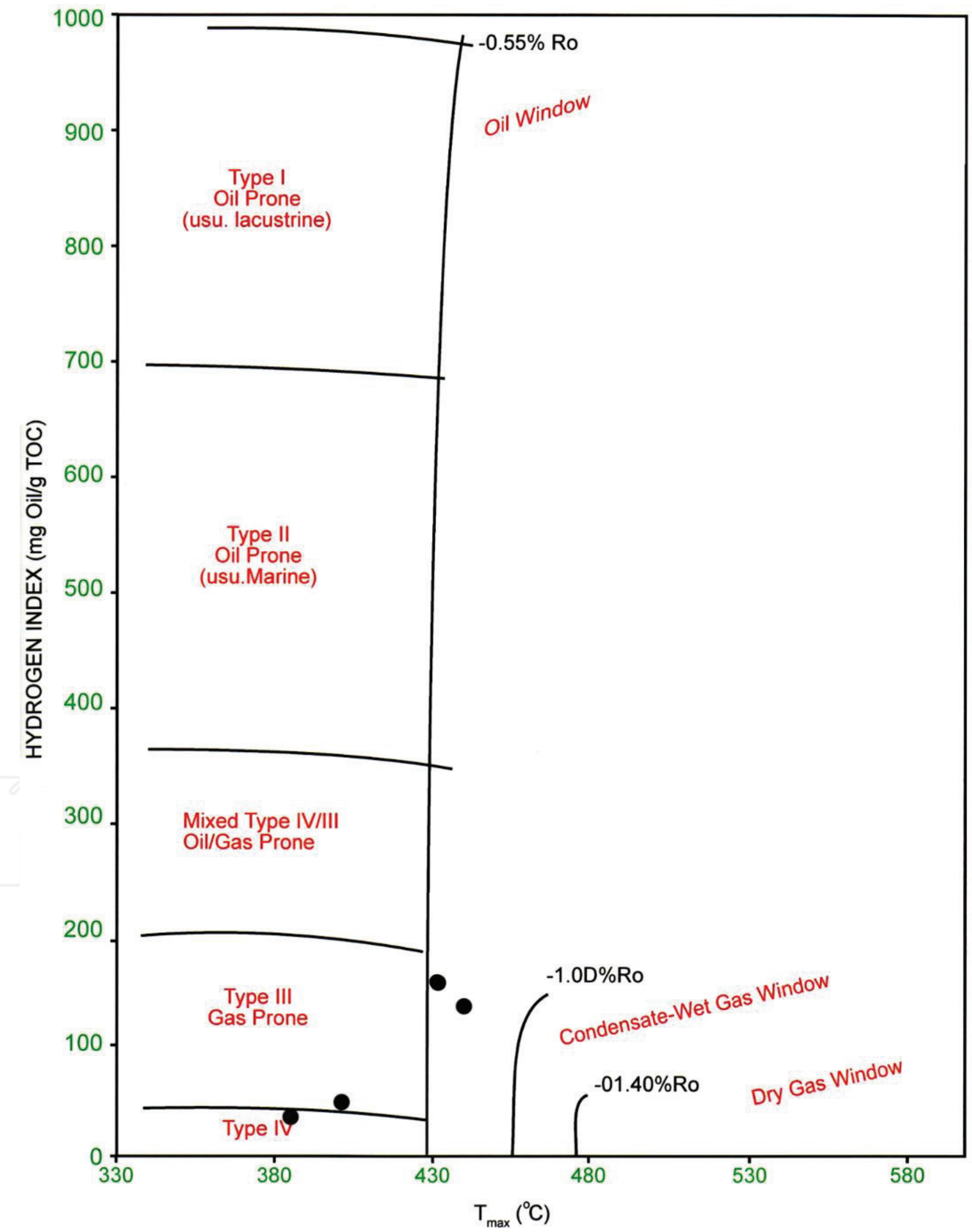

Figure 7. Plot of rock-Eval Tmax versus HI (hydrogen index) for Silurian hot shales (the right two samples) from western Iraq [17].

are either filling fractures or randomly distributed in the sample (**Figure 6C**). Pyrite cubes are also common in the Silurian hot shales (**Figure 6E**).

4.3. Hydrocarbon source rock

Paleozoic shale is organic rich and the most likely source rock of the low-sulfur, high-gravity oil, condensate, and gas in the Paleozoic rocks of western Iraq. Lithologically, similar Silurian sequences were deposited over most of the broad stable shelf of Gondwana from the Middle East to the African Sahara.

In the basal Silurian hot shale in Akkas-1, western Iraq, the TOC ranges between 0.96% and 16.62% compared to that in Khlesia-1 which ranges from 1.0% and 9.94%, with a hydrocarbon potential of about 49 kg HC/tonne [12]. The organic geochemical analysis of the hot shale is summarized in **Table 1**. In some deeper areas of the Southwestern Desert the Silurian hot shales could be over-mature, whereas in other shallower western areas, they might be immature [12]. The maturation distribution is complicated by an intense Hercynian-age horst-graben relief. The Paleozoic hydrocarbons of the Western Desert of Iraq are almost free of H_2S and composed of up to 85% methane and ethane [1].

In the present chapter, TOC value over 9% and a hydrogen index of 260 and Tmax of 438°C for the upper hot shale sample reveal that this sample could be within the oil window. Results are presented on diagrams of hydrogen index versus Tmax (**Figure 7**). These plots indicated the presence of kerogen Types II and III which is at oil-gas window maturities.

5. Hydrocarbon potential and reservoir development estimation

5.1. Hydrocarbon potential

The formations with hydrocarbon potential in Akkas field are as follows:

The Ora, Kaista and Harur formations at 1365–1424 m is a sequence of sandstone, a compact shale layer of low and medium porosity, followed by dolomite and limestone.

- The Akkas Formation at 1993–2002 m is sandstone with compact shale layers of low porosity.
- The Khabour Formation, at 2332–2360 m in Akkas-1, 2365–2375.5 m in Akkas-2, and 2341–2355 m in.

Akkas-3 (SA-3), is sandstone and compact shale layers of low porosity. The specific gravity of the tested gas was 0.726–0.6953 and of the condensate was 0.7792.

In Akkas-1 (SA-1), there are indications of light oil (density 0.8326 gm/cu cm). An Akkas-4 (SA-4) test showed gas, and the author believes condensate may also be present in this well.

Samples of cores and cuttings were collected from the Khabour, Akkas and Upper Devonian Kaista formations in wells Akkas 1–6 (SA 1–6), Khleisia-1, KH 5-6, and KH 5-1. Their diagnostic organic matters are abundant and a few spores and chitinozoa as well as scolecodonts, graptolite siculae, cuticles and amorphous organic matter are present (see **Figures 3** and **4**) [19].

Hydrocarbon generation potential is assessed by plotting organic matter up to 16% TOC, especially the hot shale of the Akkas formation, which is very low asphaltene and sulfur. The saturated and aromatic hydrocarbons of more than 96% and high peaks of C2-C20 gas chromatography could indicate predominant gas generation with some light oils.

The associated gases are mainly methane and ethane of CH4, C4H6 and C3H8. Accordingly, source potential for wet gas and condensate could be assessed at a depth of 2750–3000 m and dry gas at a depth of 3570–3650 m in Akkas-1 only from the Khabour Formation. Little oil might be generated from the Akkas Formation in Akkas-1 (SA-1) well (**Figure 8**) [8, 19].

These potential source rocks are extended toward neighbor countries. Accumulation sites of these generated gases and a little oil could be within the sandstone porosities of 10–17% and permeability of 500 md sealed by the non-permeable shale along closures of the structured anticline fold and fault of this field as well as along the unconformity of the boundary of the Akkas Formation with the Kaista Formation.

Accordingly, Lower Paleozoic Total Petroleum System of generation, migration and accumulation that could be assessed for a basin includes West Iraq and extensions in the neighboring regions.

5.2. Formation evaluation

In Akkas-1 (SA-1), the borehole generated condensates and wet and dry gas of mainly 85% methane and ethane. Little oil could have been generated from the upper part of the Lower Silurian rocks.

Increasing thermal alteration (>170° C., TAI = 3.8) applied to rocks containing more than 0.5% TOC would be a reason for generating gas from Ordovician rocks. Trapped gas and oil could be accumulated along anticline and fault structural traps within Ordovician and Silurian sandstone’s interlayers in western Iraq. **Table 2** shows summarized characteristics of the Akkas gas obtained from the tests made in the Akkas-1 well [19]:

5.2.1. Wet gas and condensate generation

The Akkas-1 borehole has total organic carbon of 0.71–1.42 wt% at 2750–3000 m.

The biodegradation and thermal alteration of the organic matter resulted in abundant amorphous organic matter (70–75%).

The Khabour B rock unit started the generation of wet gas and condensates hydrocarbons during the Mississippian time and continued until now with the expulsion quantity of 65% of its proven reserve [19].

5.2.2. Dry gas generation

The Akkas-1 borehole has TOC of 0.5–1.0% at 3570–3650 m.

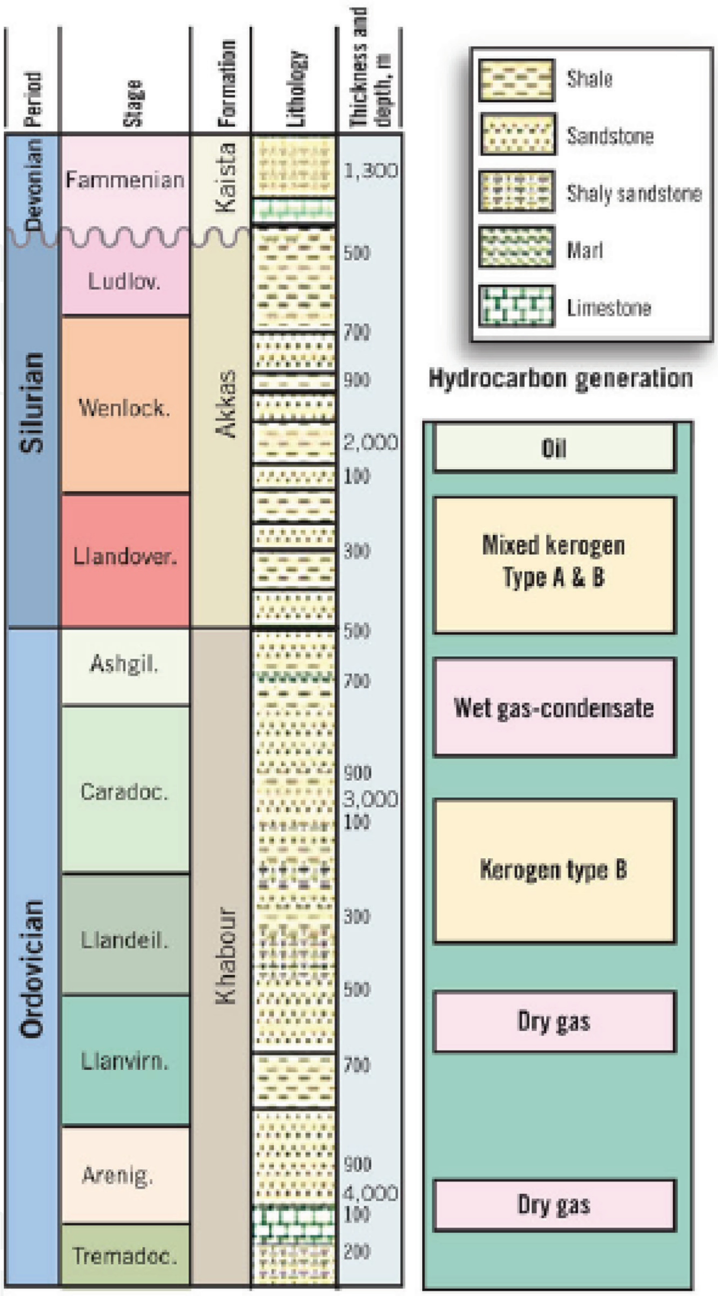

Figure 8. The hydrocarbon generation and the stratigraphy column of Akkas-1 (SA-1) well (Bujak et al. [18]).

The biodegradation and thermal alteration of the organic matter led to abundant amorphous organic matter. The analysis for this shale unit (Khabour D) gives results of starting dry gas generation during Silurian time and ended generation during late Triassic.

5.2.3. Oil generation

Potential source rocks for oil have been encountered from the Akkas Formation depths of 2280–2330 m in Akkas-1. The analyses for this lithostratigraphic unit of Akkas hot shale have resulted in no hydrocarbon generation although it has very high organic content [8, 9, 19].

5.3. Subsurface condition

Low sulfur content of the generated hydrocarbons in Akkas field could be explained by the presence of iron in these clastic marine rocks that combines with sulfur and precipitates as iron pyrites (which is found in abundance with the organic kerogen). The free sulfur content is reduced in the organic matter and in the released hydrocarbons. In addition, an increase in the geothermal gradient due to the presence of radioactive shales has caused the breakdown of long chain hydrocarbon compounds into simpler compounds forming very light oil, condensate and gas with low sulfur contents [1, 3, 19].

This was proven by the test results from Akkas-1, which has 42° gravity light oil in sandstone units at the base of Silurian and free sweet gas in the upper part of the Khabour Formation. The results of bitumen analysis from the shale source rock unit, at the base of Silurian, indicated that saturated hydrocarbons and aromatics make up 96 wt% and asphalt compounds 3.89 wt% of the extract. The saturated compounds are of low molecular weight (C2-C20) by gas chromatography and hence could indicate predominant gas generation with some light oils.

5.4. Reservoir and seal

This principal reservoir (Khabour Formation) is the oldest known sedimentary rock unit in Iraq. It consists entirely of siliciclastic sequences, comprising thin-bedded, fine-grained sandstone, quartzite graywackes and silty micaceous shale with some intercalation of dolomite and limestone.

The base of the formation, which may be more than 1000 m thick, has not been reached in wells. It was deposited in shallow marine inner to outer neritic environments that prevailed over the entire eastern part of the Arabian Plate. In Akkas field, the Khabour Formation is found at depths below 2310 m and exhibits good reservoir properties. It comprises sandstone with silty shales and has a gross thickness of approximately 38 m and an average thickness of 25 m.

Core analysis of the reservoir intervals generally indicated an average porosity of 10% and permeability of 500 md. Its depth in Akkas-1 is at 2040 m below sea level. Formation temperature is 146°C at 3300 m. The high temperature is caused by the Silurian shales' radioactivity and decreases downward in the Khabour Formation to normal gradients. The gross hydrocarbon reservoir column is about 80 m.

A secondary reservoir is provided by the Akkas Formation found above the Khabour Formation at a drilled depth of 1465–2326 m. It is comprised of a sandstone unit interbedded within the basal hot shale unit, with a gross thickness of 10 m and net thickness of 1.5 m. Core analysis of the reservoir intervals indicated porosity of 17% and a permeability of 500 md. The Akkas Formation was found to contain 42° gravity light oil only from the

GIIP	5.680 Tcf	N2	0	Wellhead Pressure	2015 lb/in2
Condesate Gas Ratio	Condesate Gas Ratio	Water Salinity	120000	Pressure at Sep.	1100 lb/in2
Cond. Gas Spec.Garv.	0.779	Gas Density at 1 at	0.89	Chock Temp.	135 F
Conden. Gas Gravity	50 API	Reservoir Temperature	210 F	Pipe temp.	130 F
Conden. Water Gas Ratio	0.20%	Reservoir Pressure	3720 lb/in2	Survey Depth	2100/3000/1000 m
Condens. H2S	0.06	Flow rate	17.3 MMscf/d	Pipe length to Sep.	1000 m
Gas Spec. Garvity	0.726	Flow Pressure	3045 lb/in2	Tubing Depth	2150 is 3.5 inch
CO2	0.04	Chock Size	0.5 inch		

Table 2. Published data of Akkas gas field from the Akkas-1 (SA-1) well.

http://dx.doi.org/10.5772/intechopen.77246

thin sandstone horizon sandwiched between the hot shales at the base; it is therefore considered a minor reservoir. The overlying Silurian shale of the Akkas Formation is an effective local regional seal.

5.5. Reservoir engineering

The author's MBAL material balance model indicates that cumulative recoverable gas at Akkas would be 3.553 tscf.

A possible production profile plateau is 500 MMscfd from 50 wells and for contract; the reason can be 55 wells. Published data show many uncertainties in the reservoir like bottomhole pressure, wellhead pressure, density and downhole equipment. From published information, it is impossible to calculate the vertical lift performance (VLP) and the inflow performance relationship (IPR). The author estimated the wellhead pressure according to the given reservoir pressure of 3720 psi.

In order to design and allow for the building of reliable and consistent well models with the ability to address each aspect of wellbore modeling, PVT (fluid characterization), vertical lift performance (VLP) correlations (for calculation of flow line and tubing pressure loss) and IPR (reservoir inflow), the author used Prosper. According to the available data from Akkas-1, the Prosper model shows the absolute open flow of 214 MMscfd (**Figure 9**). It shows VLP and inflow performance relationship (IPR) with production rates of 17.4 MMscfd (**Figure 10**).

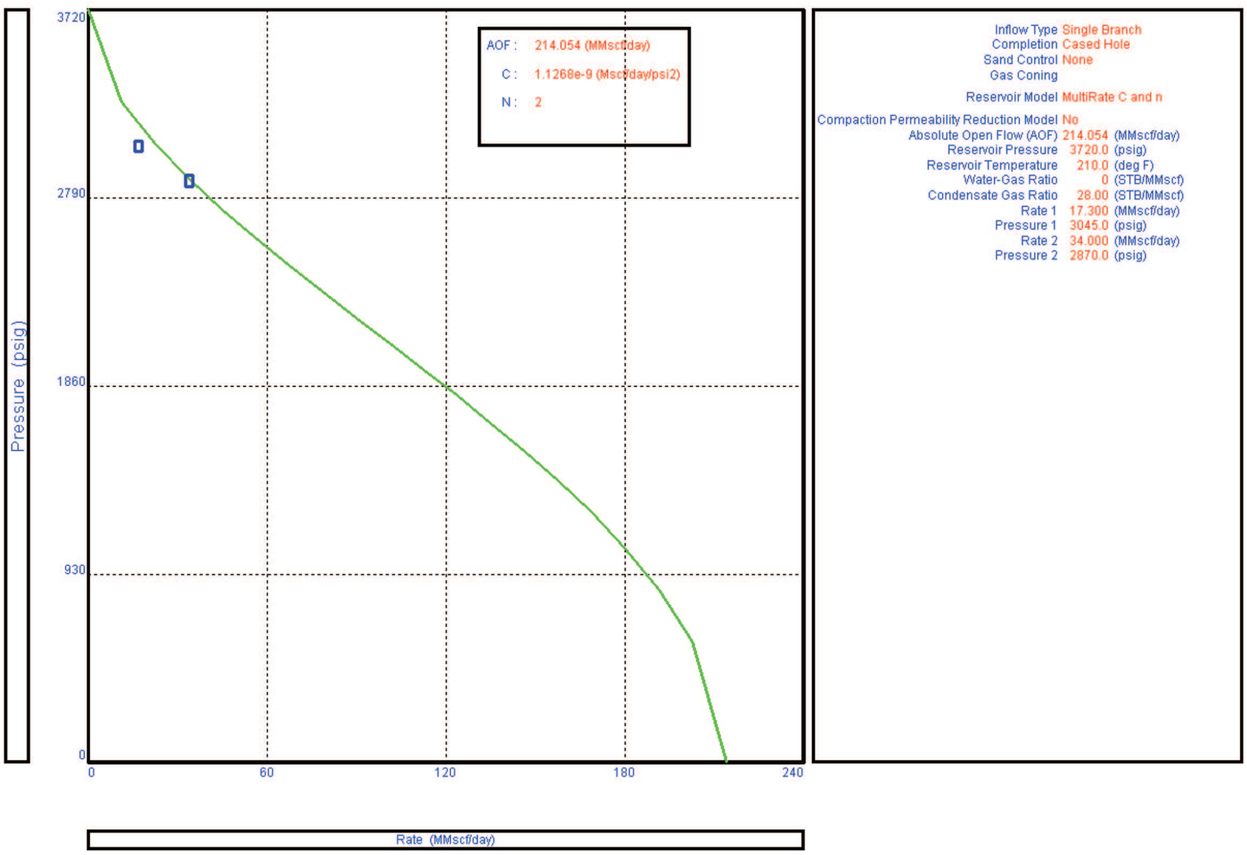

Figure 9. Absolute open flow (AOF), IPR plot multi rate C and n.

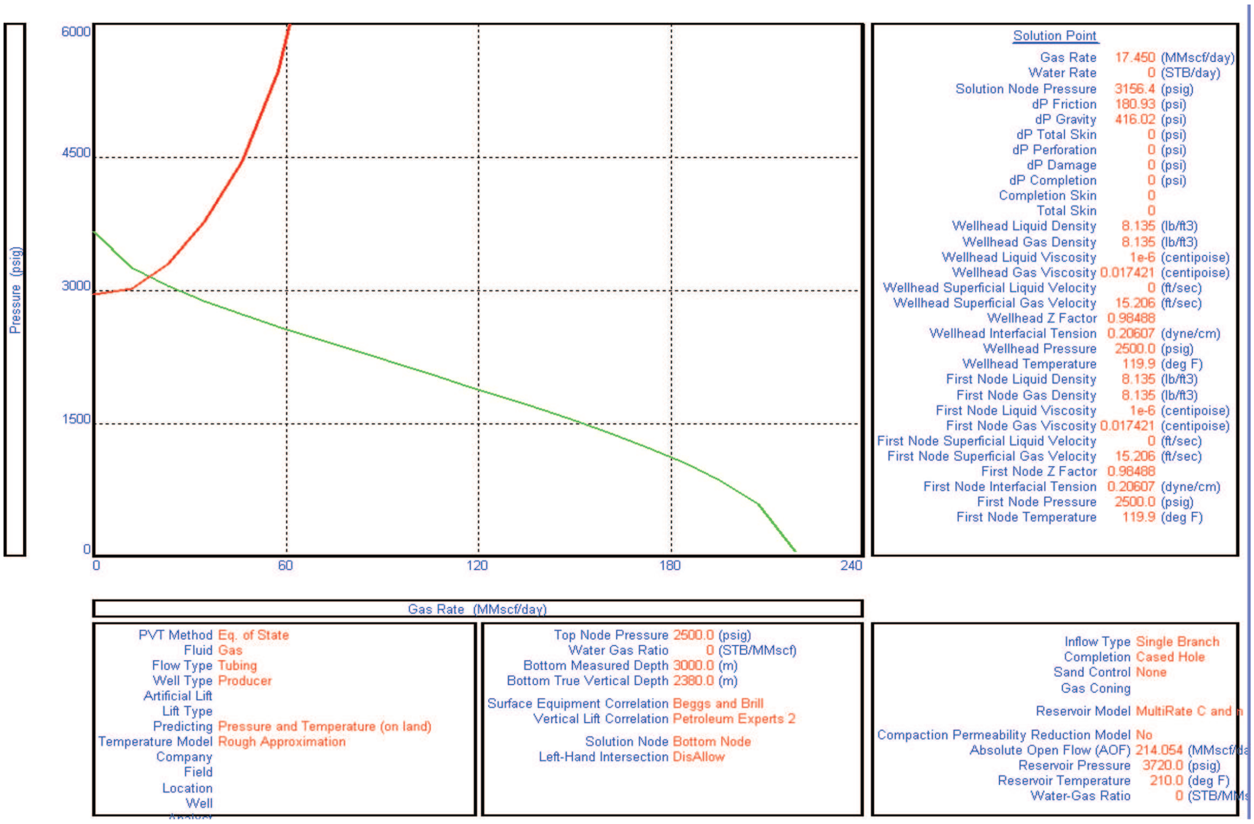

Figure 10. Inflow (IPR) versus outflow (VLP).

Efficient reservoir development requires a good understanding of reservoir and production systems.

Figure 11 shows the rough MBAL model for the tank Akkas-1 (SA-1) and extrapolated rates of the 50 wells including the five existing wells. According to the well test rates from the exploration wells, conservative average production of 10 MMscfd/well was taken.

5.6. Condensate production profile

From the extent geological knowledge of the area, the author estimated one of the deeper layers to contain recoverable condensate of 14 billion barrel (**Figure 12**).

5.7. Field development plan

Iraq proposed a strategy plan and wished to use methane to satisfy domestic power/water demand, C1-, C2-, C3-based petrochemicals for export. Ethane and propane are used for olefins production. Butane and condensates are for domestic use, export and petrochemical production.

The proposed development plan can be divided in two phases: The first phase is 250 MMscfd gas rate. Power generation and methanol use natural gas. Propane, butane and condensate are for export. The second phase is an additional 250 MMscfd gas processed including ethane recovery for olefin production.

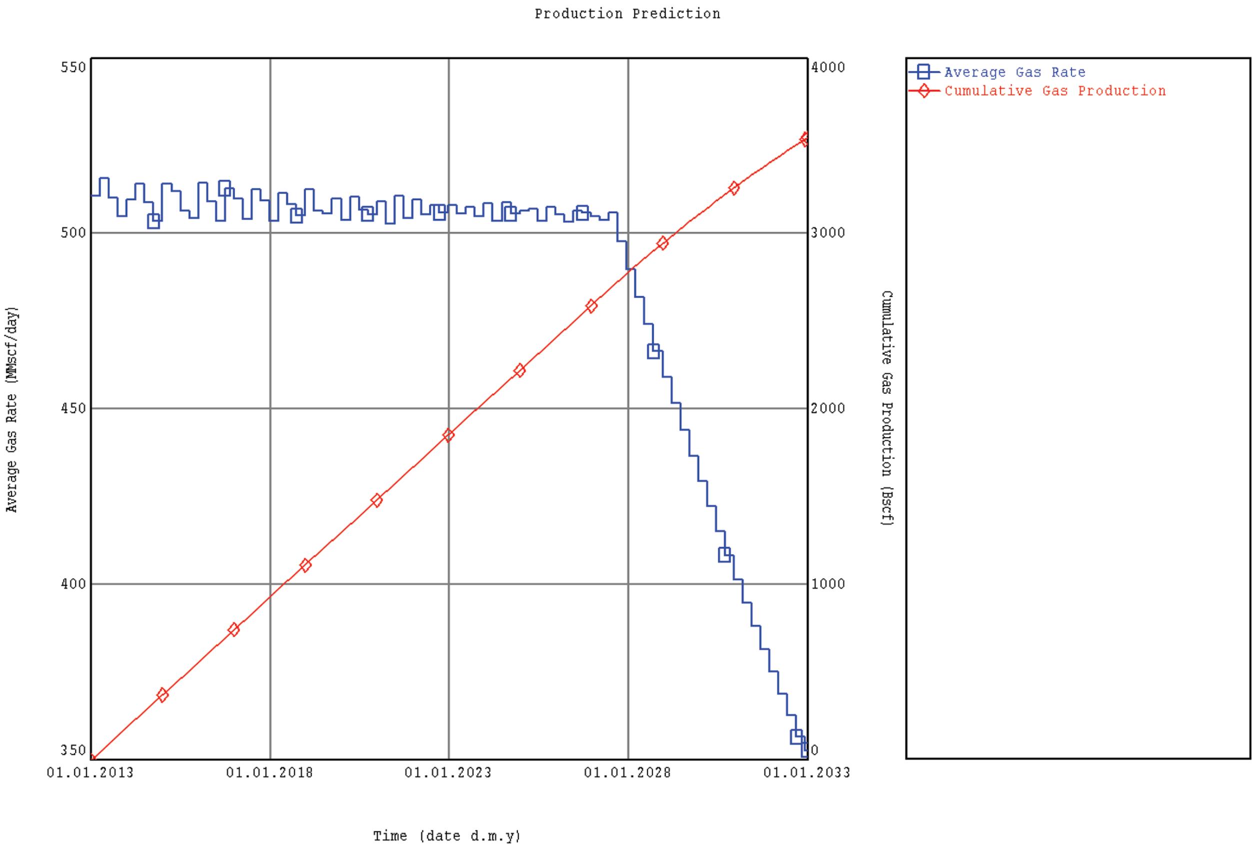

Figure 11. Production profile of the 50 production wells.

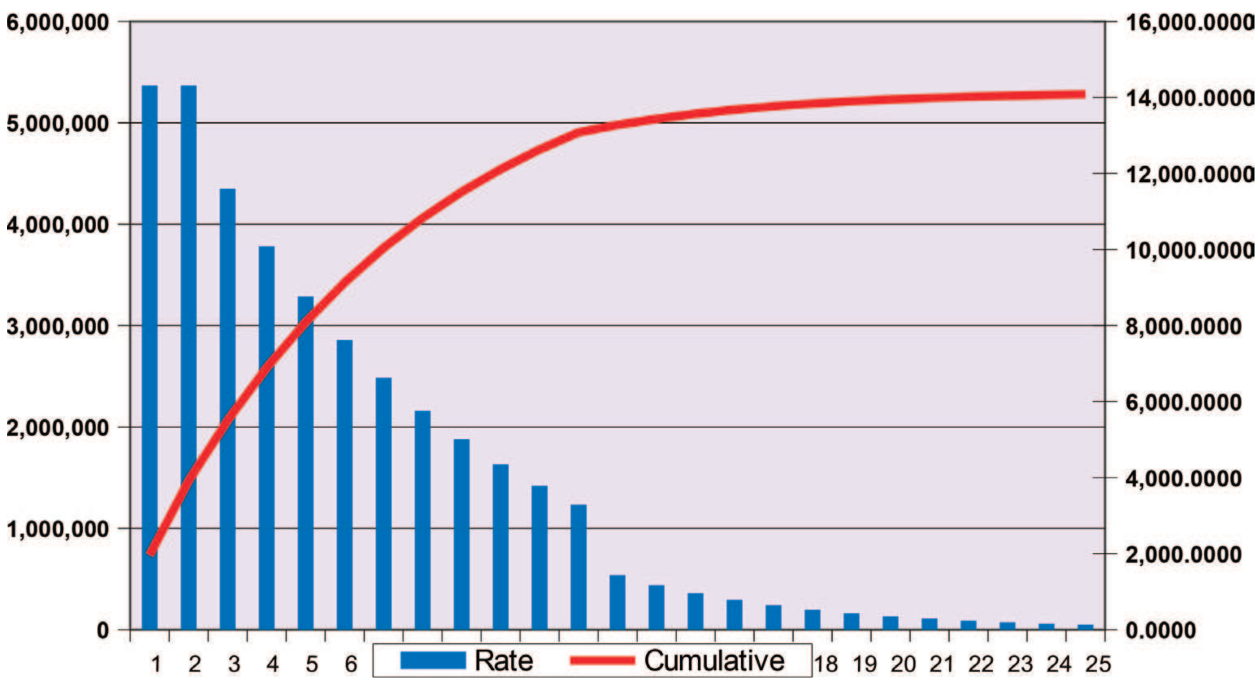

Figure 12. Estimates of condensate production profile.

Furthermore, power generation and ammonia use the incremented gas. Ethane is to be used for ethylene production, with the option to use some propane and butane. Polyethylene production is the main ethylene derivative.

5.8. Gas and condensate specifications

The samples are taken from the separator (**Tables 3** and **4**).

Reference: oil ministry Iraq, report 2004.

5.9. Central plant facility

The proposed central plant facility is according to the possible development scenarios of the field and the use of the hydrocarbon and their derivatives (**Figure 13**).

5.10. Pipelines and route connection

There are many possibilities to transport the gas and their products. The optimized way is to use the route of T1 to the Baniyas port in Syria (**Figure 2**).

5.11. Possible contract conditions

Currently the main Iraq has only the service contracts, which still do not have the approval of political actors and public organs. The term service contracts encompass those various contracts in which the host government has a contract with a service company or an international oil company for the performance of services related to the exploitation of petroleum resources.

Component	SA-1 (2332-2360m)	SA-2
N_2	1.54	0
C_1	80.49	80.5299
C_2	8.92	8.9407
CO_2	2.2	2.0683
H_2S	-	-
C_3	3.54	3.3636
$I\text{-}C_4$	0.4	0.3788
$n\text{-}C_4$	1.0	0.9898
$i\text{-}C_5$	0.35	0.2924
$n\text{-}C_5$	0.41	0.3768
C_6	0.54	0.6784
C_7	0.39	0.7881
C_8	0.22	1.593
Specific Gravity	0.726	0.787
Density 15.5, 1AT-G/L	0.89	-
Molecular Weight	21.02	22.811
Heating Value Kcal/m^3 - Gross: Net:	10702 9700	-

Table 3. Specifications of the free gas from the wells Akkas-1 (SA-1) and Akkas-2 (SA-2).

Specifications	SA-1	SA-2	SA-3
Specific Gravity	0.779	0.7538	0.7448
Water Content (% by volume)	0.2	Nil	Nil
Sulphur Content (% by weight)	0.06	0.0163	0.0131
Asphalt Content	Nil	Trace	Nil
Pour Point (°F)	- 30	- 45	- 45
Kinematics Viscosity (Cst) at:			
80 °F	1.52	0.98	1.016
100 °F	1.27	0.82	0.941
120 °F	1.08	0.75	0.876

Table 4. Specification of the condensates.

The risk service contract appears similar to the production-sharing contract but differs in certain important matters. Its basic distinctive feature is that it reimburses the contractor in cash, not in crude oil or gas, although it may have provisions permitting the contractor to buy back an amount of crude oil at an international selling price equivalent to the amount to be paid to the contractor.

A pure service contract is an agreement between a contractor and a host country that typically covers a defined technical service to be provided or completed during a specific period. The service company investment is typically limited to the value of equipment, tools and personnel used to perform the service.

In most cases, the service contractor's reimbursement is fixed by the terms of the contract with little exposure to either project performance or market factors. Payment for services is normally

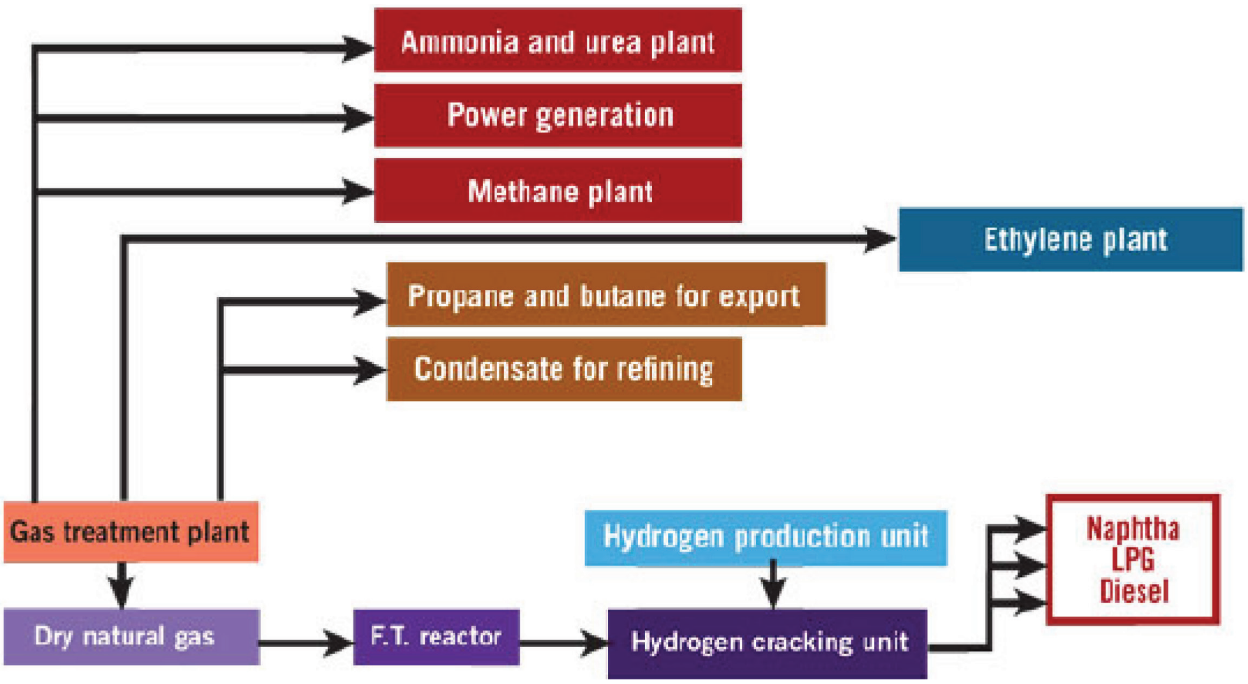

Figure 13. Possible design of the CPF, use of the hydrocarbons and their products, reference: Oil ministry Iraq, report 2004.

Year	Seismic	G&G	G&A	Drilling	Facilities Mn USD	Pipelines Mn USD
	Mn USD	Mn USD	Mn USD			
1	14	5	10	40	70	18
2	14	5	10	80	80	
3				120	60	
4				120		
5						
6						
7						
8				40		

Workover rig rates will be around $20,000/day.

Table 5. Cost estimations of the proposed development.

based on daily or hourly rates, a fixed rate or some other specified amount. Payments may be made at specified intervals or at the completion of the service. Payments, in some cases, may be tied to the field performance, operating cost reductions or other important metrics.

These agreements are similar to the production-sharing agreements with the exception of the contractor payment. With a risk service contract, the contractor usually receives a defined share of production (in kind). As in the production-sharing contract, the contractor provides the capital and technical expertise required for exploration and development. If exploration efforts are successful, the contractor can recover those costs from the sale revenues and receive a share of profits through a contract-defined mechanism.

5.12. Cost estimation

The approximate cost estimation for Akkas development phases are illustrated in **Table 5**. The calculations have been made for operating costs, based on the gas price for October 2010.

The annual fixed operating costs for the central processing facility will be in the range of $30–40 million/year. In addition, the fixed operating costs for the existing Iraqi pipelines will be $2 million/year. The variable operating costs are 20–30¢/bbl of oil or condensate and 4.5–7.5¢/Mcf.

6. Discussion and conclusion

The Silurian hot shales are believed to be the main Paleozoic source rocks in the western and southwestern deserts of Iraq [1].

Hot shales of the Akkas Formation in the Akkas-1 well of western Iraq were deposited in anoxic-dysoxic marine shelf environment that extended across the northern margin of the Gondwana Continent characterized by provincial achritarchs, [19]. These deposits were extending from outer to inner neritic with effects of local upwelling currents. The presence of marine algae such as Tasmanites (**Figure 4C**) and prasinophyte achritarchs [19], in the ecosystem of the lower Silurian Akkas Formation sediments could delineate highly oil-prone materials following Tyson's [20] simple classification of sedimentary organic matter types for rapid assessment of hydrocarbon potential.

According to the organic geochemical, the studied Silurian shales especially those of the hot shales could be considered as source rocks for oil in the western Iraq. TOC of 9.6 wt%, HI 260 and Tmax 438°C, and with TAI 2–3, VRo up to 1 and brown acritarch colors of (Al-Ameri, [19]).

Higher compositional organic matter contents for the marine algae Tasmanites and prasinophyte algae may hold their ability to generate light oil. In the present study, the organic matter types of algal-type Tasmanites and traces of vitrinite are common in hot shale samples from the Akkas-1 (SA-1) well (**Figure 4C** and **D**). This marine algal phytoplankton Tasmanites sp. is an important type of organic matter in the Paleozoic (Ordovician to Devonian black shales of the Appalachian basin.

They correspond to types I and II kerogen that appear to be derived from extensive bacterial reworking of lipid-rich algal debris [21]. Silurian hot shales form the main source rock in the Paleozoic sequence of western Iraq and it has regional extent in Jordan [22] Syria, Libya and Saudi Arabia [23]. Modeling of the Silurian hot shales in well Akkas-1 [12] indicates that the unit has remained in the oil generation window since Late Paleozoic times. Variation in maturation between the lower hot shales and the overlying shale horizons may relates also to the effect of the intense Hercynian-age extensional tectonics in the area under study.

Various clay and non-clay mineral constituents are observed in the Silurian shale from western Iraq (**Figure 5**). Illite and kaolinite are the main clay minerals observed, while quartz, carbonates (calcite dolomite and/or siderite, feldspars (microcline)), pyrite, rare apatite, anatase and occasional gypsum are the main non-clay minerals. Clay minerals illite, kaolinite, show an overall increase with depth especially in the lower and upper hot shale samples.

Increase in illite accompanied with organic matter increase in deeply buried shale. Transformation of smectite (suggested to be a source for the present illite since the Silurian shale is of marine origin) to I-S and finally to illite may be coeval with generation of oil in sedimentary basins. The top of most oil-bearing horizons in the US Gulf Coast Tertiary horizons occur at depth intervals where reactions, transformation and illite formation are manifested [24].

Scanning electron microscopy gives clues for better identification of the authigenic and detrital components of the studied shale (**Figure 6**). Quartz authigenic syntaxial overgrowth (**Figure 6C**) also is recorded in the studied shale. Compaction on the shale beds enhanced the transformation of smectite to illite, and thus represents a possible source for the silica for quartz overgrowth formation. Additionally, burial depth conditions may led to feldspar dissolution as well as partial and/or complete replacement of detrital silicates (quartz and feldspar) by calcite and is an alternative source for silica [25].

Pyrite is present as clusters of crystals in cubic forms or as discrete euhedral crystals (**Figure 6E**). The stagnant reducing conditions during deposition of organic matter were favorable for sulfate-reducing bacteria to reduce the sulfate ions of seawater to sulfide ions which then reacted with any available iron to form pyrite (FeS2). These conditions prevailed during deposition of the Silurian shales.

Calcite and ferroan dolomite (ankerite) also are recorded in the XRD analysis (see **Figure 5**) and some scattered carbonates (calcite) are also revealed by SEM investigation (see **Figure 9C**). Conversion of smectite to illite during burial is a common diagenetic process which is capable for releasing large amounts of Fe, Mg, Ca, Na and Si. Some of these elements may enhance late-stage dolomitization process [26].

Organic matter type of the Silurian hot shale of Saudi Arabia consists of amorphous matter, marine algae (phytoplankton), intertinite, and occasional chitinozoans and graptolites. Generally, they are dark gray to black, organic-rich, oil-prone, marine shales [27].

7. Recommendation concerning development of Akkas field

Concerning the development of the Akkas field, the inconsistency between the downhole pressure, reservoir pressure and the wellhead pressure published numbers is solved by estimation. The possible production rate and plateau is based on a conservative production development scenario. Akkas field shows very high gas rate potential. The following steps should further be taken:

- Analyze samples from Akkas wells to evaluate their biomarkers and thereby confirm the oil and gas sources in order to find other oil and gas pays in Akkas and oil and gas fields in the west of Iraq.
- Analysis of local oil seeps has been conducted to find their affinity and the structural relation to Akkas oil and gas fields. It is also possible that they lead to other oil fields that have been charged by oil migration from Mesopotamian basin to structural closures in western Iraq.
- It is important to drill deeper at least in the exploration/appraisal phases to find possible gas accumulations.

It is well known that the Iraq government would like to develop Akkas and is looking for new discoveries in the Western Desert of Iraq. This region has not yet been explored and may hold potential.

The development plan for the use of Akkas gas is more likely to serve the national grid of electricity, future and existing petrochemicals and other industrial plants. Part of the derivatives will be exported. Most likely Iraq will follow the Saudi Aramco plan that uses the gas for development of national industry and demand. Those can multiply the profits from the petrochemicals and other industries of the petroleum resources.

The Iraq government chooses the service contracts for different political and regulatory reasons (like delays or unapproved petroleum law). The long-term service contracts in Iraq are similar to PSAs, the SC is signed without the agreement of the parliaments; it can lead to escalation between IOCs and future governments in Iraq.

In order to have clean and transparent business for all participants, the IOCs should press to have the right regulation and a law to cover legal activities (investment), tax and environmental issues related to the oil industry in Iraq.

The political turbulence and mismanagement in the country make the development of the oil and gas industry and the country development questionable. There can be no concrete development of oil and gas fields without the parallel development of the infrastructure of the country; without this, turbulence may arise.

The CAPEX for the exploration and development phases and OPEX are simulated with cost simulation taking into account the security factor. Even with high contingencies, still the 4.5–7.5¢/Mcf is low compared with that of other OPEC countries.

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