Identification and Evaluation of Unconventional Hydrocarbon Reserves: Examples from Zagros and Central Iran Basins

Mohammad R. Kamali[1] and M. Reza Rezaee[2,3]

[1]Center for Exploration and Production Studies and Research, Research Institute of Petroleum Industry (RIPI)

[2]Department of Petroleum Engineering, Curtin University of Technology

[3]Department of Geology, College of Science, University of Tehran

Abstract

It is notable that over the past decade, proven reserves of natural gas have dramatically increased as higher prices and advances in technology have turned previously unrecoverable resources into major sources of domestic production. Moreover, the decline in crude oil reserves has significantly slowed over the past decade. Therefore, there would be an end to the conventional hydrocarbon resources sooner or later and in the meantime; global natural gas consumption is projected to grow 52%, an increase by nearly 2% annually from about 108 Tcf in 2009 to about 163 Tcf in 2030. In addition, since natural gas combustion produces less CO_2 than coal and other petroleum products, governments are encouraged to use it as an alternative for other fossil fuels to reduce greenhouse gas emissions.

Shale gas accumulations, with a unique all in one nature, where all petroleum system elements reside in just one lithology, have become the focus of gas exploration strategies after recent successes in the Barnett Shale gas production. Meanwhile, significant advances in drilling and stimulation technologies have made gas shale attractive for development in many countries including Iran. The unconventional gas resources such as coal bed methane and gas trapped in shale are growing in importance. Such estimated reserves account for approximately 18% of total proven gas reserves. Shale formations in particular offer enormous potential for future production.

This study compares several shale gas resources in different areas and highlights the possible potential unconventional resources in Iran.

Keywords: Unconventional Reserves, Shale Gas, Coal Bed, Tar Sands, Oil Shale, Gilsonite, Bitumen, Gas Hydrates, Iran

Introduction

Conventional gas reserves seem to be inadequate due to growing energy demands. Therefore, exploration and production of unconventional gas reserves seems to be very essential in order to meet growing energy demands. There has been a great deal of discussion in recent years regarding the future of world's energy supply. Many proponents of renewable energy have based their arguments on the downward trend of world crude oil reserves over the past 30 years. Although this is a legitimate point, it does not take into account domestic reserves of other fossil fuels, particularly natural gas. Over the past decade, U.S. proven reserves of natural gas have dramatically increased as higher prices and advances in technology have turned previously unrecoverable resources into major sources of domestic production.

Moreover, the decline in crude oil reserves has significantly slowed over the past decade, and with the opening of portions of the Outer Continental Shelf, previously off limits to drilling activities, crude oil reserves look set to at least maintain their current levels in the medium term. The Energy Information Administration (EIA) recently released its annual estimates for crude oil and natural gas reserves in the U.S. for 2007. Crude oil reserves were estimated to have risen by 1.6%, while dry natural gas reserves were estimated to have risen by 12.6%. This was the ninth straight year dry natural gas reserves increased. However, the increase in crude oil reserves was less than half of the previous year's decline. Additionally, reserves of natural gas liquids, which are by-products of natural gas processing and include fuels such as propane and butane, rose by 7.9% from the previous year. Natural gas proven reserves for 2007 were the highest in the 31 years the EIA has published reserve estimates. Moreover, natural gas reserves have now increased by approximately 46% since 1993.

Natural gas

The most important aspect of the EIA's report was the unprecedented increase in natural gas reserves. This reflects the rapidly growing importance of unconventional gas resources such as coal bed methane and that gas trapped in shale formations is rapidly becoming an important domestic production. Reserves in coal and shale reservoirs now account for approximately 18% of total proven gas reserves and given the fact that they have been increasing at a much more rapid pace than traditional reserves, it is likely that this number will continue to rise. Shale formations, in particular, offer enormous potential for future production. With the exception of the Barnett Shale in Texas, most shale formations remain in the embryonic stages of development. Estimates of the total recoverable reserves in the Barnett, Fayetteville, Haynesville, and Marcellus shale formations have reached into the hundreds of trillions of cubic feet. To put this into context, the country's proven gas reserves in 2007 totaled approximately 238 trillion cubic feet. The Marcellus shale formation, which stretches from New York to West Virginia, could have an especially profound impact on the nation's energy supply due to its proximity to major consumption areas in Pennsylvania, New Jersey, New York and New England. The importance of the steady increase in natural gas reserves over the past decade cannot be overstated. Due in large part to uncertainty over potential regulations of greenhouse gas emissions, electric utilities have been investing heavily in new gas fired power plants instead of coal fired plants. Natural gas emits about 40% less carbon dioxide than coal and since it does not pose any of the technological hurdles that renewable sources of energy such as biofuels do, it has become increasingly popular among electric utilities looking to hedge against the risk of a carbon tax or a cap-and-trade system. Natural gas reserves will remain on an upward trend over the medium term as technological advances allow producers to extract a larger percentage of the gas trapped in shale formations. Proven reserves of natural gas liquids increased for the fourth consecutive year, reaching an all time high of more than 9 billion barrels. Due to their relatively low emissions of carbon dioxide, the possibility of switching to these fuels as a medium-term substitute for gasoline and diesel fuel until electric vehicles can be mass produced has gained some attraction. With dry gas reserves likely to continue rising over the next few years, reserves of natural gas liquids will steadily increase as well.

Crude oil

Domestic crude oil reserves rose for the second time in three years, as growth in reserves outpaced production in Alaska, Texas and North Dakota. After declining rapidly during the 1980s and the first half of the 1990s, crude oil reserves have stabilized over the past decade. This is a trend that is likely to continue, at least over the next decade, as more unconventional resources such as the Bakken Formation in North Dakota are developed. Consequently, the steady decline in domestic crude oil production over the last 25 years will moderate (Chart 4). Although the moratorium on oil and gas drilling in certain portions of the Outer Continental Shelf was not renewed last year, it will likely be more than a decade before large scale drilling activities commence. According to estimates by the U.S. Geological Survey, the OCS areas that were previously off limits are believed to contain reserves of approximately 18 billion barrels, or around 85 % of existing proven reserves. However, the true wild card in the long term outlook for domestic crude oil reserves is the development of oil shale resources in the Midwest. These resources, which are primarily located in Colorado, Wyoming, and Utah, are believed to contain more than 800 billion barrels of oil. To put this into perspective, Saudi Arabia's proven reserves, currently more than double that of any other country, total approximately 267 billion barrels.

However, the technology to fully develop oil shale resources is still in its infancy and current oil prices do not provide a strong incentive for firms to invest in more advanced production technologies. Moreover, at the current rate of production, the country has enough supplies for at least the next 150 years. Despite its abundance and affordability relative to crude oil and natural gas, coal faces an uncertain future as a part of the nation's energy supply. Of the three types of fossil fuels, coal emits the most carbon dioxide when it is burned. With the new administration advocating a cap-and-trade system to reduce carbon emissions, there is a possibility that it could be phased out as a major source of energy in the U.S. over the next few decades. Coal's largest use is in electric power generation and accounts for nearly half of the electricity generated each year. However, wind and natural gas generating capacity have significantly increased more than coal generating capacity over the last few years and this looks set to continue as utilities brace for harsher regulations on CO_2 emissions. The rapid increase in natural gas reserves in recent years has come as a blessing for domestic oil and natural gas exploration firms. Although domestic crude oil reserves have stabilized, it is unlikely that any major new oil fields will be discovered onshore in the lower 48 states, excluding oil shale deposits. Moreover, with many governments around the world nationalizing their countries' energy resources, especially countries such as Venezuela that have large crude oil reserves, finding major new sources of production internationally has become a less promising option in recent years.

According to the EIA, investor owned oil companies such as Exxon Mobil are in possession of only 12% of the world's proven reserves and this number has been falling for decades. Therefore, the enormous increase in natural gas reserves is such an important development for the industry that it has given firms the potential to offset declines in oil production with increased natural gas production. Moreover, the transition to a cleaner fuel like natural gas will allow them to more easily absorb the effect of restrictive greenhouse gas regulations.

A major challenge facing the industry is its ability to attract enough skilled labor, particularly engineers, to develop unconventional natural gas fields and, longer term, to find an economical way to develop the oil locked away in shale formations. In order for the Barnett Shale formation to become one of the largest sources of natural gas production in the country, new techniques such as horizontal drilling had to be developed. If domestic oil and gas exploration companies are to take advantage of the production potential of shale formations, they will need to invest heavily in human capital.

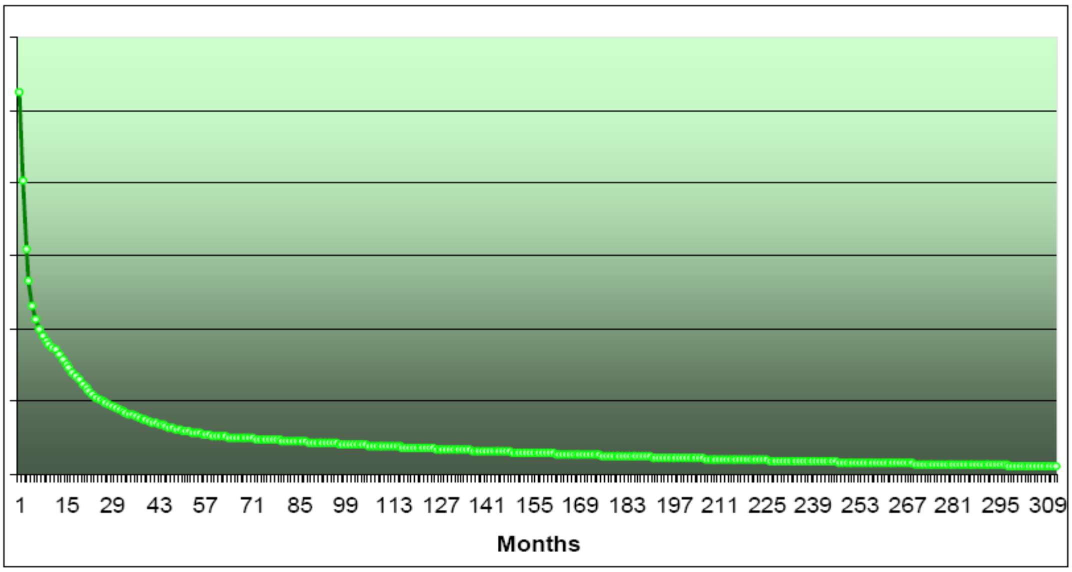
UNCONVENTIONAL GAS

Unconventional gas formations are "continuous", deposited over large areas rather than in discrete traps. The geologic setting of unconventional gas is several orders more complex and challenging than that of conventional gas. Third, for two of the unconventional gas types, coalbed methane and gas shales, the gas source, trap and reservoir are the same, not three distinct elements as in the case of conventional gas.

Three natural gas sources, namely tight gas sands, coal bed methane and gas shales comprise today's unconventional gas. Methane hydrates, a future candidate, is not yet ready for "prime time".

Shale gas by definition is an organic rich fine grained rock storing gas in commercial quantities. Rocks included in this definition are organic rich: shales, mud rocks, siltstones, and very fine grained sandstones. In many areas, gas shales are gradational with tight sands.

Shale gas formations are generally thick and widespread in nature, very low matrix permeability (nanodarcies). Fractures are necessary for economic production from shale gas. Primary porosity is low because of that, production rates is low (20 Mcf/d to 500 Mcf/d) but cover very large areas. Production life is long and it continues typically 25 to 80+ years with low decline rates (Figure 1). Total organic carbon (TOC) in shale gas reach 1 to 20%.



Source: Howard Weil

Figure 1. A typical Shale Gas Decline Curve.

Several characteristics of the shale should be evaluated to understand the shale quality in terms of gas production. These characteristics include: 1-Total organic carbon (TOC) content; 2- Thermal maturity status; 3- Porosity & gas saturation: (free and sorbed gas) and 4-Thickness and aerial extent.

Analytical methods

Geochemical analysis is considered as a direct measurement of total organic carbon. In this method, the evolved carbon dioxide is determined while combustion of organic matter in oxygen. Log analysis using NGS, DlogR is an indirect method for measurement of total organic carbon.

Thermal maturity status of shale gas can be directly determined by Rock-Eval pyrolysis (Tmax), Paleothermometers, vitrinite reflectance (Ro), and Thermal Alteration Index (TAI), and indirectly by reconstructing burial history modeling, log analysis (N-D separation) and seismic inversion.

Figure 2 illustrates Rock-Eval programs showing; S: free hydrocarbons already present in the sample at a temperature of 350°C. S2: generated hydrocarbons through thermal cracking of kerogen when the sample temperature is increased to 550°C. S3: CO_2 released during pyrolysis up to a temperature of 390°C.

Log data can also be very useful for shale gas evaluation. Log data could be used as input for intelligent systems such as Fuzzy Logic, Neural Network and Committee machine to predict shale properties such as TOC, NOC, porosity and permeability.

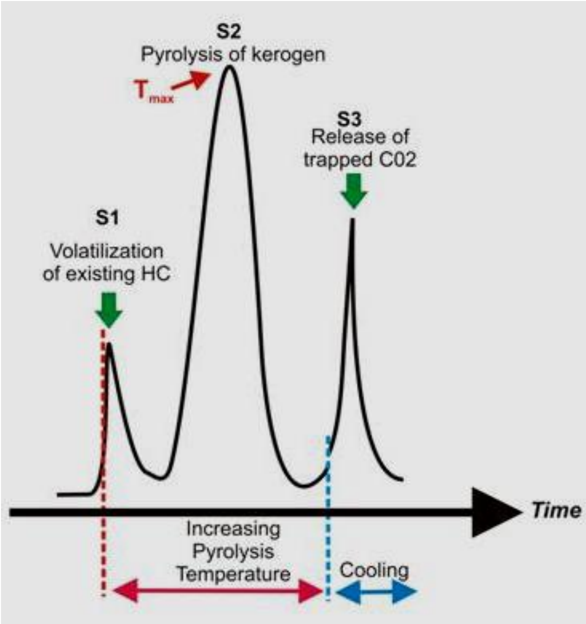


Figure 2. Rock-Eval Pyrolysis pyrogram with S1, S2 and S3 peaks.

Barnett Shale example

Barnett Shale (Figure 3) is an example of successful shale gas production. There are more than 64 public companies involved, about 5,900 producing wells, 2 Bcf/d of production, 160 rigs currently running and ultimate recovery is estimated at 39 Tcf.

Figure 4 shows Barnett gas production from 1997 to March 2008. As it can be seen, the production from this shale has increased from 28 bcf in 1997 to more than 1 Tcf in recent years. The increase in production is due to an increase in well number, advancement in drilling and stimulation technologies. Table 1 summarizes the Barnett Shale characteristics.

Table 1- Barnett Shale characteristics

Depth (m)	1980-2600
Net thickness (m)	15-30
Bottom hole temperature (C)	90
Total organic carbon content (%)	4
Mean vitrinite reflectance (%)	1-1.3
Porosity (%)	5
Permeability (nD)	150
Pore pressure (psi)	3000-4000

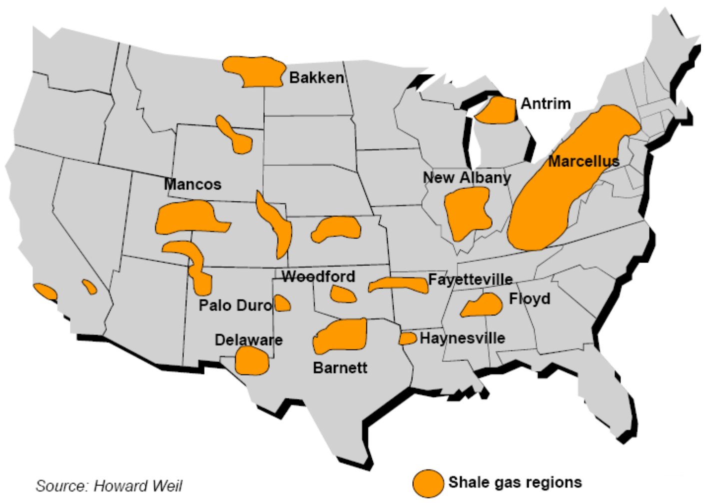


Figure 3. Location map of the Barnett shale.

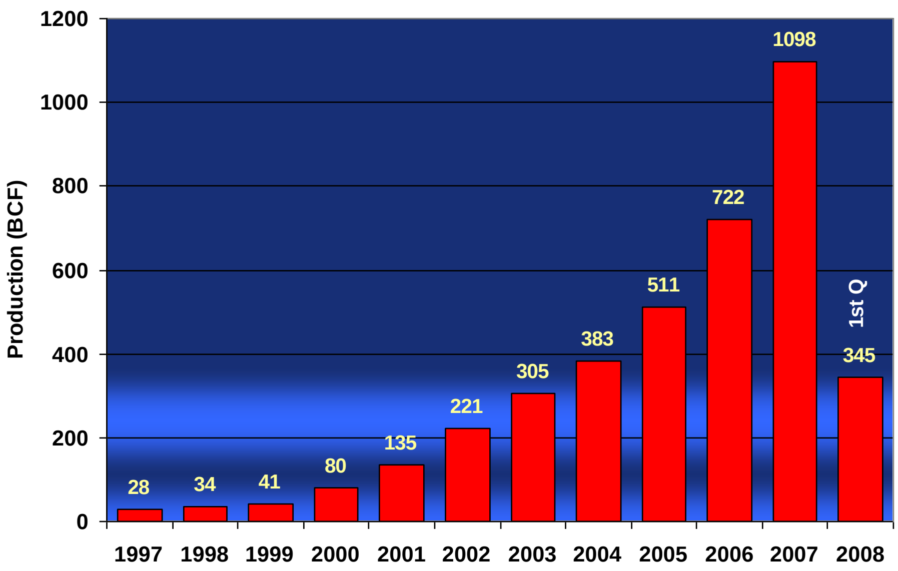


Figure 4. Barnett gas production (1997-March 2008).

Shale Gas in Central Iran and Central Alborz Basins

Pre-Triassic sediments are unconformably overlain by the Shemshak formation of the lower Jurassic, partly including the upper Triassic (Rhaetian to Bajocian).

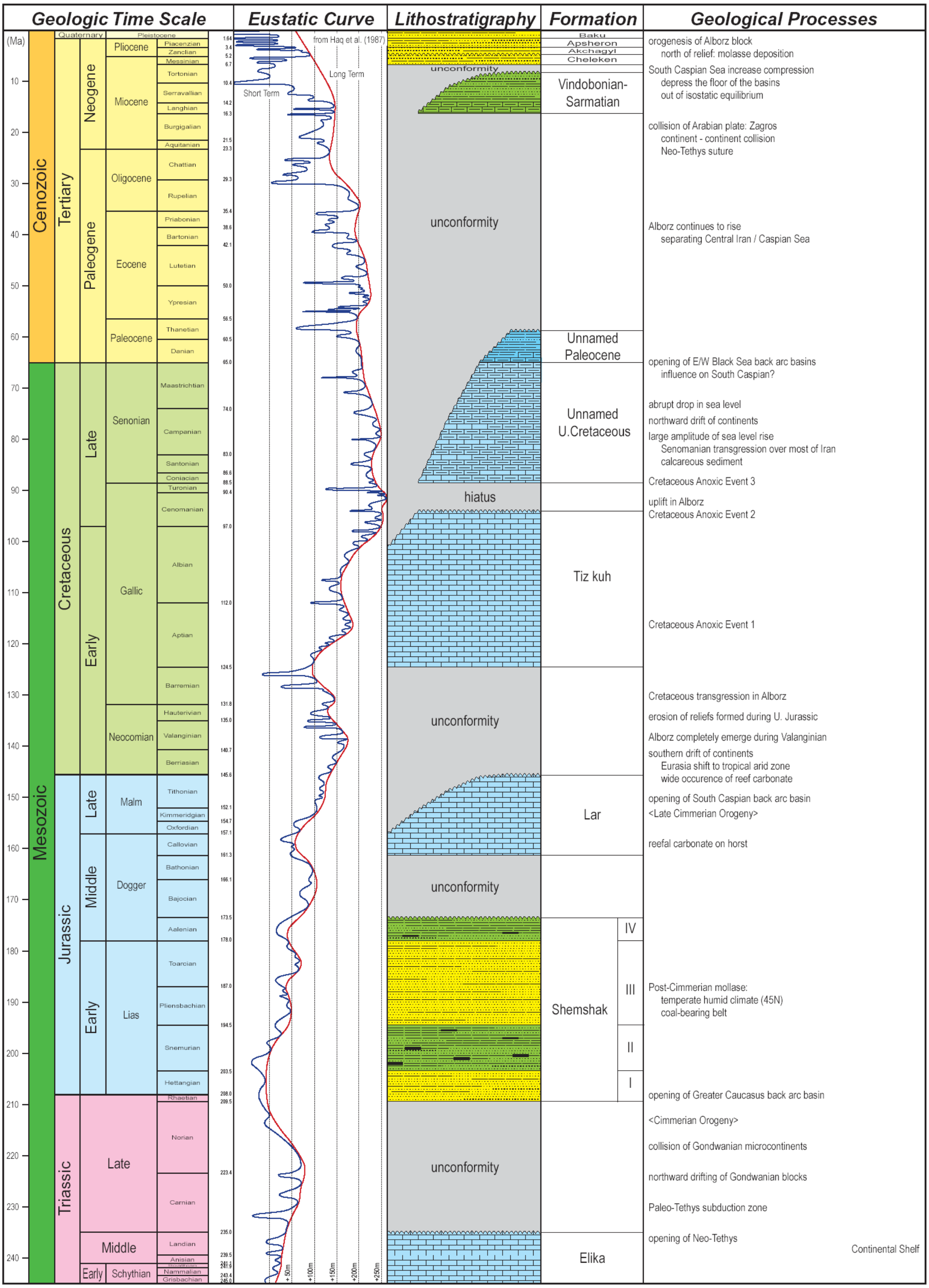


Figure 5. Stratigraphic summary of the Central Alborz Basin.

Shemshak formation extends from north to southeast of Centeral Alborz and its thickness increases towards the south (Figure 6). Pre-Triassic sediments are unconformably overlain by the Shemshak formation of the lower Jurassic, partly including the upper Triassic (Rhaetian to Bajocian). A generalized stratigraphy is given in figure 5.

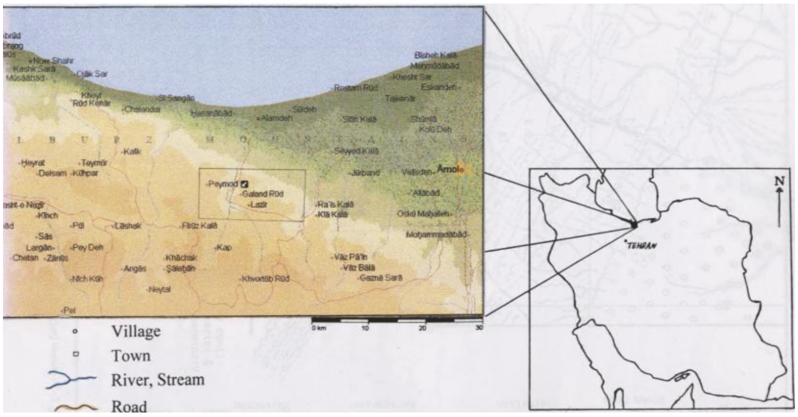


Figure 6. Location map of the studied area in north of Central Alborz

Shemshak Formation is a non-marine terrestrial source rock. Its organic matter is composed of type III and a mixture of type III-II kerogens with a total organic carbon of more than 1%. Organic rich beds have already reached oil window (Ro=0.6-0.8%). Photomicrographs (figure 7) show occurrence of organic matter that are aligned within the stylolites running parallel to bedding plane.

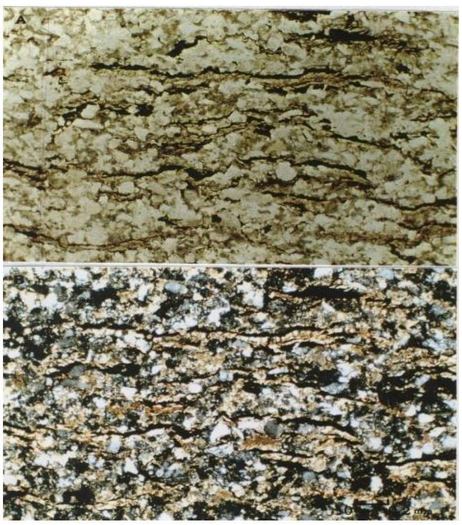


Figure 7. Chert arenite with stylolite and organic matter along them.

Shemashak formation consists of coal seams interbedded with shale and siltstone beds. Succession of shale and coal layers is well noticed in the studies section called Galand roud coal mine located near Noor in Central Alborz Basin. Shaly intervals have kerogen type III and vitrinite form the dominant maceral (figure 8). However, a mixture of kerogen type I-II and II- III are inferred when resinite, cutinite and sporinite occur in appreciable and subordinate quantities, respectively.

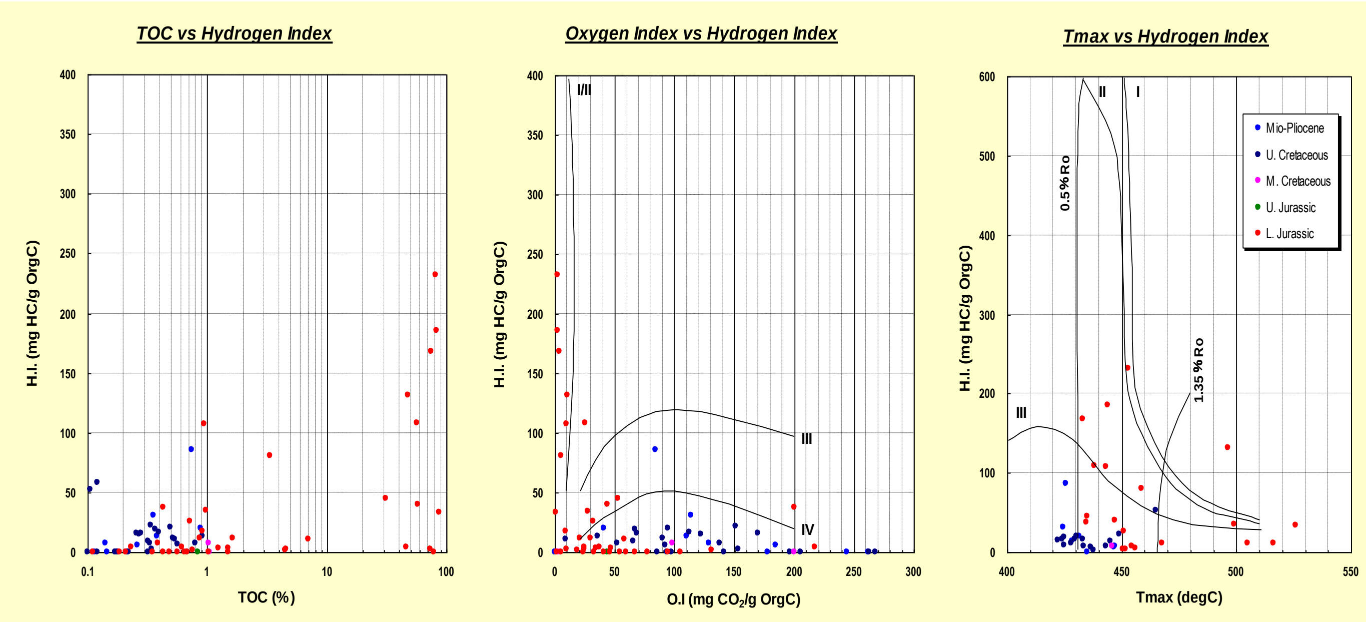


Figure 8. Conventional TOC vs HI, HI vs OI and Tmax vs HI for Jurassic coal and shale layers of Shemshak formation Galand roud, Central Alborz Basin.

Four lithological units are distinguished in Shemshak formation (Assereto, 1966). Unit 1, the lowest unit, consists of alternated sandstones, shales and coaly shales. Unit 2, second lowest, is mainly characterized by shales with intercalations of coal beds. Unit 3 consists of sandstones, siltstones and shales. Unit 4 is predominantly composed of shales with intercalations of coal seams. Much of the Shemshak formation is thought to have been deposited under deltaic environment and unit 3 (upper sandstone unit) includes marine components. The thickness of the Shemshak formation exceeds 2,000 meters in the Alasht area.

In the type locality of the Shemshak formation, it was reported that thinly bedded marly limestones, sandy oolitic limestones and ammonite bearing marls interbedded with shales and greywackes of the Upper Dogger (Dalichai Formation) conformably overlie the Shemshak formation (Assereto, 1966). However, Dalichai formation was not observed in the studied area.

Oil Shale deposits in Zagros Basin Iran

Oil shale by definition is an organic rich rock, which has not gone through the “Oil window” of heat needed to alter it into liquid petroleum. However, oil shale can be converted into synthetic crude-like oil called “Shale Oil” through a heating process called retorting.

Oil seeps in Middle East have a long history being mentioned by Herodotus in history, Strabo in his Geography and other ancient texts. As far back as 3500 BC, hydrocarbons played a key role in the region and were used in construction, shipbuilding, and ornamental works by the early Sumerians. Natural gas fires were a source of religious inspiration.

In Zagros basin, hydrocarbon extrusions have been reported as Gilsonite (uintaite) synonymous with the word Mumiyaie in Farsi, used as a medicine, bituminites, asphaltites and so on. Known deposits include Gilstone deposits from Kalak Bishe at Puledokhtar mine in Lorestan province, Kazhdumi oil shales (Cretaceous) from Kuhe Bangestan outcrops in Khuzestan Province, Kazhdumi oil shale from Kuhkluyeh and Boyer Ahmad province, Garau oil shales from Kabir Kuh (Lorestan Province) and Ghali Kuh oil shale (Sargelu formation) from Lorestan province.
In this study, a total of 12 outcrop samples collected from Ghali Kuh section were subjected to Rock-Eval pyrolysis in order to assess generation potential. Most samples are rich in organic matter and their TOC range from 2.8 to 20.81%. Hydrogen Index (HI) varies from 422 to 576 mg HC/gTOC suggesting highly oil prone source rock (Table 2). A plot of HI versus Tmax reflects Kerogen type II (Figure 8).

Ghali Kuh oil shale was deposited in euxinic basin. Preservation of organic matter was good with no bioturbation and the presence of pyrite indicates anoxic conditions during early deposition. Sargelu carbonaceous shale yields up to 26 gallon per oil. This figure is a rough estimate and does not seem to be a good representative since not enough samples were taken systematically (Afshar, 1975). Meanwhile, a comparison of oil yields for Green River shale, Siberia shale and Sargelu shale is given in figure 9.

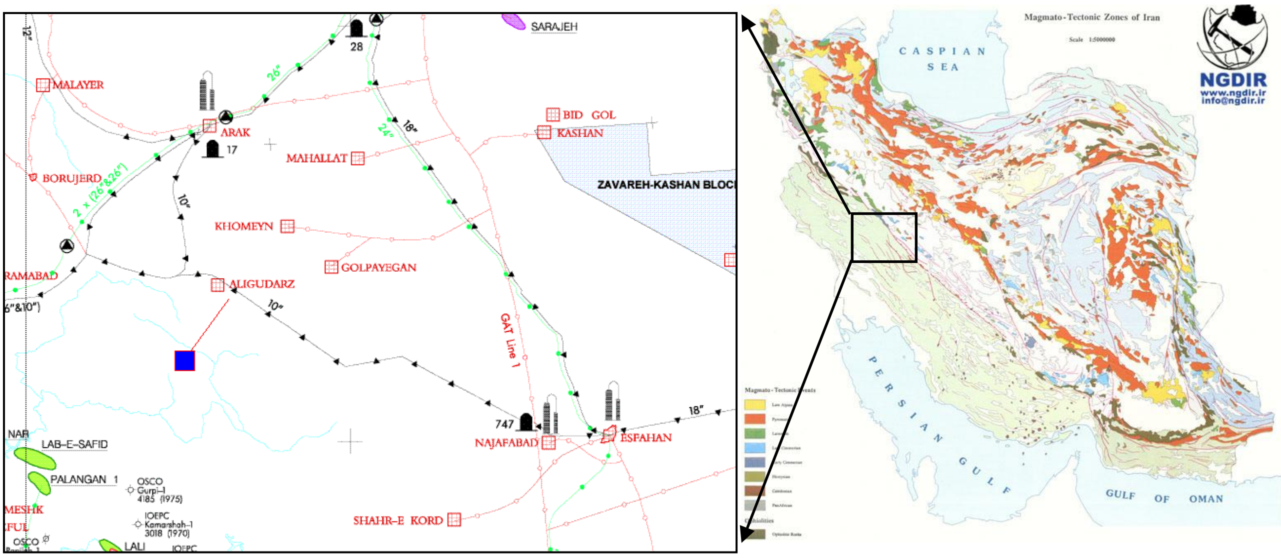


Figure 9. Location map of the Ghali Kuh oil shale.

Table 2. Rock –Eval pyrolysis analysis for Bituminous Shaly carbonate of Sargelu formation at Ghali Kuh Section, Zagros Basin.

Sample No	Section	Lithology	S1	S2	TPI	Tmax (^{o}C)	TOC (%)	HI
SR-A1	Ghali Kuh	Bituminous Shaly Carbonate	1.26	61.39	0.02	436	11.88	517
SR-A2	Ghali Kuh	Bituminous Shaly Carbonate	2.2	42.83	0.05	437	10.16	422
SR-A3	Ghali Kuh	Bituminous Shaly Carbonate	0.99	12.07	0.08	431	2.81	430
SR-A4	Ghali Kuh	Bituminous Shaly Carbonate	6.05	100.7	0.06	437	20.8	484
SR-A5	Ghali Kuh	Bituminous Shaly Carbonate	2	81.61	0.02	436	16.99	480
SR-A6	Ghali Kuh	Bituminous Shaly Carbonate	1.94	59.32	0.03	431	11.41	520
SR-B1	Ghali Kuh	Bituminous Shaly Carbonate	2.66	64.08	0.04	436	15.05	426
SR-B2	Ghali Kuh	Bituminous Shaly Carbonate	3.51	72.82	0.05	436	14.31	509
SR-B3/	Ghali Kuh	Bituminous Shaly Carbonate	2.22	63.61	0.03	431	13.49	472
SR-B4	Ghali Kuh	Bituminous Shaly Carbonate	2.07	68.69	0.03	435	11.92	576
SR-B5	Ghali Kuh	Bituminous Shaly Carbonate	2.89	73.08	0.04	434	14.31	511
SR-B6	Ghali Kuh	Bituminous Shaly Carbonate	1.6	67.32	0.02	437	12.07	558

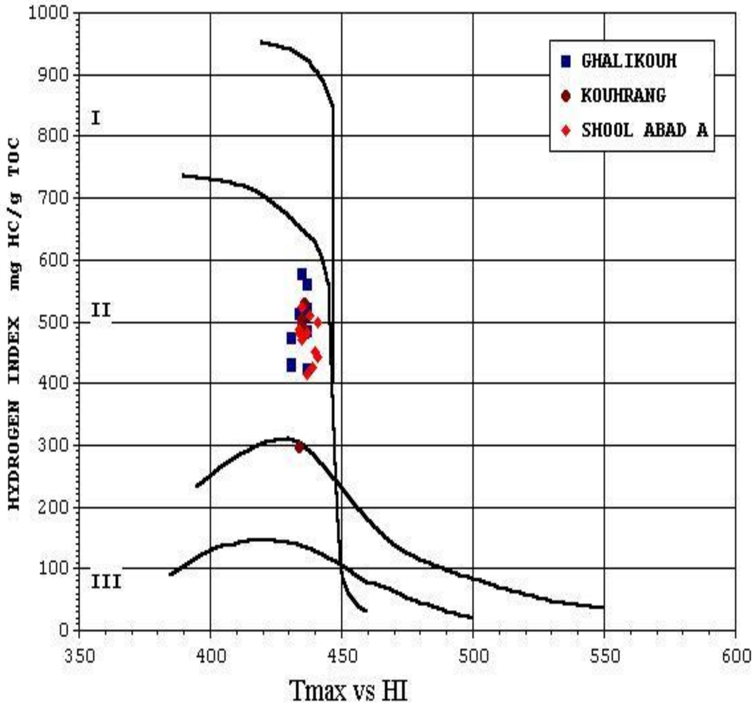


Figure 10. Tmax Vs HI for Sargelu Formation, Zagros Basin.

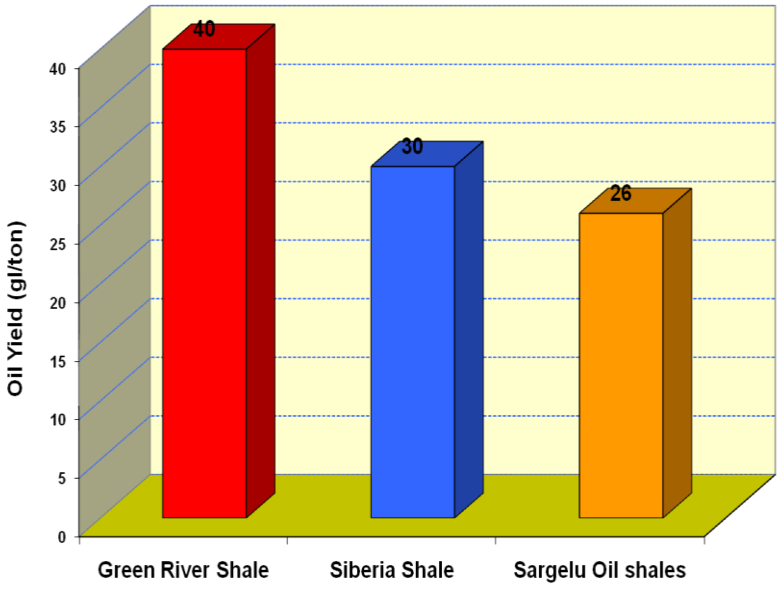


Figure 11. Comparison of oil yield from three well known source rocks.

Gas Hydrates

Gas hydrates are crystalline water based solids physically resembling ice, in which small non-polar molecules (typically gases) are trapped inside "cages" of hydrogen bonded water molecules. In other words, clathrate hydrates are clathrate compounds in which the host molecule is water and the guest molecule is typically a gas. Without the support of the trapped molecules, the lattice structure of hydrate clathrates would collapse into conventional ice crystal structure or liquid water. Most low molecular weight gases (including O_2, H_2, N_2, CO_2, CH_4, H_2S, Ar, Kr, and Xe), as well as some higher hydrocarbons and freons will form hydrates at suitable temperatures and pressures.

Promising gas hydrate deposits in Iran include those in the Oman Sea, where a total of 55 exploration targets were identified in Iranian waters including an area of 27000 km^2. In the Caspian Sea, possible targets are identified at depths close to 4000 meter located at depocenters of Northern and Southern parts of Caspian Sea. Another unconventional reserve in Iran in addition to Gas Shales from Shemshak coal beds in Central Iran and Central Alborz Basins is low permeability oil from Moghan Plain east Azerbaijan province, where commercial quantities of trapped oil in porous reservoir are immobile due to poor permeability.

Summary

Conventional worldwide oil production will begin to decline soon. The decline will be difficult to stop. The difference between demand and supply can be made up with production from unconventional reserves. The cost to produce large volumes of oil and gas from unconventional reserves will be high. Shale gas deposits have shown good potential and are promising for exploration and long term production. Unconventional gas shale deposits in Iran include Shemshak formation (Jurassic) from Central Alborz and Central Iran basins. Potential oil shales include Ghali Kuh Sargelu formation with oil yield reaching 26 gallon/ton and gilstone deposits from Kalak Bishe at Puledokhtar mine in Lorestan province. Other studied outcrops are Kazhdumi oil shales (Cretaceous) from Kuhe Bangestan, Khuzestan province, Kazhdumi oil shale from Kuhkluyeh and Boyer Ahmad province and Garau oil shales from Kabir Kuh, Lorestan province.

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