Oil Shale, 2006, Vol. 23, No. 3
pp. 211–227

ISSN 0208-189X

OIL SHALES IN THE WORLD AND TURKEY; RESERVES, CURRENT SITUATION AND FUTURE PROSPECTS: A REVIEW

N. E. ALTUN*[(a)], C. HIÇYILMAZ[(a)], J.-Y. HWANG[(b)],
A. SUAT BAĞCI[(c)], M. V. KÖK**[(c)]

[(a)] Department of Mining Eng.
Middle East Technical University
06531, Ankara, Turkey

[(b)] Michigan Technological University
Institute of Materials Processing
1400 Townsend Dr.
49931 Houghton, MI, USA

[(c)] Department of Petroleum and Natural Gas Eng.
Middle East Technical University
06531, Ankara, Turkey

Oil shales, which are kerogen-rich sediments, are one of the most important energy alternatives. The widely distributed deposits around the world and their vast amounts make them a promising option as a source of oil or as a solid fuel supplement. Nevertheless, the economics of retorting does not allow their utilization for oil production on a large scale with a few exceptions. Oil shale is an important potential energy resource for Turkey, being the second largest fossil energy source after lignite. This paper aims to emphasize the important aspects about oil shales so as to give ideas about their importance as an alternative source. The definition of oil shale, mode of occurrence and the use of resources in the world and in Turkey are reviewed and the opportunities for prospective utilization in the future are provided.

Introduction

Energy production is one of the most important concerns of the world. The inevitable dependence of the industrialized world on energy requires the sustainable development of energy. To develop an energy policy that can both ensure current needs and meet future expectations, a number of aspects

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* Corresponding authors: e-mail *naltun@metu.edu.tr*
** *kok@metu.edu.tr*

have to be considered. These aspects include new techniques for efficient source utilization, exploration of new deposits and evaluation of potential alternatives. The common point of all these aspects is the suitability for all existing and prospective sources from the view of feasibility and environmental concerns.

Comparing the energy demand of the developing countries with that of the industrialized nations, the energy demand by countries such as USA, Canada, Germany is expected to increase at a stable level, whereas, the demand by developing countries is expected to increase by a factor of three [1]. Most of the developing countries rely on imports in meeting their energy requirements [2]. The need to find and use alternative energy resources is much more critical for developing countries to sustain industrialization.

The need for energy is a critical concern for Turkey, a developing country with a population more than most European and Middle East countries. The energy consumption of Turkey was recorded to increase from 53 to 77 Mtoe (million tons of oil equivalent) from 1990 to 2001, corresponding to a rise of around 50%. On account of the growing population and increasing industrialization, the rapid growth of energy consumption was predicted to continue for the next 15 years. On the other hand, energy production in the country was 26 Mtoe in 2001 and this supplied only 33% of the total demand [1, 3]. Energy imports cover the wide gap between demand and supply and is a considerable burden on the country’s economics. The oil and natural gas reserves in Turkey are minor; solid fossil fuels are the primary potential energy resources. These resources include a wide variety of bituminous coal, lignite, oil shale, asphaltite, and peat deposits and vary in reserve quality and physical characteristics [4]. Lignites, which are used mainly for power generation in coal-fired thermal plants, are of poor quality and highly polluting. For instance, the average calorific value of lignite from the Afsin-Elbistan basin, which accounts for 40% of the country's lignite reserves, is 800–1000 kcal/kg. The lignite also contains a considerable amount of sulphur. This low-quality lignite is not a promising option for power generation in the mid and long terms.

Oil shale comprises the second largest potential fossil fuel in Turkey. The main oil shale resources are located in middle and western regions of Anatolia. The amount of proved explored reserves is around 2.22 billion tons while the total reserves are predicted to be 3 to 5 billion tons. Despite this vast potential, the stated amount cannot be accepted as a the amount of commercial reserves. The deposits vary from 500 to 4500 kcal/kg in calorific value, revealing that each deposit requires a detailed study regarding its possible use [4, 5]. Numerous studies carried out to recover shale oil have ended with positive but unfeasible results [6]. Treating oil shale as a supplement to coal or lignite in power production is a more realistic approach and would be possible in boilers used for firing coal.

Definition and origin of oil shales

The term ‘‘oil shale’’ does not have a definite geological definition nor a specific chemical formula, but is a general term used for usually fine-grained sedimentary rocks that yield significant amounts of shale oil upon pyrolysis [7, 8].

Gavin [9] described oil shale as any compact laminated sedimentary rock with more than 33% ash which is capable of yielding a certain amount of organic matter under a suitable process.

Lithologically, oil shale covers a broad range of rocks from shales to marl and carbonates, which forms a mixture of tightly bound organic and inorganic materials. The general composition of oil shales is given in Fig. 1 [10]. The nature and extent of inorganic materials depend mainly on depositional conditions and the characteristics of the host rock. For instance, true shales contain primarily clay minerals while the well-known Green River shale is mainly carbonates in association with quartz, feldspars, and illite.

The organic matter in oil shales is predominantly kerogen, which is an insoluble material. Bitumen and/or prebitumen may also exist in addition to kerogen, but in relatively low amounts. Although it has been shown that

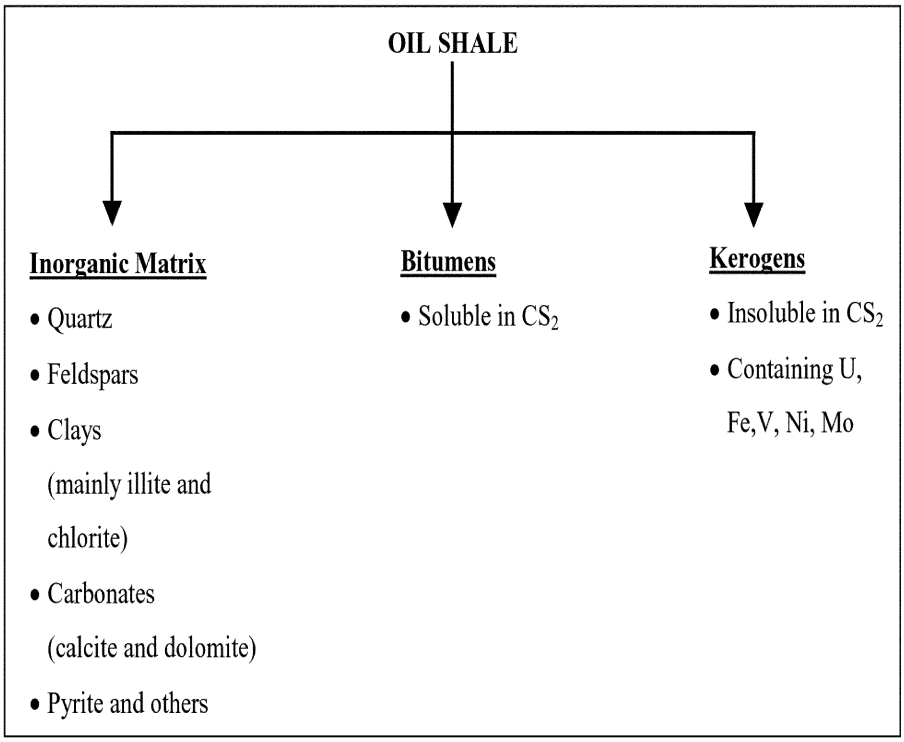
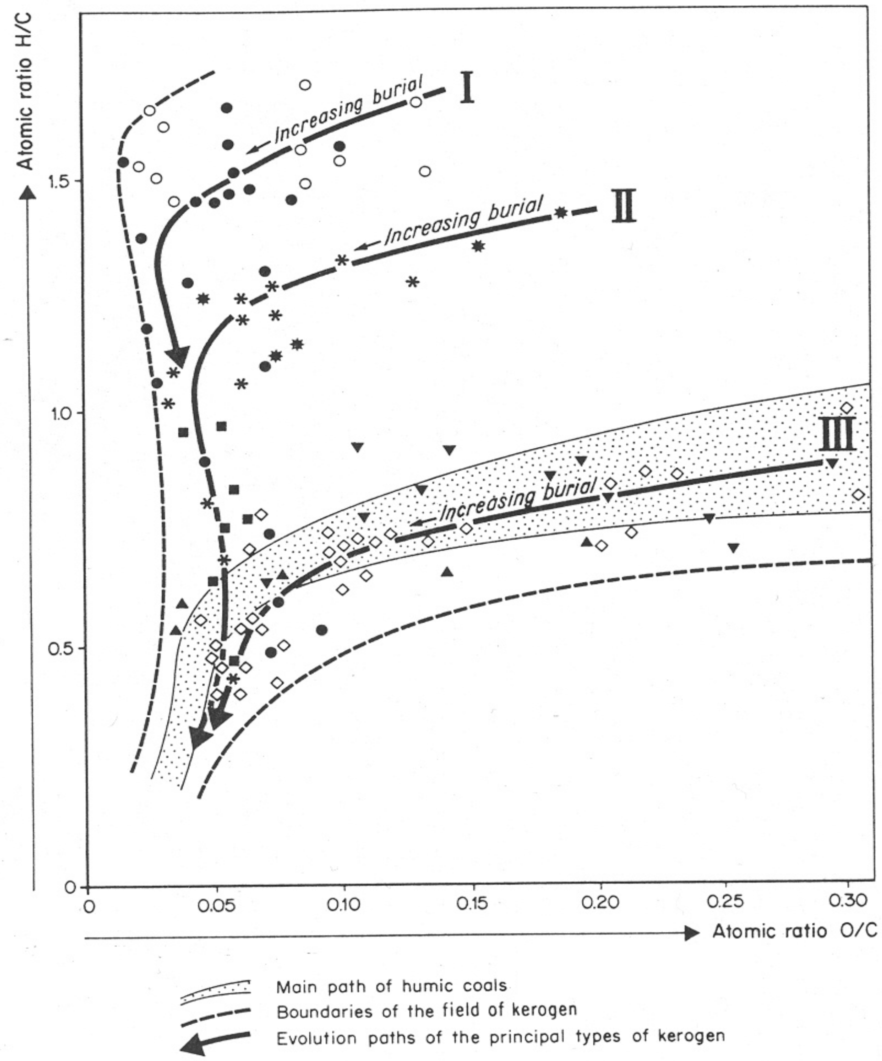


Fig. 1. General composition of oil shales [10]

kerogen predominates in the makeup of the organic matter, the chemical form or composition of the kerogen may vary extensively from deposit to deposit. This is due to variations in the amounts of organic carbon, hydrogen and oxygen. Classification of oil shales according to their kerogen type using the van Krevelen diagram is useful [7, 11]. The van Krevelen diagram interprets the kerogen type within a solid fossil fuel through thermal evolution paths as a function of burial depths on plots of atomic H/C versus O/C ratios of the kerogen. Thus, classification of the kerogen type is made as a function of hydrogen, carbon and oxygen content of the fossil fuels (Fig. 2).

Type I refers to kerogen content with a high initial H/C, but a lower O/C ratio. Type I kerogen oil shales are derived from algal lipids or from organic matter enriched in lipids by microbial activity, which are mostly aliphatic chains. They yield a larger amount of volatile or extractable compounds than other types upon pyrolysis. Hence, from the theoretical view, type I kerogen oil shales provide the highest yield of oil and are the most promising deposits in terms of conventional oil retorting. Type II kerogen is common in many oil shale deposits. This type is also characterized with relatively high H/C and low O/C ratios. Type II kerogen is based on marine organic materials which are formed in reducing environments. In type II kerogen, the polyaromatic nuclei, the heteroatomic ketone and carboxylic groups are more significant than in type I, but still less than type III. The naphthenic rings in the chemical structure are also abundant and aliphatic chains occur with moderate lengths. Sulphur is found in substantial amounts in the associated bitumen and generally higher than the sulphur content of type I or III kerogen. Although pyrolysis of type II kerogen yields less oil than type I, the amount acquired is still sufficient to consider type II bearing rocks as potential oil sources. Type III kerogen refers to a low H/C ratio, but a high O/C atomic ratio that is derived from terrestrial higher plants. Another distinct characteristic is their relatively higher proportion of polyaromatic nuclei, heteroatomic ketone and carboxylic acid groups. Aliphatic groups contain only a few long carbon chains, the rest being composed of medium and dominantly short ones. Type III kerogen involving rocks are found to be the least productive on pyrolysis and probably the least favorable deposits for oil generation [7]. Geothermal maturation of oil shale could lower the H/C ratio to suggest a type III kerogen when, in fact, it may be a type I or II kerogen.

In addition to classification of kerogen types, oil shale deposits can be characterized by their depositional history including the organisms from which they were derived [12]. The age and depositional history are major factors that determine the extent and nature of the organic and mineral content, and relative quality, of any deposit.



Type	Age and / or formation	Basin, country	
I	Green River shales (Paleocene - Eocene)	Uinta, Utah, U.S.A.	●
	Algal kerogens (Botryococcus, etc...). Various oil shales		○
II	Lower Toarcian shales	Paris, France; W. Germany	*
	Silurian shales	Sahara, Algeria and Libya	■
	Various oil shales		✸
III	Upper Cretaceous	Douala, Cameroon	◇
	Lower Mannville shales	Alberta, Canada	▲
	Lower Mannville shales	Alberta, Canada	▼

Fig. 2. Classification of kerogen types from various oil shale samples according to van Krevelen diagram [7]

Oil shale potential and utilization in the world

Oil shale potential in the world and characteristics of important fields

The physical and chemical characteristics of oil shale deposits vary widely due to geological conditions and age of formation.

Although oil shales exist in the form of wide spread deposits in many countries, those in USA, Estonia, China and Brazil have been of distinguished importance over the past hundred years. The vast amounts of the resources, the availability of the deposits to exploitation and their potential to yield considerable amounts of shale oil attracted significant interest in developing these deposits. Recent geological findings have revealed that oil shales in Australia, Jordan, Morocco and Zaire are also promising deposits, but information about these deposits is quite limited. Table 1 presents some characteristics of several well-known oil shale deposits in the world. Also, some of the important economic oil shale reserves, reported by world energy council, are provided in Table 2 with the reserve amounts, oil-yield potentials and shale-oil production figures for 1999 [13].

The United States has the largest oil shale resources in the world. The total amount of 3340 billion tons, which constitutes 62% of the world's known recoverable oil-shale potential. The most important deposits are the Green River oil shale and the Devonian black shales [14, 15]. The Green River oil shales which exist as the largest reserve in the world are the main tertiary age oil shales and of lacustrine origin. The deposit of Eocene age extends mainly over Piceance Creck basin (Colorado), Uinta basin (Utah), and Green River basin and Washakie basins (Wyoming). Although the largest deposits are located in the Green River Formation, the reserves in Piceance Creck and Uinta basins are the richest and the most easily recoverable deposits, where shale oil could be extracted by surface and/or in-situ retorting. The total shale oil potential of the Green River Formation is estimated to be around 250 billion tons. Recoverable in-place resources of Devonian black shale, found mainly in Indiana, Kentucky and Ohio, estimated to be around 10 billion tons [7, 15-17].

Brazil follows United States, having the world's second largest known oil shale resources, the Irati shale in Sao Mateus do Sul, Parana. The upper Paleozoic Irati Formation is of Permian age and lies in the form of two horizons separated by a thick sediment layer in between. The horizons differ both in thickness and shale oil yield potentials. The first horizon is about 3.2 m thick with a 9% oil yield, where the second one is characterized as a thicker (6.5 m) layer, but poorer in oil yield potential (6.4%). There are also lacustrine deposits of Tertiary age in Paribas Valley, but these deposits are not as large as the Irati Formation, although they still account for a respectable amount of shale oil potential. According to the reports of the Brazilian Ministry of Mines and Energy in 1999, the amount of proven oil shale resources was 445.1 million m^3 whereas the probable reserve potential of the country was around 9402 million m^3 [15, 18, 19].

Table 1. **Properties of some important oil shale deposits [7]**

Country	Location	Age	Oil shale	Kerogen (atomic ratio)		Retorting			Shale oil		
			Organic carbon, %	H/C	O/C	Oil yield, %	Conversion ratio[1], %	Density (15^{O}C)	H/C (atomic)	N , %	S, %
Australia	Glen Davis	Permian	40	1.6	0.03	31	66	0.89	1.7	0.5	0.6
Australia	Tasmania	Permian	81	1.5	0.09	75.0	78				
Brazil	Irati	Permian		1.2	0.05	7.4		0.94	1.6	0.8	1.0–1.7
Brazil	Tremembé-Taubaté	Permian	13–16.5	1.6		6.8–11.5	45–59	0.92	1.7	1.1	0.7
Canada	Nova Scotia	Permian	8–26	1.2		3.6–19.0	40–60	0.88			
China	Fushun	Tertiary	7.9			3	33	0.92	1.5		
Estonia	Estonia Deposit	Ordovician	77	1.4–1.5	0.16–0.20	22	66	0.97	1.4	0.1	1.1
France	Autun, St. Hilarie	Permian	8–22	1.4–1.5	0.03	5–10	45–55	0.89–0.93	1.6	0.6–0.9	0.5–0.6
France	Crevenay, Severac	Toarcian	5–10	1.3	0.08–0.10	4–5	60	0.91–0.95	1.4–1.5	0.5–1.0	3.0–3.5
S. Africa	Ermelo	Permian	44–52	1.35		18–35	34–60	0.93	1.6		0.6
Spain	Puertollano	Permian	26	1.4		18	57	0.90		0.7	0.4
Sweden	Kvarntorp	Lower Paleozic	19			6	26	0.98	1.3	0.7	1.7
UK	Scotland		12	1.5	0.05	8	56	0.88		0.8	0.4
USA	Alaska	Jurassic	25–55	1.6	0.10	0.4–0.5	28–57	0.80			
USA	Colorado	Eocene	11–16	1.55	0.05–0.10	9–13	70	0.90–0.94	1.65	1.8–2.1	0.6–0.8

[1] Conversion to oil based on organic carbon

Table 2. **Economic oil shale reserves and production in 1999 as reported by WEC [13]**

Region / Country	Recovery method	Proved oil shale reserves ($\times10^6$ tons)	Proved recoverable oil potential ($\times10^6$ tons)	Average shale oil yield, kg oil/ton	Estimated additional oil potential ($\times10^6$ tons)	Shale oil production in 1999 ($\times10^3$ tons)
Africa / Morocco	Surface	12300	500	50–64	5400	–
Africa / S. Africa	In-situ	73		10		–
N.America / USA	Surface	3340000	60000–80000	57	62000	–
S.America / Brazil	Surface			70	9646	195
Asia / Thailand	In-situ	18668	810	50		–
Asia / Turkey	Surface	1640	269	56		–
Europe / Albania	Surface	6			5	–
Europe / Estonia	Surface	590		167		151
	In-Situ	910				–
Europe / Ukraine	In-Situ	2674	300	126	6200	–
Middle East / Israel	Surface	15360	600	62		–
Middle East / Jordan	Surface	40000	4000	100	20000	–
Oceania / Australia	In-Situ	32400	1725	53	35260	5

China has an important amount of oil shale potential in Manchuria and particularly near Fushun, a city which is also known as the coal capital of the country. The oil shale of Tertiary age, lacustrine type, and deposited in non-marine regions is mostly associated with coal beds. The oil shale reserves in Fushun region was reported to be around 3.6 billion tons while the total oil shale potential of the country approximates to 4.4 billion tons. The oil shale, known as the Eocene Jijuntun Formation, is found in association with coal and, open-pit mined together. The thickness of the Jijuntum deposit ranges from 48 to 190 m, with an average of 115 m. The deposit is characterized by a thin low-grade layer below a higher quality layer of about 100 m thick. The oil content of the lower layer is less than 4.7%, while the upper layer contains as much as 16% oil by weight in some parts. The oil yield from the deposits varies between 79–89 liters per ton of shale depending on ore quality [15, 20–22].

The kukersite oil shale deposit in Estonia is of Ordovician age, which was deposited in shallow sea basins. The Estonian oil shale resources are part of the Baltic Oil Shale basin and are exploited by both surface and underground mining. The deposit is one of the world’s highest-grade deposits with more than 40% organic content and 66% conversion ratio into shale oil and gas. The mineable zone is a single calcareous layer 2.5–3 meters in thickness and is buried at depths from 7 to 100 m. The Estonian oil shale reserves are estimated to be equal to 21 billion tons, which would yield a total of 3.5 billion tons of shale oil [23–25].

History and background of oil shale utilization in the world

Although the literature and definition of oil shales is rudimentary from a number of aspects, recognition of oil shale as an energy source can be traced back to the early 1800's [17]. In Canada, shale oil production was reported in the mid 1800's from deposits in New Brusnwick, Ontario and Nova Scotia. As early as 1839 an oil shale deposit was discovered in Autun, France and exploited commercially for the next few decades for oil based products. Oil shale was mined until the 1950's and annual production of about 1.5 million tons was achieved in these years. However, operations closed by 1957 due to economic reasons [26]. Studies of oil shales started in Scotland during the mid 1800's. In 1862, James Young applied his low temperature distillation process from coals to local oil shale. Afterward, around 20 oil shale deposits were mined at different periods in Scotland. The amount of oil shale processed for oil production reached 3.3 million tons in 1913. Production continued from 1881 to 1955, when it started to decline, and completely ceased in 1962 due to non-competitive oil distillation and retorting costs [26].

In the late 1800's, a large oil shale deposit was discovered in the state of Bahia, Brazil. The studies on the utilization of oil shales continued and in 1935, shale oil was produced near Sao Mateus do Sul in Parana state with government support, the industry grew fast and the company Petrobras, which was established in 1953, developed the ''Petrosix'' retort. The company concentrated activities on the Irati deposits near Sao Mateus do Sul and started a pilot-scale operation in 1972 with a 2500 ton per day processing capacity. The pilot plant was upgraded to a commercial scale operation in 1982 when another larger industrial Petrosix retort was put into service in 1991. The total capacity of 7800 ton of oil shale per day was achieved, which yielded a daily output of 3870 barrels shale oil, 120 tons of fuel gas, 45 tons of liquefied shale gas and 75 tons of sulphur. The total amount of shale produced in 1999 was 195.2 thousand tons [15, 27].

One of the first attempts to commercialize oil shales was made in Estonia in 1838. The aim was to obtain oil by distillation using oil shales from the Rakvere open-pit mine. Significant shale oil production started after the World War I. The availability of the kukersite deposit for low-cost mining and direct utilization made oil shales Estonia's primary energy source after 1918. Electric power production, heating, shale oil production and the use of shale ash in the cement and brick industries accounted as the major areas of consumption. In the mid 1950's Estonian oil shale production reached a peak of 7 million tons. Three thermal power plants, which started operations in 1965, 1973 and 1980, boosted oil shale utilization even further. By 1980, production increased to around 31 million tons/year. After the opening of a nuclear power plant in Leningrad, oil shale production decreased, and the decline continued until 1995 [24] when oil shale production stabilized at about of 9–10 million tons/year. In 1999, a total of 12.1 million tons was produced. Most of this amount was utilized for power generation and heating and the rest was retorted to produce 151,000 tons of shale oil. These recent figures also imply that Estonia is still the leading country in oil shale utilization [15, 17, 25, 26].

In China, the use of oil shale for shale oil extraction on a commercial scale started in the 1920's at Fushun, Manchuria. After World War II, the number of retorts increased rapidly at Fushun and 266 retorts were reported to operate in the 1960's. The amount of oil shale treated increased to an annual amount of 24 million tons in this period. During the 1970's, the oil shale industry continued to grow and China became the world's leading oil shale processing country utilizing annually 35 to 50 million tons oil shale in Fushun and some 10-20 million tons at Maoming. The most recent oil shale facility at Fushun started operations in 1992 with a capacity of 60,000 tons/year. This suggests that, unlike most countries, the oil shale industry in China will preserve its expanding tendency both in the short and long terms [21, 22, 26, 28].

Although United States has the world's largest known oil shale reserves, the oil shale industry never attained commercial production during the past decade. The deposits were first studied during the early 1900's, but oil shales started to attract considerable interest after World War II when the US became one of the leading oil consumers in the world. During the period of 1944–1955, a comprehensive research program was conducted covering all aspects of oil shale processing, retorting, shale oil production and refining under the auspices of the US Bureau of Mines. In 1946, the Bureau of Mines established the Anvils Point oil shale demonstration project in Colorado for advanced oil shale research and production. Upon these efforts oil shale production with a capacity of 360 tons/day was attained in 1967 in Colorado. However, in most of the cases production costs were too high to compete with petroleum, and the amount of production remained small. The oil crises in 1973 and 1979 reawakened the interest in shale oil. Projects of full-scale production through modified in-situ retorting with a 50,000 tons/day total capacity were initialized in Colorado in these years. All these activities have then ceased and the last in large-scale plant, operated by Unocal since 1980, ended its activity in 1991. Unocal produced 4.5 million barrels of shale oil from its Colorado operation [15, 16, 26].

Oil shale potential in Turkey

The oil shale resources of Turkey are distributed mainly in middle and western Anatolia. Presence of authigenic zeolites and preservation of the organic matter reveal the influence of hypersaline conditions during formation in closed basins during the Paleocene-Eocene and Upper Miocene Epochs [29]. Generally, marl, clay and carbonates are the host rocks and organic matter is found in disseminated form. The main oil shale deposits in Turkey are shown in Table 3 with the amounts of their geological (proved) and possible reserve [4, 30]. Among the potential resources, Beypazarı (Ankara), Seyitömer (Kütahya), Himmetoğlu (Bolu) and Hatildağ (Bolu) deposits are of major importance in terms of quality, amount and exploitability. The characteristics of these four deposits, which constitute around 50% of the total oil shale potential of Turkey, are given in Table 4 [5, 31]. Other potentially important resources are in Mengen (Bolu), Ulukışla (Niğde), Bahçecik (İzmit), Burhaniye (Balıkesir), Beydili (Ankara), Dodurga (Çorum) and Demirci (Manisa).

Table 3. **Main oil shale reserves in Turkey [4, 30]**

Name of the deposit	Geological reserve ($\times 10^6$ tones)	Possible reserve ($\times 10^6$ tones)	Total reserve ($\times 10^6$ tones)
Beypazarı	327.68	–	327.68
Seyitömer	83.32	38.85	122.17
Himmetoğlu	65.97	–	65.97
Hatıldağ	78.37	389.20	467.57
Mengen	–	50.00	50.00
Ulukışla	–	130.00	130.00
Bahçecik	–	42.00	42.00
Burhaniye	–	15.60	15.60
Beydili	–	300.00	300.00
Dodurga	–	138.00	138.00
Demirci	–	172.00	172.00
Sarıcakaya	–	300.00	300.00
Çeltik	–	90.00	90.00
TOTAL	**555.34**	**1665.65**	**2220.99**

Table 4. **Characteristics of the major oil shale deposits in Turkey (EGOS, on average basis) [5, 32]**

Deposit	Upper calorific value, kcal/kg	Total organic carbon, %	Oil content, %	Oil content, l	Total sulphur, %
Beypazarı	812.07	4.8	5.4	60.0	1.4
Seyitömer	847.90	6.9	5.0	54.3	0.9
Himmetoğlu	4991.88	30.9	43.0	482.0	2.5
Hatıldağ	773.86	5.6	5.3	58.0	1.3

Beypazarı deposit

The Beypazarı oil shale deposit is located at the northwestern part of Ankara, in the neighborhood of the Beypazarı-Çayırhan lignite field. The deposit is of Middle Miocene age and was formed in an extended limnic basin. The amount of the resource having a calorific value above 850 kcal/kg is around

340 million tons. The stratigraphic data revealed that well consolidated marl and clays occur as host rocks. Carbonates (dolomite, calcite) and quartz occur in significant quantities as the main inorganic constituents. Localized occurrences of trona are also found [31, 32]. Si, Mg and Ca occur as major elemental constituents but trace elements are rare. The organic material consists mainly of liptinite, huminite and prebitumen. Economic grade oil shale (EGOS) over an oil shale deposit was defined by 5 m minimum seam thickness, 750 kcal/kg minimum lower calorific value and 4% minimum oil content [33]. The EGOS in Beypazarı oil shale field is persistently found over the reserve area with a thickness between 8–22 m. The lower calorific value ranges between 752 to 929 kcal/kg, and the average total organic carbon content is 4.82% on a dry basis. The maximum oil content of the EGOS is 8.7%, and the average shale oil yield potential is 60 l/ton shale. The EGOS in the Beypazarı field has an average of 1.4% total sulphur, found mostly in inorganic form [31, 33]. Beypazarı oil shale is classified as a poor-quality fuel with its low calorific value and oil content and high ash content (≈ 68%) [34]. However, it ranks as the largest oil shale deposit in Turkey (Table 3). Also, the presence of abundant carbonates favors its utilization by blending with the high-sulphur Beypazarı – Çayırhan lignites, in the neighboring thermal power plants.

Seyitömer deposit

The Seyitömer oil shale deposit is found in the northwestern part of province of Kütahya. The deposit overlies the Seyitömer lignite basin, which supplies a 300 MW thermal power plant at the mine site. The amount of Seyitömer oil shale is around 122 million tons, and more than 75% is in the form of geologically proved reserves (Table 3). Seyitömer oil shale is rich in quartz, dolomite, calcite and clay minerals such as muscovite, illite and smectite [35]. Geochemical analysis revealed that the organic content of Seyitömer oil shale was mainly originated from algae, pollen and planktonic algae as well as bacteria. Also traces of liptodetrinite and humic organic material were observed [36, 37]. Specifically, Seyitömer oil shale is characterized with its grey to green colored organic-rich zones. The EGOS in the Seyitömer oil shale basin varies widely in terms of thickness and quality. The thickness ranges between 3 to 29.5 m, with an average of 12.4 m. The average upper calorific value of the EGOS is around 850 kcal/kg. The average oil content of the seam is around 5%, corresponding to an approximate shale oil yield potential of 54 l/ton of shale. It contains a relatively high amount of ash (≈70%), however the total sulphur content seldom exceeds 1.5%, with an average lower than 1% [31, 37]. Since the oil shale seam extends over the Seyitömer lignite, it is being excavated during the open-pit mining of Seyitömer lignite. This serves as an opportunity for the utilization of Seyitömer oil shale.

Himmetoğlu deposit

The Himmetoğlu oil shale deposit is located in the southwestern part of province of Bolu, in the neighborhood of the Beypazarı, Hatıldağ and Mengen oil shale deposits. The Himmetoğlu oil shale basin is of Neogene age, and volcanism and tectonic activity have considerable influence on the environmental conditions during the deposition period [38]. The drill hole data shows three main zones from top to bottom: bituminous marl (BLM), bituminous banded marl (BBM) and the major oil shale formation of the Himmetoğlu (HOS) seam. The Himmetoğlu oil shale strata overlie a lignite zone and extend throughout the deposit. The Himmetoğlu oil shale seam consists of more than 50% liptinite, 20–50% huminite and 0–20% inertinite maceral groups and is characterized by its high organic content [38]. The origin of the organic matter is mainly algae and land plants [37]. The major inorganic constituents in the organic-rich zones are calcite, dolomite, silica, and considerable amounts of pyrite. The average calorific value of the EGOS zone is around 4900 kcal/kg. The in-place shale oil content of the Himmetoğlu oil shale is 43% by weight or approximately 482 l/ton of shale. However, the average total sulphur content is high (2.5%) due to considerable pyrite (Table 4). The Himmetoğlu oil shale is the highest quality oil shale in Turkey. The Himmetoğlu oil shale zone is being excavated (2005) to exploit a underlying high-quality lignite seam utilized for domestic heating. On account of its high thermal quality, the Himmetoğlu oil shale is an attractive alternative for power generation in Turkey, which relies mostly on poor-quality lignites [33, 39].

Hatıldağ deposit

The Hatıldağ oil shale deposit is located in the Hatıldağ-Bolu lacustrine basin at the south-eastern part of Göynük in Bolu province. The deposit, of Paleocene-Eocene age, is in a 50 to 75-thick limic series of calcareous bituminous rocks. The series consists of two zones, an economic grade oil shale and a bituminous marl [40]. It contains around 80% liptinite, 5–10% bituminite and 5–10% huminite. The high liptinitic content shows that the organic matter originated mainly from hydrogen-rich organic remains of algae and pollen. Calcite, dolomite, quartz and smectite are the major inorganic constituents. Analcime, feldspar, chlorite and mica-illite are found in lesser amounts (5–10%). The economic grade oil shale zone is in the lower part of the bituminous sequence. Average thickness and average upper calorific value of EGOS are 30.5 m and 774 kcal/kg, respectively. The Hatıldağ oil shale is characterized as a poor-quality deposit with a shale oil yield of 5.3%, which is similar to the Beypazarı and Seyitömer deposits (Table 4).

Other potential reserves

The other potential oil shale deposits at Mengen, Ulukışla, Bahçecik, Burhaniye, Beydili, Dodurga, Demirci, Sarıcakaya and Çeltik have not yet been investigated in detail. The information about these deposits is derived from preliminary geological borehole data and analysis. Among these deposits, Beydili and Sarıcakaya are distinguished by their huge resources (Table 3). The Mengen deposit is of Eocene age and is located near the Hatıldağ and Himmetoğlu deposits. The Mengen deposit overlies a lignite seam and is 24 m thick. The Bahçecik oil shale bed lies between two tuffs. The average thickness of the oil shale is 4.30 m. and the shale yield ranges between 2 and 19%. The Ulukışla oil shale deposit underlies conglomeratic rocks and the average thickness of the oil shale bed is 13 m. The calorific value and oil content of the deposit averages 2790 kcal/kg and 13.7%, respectively. The Demirci oil shale field is of Miocene age. The thickness of the oil shale bed ranges between 3 and 15.60 m. Its total organic carbon content ranges from 10.40 to 22.50%).

Prospective use of oil shales

Most previous efforts of oil shale utilization have focused on shale oil production. However, only a few of these attempts produced satisfactory results, and processes for shale oil retorting mostly proved to be non-favorable due to non-competitive cost of shale oil production. Today, large-scale shale oil retorting is performed only in countries which have high-quality oil shale reserves and lacking of petroleum and/or coal resources like Brazil, China and Estonia.

Despite the unsatisfactory utilization of oil shales as an alternative oil source, the vast and wide spread oil shale resources in the world offer opportunities for burning as a solid fuel. Oil shale utilization is shifting towards its use as a fuel with novel combustion technologies such as fluidized-bed. Carbonate minerals, which commonly dominate the inorganic content of high-ash oil shale reserves, provide a natural SO_2 adsorption medium during burning. This condition eliminates the cost of limestone used as a SO_2 retardant during combustion in fluidized bed and provides an important advantage for the utilization of low-quality oil shales over high-sulphur lignites in these systems. Hufnagel, Schmitz and Şengüler reported favorable results regarding the oil shale combustion in fluidized bed systems [29, 31, 33]. Studies of pilot-scale testing of low-quality oil shale fines (–8mm, < 1158 kcal/kg) are currently continuing in Maoming, China [15].

By-products handling from oil shales also add considerable value. Some of oil shale deposits contain valuable metals like uranium, vanadium, zinc, alumina, etc. Post-combustion use of spent oil shale is also possible in many ways. Oil shale ash is being utilized effectively as a cement raw material in China [15]. Studies have shown that fly-ash residues of high-quality oil shales involve significant amount of carbonaceous material with a macro porous network, and these residues may be used as an activated carbon source having considerable adsorption capacity [31].

In conclusion the oil shale industry is leaning towards its utilization as a direct source of energy and the recovery of by-products. This trend is predicted to continue at least during the near future. However, the bottom line for reawakening of large-scale shale oil production is governed by crude oil prices. For the long term, stimulation of shale oil production to fill, the gap between demand and supply of crude oil becomes greater because of depleting petroleum resources. However, it will be necessary to develop more advanced and cost-effective processes to produce shale oil at affordable and competitive prices.

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Received May 07, 2005