Chapter 7
CENTRAL AMERICA

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General

Little is known regarding the oil shale of Central America. The only early mention was of oil shales in Panama by McKee(1) in 1925. Apparently these occurrences have never been investigated.

On the basis of the Geology of the Costa Rica area it appears reasonable to expect that oil shales may be found in areas of Nicaragua and Panama that are adjacent to known deposits in Costa Rica (see Fig. 7.1).

COSTA RICA

INTRODUCTION

It is not known when the oil shales of Costa Rica were first recognized.

The Government of Costa Rica requested assistance from the United Nations and a brief examination relative to the possibility of utilizing oil shale and carbonaceous rocks was made in April, 1967.(2)

The resulting report stated: "There has been as yet no serious prospecting of these fuel reserves. The data available are fragmentary and not sufficient for a proper evaluation of exploitation possibilities."
Fig. 7.1 Oil shale areas of interest in Costa Rica. From A Review of the Costa Rica Oil Shale Program, United Nations Development Programs.
A very brief description of the origin of the oil shales was noted as follows:

"Between Columbia of South America and Nicaragua of Central America, the Caribbean sea long flowed westward into the Pacific Ocean through a very wide and deep portal, but now these two bodies of water are barred from each other by a young land bridge, an isthmian link connecting the two American continents. This bridge, the Panama-Costa Rica isthmus, includes the countries of Panama, Costa Rica and the low southern part of Nicaragua."

"The connecting land between North and South America was present, as an active volcanic zone at least, during early Eocene time, and as a land bridge, seemingly during most or all of Upper Cretaceous time. At the Upper Eocene the Caribbean sea transgressed the bordering lands in many places. Marine transgression persisted until the close of Lower Miocene times when most of Costa Rica was submerged. Then after mild deformation forced a brief withdrawal of the sea, renewed submergence during Middle and Upper Miocene times reopened the interoceanic strait. Volcanism continued intermittently throughout this period."

"At the Upper Miocene the Caribbean sea regressed. Land masses in western Costa Rica rose and during Upper Pliocene-Pleistocene only the Caribbean lowlands were submerged."

"Sedimentation which began in Oligocene and lasted to the end of Middle Miocene, took place under typical shallow epicontinental sea conditions. During this time organic matter was laid down in coastal areas, platform sections and lagoons. Under certain favorable conditions, this organic matter was formed into oil shale."

"Outcrops of bituminous shales are known to occur on the Nicoya peninsula and near Esparata; asphalt impregnations occur near Suretka and near Limon; thick sediments of black shale occurs in the Terraba formation near Villa Colon; and lignite occurs in the area of Venado."

The oil shales of Costa Rica were visited by John Hutchins in late April and early May of 1980 at the request of the United Nations Development Programme and the Republic of Costa Rica. Hutchins reports as follows:

Visits to oil shale and other hydrocarbon sites were made accompanied by representatives of the Office of the Director of Geology, Mines and Petroleum (MEIC). Sites visited included San Jose South (Puriscal), Tampaste, Esperata, and Nicoyan Peninsula to the Pacific. Because of time limitations, three other areas of interest - Osa Peninsula, Venado de San Carlos and South of Limon - were not inspected. All areas are shown in Fig. 7.1.

Details of examinations are not available, but reference is made to the studies conducted by MEIC over the past several years that map and document these areas. (This report was not available). However, it was also stated that: "The viability (that is the extent of deposits) of commercial level of oil shale deposits cannot be confirmed until recommendations herein are carried out, nor can any specific outcrop be recommended for special development work since insufficient data exists at this time."

(The recommendations made are extensive and essentially provide for the development of a complete in-house oil shale capability within the country).

The report continues: "Outcroppings in each of these areas (Fig. 7.1) indicate existence, subject to confirmation by the U.S. sources of assay data, of subsurface oil shale resources. The extent, depth, thickness and richness of deposits is totally unknown as current data is insufficient for such estimates."
The only assay of Costa Rica deposits run on a controlled basis by an experienced laboratory (Department of Energy, Laramie, Wyoming) confirms a sample of the Nicoyan Peninsula at 167 L/MT (36 gal/st).

There were no records found showing that the recommendations of this report were ever implemented.

FUTURE PLANS

While the potential for development of Costa Rica oil shales appears promising, there are no known plans for exploration and/or development.

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General

The oil shales of South America have been known for over a century.

Oil shale deposits in several areas have been explored but only deposits in Argentina, Brazil, Chile and Uruguay have received consideration for development. However, many other organic-rich shales ranging from Cambrian to Tertiary Age have been examined for their potential energy content since exploration has, for the most part, been quite limited. Some of the Marine, Devonian, Cretaceous and Tertiary deposits are large.

As of 1989, only the oil shales of Brazil have been exploited commercially, and are currently being developed.

Hook(2) estimated in 1982 that total South American oil shales reserve may contain 7.9 billion m$^3$(50 billion bbl) of recoverable oil plus an additional 119 billion m$^3$(750 billion bbl) in marginal and submarginal deposits that yield 46 to 115 L/MT(10-25 gal/st).

Possible extensions could add 509 billion m$^3$(3.2 trillion bbl) in shales that yield 46 to 115 L/MT(10-25 gal/st) and 636 billion m$^3$(4 trillion bbl) in shales that yield 5-10 gal/st.
ACKNOWLEDGEMENTS

Requests for information regarding South American oil shales did not result in a single reply by any of the countries contacted. Data presented here has been obtained from information available in the literature and from individuals with personnel knowledge of some areas.

Data on each country listed is presented in a separate section along with references. Fig. 8.1 is a map of known oil shale deposits and is not repeated there.
Chapter 8

ARGENTINA

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HISTORY

Oil shale deposits of Argentina are located at or near Poterillos, Uspallata, Mendoza, Malargue, Neuquen, San Julian, Santa Cruz and Rio Grande, Fig. 8.1.(1)

These deposits were all known before 1920(2) and later the deposit at Mendoza was considered for possible use of the ash (spent shale) for making cement.(1) No industry resulted, however.

In 1921, Alderson(3) reported that of the several deposits known at that time that time that the oil shale deposit of Rio Grande, 386 km(240 mi) from Alvear, on the Western Railway, was the most important. The outcrop had been traced for 32 km(20 mi) and the deposit was known to extend for 2.4 km(1.5 mi) back of the outcrop. Average thickness was given as 30 m(100 ft), but no mention of oil content was made.

Apparently little exploration and development of oil shales has taken place since 1921, as the need for the products did not develop. Oil reserves in Argentina are listed in 1987 as 365 million m³(2.3 billion bbl).(4)

RESERVES

In 1953(1) it was noted that practically none of the areas was considered as commercial reserves. The total reserve for all areas was estimated as 750 million MT(825 million st). In 1981, Delahaye(5), and Hook(6) in 1982, both reported estimated reserves of 63.5 million m³(400 million bbl) of oil. All reserve estimates are based on very limited data.

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Fig. 8.1 Oil shale deposits in Argentina and Chile. Compiled by Author.
FUTURE PLANS

So far as is known, there are no plans for future developments of Argentina oil shales.

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BRAZIL

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INTRODUCTION (1)

Brazil is the largest and most populous country in South America. It extends 7242 km (4500 mi) along the coast of the Atlantic Ocean and borders all other South American countries except Chile and Ecuador. It ranks fifth in the world in terms of land area and sixth in terms of population.
While Brazil does not lack energy resources, it is deficient in petroleum and natural gas. Large coal resources are found in the States of Rio Grande do Sul and Santa Catarina. This coal has long been used for steel production in Sao Paulo, Rio de Janeiro, Santos and Belo Horizonte. Although many of the coal deposits are near the surface and are strip mined, the coal is of poor quality with high ash (50%) and high sulfur.

Brazil has excellent hydropower potential and this source currently supplies about 90% of the countries electricity. (1)

The development of Brazil's abundant non-petroleum resources did not parallel economic growth that began some two decades ago. As in many other countries, Brazil came to rely increasingly on oil and gas. Brazil supplied about 65% of its need for petroleum products from its own resources in 1986. However, this has resulted in a large outflow of currency to meet the demand for oil.

Brazil, in an effort to conserve energy has established a concerted public policy to increase the role of domestic energy resources by:

- The substitution of alcohol, steam coal, and electric power for oil;
- The exploration and development of domestic petroleum resources;
- The increased development of coal and oil shale.

Efforts to use Brazil's oil shale resources first occurred about 1881 when a plant for its extraction was established. The plant met with moderate success but could not compete with imported oil. Many attempts have been made since that time to exploit the oil shales of Brazil but most have met with little success. (4)

Oil shale has been found in eleven of Brazil's 22 states and four Federal Territories, Fig. 9.1. The two deposits of most commercial promise are in the southern part of the country. One is the Tertiary-Age deposit in the Paraiba Valley in the state of Sao Paulo. The other is known as the Itat Formation, a large Permian-Age deposit underlying portions of Sao Paulo, Parana, Santa Catarina, and Rio Grande do Sul. (1)(3)

The site selected for development by PETROBRAS, the oil development agency of the government of Brazil, is located near the village of Sao Mateus do Sul in the state of Parana, Brazil. (1)(3)

ACKNOWLEDGEMENTS

Information furnished by Thomas A. Sladek, Chemical Refining Engineer and Charles O. Hook, Publisher, New Energy Technology, both of Denver, Colorado, supplied reports and essential data on Brazil.

Edwin M. Piper, Manager, Stone and Webster Engineering Corp., Denver, also furnished data and photographs as well as reviewing the completed report.

My thanks to all for their most helpful assistance.

HISTORY

The recognition of Brazilian oil shales apparently began in the very late 1790's or about 1880 when Jose Francisco Thomas do Nascimento, a Captain of the Portuguese merchant service requested a license from the imperial government to work the "Marau peat" of Bahia. However, no record of actual operations apparently exist. (2)
Fig. 9.1 Location of major oil shale deposits in Brazil. From Paudla, V.T., U.N. Symposium, Tallinn, Estonia, 1968.
Utilization of oil shale began in Brazil in 1881 when a battery of 20 Scottish Henderson retorts was erected at Taubate near Tremembe, state of Sao Paulo, to make illuminating gas for the town. (3) The Henderson retort, a Scottish-batch-type vertical kiln (see United Kingdom) was designed for use. The plant operated until the early 1920's when cheap conventional petroleum became readily available. (1)

In 1941, the abandoned plant near Tremembe was acquired by the Campanhia de Oleos Minerais S.A. which added several retorts and produced fuel oil and waxes in addition to the combustible gases. The facilities were purchased by the national government in 1951 and The Comissao de Industrializacao do Xisto Betuminoso (CIXB) under the supervision of the Conselho Nacional do Petroleo (CNP) was created to study the Paraiba shales and the other Brazilian deposits. In 1954, the CIXB activities were incorporated into Petrobras, the national oil company. (1)(10)

Much of the early oil shale history of Brazil is related to the efforts to utilize the Marau shales in the southern part of the state of Bahia. (4)

A concession in the locality of "Joao Branco", was granted to Edward Pellew Wilson, an Englishman, who transferred it in 1884 to John Cameron Grant and Co., which operated a plant consisting of 52 Scottish Henderson retorts imported from Sweden having a total production capacity of 14,000 L/day (3,700 US gal/day) of oil. The products were, illuminating gas, oils, paraffin, candles, soap and sulfuric acid. (4)

Construction consisted of the retorts, chimneys, processing buildings, workshops, a sawmill, a railroad, trains and locomotives, boilers, chemical laboratories, a candle plant, necessary embankments and drainage, along with a work force of some 3,500. (4) (See Fig. 9.28).

The products "brasoline" marketed in Bahia as "Marau gas", gas meaning fuel oil for lamps or lanterns. There was a large consumption of "Marau candles." Use of the name continued for some half a century implying satisfaction with the product. (4)

It was reported Niteroi was illuminated one night, in the presence of the Emperor, by the shales distilled in the retorts of the British Gas Company of Niteroi. (4)

Prosperity ended with the abolition of slavery, as the slaves, once freed from the white masters, all fled the district. (4)

The area was again investigated in June and July 1902 by Luis Felipe Gonzaga de Campos, who was hired by a number of capitalists from the south. His enthusiastic report became the "classic" for the area for many years. (4)

His report noted that the Marau deposits were not continuous beds, but were scattered deposits "which", he said, "fill hollow areas occupied by ponds of still water charged with humus which has precipitated." He also noted that the product should not be burnt on a mechanical stoker, nor used as industrial fuel. (4)

Gonzaga de Campos was of the opinion that the crude oil should be exported for fuel for industrial furnaces, locomotives, and above all, steamships, as fractional distillation into many products would be uneconomic unless huge amounts of crude were produced. (4)

In 1913, a new attempt was made at finding a use for the Marauite, as the rock was called by Orville Adalbert Derby. An engineer, Robertson, sent by a famous Edinburgh firm prepared a voluminous report on the area. Later an American Mining Engineer, Thomas Preston Courley, prepared a report in which he described the equipment he saw in Marau, the most complete description of the 19th century
Eugenio Bourdot Dutra, who visited "Joao Branco" in 1918, described the equipment and reported in full detail on the distillation process. The report was published in Bulletin No. 1 of the Geological Survey and Mineralogical Service (Servico Geologico de Mineralogico). The equipment, unprotected from the weather, lay in a state of utter dilapidation.(4)

From 1918 to 1922 T.P. Courley extracted 2440 m³(15,330 bbl) of oil from the Marauite.(4) (The retorting method was not noted.)

The Ministry of Agriculture reported on the Exploratory drilling in the Marau area. The Annual Report of 1923 emphasized the fact that Marauite was a special kind of fuel, exceedingly valuable for its richness in oils and capable of yielding up to 40% in fuel oils which had a heating capacity of 10,000 Kcal/Kg (4,535 Kcal/1lb). In the form of "powdered coal", Marauite would be the most efficient of any fuel ever tested in the Experimental Station for Fuels and Minerals (Estacao Experimental de Combustiveis e Minerios).(4)

On June 1, 1932, the "Central de Brazil" railroad had a Marauite-burning locomotive run between Betem and Tomaz Coelho. The engineers' conclusion was that a mixture of 20% of this bitumen with 30% Brazilian coal and 50% imported coal would constitute a highly economical fuel.(4)

Exploration of the Marau deposits continued by the Federal Government. In 1935, Engineer Nero Passos described three kinds of "peat" which he discovered: yellow, streaked, and black. He estimated the volume of the deposit at 748,820 m³; overburden 640,000 m³. Average density of the marauite after drying was 0.4. The total capacity of "Joao Branco" bed was 283,000 MT(311,300 st); the economically workable "peat", 256,000 MT(281,600 st). The average proportion of crude oil was 25%. Recoverable oil from the "peat" was 70,600 m³(440,000 bbl), while the quantity of workable "peat" was 64,000 MT(71,400 st). There was 59,990 m³ (377,344 bbl) of diesel fuel.(4)

Professor Crum Brown gave the name "querogen" to the oil obtained from the shales by pyrogenation. The name querogen meaning an undefined chemical compound. Marauite was classified as "a type of clay containing a high proportion of querogen."(4)

Froes de Abreu established that Marauite varied widely in richness from 144 L/MT to 580 L/MT(31 to 125 gal/st), because during formation of the deposit there had been interruptions in the percolation of the matter accumulated. Marauite was not a kind of "oil shale" but a kind of "oleigenous shale", because the oil was not originally found within the rock. Lastly, according to the terminology of the mining code, Marauite was a "pyrobituminous rock".(4)

It was determined that "the undertaking would be profitable only on the basis of 300 MT(330 st) of distillable "peat" per day."(4)

Exploration continued in 1936 and 1937 when some 92 core holes were drilled by the Bahia Work and Studies Committee (Comissaro de Obras e Estudos da Bahia) in "Joao Branco" and nearby.(4)

Marcelo Taylor, Carneiro de Mendonca, Rafael Cresta Barros and Ralf Rezende Decourt were among those who studied the possible uses of Marauite. "This material", they reported, "produces twice as much heat, in the form of gas, as the ordinary bituminous coals and can be used in the existing gasification retorts in Rio de Janeiro and Sao Paulo. Mixed with appropriate quantities of imported coal, it would prove economically advantageous, without, however any adjunction of coke."(4)
To resolve the question of volume of the deposits the State of Bahia hired a geologist designated by the German Institute of Geology. After six months study, Curt Dietz gave the opinion that a plant should be set up, since the 900,000 MT (990,000 st) of Marauite he had discovered would allow for exploitation for a decade.(4)

On the strength of this report, and confident that Marau could at least meet the Navy's need for fuel, the State of Bahia asked the Federal Government for financial aid. The request was approved by the Brazilian Congress.(4)

An agreement entered into with Julius Pintsch and Co., stipulated that the firm would set up in Marau all the equipment needed for the daily distillation of 35 to 40 MT (38.5 to 44 st) of the raw material, the operation being regulated on the production of marketable fuels.(4)

To this end, and once the presence of the hardware in Hamburg was confirmed, the first payment was made to Julius Pintsch and Co. But alas, it was paid to no avail, for in July 1939 Germany became involved in the Second World War.(4)

The fact is that the Brazilian Geological and Mineralogical Service was never enthusiastic about the exploitation of Marauite, according to the testimony of the eminent Eusebio Paulo de Oliveira in his work published posthumously: "1. because the data of the English were accepted as being true in all probability; 2. because the aim of the service was prospecting for oil not marauite, a polybutumen yielding oil only when heated in the absence of air; 3. because the scarcity of the raw material would not make it possible to meet the country's need for petroleum products."(4)

Very little development took place concerning oil shale until the 1940's at which time extensive studies were conducted by the Government to examine the possibility of an installation to produce approximately 1055 M^3 (6,636 bbl) of shale oil per day. A commission was formally created in 1950 by the Federal Government to study Paraiba Valley oil shales as well as all deposits of oil shale in Brazil.(5)

During and following the World War II years several oil shale operations produced needed fuels. (Some of these plants are shown in Fig. 9.25, 9.26, and 9.27, while Fig. 9.28 shows remains of an early plant in Marau, Bahia, date unknown).

A pilot plant facility for developing a process to obtain the shale oil was designed and constructed in the early 1950's in the Paraiba Valley by Foster Wheeler Corp. The firm of Cameron and Jones, Denver, Colorado, were retained by Petrobras as consultants in June 1955.(5)

As additional information on the abundant Irazi oil shales was compiled their inherent advantage plus the economic favorability shifted the emphasis from the Paraiba oil shales.(5)

**GEOLOGY**

**Principal Known Oil-Shale Deposits**

Deposits of oil shale and other rocks from which oil can be retorted has been found in eleven of Brazil's 22 States and four Federal Territories, Fig. 9.1.

Devonian Age deposits are found in the states of Amazon and Para, while Cretaceous Age deposits occur in the States of Maranhao, Ceara, Alagocs, and Bahia. The Amapa Territory contains shales of unknown geologic age. The two deposits which have shown the most commercial promise lie in the southern part of the country. One is the Tertiary-Age deposit in the Paraiba Valley in the state of Sao Paulo, while the other is the large Irazi Formation which underlies portions
of Sao Paulo, Parana, Santa Catarina, and the Rio Grande do Sul. (1)

Earliest efforts at commercialism were directed toward the Marau shales in the state of Bahia and toward the Paraiba Valley deposits of Sao Paulo. The most recent emphasis has been directed toward the Itararé shales because of their lower moisture content, favorable physical properties, high sulfur content and extensive reserves. (1)

Codo Shale

These shales outcrop in the upper Cretaceous horizons near the town of Codo, State of Maranhao, in the upper Itapicuru River Valley. The shales are described by Froes Abreu (3) as being black and hard and yielding much oil (128 L/MT (27.6 gal/st)).

Barra do Corda Shale

This black shale of upper Cretaceous Age is found in the State of Maranhao, near the town of Barra do Corda, in the valley of the Mearim River. Froes Abreu (6) reported samples yielded 189 L/MT (41 gal/st). (3)

Araripe Shale

This shale occurs near the town of Crato, State of Ceara, and is reported to be of upper Cretaceous Age. Abreu (6) characterises it as a thin deposit not suitable for industrial exploitation. Samples yielded 220 to 243 L/MT (48 to 53 gal/st). (3)

Alagoas Shales

These shales, which occur along the coast of the State of Alagoas, are classified as Miocene. According to Nabuco de Araujo and Mariti (2). "The rocks are impregnated with asphalt, which is stated to be the result of local metamorphism. They are the only known sediments considered as possible oil bearing." (Samples yielded 133 to 193 L/MT (29 to 42 gal/st).

Cacapava Lignite Shale

There appears to be rather large deposits of lignitic shale or turfa a few miles south of Tremembe-Taubate area near the town of Cacapava in the State of Sao Paulo. The turfa is close to the surface, and the minable portion ranges from 1 m (3.3 ft) or less to approximately 3 m (10 ft), with an average of about 1 m (3.3 ft). Oil yield is about 66 L/MT (14.2 gal/st).

Marau of Marauite Shales

This Tertiary Age deposit on the coast of the State of Bahia has been exploited to some extent since 1884 (see History). H.E. Williams (7) describes this deposit as follows: In the lowermost beds, almost at tide level, a boghead coal known as the "Turfa de Marau" is found. It is a most peculiar mineral, being quite different from other known bitumens. It is light yellow in color, with brown and gray veins, which appear as stratified planes. The rock separates along these planes, and frequently plant leaves and other fossils of vegetable origin are found. It is easily cut with a knife and is elastic to a blow with a hammer but readily reduced to a fine, light powder. Neither alcohol not ether
dissolves the material, but it is highly bituminous. It burns readily with a yellow smoky flame. An analysis gave the following: Water at 110°C = 2.75%; volatile matter = 71.65%; non-volatile combustible matter = 9.75%; mineral residue = 15.85%.

Beds of this material are horizontal and exposed to a depth of 3 to 4 m (10 to 13 ft) and are said to extend to a depth of over 15 m (50 ft). (7)

Slow distillation yielded 430 L/Mt (93 gal/st) of crude oil with a density of 0.870 to 0.880 to the ton. It is not bituminous schist because the organic material greatly predominates over the mineral. (3)

The limited extent 816,300 Mt (approximately 900,000 st) limits the commercial interest in this deposit.

Olyoca and other Turfas

Deposits of substances similar to the Marau known as "turfa" or "boghead", and sometimes designated as "Olyoca" have been found in widely separated areas of Brazil, from the States of Pernambuco and Sergipe to Rio de Janeiro. According to Froes Abreu (6): "The Turfa de Ville Nova" in the State of Sergipe --- and those occurring near the coast of the State of Espirito Santo, and the turfa of Resende, in the Paraiba Valley in the State of Rio de Janeiro, are the same thing as "Olyoca". Olyoca was the name given to the material from a deposit near Victoria, Espirito Santo. These varieties of "turfa" consist of a claylike material containing about 85% water which when dried changes to a yellow or brown-yellowish material, very light and porous, formed by the algae which grew in the fresh water swamps of Brazil.

All these algae turfas have a low (10%) ash content and yield an oil very rich in paraffin. The deposits are very limited in size and can not be utilized profitably as sources of liquid fuels because of the high water content.

Tremembé-Taubate Shales

This area was the earliest sustained shale oil producing section of Brazil. Operations first started in 1881 and continued at intervals until about 1970 when the current operations at Sao Paulo do Sul were started. (3)(4)

The Tremembé-Taubate oil shale formations are mainly below the ground surface, although outcrops occur near banks of the Paraiba and Una Rivers, Fig. 9.2. The overburden ranges from a few m (feet) to about 30 m (100 ft) in thickness and averages approximately 6 to 7.6 m (20 to 25 ft), Williams (7) stated in 1920:

"The Tertiary basin in eastern Sao Paulo, on the upper reaches of the Rio Paraiba is perhaps 150 km (93 mi) long by 15 to 20 km (9 to 12 mi) wide. Over a considerable part of this basin oil shales have been found. These shales outcrop 10 to 15 m (33 to 50 ft) above the Paraiba River, near Tremembé and Pindamonhangaba, where they are being mined".

Three types of shales are found in this area: (1) massive or "bituminous" shale (folhelho betuminoso), which breaks with a conoidal fracture and occurs in a strata ranging from a few inches to a foot or more in thickness; (2) "semi-paper" shale (folhelho semi-papryraceo), which has a hackly fracture - that is, broken edges that are rough and angular - and in which the individual layers usually are less than 2.5 cm (1 in.) thick; and (3) "paper" shale (folhelho papryraceo), which occurs in layers that are as thin as paper. A considerable portion of the deposit is of this "paper" type. In some instances the three types of shale alternate in the same continuous bed, without separating strata of barren material such as clay.
Fig. 9.2 Map of Taubate - Tremembe area. State of Sao Paulo. U.S. Bureau of Mines, R.I. 4655, 1950.
or sandstone. Drilling has shown the shales extend for an indefinite depth. Yields range from 115 to 252 L/Mt (25 to 55 gal/st), and have a rather high water content (33%).

The principal visible constituents in the Tremembe shales were yellow organic matter, black organic matter, calcite, dolomite, montmorillonite, muscovite, granular pyrite, magnetite and bright-yellow organic material, possibly resin.

Oil Shale Mining at Tremembe (1948-49): The mine was entered through a vertical shaft, serviced by an electrical hoist to raise the mined shale to an elevated bin at the surface. The shaft was approximately 16.5 m (54 ft) deep and the main entry is about 2.5 m (8 ft) high and 11 m (36 ft) wide; the roof was supported near the shaft and only in a few other places. No evidence of spalling was observed throughout the mine.

The mine was non-gassy, and was illuminated by stationary electric lights. There was no mechanical ventilation, and no explosives were used. No machinery was used underground. Surface equipment was limited to the elevated ore bin and a small building on which the electric hoist was housed.

Although the shale was permeated with water and the walls were wet to the touch, no running water was observed in the mine, and it was evident the shale holds water so tightly that the walls can not bleed.

Mining was by the “room-and-pillar” method and substantial pillars were left as roof supports. The shale was broken manually using picks and was hand-shoveled into 1 Mt (1.1 st) steel ore cars, which were trammed by hand on steel rails to the base of the shaft. The shale was hoisted to the surface bin, from which it was hauled by trucks to the retorting plant at Taubate. No crushing was done at the mine (Figs. 9.21, 9.22, 9.23, and 9.24 are view of the operations at Taubate-Tremembe in the 1940’s).

The moist shale breaks very easily. It cuts like cheese, and the mine walls had the appearance of a stipple-finished plastered wall, except that the shale has a shiny black cast, due to the high moisture content.

Irati Black Shales

The Irati black shale was named by I.C. White from its occurrence near the town of Irati on the Sao Paulo-Rio Grande Railway.

The shale beds (known in Brazil as XISTOS) of the Permian Irati are the most extensive and the most promising for commercial exploitation. They have been under study since 1955 by the Superintendencia da Industrializacao do Xisto (six) a subsidiary of PETROBRAS, the Brazilian oil company. Although the Tertiary shale beds, which are of lacustrine origin, are some 35 m (115 ft) thick, yield 4 to 13% oil, 1.8 - 2/3% gas and contain about 318 million m³ (2 billion bbl) of oil, their moisture content poses difficult problems for exploitation.

The Irati Formation belongs to the Estrada Nova Group of the Passa Dois Series. The formation, extends for some 1700 km (1056 mi) from the State of Sao Paulo to the southern boundary of Brazil and into the country of Uruguay. The entire formation is underlain by the Palermo Formation and overlain by the Sierra Alta Formation. The Irati Formation has considerable lateral continuity, but does not remain in the same stratigraphic position as the deposit runs from Rio Grande do Sul to Sao Paulo. In the southern part of the deposit, there exists two distinct oil shale beds separated by a bed of shale and limestone. To the north, the oil shale beds are irregularly distributed within sections of limestone and dolomite.
Intrusions of basalt and diabase are wide-spread in the Irati Formation throughout Brazil. (1)(8)

The Irati oil shales are dark gray, brown to black in color, very finely grained, finely laminated, and fissile. The specific gravity ranges from about 1.8 to 2.45, generally decreasing with oil content. The kerogen content ranges between 2 and 14%, 21 to 146 L/MT (4.6 to 32 gal/st) and the shale typically contains less than 5 wt.% moisture. (1)(8)

Although the fresh shale is generally very hard, its lamination facilitates rapid weathering and the oil shale forms few outcrops. It commonly decomposes into the regolith as much as 10 m (33 ft) thick of reddish to yellowish-brown argillaceous soil.

The environment of deposition of the Irati Formation is controversial. The most widely accepted hypothesis is that of Beurten (1953, 1955), who postulated that at the end of the Carboniferous glaciation, the melting of the ice that covered the basin early in the Late Carboniferous led to custatic adjustments in the region. The sea water encroached, forming an intra-continental marine basin of reduced salinity with narrow and shallow communication with the ocean. Within this semi-enclosed environment a characteristic fauna and flora proliferated. Remains of these organisms and the fine-grained clastic material brought in by the rivers formed the carbonate rocks and shale of the Irati Formation. Later as a result of further custatic movements, the basin became shallower and the nonbituminous sediments of the Sierra Alta shale accumulated. (8)

Exploration and Reserves: The Irati Formation has been sampled by drill holes spread about 800 m (2,625 ft) apart across the outcrop at intervals of 10 km (6.2 mi) along the outcrop. Following this work three areas were selected for detailed surveys and systematic sampling. (8)

Two of the sites, the Sao Gabriel Area in the southwestern or "Campanha" section and the Don Pedrito Area in the southern section of the State of Rio Grande do Sul, were both found to contain 111 million m³ (700 million bbl) of oil in place. In these areas, the oil shale is located in two beds; the lower being 2.5 to 3.2 m (8.2 to 10.5 ft) thick and averaging approximately 7 wt.% oil content 79 L/MT (17 gal/st), and the upper bed being 9 m (29.5 ft) thick containing less than 3 wt.% oil 33 L/MT (7 gal/st). Separating the beds is a layer of barren shale approximately 10 m (33 ft) thick. The dominate terrain consists of gently rolling hills and normal dip of the oil shale beds is about 1.5%, both favorable conditions for surface mining. (1)(3)

The third potential site for mining, and the one selected for initial development, is located near the village of Sao Paulo Mateus do Sul in the State of Parana. The dominate geologic features of this area is shown in Fig. 9.2. (1) The two distinct oil shale beds are separated by an 8.6 m (28.2 ft) barren zone composed of 50% limestone and 50% shale. The lower bed contains an average 9.1 wt.% oil 115 L/MT (25 gal/st) and is approximately 3.2 m (10.5 ft) thick. The upper bed averages 6.5 m (21.3 ft) in thickness and contains about 6.4 wt.% oil 71 L/MT (15 gal/st). The combined oil content of both beds is 7.4 wt.% 83 L/MT (about 18 gal/st), Fig. 9.3 and Fig. 9.4. (1)(3)

The oil shale beds near Sao Mateus do Sul dip about 1.5% to the southwest. The topography is characterized by rolling hills with gentle slopes. The mining zone will be about 6 km (2.5 mi) wide, being determined in part by the limitation of 30 m (100 ft) maximum overburden set for economic reasons. The reserves under the conditions are estimated to be 95 million m³ (600 million bbl) of oil. Fig. 9.5. (1)

The Irati oil shales are Permian Age and are classified as the second largest
Fig. 9.3 Geologic map showing distribution of Irati oil shales in Sao Paulo, Parana and Santa Catarina. After Padula, U.N. Symposium, Tallinn Estonia, 1968.
Fig. 9.4 Geologic map showing distribution of Irati oil shales in Southern Santa Catarina and Rio Grande do Sul. After Padula, V.T., U.N. Symposium, Tallinn, Estonia, 1968.
Fig. 9.5 Typical section of Irati Formation, Sao Mateus do Sul, 1968. Tallinn Symposium, Estonia, 1968

Fig. 9.6 Main units of prototype complex, 1985. From Piper, E.M. et al., Worldwide commercialization.
known oil shale reserves in the world. The recoverable oil reserves are estimated at over 19 billion m$^3$ (119 billion bbl). The area of 92 km$^2$ (32 mi$^2$) near Sao Mateus, the site of the demonstration plant has a potential yield of approximately 117 million m$^3$ (737 million bbl) of oil, 22 billion m$^3$ of light gas (777 billion ft$^3$), 5.2 million m$^3$ (33 million bbl) of LPG and 10 million MT (11 million st) of sulfur.\(^{(5)}\)

Studies have indicated that full scale operations of the proposed facilities can be accomplished without adverse environmental effects.

**RETORt DEVELOPMENT**

**Tremembe-Taubaté**

Small scale oil shale industries in the State of Bahia and Sao Paulo produced illuminating gas, oil, locomotive fuel and wax products as early as 1881 using Scottish Henderson retorts. These operations all ceased by the 1920's (or before) when cheap conventional petroleum became available in the 1920's.\(^{(1)}\)

The abandoned plant near Tremembe was acquired in 1941 by the Companhia de Oleos Minerais S.A. which added several retorts and produced fuel oil and waxes in addition to combustible gases. The new retorts constructed in 1942, included a "gas circulation" type known as the Martin retort; and three producer-type retorts similar to those developed in Estonia. A Grondal-Ramen "tunnel oven" was proposed but never built.\(^{(3)}\)

**Henderson Retorts:** The Scottish Henderson retort battery (see United Kingdom) was installed originally to manufacture illuminating gas for the town of Taubaté. The 20 retorts were set in a series of five furnaces, four retorts to a furnace, and five furnaces being enclosed by an integral brick structure.

Capacity of a single retort was 590 kg (1,300 lb) of undried shale, and the operating cycle was 24 hours, during which a total of approximately 15 MT (16.5 st) of shale was processed. Some of the spent shale was ground for paint pigment.\(^{(3)}\)

**Producer-Type Retorts:** The operating retorts at Taubaté were a simple brick-lined vessel 2.2 m (7.25 ft) inside diameter and 6.3 m (20.7 ft) tall. The medium-size shale on 2.56 cm through 7.62 cm (1 in. to 3 in.) was gravity fed from the top of the retort, heated by direct contact with gases formed in the combustion zone formed by burning of the residual carbon on the spent shale after it passes through the combustion zone. Spent shales was continuously discharged at the bottom and oil vapors diluted with combustion gases and water vapor passed out of the side of the retort near the top of the condensing system.\(^{(3)}\)

**Martin Retort:** In this retort heat was supplied by transverse flow of hot gases through a vertical column of shale that moves downward by gravity between louvered walls of the retorting section, as in the Grande Paroisse retort.\(^{(9)}\) The heat-carrying gas is a portion of the mixture of vapors and fixed gases given off by the shale in passing through the retorting section. Heat was supplied at three different levels by three superimposed gas-heating and circulating systems.\(^{(3)}\)

This retort did not prove satisfactory, chiefly because of mechanical difficulties, and was only operated occasionally.\(^{(3)}\)
Refining at Taubate

The small capacity of the retorts did not warrant installation of modern continuous refining equipment, and batch or intermittent refining methods were used. (3)

PETROBRAS

The national government bought the facilities in 1951 and created the Comissao de Industrialization do Xisto Betuminoso (CIXB) under the supervision of the Conselho Nacional do Petroleo (CNP) to study the Paraiba shales and other Brazilian deposits. A year later the CIXB became part of the National Petroleum Council (CNO). A pilot plant was designed and built by Foster Wheeler Corp., a U.S. firm, to develop a retorting process for the Paraiba shales. Cameron and Jones, later a part of the Pace Companies, consulted on process development. Under CIXB responsibility, pilot scale experiments were performed abroad in 1952-53 to determine the potential for using available processes. (1)(10)

In 1954, the formation of PETROBRAS as the national oil company resulted in the transfer of CIXB responsibilities to the Superintendencia da Industrializacao do Xisto (SIX), a PETROBRAS division. Since 1954 SIX has been responsible for developing the Brazilian oil shale industry.

After concluding that no existing process was well suited to the high-moisture Paraiba shales, a pilot plant facility with a 2,200 MT/day (2,420 st/day) capacity was constructed at Tremembe to develop a process to produce oil specifically from Brazilian shales. The plant, as previously mentioned, was constructed by Foster Wheeler Co.; Paul Weir Co. of Chicago participated in the mining studies, and Cameron and Jones, Inc. were consultants until 1972. (1)

The Foster Wheeler plant became operational in 1955. Laboratory research and later pilot plant experiments on Irati shale at Tremembe revealed that the Irati shales were superior to the Paraiba shales in important ways; moisture content was 5%, in contrast to 33%; the sulfur content was approximately twice as large (sulfur is a shortage item in Brazil). Although the Irati shale yielded less oil on a dry basis, the lower moisture content resulted in the recovery of twice as much oil per unit mined. (1)

The favorable characteristics of the Irati shales led PETROBRAS to redirect its research to the development of a retorting process suitable for the Irati Formation. Preliminary tests indicated that directly heated retorts, in which the shale is burned in the pyrolysis vessel to generate process heat, were not suitable for the Irati shale because it tended to swell, soften, and agglomerate when heated to combustion temperatures. This prevented a uniform flow of solids through the retort and caused severe operating problems. The general approach that was adopted retorting the Irati shale in a stream of gasses that had been heated outside the retorting vessel. The process that evolved into the Petrosix retorting method was patented by PETROBRAS in 1959. (1)

The Petrosix process developed (name derived from Petrobras-Superintendencia da Industrializacao do Xisto) has been modified and remodeled since 1959 in an attempt to solve Brazil's unique problems. (10)

The main difference between the Petrosix process and other known retorting schemes is the use of external heating to achieve temperatures required to pyrolyze the previously crushed shale inside the retort.

The encouraging results led to the design of the UPI demonstration plant at Sao Mateus do Sul.

PETROBRAS invested 68 million U.S. dollars in the facility with the construction
work completed in 1972. The facility went on steam the same year, Fig. 9.6 and Fig. 9.7. (10)

COMMERCIAL PLANT (12)

The information here was supplied by Rezende and Piper (12). For the most part the data is presented as received. This is probably the latest and most complete report of the costs and equipment requirements of a large scale oil shale facility available. The figures of plant facilities are of the UPI plant. (Fig. 9.16 and 9.17 are views of the 1972 operations, while Fig. 9.18 is a 1987 view of the current complex. Fig. 9.20, is an early view of the open pit).

Economic Aspects of the Project

Typically, oil shale projects require high capital costs and give rather low investment rates of return, because of the large mass of solids that has to be mined, crushed and heated to yield relatively small amounts of product oil. Also, the shale pyrolysis and the oil recovery operations involve many problems whose economic solutions are not apparent.

Plant Capacity: The San Mateus do Sul shale deposit entails an economically minable area of 64 km$^2$ (24.8 mi$^2$). The deposit contains over 89 million m$^3$ (560 million bbl) of shale oil. The plant capacity was based upon several factors.

The market presents no limitations, since oil and sulfur needs in Brazil are supplied mostly by imports. Extrapolation of economic data shows that shale oil costs decrease with capacity, Fig. 9.8, until mining and shale transportation costs become so high as to balance the decrease in processing costs. An economic optimum occurs at a capacity of several hundred thousand barrels per day. Various problems exist with such a large capacity plant. The mine would be depleted before the useful life of equipment is reached. Construction would be difficult, because of limited local resources and equipment manufacturers would probably not be able to meet schedule requirements. Also, the high investment costs magnify risks and result in considerable financial problems.

Minimum economic capacity is about 1,590 m$^3$ (10,000 bbl/day), when shale oil cost approaches the international fuel price, Table 9.1. The 1,590 m$^3$ (10,000 bbl/day) plant is less economically attractive than the larger plant although presenting fewer problems.

The final decision was to set the commercial plant capacity at 7,949 m$^3$ (50,000 bbl/day) which is still a significant production compared with domestic oil production and also presents an acceptable investment return.

Plant Location: In order to keep raw shale and spent shale transportation costs to a minimum the plant must be located as close as possible to the center of the mining area. However, location of the plant right in the center of the area would interfere with mining operations and hinder access to the plant. A significant loss of recoverable shale under the plant would also occur. The optimum location was found to be at that side of the mine where topographical, waste disposal, raw water supply conditions and other factors were most favorable.

Power Supply: In the demonstration plant the recycle gas compressor is driven by a steam-turbine. Steam is generated in the plant using shale oil as fuel. The turbine driver was a requirement for operating flexibility, since wide ranges of recycle gas flow had to be tested.
Fig. 9.7 The Petrosix process. From E.M. Piper, et al., Petrosix Application for Worldwide Commercialization of Oil Shales, 1985.
Fig. 9.8 Shale oil costs versus capacity-first stage. From J. Rezende and E.M. Piper, Oil Shale Technology in Brazil, Curitiba, 1982.
The recycle gas flow in the industrial plant will be maintained at or near design conditions, and no flexibility is needed beyond normal process variations. This allows the use of electric motors to drive the compressors using inexpensive purchased electric power. This will result in savings of about 1,740 m³ (11,000 bbl/day) of shale oil in the industrial stage plant. Construction of a 10 km (6.2 mile) transmission line is necessary to supply the plant.

Retort Diameter: Due to the high investment required for shale processing capital-related costs such as depreciation, interest and maintenance become an important part of production costs. Therefore, significant reduction in costs can be achieved by using large size equipment. In the design of the PETROSIX industrial plant, equipment having the largest possible size was selected, providing continuous and efficient operation could be assured.

In the retorting section, equipment size depends on retort capacity. Structural calculations for the hot gas injectors (which also act as beams, supporting part of the weight of the shale above) and for the discharge mechanism showed that diameters larger than 11 m (36 ft) would present some mechanical design problems without a compensating benefit. Furthermore, increasing the retort diameter could adversely affect solids and gas flow distributions. A great part of the demonstration plant work was dedicated to this problem. Correlations were developed, and a full size 11 m (36 ft) diameter retort was constructed to test the flow pattern. Results confirmed that behavior of shale and gas in the large retort are very similar to that observed in the demonstration unit.

Retorting Rate: One of the most important variables affecting economics of the PETROSIX plant is the retorting rate. High retorting rates have been reached in pilot and demonstration plant operation, but design retorting rate for the industrial plant was selected by optimization of annual costs.

For a given total shale processing capacity, low retorting rates result in an increased number of retorts and ancillary equipment in each retorting unit. This increases capital and operating costs. On the other hand, gas velocity in the retort will be low, and pressure drop is reduced. Therefore, compressor costs decrease. The influence of retorting rate on operating costs is shown in Fig. 9.9. Minimum operating costs occur at a retorting rate of 2,700 kg/hr/m² (5,940 lb/hr/ft²). For the PETROSIX industrial plant, eighteen units are required with this retorting rate. Two more retorts were added to achieve the plant overall operating service factor of 95%.

Equipment Optimization: A similar optimization procedure, relating investment costs to compression costs, was followed to establish the design pressure drops for the cyclones, gas heater and large ducts. The analysis considered the effect of gas velocity on the collection efficiency of the cyclones and on the heat transfer coefficient of the gas heater. Other economic studies included the optimization of the water recirculation rate at the oil condensing system, selection of equipment and construction materials, optimum pipe diameters, etc. In the PETROSIX industrial plant all costs of a retorting unit were to be multiplied by twenty, each single piece of equipment received careful economic analysis.

Main Characteristics of the Commercial Plant

The Sao Mateus do Sul Industrial Plant was designed for processing 112,000 MT/day (123,200 st/day) of oil shale and for producing about 7,949 m³ (50,000 bbl/day) of shale oil. The plant facilities will occupy an area of 2.5 km² (0.97 sq. mile) located about 13 km (8 miles) northwest of Sao Mateus do Sul (Fig. 9.14).
Fig. 9.9 Optimum retorting rate. From J. Rezende and E. M. Piper, Oil Shale Technology in Brazil, 1982.
The industrial plant is composed of the following units.

- U-100 - Mining
- U-200 - Solids Handling
- U-300 - Retorting
- U-400 - Gas Treating
- U-500 - Oil Pre-Treating
- U-600 - Oil Transfer and Storage
- U-700 - Utilities
- U-800 - Auxiliary Systems
- U-900 - Maintenance
- U-1000 - Administration

There will be a pipeline from Sao Mateus do Sul to Araucaria, the nearest petroleum refinery of PETROBRAS.

It is planned to build a hydrotreating unit at the Parana Refinery for upgrading the oil.

The Commercial Plant will be in two stages, each one with 50% of the total capacity.

**Mining:** There will be two mines, one for the first stage and one for the second stage. Each strip mine is sized to remove yearly 33 million m³ (43 million yd³) of barren material and 23 million MT (25.3 million st) of oil shale. Each mine will have the following equipment:

- 1 electric walking dragline with 84 m³ (110 yd³) bucket for removing the overburden
- 1 electric walking dragline with 59 m³ (77 yd³) bucket
- 3 electric shovels with 23 m³ (30 yd³) bucket for loading oil shale
- 9 electric rotary blast hole drills
- 20 rear dump trucks, diesel-electric, 154 MT (170 st) payload for transporting oil shale to primary crushers and soil to cover the retorted shale
- 2 wheel loaders with 19 m³ (25 yd³) bucket
- 11 crawler tractors of 400 hp
- 4 wheel-tractors of 300 hp.

**Solids Handling:** The solids handling installation was designed in two identical units, one for the first stage and one for the second stage. Each unit will process about 2,700 MT/hr (2,970 st/hr) of mined oil shale and will consist of the following main sections:

**Primary and secondary crushing section, Fig. 9.10:** This section consists essentially of 2 primary crushers, 4 scalping single-deck screens, 4 secondary crushers and 1 two-way belt conveyor 4 km (2.5 mi) long. The crushers, gyratory type, are placed inside the mining area in order to reduce transportation cost. The crushed shale 20.3 cm (8 in. max) is conveyed to the long storage piles near the industrial plant.

**Storage and blending section:** This section is not equal for the two stages. In the first stage it will have 4 long piles, 1 two-arm stacker and 2 bucket-wheel bridge reclaimers. For the second stage only 2 more long piles, 1 stacker and 1 reclaimer will be added. Each long pile stores approximately 150,000 mt (165,000 st) of raw shale.
Fig. 9.10 Crushing operations at Sào Mateus do Sul, from A. Varisco, O Processo Petrolífero - A Usina Prototipo do Irati, Curitiba, Brazil.
Screening and Tertiary Crushing: The screening will be performed by 19 primary double-deck screens and 14 secondary double-decked screens. The tertiary crushing will be done by 5 cone crushers. The material between 0.63 and 6.3 cm (1/4 in., and 2 1/2 in.) will be sent to the retort feed bins and the fines will be returned to the mining area together with the retorted shale.

Retorting: The retorting section consists of 20 units physically distributed in pairs, each pair called a module. Each module contains the following equipment: 2 retorts with a diameter of 11 m (36 ft), 4 cyclones, 2 electrostatic precipitators, 2 recycle gas compressors, 2 fired gas heaters and 2 light oil condensers.

The oil shale is fed to each retort by an individual belt conveyor at a rate of 360 MT/hr (286 st/hr).

The shale, after passing through the sealing and distribution devices, enters the retort and flows down countercurrent to the hot gas stream ascending through the retort, Fig. 9.11. After being retorted and cooled by the cold recycle stream, the processed shale is discharged in a hydraulically sealed vessel from which it is removed by a flight conveyor and then transported by belt conveyor to the mining area for disposal, Fig. 9.12.

Products from the retorting unit consists of heavy oil which is collected in cyclones and precipitators, light oil and retort water collected in the condenser and pyrolysis gas. The heavy and light oils are sent to the Gas Treating Area.

Gas Treating: In the Gas Treating Area the pyrolysis gas is first compressed and desulfurized in a DEA tower for separating the sour gas, Fig. 9.13.

The sour gas is sent to the Claus Unit to recover sulfur. The purified gas is sent to the LPG Unit for recovering LPG and naphtha. The remaining light gas is used as fuel in the plant.

The retort water is steam stripped and the sour gas obtained is also sent to the Claus Unit for sulfur recovery, Fig. 9.14.

In the first stage, one unit for gas desulfurizing, one for LPG recovery and one for water stripping will be built. Each of them are designed with 50% of total capacity. The Claus plant will be built in 2 units in the first stage, each with 45% of the total capacity. In the second stage one more unit will be added to each treating section.

Oil Pre-Treating: The Oil Pre-Treating Area was designed to process the composite oil in order to produce the fuel oil needed by the plant and prepare a better feed for hydrotreating, Fig. 9.15.

The composite oil will first be centrifuged to remove the solids and water. After cleaning, the composite oil will be submitted to atmospheric and vacuum distillation in order to produce the heavy fuel oil to be burned in the plant and a lighter fraction for hydrotreating. Because of the high capital investment of the hydrotreating it was decided not to build a unit in the first stage. In this case, all the shale oil will be used as fuel oil and the vacuum distillation becomes unnecessary. Therefore, in the first stage only a pre-flash tower will be built to adjust the flash point of the shale oil for local consumption.

The naphtha produced in the pre-flash and gas treating units will be sent to the Parana Refinery for stabilizing in the FCC and conversion into gasoline. Fig. 9.16 is a 1972 view of the Sao Mateus do Sul complex. Fig. 9.17 is a view of the 1972 Pertosix retort. Fig. 9.18 is a 1987 view of the entire complex. Fig. 9.19
Fig. 9.11 Retorting and oil recovery operations at São Mateus do Sul. From A. Varisco, O Processo Petrosix – A Usina Protótipo do Irati, Curitiba, Brazil.
Fig. 9.12 Handling retorted shale at Sao Mateus do Sul. From A. Varisco, O Processo Petrosix - Usino Prototipo do Irati, Curitiba, Brazil.
Fig. 9.13 Oil treatment at Sao Mateus do Sul. From A. Varisco, O Processo Petrosix - A Usino Prototipo do Irati, Curitiba, Brazil.
Fig. 9.14 Gas cleaning at Sao Mateus do Sul. From A. Variosco. O Processo Petrosix - A Usina Prototipo do Iraí, Curitiba, Brazil.
Fig. 9.15 Sulfur recovery at Sao Mateus do Sul. From A. Varisco, O Processo Petrosix - A Usino Prototipo do Irati, Curitiba, Brazil.
is a graph showing shale oil costs versus oil shale grade per ton. Figs. 9.20, 9.21, 9.23, 9.24, 9.25, 9.26, 9.27 and 9.28 are views of early oil shale operation in Brazil.

Utilities: This area was designed to provide the utility requirements of the entire plant.

The main installations are:

- 4 boilers with a capacity of 100 MT/hr (110 st/hr) each of steam at 42 bar and 394°C (741°F).
- Modular cooling tower for 14,500 m³/hr (3.8 million gal/hr) of cooling water
- Water treatment for 1300 m/hr (343,000 gal/hr) impoundment for 1630 m³/hr (430,000 gal/hr) of raw water
- 3 inert gas generators for 12000 Nm³/h each
- Electric power installation for receiving 235 MV of primary electric energy at 230 kV, transforming it to 23 kV and 13.8 kV and a power distribution network
- Compressed-air station for 11000 Nm³/hr
- Fuel oil and fuel gas distribution system
- Fire protection water system

In the first stage approximately 50% of the utility installations will be built.

Oil Transfer and Storage: The most important part of this area is the Tank Farm:

- 4 tanks for dirty oil with 11,900 m³ (3.14 million gal) each.
- 4 tanks for clean oil with 32,900 m³ (8.7 million gal) each
- 4 tanks for the 1st stage fuel oil with 16,500 m³ (4.4 million gal) each, these tanks will be used for pre-treatment oil in the second stage.
- 2 tanks for start-up fuel oil with 8,500 m³ (2.2 million gal) each
- 4 tanks for light naphtha with 6,900 m³ (1.8 million gal) each.
- 6 spheres for LPG with 3,000 m³ (792,000 gal) each

It was decided to construct all the tanks in the first stage with only 4 LPG spheres.

The other parts of this area are:

- Pump House
- Diesel Oil Receiving Stations
- Propane Receiving Station
- Storage and Delivery of Sulfur

Auxiliary Systems: This area consists of the following installations:

- Interconnecting pipe-ways
- Flare system
- Liquid effluents treatment

The effluents treatment will be built completely in the first stage.

The interconnecting pipe-ways will be constructed in the first stage and the pipes will be installed as required by each stage.

The flare system is, for reasons of size, a double installation, half of which will be built in the first stage.
Maintenance: The Maintenance Facilities were designed to accomplish all the necessary services to maintain the plant in good operating conditions. Some services were assumed to be contracted in order to reduce costs.

Administration and General Support: The general administrative and support facilities are as follows:
- Administration Building
- Reception and Security
- Medical
- Training Center
- Telecommunications Center
- Transportation Facilities
- Restaurant
- Workshop for Miscellaneous Services
- Warehouse
- Industrial Safety
- Equipment Inspection
- Laboratory

Main Data

Table 9.1, presents the data about daily production and consumption of oil shale products.

Table 9.2, shows the energy balance and efficiencies for the retorting section and for the whole industrial plant.

When calculating the energy balance and efficiencies two questions arose. (1) What factor should be used to convert the electric power to equivalent petroleum? Should it be based on power costs based on the usual conversion of thermal to electric energy? Because of the low cost of electric power in Brazil these two figures are quite different. (2) Why not include the sulfur in the energy balance? As Brazil imports most of the sulfur it consumes, the internal production of sulfur helps the balance of trade.

These comments explain the several different results for energy balances and efficiencies shown in Table 9.2.

Main Economic Results: After the basic design was completed, a cost estimate and economic evaluation was performed. The main results are presented in Tables 9.2, 9.3, 9.4, 9.5, and 9.6. A sensitivity analysis was also performed, and results showed the project economics to be moderately sensitive to estimating errors. Table 9.7, shows the results for simultaneously increasing the investment by 20% and reducing the on-stream from 90% to 80%.

An estimated effect of shale oil content on product oil cost based upon the PETROSIX process, is shown in Fig. 9.19.

FUTURE PLANS (12)

In mid-1982 a decision was made to build a complete Industrial Plant of 413 m³ (2,600 bbl/day) capacity, with one retort 11 m (36 ft) in diameter and gas treatment (DEA-Claus) facilities. Operation was scheduled for mid-1988.

The plant will be located at the same site of the UPI facilities thereby utilizing infrastructures such as offices, shops, laboratory and utilities. Tank storage
Fig. 9.17 View of Petroxix plant in 1970's. From Cameron Engineers, Denver, Colorado.
Fig. 9.18 A 1987 view of Petrosix operations at Sao Mateus do Sul. From E.M. Piper, Stone and Webster Engineers, Denver, Colorado.
Fig. 9.19 Shale oil costs versus oil content in shale. From A. Varisco, O Processo Pertosix - A Usino Prototipo do Irati, Curitiba, Brazil.
and some other facilities will be increased in size to accommodate the additional capacity.

The present status of the plant (December 1985) is:
  o PETROSIX engineering: completed.
  o Materials Handling Unit: Installed.
  o Retort: Erected.

Current operating time as of April 1989, exceeds 105,000 hours during which the processing of over 6 million metric tons of shale has produced over 3 million barrels of oil.

Research is underway to utilize the 20% of fines from the ore that are now lost. A "spouted bed process" together with a circulating fluidized boiler process are being tested with considerable success.

Table 9.1 Oil Shale Industrial Plant Production and Consumption

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>FIRST STAGE</th>
<th>SECOND STAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MT/day</td>
<td>m³/day</td>
</tr>
<tr>
<td>Mining oil shale</td>
<td>66,000</td>
<td>-</td>
</tr>
<tr>
<td>Rejected shale fines</td>
<td>10,000</td>
<td>-</td>
</tr>
<tr>
<td>Retort feed</td>
<td>56,000</td>
<td>-</td>
</tr>
<tr>
<td>CROSS PRODUCTION</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- sulfur</td>
<td>496</td>
<td>-</td>
</tr>
<tr>
<td>- Fuel gas</td>
<td>436</td>
<td>622,900</td>
</tr>
<tr>
<td>- LPG</td>
<td>326</td>
<td>593</td>
</tr>
<tr>
<td>- Naphtha</td>
<td>516</td>
<td>674</td>
</tr>
<tr>
<td>- Pre-Treated oil</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Fuel oil-OC-1</td>
<td>3,250</td>
<td>3,403</td>
</tr>
<tr>
<td>- Fuel oil-OC-2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CONSUMPTION</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Fuel gas</td>
<td>436</td>
<td>622,900</td>
</tr>
<tr>
<td>- Fuel oil-OC-1</td>
<td>720</td>
<td>754</td>
</tr>
<tr>
<td>- Fuel oil-OC-2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NET PRODUCTION</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Sulfur</td>
<td>496</td>
<td>-</td>
</tr>
<tr>
<td>- LPG</td>
<td>326</td>
<td>593</td>
</tr>
<tr>
<td>- Naphtha</td>
<td>516</td>
<td>674</td>
</tr>
<tr>
<td>- Pre-treated oil</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Fuel oil-OC-1</td>
<td>2,530</td>
<td>2,649</td>
</tr>
</tbody>
</table>

Table 9.3 Total Capital Investment (Millions of U.S. Dollars)

<table>
<thead>
<tr>
<th></th>
<th>Stage-1</th>
<th>Stage-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Shale Plant</td>
<td>1,148</td>
<td>2,001</td>
</tr>
<tr>
<td>Pipeline</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>Hydrotreating</td>
<td>-</td>
<td>166</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,198</td>
<td>2,218</td>
</tr>
<tr>
<td>Cost in Cruzeiros</td>
<td>87%</td>
<td>84%</td>
</tr>
<tr>
<td>Foreign Purchases</td>
<td>13%</td>
<td>16%</td>
</tr>
</tbody>
</table>

(1) Brazilian taxes (imports, sales) not included. Project is to be tax exempted.
Table 9.2 ENERGY BALANCE AND EFFICIENCIES IN THE INDUSTRIAL PLANT (112,000 MT/d SHALE)

(Energy Unit: 1 bbl of petroleum = 5.5 x 10^6 Btu)

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>UNITS</th>
<th>RETORTING SECTION</th>
<th>WHOLE INDUSTRIAL PLANT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>I - ENERGY IN RAW OIL SHALE</td>
<td>bbl/d</td>
<td>113,259</td>
<td>113,259</td>
</tr>
<tr>
<td>II - GROSS PRODUCTION</td>
<td>bbl/d</td>
<td>68,363</td>
<td>68,363</td>
</tr>
<tr>
<td>III - CONSUMPTION</td>
<td>bbl/d</td>
<td>12,466</td>
<td>17,139</td>
</tr>
<tr>
<td>IV - BALANCE</td>
<td>bbl/d</td>
<td>55,897</td>
<td>51,224</td>
</tr>
<tr>
<td>V - EFFICIENCIES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-IV - I</td>
<td>%</td>
<td>49</td>
<td>45</td>
</tr>
<tr>
<td>-IV - II</td>
<td>%</td>
<td>82</td>
<td>75</td>
</tr>
</tbody>
</table>

(1) To convert sulfur to equivalent petroleum the ratio of CIF prices was used.
(2) Conversion of electric power to equivalent petroleum based on the respective prices in Brazil.
(3) Conversion of electric power to equivalent petroleum based on the thermal equivalent factor multiplied by 3.3 to take into account the efficiency of thermal to electrical energy transformation.
(2) Values for January 1981

### Table 9.4 Oil Shale Industrial Plant

**Capital Investments:**

(Millions of U.S. Dollars)

<table>
<thead>
<tr>
<th></th>
<th>Stage-1</th>
<th>Stage-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities</td>
<td>135</td>
<td>260</td>
</tr>
<tr>
<td>Mining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Handling</td>
<td>210</td>
<td>341</td>
</tr>
<tr>
<td>Retorting</td>
<td>306</td>
<td>607</td>
</tr>
<tr>
<td>Gas Treating</td>
<td>43</td>
<td>85</td>
</tr>
<tr>
<td>Oil Pre-Treating</td>
<td>26</td>
<td>55</td>
</tr>
<tr>
<td>Storage</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Utilities</td>
<td>68</td>
<td>96</td>
</tr>
<tr>
<td>Auxiliary Systems (1)</td>
<td>21</td>
<td>27</td>
</tr>
<tr>
<td>Maintenance</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complementary Items</th>
<th>Stage-1</th>
<th>Stage-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Acquisition</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Site Preparation &amp; Others (2)</td>
<td>86</td>
<td>117</td>
</tr>
<tr>
<td>Start-Up Expenses</td>
<td>91</td>
<td>147</td>
</tr>
<tr>
<td>Working Capital</td>
<td>36</td>
<td>76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contingencies (6.5%)</th>
<th>Stage-1</th>
<th>Stage-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70</td>
<td>122</td>
</tr>
</tbody>
</table>

**TOTAL**

1,148                  2,001

(1) Pipeways, flair, waste treatment and disposal facilities, fire protection.

(2) Construction administration and insurance.

### Table 9.5 Operating Costs

(Millions of U.S. dollars per year)

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Costs (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchased Power (demand)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Maintenance Materials</td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td>Labor</td>
<td>45</td>
<td>71</td>
</tr>
<tr>
<td>Contracted Services (2)</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable Costs (1)</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Materials (3)</td>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td>Purchased Power (consumption)</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Purchased Fuels (4)</td>
<td>5</td>
<td>32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contingencies</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>12</td>
</tr>
</tbody>
</table>

**TOTAL**

113                  272

(1) No Taxes included.

(2) Maintenance, personnel transportation & others

(3) Explosives for mining, chemicals & other.

(4) Diesel for mine trucks and naphtha for hydrotreating.
Fig. 9.20 Early view of open pit mine at Sao Mateus do Sul
From Kay Berry, Cameron Engineers, Denver, Colo.

Fig. 9.21 The oil shale plant of Taubate. From Boletim 28, Estada De Parana, Curitiba, Brazil.
Fig. 9.22 View of Taubate oil shale plant, 1940's. From Boletim 28, Estada De Parana, Curitiba, Brazil

Fig. 9.23 Condensers and retorts at Taubate plant. From Boletim 28, Estada De Parana, Curitiba, Brazil
Fig. 9.24 Underground mine at Tremembo, 1940's. From Boletim 28, Estada De Parana, Curitiba, Brazil

Fig. 9.25 Bachacheri plant, Curitiba, 1941-42. From Boletim 28, Estada De Parana, Curitiba, Brazil
Fig. 9.26 Lupion and Co. retort, Curiuwe, Parana, 1940's. Boletim 28, Estrada De Parana, Curitiba, Brazil.

Fig. 9.27 Sociedade de Minerals Ltd., Sao Gabriel, State Rio Grande do Sul. Boletim 28, Curitiba, Brazil.
Fig. 9.28 Distillation plant of the Joao Branco Co., in Marau, Bahia, date unknown. From Boletim 28 Instute De Biologia E Pesquisas Tecnologicas, Estada De Parana, Curitiba, Brazil.
### Table 9.6 ECONOMIC EVALUATION

<table>
<thead>
<tr>
<th></th>
<th>Stage-1</th>
<th>Stage-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Costs US$/bb1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Return on Investment</td>
<td>0%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>42</td>
</tr>
<tr>
<td>Product Value, US$/bb1</td>
<td></td>
<td>36(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33(2)</td>
</tr>
<tr>
<td>Expected Return Rate%</td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

1. International market price (FOB) for low sulfur fuel oil.
2. Average CIF value of PETROBRAS oil imports.
   The 30°API Syncrude is rather equivalent to a light petroleum with a CIF value of about 40 US$/bb1.

### Table 9.7 ECONOMIC EVALUATION

- Investment Increased by 20%
- Operating Factor Reduced to 80%

<table>
<thead>
<tr>
<th></th>
<th>Stage-1</th>
<th>Stage-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment, 10⁶ US$</td>
<td>1,429</td>
<td>2,644</td>
</tr>
<tr>
<td>Oil Cost (10%) Return US$/bb1</td>
<td>41</td>
<td>37</td>
</tr>
<tr>
<td>Expected Return %</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

### REFERENCES

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CHILE

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<td>Development</td>
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<td>Future Plans</td>
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<td>References</td>
<td>216</td>
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<tr>
<td>Illustrations</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 10.1 Map showing oil shale areas. See South America
Fig. 10.2 Photographs of Lonquimay Deposit.

HISTORY

The principal shale deposits are located in the Provinces of Malleco, Bio-Bio, and Antofagasta, Fig. 10.1.

The oil shales of Chile, and especially the deposit at Lonquimay, in the south central zone, have been known since the 1890's. Since then the Lonquimay deposit has been examined by a long list of geologists and engineers over a period of some 40 years. (1)

The first recorded examination was in 1897, by Leo Wehrly and Carl Buckerharot, of Germany; Dr. Smyle Framme of Scotland visited the area in 1906, followed by Dr. Ellis Jansson of Sweden in 1913. The Chilean government sent its own geologist, Dr. Johannes Felseh, of the Ministry of Industry and Public Works, to report on the deposit in 1915.

Other examinations were made by Dr. Johannes Bruggen of Germany in 1920 and by Richard T. Hird and Jorge Westman, of Scotland, also in 1920. The Cia. Asphalt et Petrole, of France, sent geologist Jean Chautard and two assistants to the deposit in 1926. In the following year (1927) the Chile Shale Corporation, in cooperation with the Bethlehem Steel Corporation, sent one of the latter's geologists to study the deposit.
GEOLGY

Lonquimay Deposit

The oil shales deposits at Lonquimay, which are estimated to cover 46,000 acres (72 mi²), were described in the 1915 report by Dr. Felseh as follows:

1. "When the Eocene rocks of the Lonquimay region settled the necessary geologic conditions existed for the formation of hydrocarbons."
2. "These hydrocarbides present themselves at present in solid form in slate and bituminous calcium carbonates of the Eocene, and also in liquid form in the same rocks."
3. "As regards the quantity of solid hydrocarbides in the Eocene rocks, it is so large that it might furnish material for a distillation industry."
4. "In that part where the bituminous rocks have not been covered from their formation the liquid hydrocarbides must have not been totally removed, and therefore at this level no petroleum deposits of importance can be expected."
5. "Only in the bituminous rocks which have been covered from their formation has it been possible for the oil to remain in the Eocene rocks, the quality of which can be determined by stratum drilling. These drillings would require a small outlay of money, for the layers or strata are formed of soft rock and moreover the depth of the drilling would scarcely exceed 200 m (656 ft)."(2)

The study of the Bethlehem geologist, A.H. Saurusbrum, reported that, "it would appear a cubic average of 200,000 tons of surface shale per hectare (2.471 acres), and since it has been estimated that there are 20,000 hectares (77 mi²) in sight, there would be sufficient deposits to last for many years"(2)

Tests of oil yield were made by many of those who examined the deposits and apparently the yield averaged about 120 kg/MT, 12% or 30 gal/MT (33 gal/st) of crude petroleum, 24 m³/MT (847 ft³) of combustible gas and 20 kg/MT (48 kg/st) of ammonia water. The following were produced from the 120 kg (264 lb) of crude oil:

<table>
<thead>
<tr>
<th>Product</th>
<th>Percentage</th>
<th>Kilograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>16</td>
<td>19.2</td>
</tr>
<tr>
<td>Kerosene</td>
<td>18</td>
<td>21.6</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>50</td>
<td>60.0</td>
</tr>
<tr>
<td>Paraffin, solid</td>
<td>11</td>
<td>13.2</td>
</tr>
<tr>
<td>Residual asphalt</td>
<td>5</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>100</strong></td>
<td><strong>120.0</strong></td>
</tr>
</tbody>
</table>

Other Deposits

No information was found regarding the oil shale deposits at Malleco and Antofagasta.

RESOURCES

An evaluation of the Lonquimay deposit by the Chilean Department de Minas y Petroleo, in 1936, reported that the higher grade in parts of the deposit yielded about 20 gal/MT (22 gal/st) and contained about 3.3 million m³ (21 million bbl) of oil. The parts of the deposit yielding 6 gal/MT (6.6 gal/st) contain about 22 million m³ (138 million bbl) of oil equivalent. This 21 million barrel figure is also reported by Delahaye.(3)
Fig. 10.1 Early photographs of the oil shales of the Lonquimay deposit. From report by American Consulate General, 1933.
DEVELOPMENT

Despite the fact that oil shale has long been known to exist in the Lonquimay region, and that representatives of various foreign firms, as well as those of the Chilean government, owners and promoters have explored the deposit, made tests, etc., no definite action has ever been taken to produce the oil. Of all early efforts, probably the one in 1927 came closest to realization when the Chile Shale Corporation, in cooperation with the Bethlehem Steel Corp. sent representatives to investigate the possibility of producing oil, constructing a railroad and a pipe line to the field.

The largest obstacle in these early efforts was the lack of a railway from Curacautín to the deposit. The required railway was 94 m (58 mi) in length including a tunnel 4.55 m (2.82 mi) long. The plans were to construct a distillation plant at Lonquimay and connect it by pipe line to a refining plant at the port of Talcahuano, 304 km (189 mi) distant by rail from the shale deposit.

Apparently when this rail route was eventually built, the lack of financing and the lack of need for the products prevented development. Fig. 10.2 shows views of the Lonquimay deposit.

It was also rumored (in 1933) that Japanese interests had obtained an option for six months with the right to extend it for a like period for the purchase of the deposit at Lonquimay. The sum mentioned was two million US dollars. However, nothing ever developed and the deposit has not been developed to this date.

FUTURE PLANS

There are no known plans for the exploitation of oil shales in Chile.

REFERENCES

2. McLain, Camden L. Vice Consul, 1933, Shale Oil Deposit in South Central Chile, Voluntary Report prepared by the American Consulate General, Santiago, Chile. 6 pages.
Chapter 11
PARAGUAY AND VENEZUELA

INTRODUCTION

No historic usage or exploration of the oil shale of Paraguay and Venezuela were found. Apparently there have been no attempts to exploit oil shales in either country. In Paraguay this is probably in part due to the apparently limited shale resource, while in Venezuela the large oil reserves make the development of shale unnecessary.

PARAGUAY

The Irati shales of Permian age underlie the Parana Basin in eastern Paraguay. No records of any attempt to define or utilize these shales was found.

VENEZUELA

Due to the large reserves of natural petroleum (28 billion barrels estimated in the 1987 World Almanac) there has been little or no interest in oil shales. However, it is known that oil shales exist south of Lake Maracaibo since they were penetrated by an American Oil Company in exploration drill holes. The extent or grade of the shales is not available.

FUTURE PLANS

There are no known future plans for oil shale development in either Paraguay or Venezuela.
Chapter 12

PERU

HISTORY

Very little information was found regarding the oil shales of Peru, other than statements that oil shales occur. McKee(1) presented the following:

"Shales from Peru yield oil having an odor closely resembling that of pine tar, but neither plant nor animal remains are recognized in the material examined."

McKee continued: "Oil yielding shales occurring in or near some of the mining districts of Peru have been examined and tested with a view to their availability as a source of fuel for mining and smelting purposes. Samples from one of these deposits yielded 110 L/MT(24 gal/st) of a high quality of oil different from that yielded by other deposits tested by the author. The geologic features of these deposits have not been described."

No records of efforts to either define or develop the oil shales were found. Peru has listed reserves of 106 million m³(670 million bbl) of petroleum(2) which may be a factor in the non-development of the oil shales.

FUTURE PLANS

There are no known plans for future development of the oil shales of Peru.

REFERENCES

Chapter 13

URUGUAY

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<th>Page No.</th>
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Fig. 13.1 State of Cerro Largo Showing Oil Shale Area.
Fig. 13.2 Mangrullo Oil Shale Area.
Fig. 13.3 Typical Core Log Showing Sequence and Thickness of Layers.

INTRODUCTION

Like many countries of the world, Uruguay has no known coal or petroleum resources. Oil Shale is the only fossil energy resource whose existence has been proven.

The "Administracion Nacional de Combustibles, Alcohol y Portland" (A.N.C.A.P.), over a six year period of exploration (1976 to 1981) has demonstrated that the extended "Mangrullo" formation possess oil shales with enough potential for economic feasibility to justify a preliminary feasibility study.

ACKNOWLEDGEMENTS

The assistance of Dr. Harry E. McCarthy, President, Synfuels Engineering and Development Co. Inc. Rifle, Colorado provided the information used here. The Masters Thesis(2) prepared by Ernesto L. Pesce, provided the basic information concerning the deposit.
GEOGRAPHY

The Oriental Republic of Uruguay is located in South America between 30 and 35° south latitude. Its coast line is formed by the River Uruguay to the west and the River "de la Plata" and the Atlantic Ocean to the south and east.

The three largest near surface oil shale deposits, Mangrullo, Villa Vinoa, and Cruz de Piedra, are located in the northeastern part of the State or Department of Cerro Largo. The major deposit, Mangrullo area, Fig. 13.1 and Fig. 13.2, lies 4 km(2.5 mi) toward the southwest from the Brazilian border and 5 km(3.1 mi) east of Interstate Route 8. Topographically, the area consists of flat undulating land with deep fertile soil at elevations that range from 85 m to 160 m(278 to 525 ft) above sea level. The area is cut by Burros Creek. The climate is moderate with moderate to heavy rainfall, but no snowfall.

GEOLOGY

The mangrullo formation is included in the "Caraguala" Group, a part of the Gondwana Supergroup and is believed to be of Permian Age.

The oil shale stratigraphically consists of an upper bituminous layer overlying a limestone horizon, an intermediate layer without oil, and a lower bituminous layer also overlying a limestone bed. The Mangrullo area is geologically complex with distortion and minor faulting.

The first layer, Pasio Aguair, is made up of fine sand, clay and silt in variable amounts. The thickness of this layer rarely exceeds 7 to 8 m(23 to 25 ft). The upper one-half contains relatively high oil content, but overall the seam or layer is considered waste. The underlying limestone bed varies between 1 and 2 m (3.3 to 6.6 ft) in thickness.

Below this limestone bed is an intermediate horizon between 11 and 14 m(36 to 46 ft) thick consisting of alternate layers of fine grained sands and silts containing some clay minerals.

Beneath this horizon lies the second or lower bituminous seam, with physical and mechanical properties similar to the upper bituminous layer. This layer is about 9.5 m(31 ft) thick, Fig. 13.3, and contains the oil shale seam of interest. Below the lower bituminous seam, a second continuous limestone bed of between 2 and 4 m(6.6 and 13 ft) occurs.(2)

The Fraile Muerto formation underlies this limestone bed and consists of silty, sandy sediments cemented with clay.

Exploration

A.N.C.A.P. conducted a systematic exploration of the area during 1976-1981. The work included geologic mapping, exploratory core hole drilling, laboratory studies, and topographic mapping.

RESERVES

Based upon drill hole cores and analytical data, the average thickness of the oil shale portion of the seam interval is about 3.5 m(10.33 ft). The average yield (US) is about 68 L/Mt(14.9 gal/st), but has a 16-19% organic content, which makes it comparable to 78-146 L/Mt(17-32 gal/st) western US shale.(1) The shale produces a high percentage of fines on crushing.(2)
Fig. 13.2 Location of the oil shale deposits within the area of interest.
Fig. 13.3 Typical core log showing the sequence and thickness of layers.
Reserve estimates were based only on the second seam and are considered to be conservative. Using the following assumptions:

- Average seam thickness: 3.15 meters (10.33 ft)
- Average oil content: 5.74%
- In place density: 1.98
- Density of oil shale: 0.932
- 100% Mining Recovery
- 100% Plant Recovery

Then 384,000 m³ (2.42 million bbl) of shale oil can be recovered per km² (0.3861² mi). A 1982 study concluded that sufficient reserves existed in Uruguay to permit mining at the rate of 60,000 MT (66,000 st) per day for at least 20 years. (2) Data appears to be lacking for a more definitive reserve estimate.

DEVELOPMENT STUDIES

Based upon the above reserve estimate and other data developed by A.N.C.A.P. and an 1982 report. The Techno-Search Corporation prepared a "Preliminary Feasibility Study of the Utilization of the Uruguayan Oil Shale Deposits". This report concluded a three phase program should be initiated to:

- Phase 1. Provide a better cost estimate.
- Phase 2. Complete the necessary laboratory, pilot plant, and engineering studies.
- Phase 3. Engineer and construct a demonstration plant or full sized plant depending on conditions.

Tentative mining systems were considered as were retorting and processing plants. Cost estimates were made for each phase of the work.

FUTURE PLANS

There are no known current plans to proceed with the development of Uruguayan oil shales. This condition could change if there is a change in the current petroleum supply and cost situation.

REFERENCES

PART IV

ASIA
Chapter 14

ASIA

Geographically Asia may be divided into the following major areas as used in the World Atlas volumes.

- Indo China
- Near & Middle East
- Russia (Eastern Asia)

General

Oil shales occur in many of the countries of Asia, but there are many areas upon which little or no information was found. Many of these areas apparently have not been explored for oil shales. In other areas large oil reserves have made exploration unnecessary.

The countries discussed in this section are listed under the geographic sections above.

INDO CHINA

The countries included in this division of Asia are:

- Burma
- Cambodia (unexplored)
- China
- India
- Japan
- Malaysia
- Russia (see Eastern Europe)
- Thailand

NEAR & MIDDLE EAST

For the convenience all of the other countries of Asia, with the exception of Russia, have been grouped together in what might be termed the "Near & Middle East". The countries included in this division are: Iraq; Israel; Jordon; Pakistan; Syria; and Turkey.
Fig. 14.1  Middle East oil shale deposits.  
(1) Abu Tartur, (2) Hamrawein,  
(3) Quseir, (4) Sabaiya West and East, (5) Safaga, (6) Qena,  
Extensive marine black shale deposits of late Cretaceous to early Tertiary age are widely distributed in the eastern Mediterranean states of Syria, Israel, Iraq and Jordan. Similar deposits occur in the North African states of Algeria, Egypt, Tunisia, and Morocco (see Africa). Other related deposits are found in Turkey, Iraq, and Saudi Arabia.

The oil shales of Syria, Israel, Egypt, Morocco and Turkey are discussed in separate chapters. Little is available on the oil shales of Iraq, Algeria, Tunisia and Saudi Arabia. Fig. 14.1 shows the location and names of some of the oil shale deposits located in these countries (Knutson 1988).

In most cases the thick continuous beds of black carbonaceous or bituminous shales, marlstones, or mudstones occur interbedded with phosphate-rich seams and other marine sediments. The black shale relationship has been well known for many years and has led to the discovery of large phosphate deposits in the region.

While the Cretaceous shales have long been considered as source rock for gas and oil, the value of near surface deposits was overlooked. Following the 1973 oil crisis, several countries in the region - particularly leading phosphate producers such as Egypt, Jordan and Morocco- became interested in developing their organic-rich shale resources. The shale-phosphate bed association provided the possibility of large-scale low cost modern mining technology. Also, processing of these shales could provide power for remote phosphate operations and provide sizable amounts of liquid and/or gaseous hydrocarbon products. A potential for cement production also exists. (see Africa Chapter).

All of Russia is covered in the section on Eastern Europe.
Chapter 15

BURMA

HISTORY

A 1923 report (R.H. Crozier), A New Developement in the Treatment of Oil Shale, Petr. Times 10-774, 1923 stated that a new retort developed in Rangoon, India was tested on Burma oil shale. No results were noted. Apparently the test was a short one as Crozier, and his retort were active in Tasmania in the early 1920's. (See chapter on Australia).

In 1924 the Petr. Times 12-564 in an article "The Oil Shale Deposits of East Amhurst, Burma, states that these (East Amhurst) deposits are the only oil shale of commercial importance discovered in the Indian Empire.

More recent information indicates that a considerable deposit of undeveloped oil shale occurs along the boundary between Burma and Thailand. This Pliocene basin occurrence is reported to yield as high as 125 to 188 L/MT (27 to 41 gal/st) of oil per ton. (See chapter on Thailand).

FUTURE PLANS

There are no known plans to explore and evaluate the oil shale deposits of Burma.
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INTRODUCTION

There are abundant oil shale resources in the People's Republic of China, one of which, the Fushun operation, has a history of over 60 years of near continuous production. Despite the current overproduction of world petroleum, China appears to be strongly committed to expanding the development of her oil shale resources. In recent years oil shale has been discovered in 22 of China's 30 provinces, Fig. 16.1, some deposits are extensive and may warrant development in the not too distant future. (1)

While the history of China's oil shale industry covers over 60 years of successful operation, its development history can be divided into three eras of production: 1912-1960, the beginning; 1961-1978, an era of discovery and production from China's first natural petroleum industry; 1979-to present, an era of recognition of oil shale as an important present and future energy source. (1)

ACKNOWLEDGEMENTS

Direct contact with Chinese officials produced very little information. Dr. Du(1) was helpful, providing data published in 1985. Dr. Jerry Sinor, Consultant, Niwot, Colorado; J.D. Fox, Consultant, Berkeley, California; and R. Glenn Vawter, Western Research Inst., Laramie, Wyoming, furnished pictures and helpful information. The bulk of the material presented was obtained from the available literature.

HISTORY

The early development of China's oil shale is related to the development of the very large coal deposit at Fushun. The present coal mine was opened in 1907, and has been in active production since that time. The Fushun coal deposit near Maui is of Tertiary and Quaternary Age. It covers an area 17.7 km(11 mi) long and 2.2 km(1.4 mi) wide. The coal beds are 40 to 130 m (130 to 425 ft) thick and are
Fig. 16.1 Some oils shale locations in China. Compiled by Author.
covered by an overburden of 80 to 150 m (262 to 492 ft) of green shale and oil shale. The coal and the shale strata dip at angles of 20 to 300.

The coal beds at Fushun have a long history. They were worked by the Koreans, between 650 and 750 years ago, for fuel for the China and earthenware industry (Fushun is located just north of the current border of North Korea). During the Kanlung Era, 300 years later, mining was prohibited by the Chinese Government, because the workings were too near the Manchu emperor's mausoleum in the suburbs of Mukden. Still later, during the 27th year of the Kuangshu Era, the Chinese government permitted resumption of mining. During and prior to the Russo-Japanese War (1904-05), the Russians produced approximately 300 MT (330 st) a day from three collieries. Large scale production began in April 1907 when the Japanese government conceded mining rights in the Fushun coal field to the South Manchurian Railway Company. The first open pit mining Operation was started in 1914. (2)

Fushun

The oil shale industry of Fushun dates from the discovery in 1909. (3) The initial operation utilized the surface or near surface oil shales and was quite small. The oil products were marketed locally for the first ten or so years without subsidy or protection from competition of petroleum oil. In 1923, the South Manchurian Railway Co., owners of the mine, sent about 500 MT (550 st) of the oil shale to the Oakbank Oil Co. Ltd., Scotland, in order to ascertain the industrial possibilities of the shale. Apparently the results were favorable, for in 1924, they erected a pilot plant capable of treating 10 MT (11 st) per day. This operation proved commercial feasibility and a 50 MT/day (55 st/day) plant was soon constructed and operated until 1929. (3) About 1924, the Japanese became reinterested in the operation having ceded the concession to the Chinese in 1907, and became associated with the South Manchuria Railway Co. About 1926, the Japanese began construction of 80, 50 MT/day (55 st/day) Fushun-type retorts, which were a modification of the Estonian Pintsch retort. By 1928 Japan began the first large scale commercial shale oil production at Fushun. (3)

On September 18, 1931 Japan seized the northwest Province (Manchuria) and set up a puppet state called Manchukuo. In July 1937, Japan invaded China proper. (4)

During the occupation, a second plant was constructed of modified retorts of the combined Estonian Pintsch and the Japanese Inabe types. These 40 retorts were capable of processing just over 200 MT (220 st) of oil shale per day, with a recovery of about 75%. This plant and these retorts supplied as much as 874 m3 (5,500 bbl) of oil per day to Japans World War II effort. (4)

The crude oil produced at Fushun was shipped to Japan to be refined. After refining a small part was used by Japanese industry and the major portion by the Japanese Navy. (4)

Japan ruled Manchuria from 1931 until 1945 and promoted industrialization of the region. After the defeat of the Japanese in World War II, the Japan gave up all seized land. (4)

Operations at Fushun were continued by the Chinese after World War II, and have continued up to the present time. A new plant was completed in 1954 and the operation was expanded until the 1970's. Increasing overburden depth on the coal has resulted in reduction of open pit coal mining and thus less oil shale is available for processing.

Shale oil production at Fushun peaked at about 1.2 million m3 (about 7.5 million bbl) annually during the mid-1950's and again during early 1970's. Current production is estimated at about 79,500 m3 (0.5 million barrels per year or less). (5)
Maoming

A second large oil shale operation was opened at Maoming in Canton (Kwangtung or Guangdong) province in the 1950's and is probable now the most important.(6)

The Maoming oil shale is also produced by an open pit mining operation, but coal is not involved, (Fig. 16.10). Oil content is 7% or 75 L/MT(16 gal/st). There is a meager amount of data available on the Maoming operation.

GEOLOGY

Known oil shale reserves of the People's Republic of China are large. The principal developed deposits are in northeastern China in the Liaoning area near Fushun and in south China in Guangdong Province at Maoming. Numerous other deposits have been found in the Provinces of Liaoning, Jilin, Shaanxi, Guangdong, Kinjinng, Gansu, Wei Moggel, and Heilungkaiung.(1)

The known deposits are mostly of Permian, Traiassic, Jurassic and Tertiary Age and contain oil in the range of 5 to 18% by weight. Many of the deposits are associated with coal-bearing strata.(1)

The oil shales were generally formed in tectonically stable areas, such as intermontane geosynclinal basins, platform margins, and basins in platforms where waters were characterized by a reducing environment, low mixing rates, and shallow depths.

The oil shale matrix composition is generally high in clay and low in carbonates, and frequently contains rare earth elements. The oil shales are usually thinly bedded, black or dark brown, and range in age from Silurian to Neogene but are most commonly Tertiary. Heating values vary between 2,300 and 2,700 Btu/lb (5.4-6.3 MJ/kg). Ash content ranges from 70 to 80%.

A type of oil shale, called sapanthracite or stone coal, is wide spread in southeast China. Although this shale has a high organic content and a significant algal fraction, heating value is a low 1,150-1,400 Btu/lb(3.35-5.0 MJ/kg).

Fushun

The age of the Fushun group is regarded by most as Oligocene (a division of the Tertiary section of the Cenozoic Era).(2)

The geologic structure is basically a syncline whose inclination varies from 20 to 40°. The coal seam varies in thickness from 40 m(131 ft) in the eastern section of the mine to 120 m(394 ft) in the west; it averages 80 m(262 ft) overall. The oil shales lie immediately above the coal seam and vary from 50 to 115 m(164 to 377 ft) in thickness, averaging 83 m(272 ft) over the mine property. Above the oil shales are green shales which average 360 m(1,181 ft) in thickness and above these are 15 to 20 m(50 to 65 ft) of soil. The floor under the coal seam consists of volcanic tuff, 5 to 100 m(16 to 328 ft) thick. The tuff, in turn, lies on a granite basement. The tuff bed, because it absorbs water, creates a problem with side walls stability and, consequently, has to be removed to improve the slope stability.(7)

Water is a big problem at the mine and seriously affects the mining operations.(7)

The generalized stratigraphic column of the Fushun district is:(2)
Oil Shales of the World

Quaternary

Alluvium - Sand, clay, and gravel, extensively cross-bedded; 10-30 m(39 to 98 ft) thick, covering bedrock in two-thirds of the coal field.

Terrace deposits - Shale, coarse sandstone, and conglomerates, composed mainly from igneous sources.

-----------------------------------UNCONFORMITY-----------------------------------

Tertiary (Fushun Group)

Upper Formations - In ascending order: bituminous coal, with shale, and coaly shale partings, 6-130 m(19 to 426 ft) thick, oil shale, 100-200 m(328 to 656 ft) thick, green to greenish gray, calcareous shale, 400-800 m(1310 to 2624 ft) thick.

Lower Formations - Shales, coaly shale, sandstone, and conglomerate, with interbedded tuff and basalt (dolorite) flows; contains two discontinuous coal seams.

-----------------------------------UNCONFORMITY-----------------------------------

Mesozoic

Cretaceous (?) - Sandstone, lenticular limestone, red and green tuff, black shale, gray shale and purplish shale; porphyrite and liparite flows are interstratified with the lower beds and andesite flows with upper beds. Rests unconformably on gneiss.

-----------------------------------UNCONFORMITY-----------------------------------

Paleozoic

Lower Cambrian - Tuff and, locally red shale. Rests unconformably on gneiss.

-----------------------------------UNCONFORMITY-----------------------------------

Pre-Cambrian

Archean (?) - Granite Gneiss.

Granite gneiss constitutes the basement rock of the Fushun coal field and crops out immediately north, east and west of the field.

The Fushun oil shale mine was visited in 1978 by Seaborg(8) who described the area as follows:

"The mine was built in 1914 and has a history of producing coal for 60 years. It is of Tertiary and Quaternary geological classification."

"The upper part is 30 meters(98 ft) of soil that must be removed. Then comes the green rock layer with a depth of 200 meters(984 ft) at places. The shale layer appears next with a depth of 110 meters(361 ft). The rich shale (more than 4.7% or 15 gal/MT organic material) is orange in color, the poor shale (below 4.5% is gray. They process only the rich shale. Then comes the coal layer, with a depth of 120 meters(394 ft). These are, however, in veins, so the geometry is not this simple. Below this is a layer of igneous rock. They are down to a depth of 270 meters(885 ft), so they are not at the bottom of the coal - the final depth will be 500 meters(1,640 ft). (We learn later that these are not vertical distances but are measured on an incline angle of some 25°)."
"There is coal down to 1,000 meters (3,281 ft). The coal below 500 meters (1,640 ft) will be mined by underground methods."

Maoming

The Maoming mining area contains one of the major oil shale deposits discovered in China. The shale deposit is in the shape of a crescent 50 km (31 mi) in length and 3-6 km (2-4 mi) in width, and has a total area of 360 km² (139 mi²). The long axis strikes northwest-southeast. The area is divided into 6 districts: the Yangjiao, Jingtang, Shigu, Shatian, Xinyu and Dishan mines.

The deposit is located in the upper Youganwo Formation of the lower Tertiary Maoming system and the lower Shancun Formation of the upper Tertiary Yongning system. The shale deposit is a gently dipping monocline. The average oil yield of the shale is 6-8%. The shale is nonporous and has distinct laminations. The Maoming oil shale is generally softer and contains significantly more water than does the Fushun oil shale. The shale is gray/brown in color and has a specific gravity of 1.7 to 3.1. The oil shale bed is relatively flat and varies between 40 and 80 m (131 and 262 ft) in thickness. The deposit has a thin overburden. Estimated recoverable reserves are 4.2 billion MT (4.6 billion st).

The open-pit Jingtang mine has operated for about 30 years. In recent years, a high-quality kaolinite was discovered in the upper part of the shale. Rare earths may also be a produced.

The Maoming oil shale used for the experimental boiler research has a moisture content of about 18%, ash content of about 65% and a heating value of 800-1,100 Kcal/kg (1,440-1,980 Btu/lb) with 650 kcal/kg (1,170 Btu/lb) as the lowest.

There is no coal associated with the Maoming oil shale deposit.

The following comparison of Fushun and Maoming oil shales were noted:

<table>
<thead>
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<th>Chemical Analysis and Ratio of Atoms.</th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>S</th>
<th>O</th>
<th>H/C</th>
<th>O/C</th>
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<tbody>
<tr>
<td>Fushun</td>
<td>79.07</td>
<td>9.93</td>
<td>2.12</td>
<td>1.86</td>
<td>7.02</td>
<td>1.51</td>
<td>0.067</td>
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<tr>
<td>Maoming</td>
<td>79.41</td>
<td>9.84</td>
<td>1.63</td>
<td>1.09</td>
<td>8.23</td>
<td>1.46</td>
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<tbody>
<tr>
<td>Fushun</td>
<td>0.25-0.30</td>
<td>0.15-0.20</td>
<td>0.50-0.55</td>
</tr>
<tr>
<td>Maoming</td>
<td>0.25-0.30</td>
<td>0.20-0.30</td>
<td>0.40-0.45</td>
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<th>Industrial Analysis - Oil Shale</th>
<th>Vol. Mat.</th>
<th>Ash</th>
<th>CO₂</th>
<th>Water</th>
<th>H.V.</th>
<th>Wt.%</th>
<th>Wt.%</th>
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<td>Fushun</td>
<td>17.45</td>
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<td>3.32</td>
<td>3.50</td>
<td>1364</td>
<td>1.95</td>
<td>4.84</td>
<td>1754</td>
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<tr>
<td>Maoming</td>
<td>20.12</td>
<td>72.10</td>
<td>1.95</td>
<td>4.84</td>
<td>1754</td>
<td>4.46</td>
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<table>
<thead>
<tr>
<th>Fischer Assay - Oil Shale (WT.%)</th>
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<th>Water</th>
<th>Gas</th>
<th>Gas &amp; Loss</th>
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<tbody>
<tr>
<td>Fushun</td>
<td>7.68</td>
<td>6.44</td>
<td>81.37</td>
<td>4.51</td>
</tr>
<tr>
<td>Maoming</td>
<td>8.28</td>
<td>10.78</td>
<td>76.48</td>
<td>4.46</td>
</tr>
</tbody>
</table>

Huadian, Jilin Province

The minable oil shales are located in Huadian County southeast of the provincial capital Changchun. The oil shale occurs in a lower Tertiary Formation in the Huadian, Jingozi and Miaoling basins. The formation thickness is 65-244 m (213-
800 ft), with 6-26 layers of oil shale.

Total areal reserves are 1.3 billion MT (1.4 billion st). The oil yield is 6-12%. Mining of oil shale in Huidian began in 1943 and stopped in 1961 because of high costs of underground mining.

Huangxian County, Shangdong Province

The Huangxian mining area is located in Huangxian and Penglai Counties of Shangdong Province. This lower Tertiary oil shale is interbedded with brown coal. The areal extent of the oil shale is about 200 km² (77 mi²) is covered with overburden ranging in depth from 0-1,000 m (0-3,280 ft). Oil yield is 9-22%, and heating value averages 12MJ/kg (5,160 Btu/lb). This fairly high grade oil shale is mined underground along with the brown coal, the combined material is burned as fuel for power generation. (Hou 1986)

Huatien

In Huatien, Hong County, Shandong Province, an oil shale layer lies above the coal seam as it does at Fushun. The oil content is more than 12% 125 L/MT (27 gal/st). Further data is lacking. This operation apparently closed about 1948.

RESERVES

The World Bank (10) reported in 1985 that China’s oil shale reserves were unofficially estimated as greater than 400 billion MT (440 billion st). The reserves may be much larger as the geological environment is favorable for oil shale formation in many of the countries sedimentary basins.

Proven oil shale reserves in the mining areas of Fushun, Maoming and Huidian are more than 10 billion MT (11 billion st). Promising oil shale deposits can also be found in areas such as Nong-an in Jilin Province, Dongsheng in Inner Mongolia Autonomous Region, Tanshanlin and Yaojie in Gansu Province, the northern foot of Bogeda Mountains in Xinjiang Uyghur Autonomous Regions, Ordos platform in northern Shaanxi and Zhanxian County of Hai-nan Island in Guangdong Province.

The major oil-shale mining areas are Fushun, Maoming, Huidian and Huang.

Fushun

The Fushun mining area, located east of the provincial capital of Shenyang, is 18 km (11.2 mi) from east to west and 2 to 3 km (1.2 to 1.9 mi) from north to south. The dipping oil shale deposit overlies a very large deposit of coal Fig. 16.2. The thickness of oil shale ranges from 48 to 190 m (157 to 623 ft), with interbedded coal seams 0.5 to 0.8 (1.6 to 2.6 ft) thick. The total proven reserves of oil shale with oil content above 4.7% is 3.6 billion MT (4 billion st).

The necessity of removing this oil shale overburden in order to mine the underlying coal deposits permitted its use for oil recovery in spite of its relatively low grade. Only the higher grade shales have been retorted. Excess oil shales removed were disposed of as waste in the open pit mine. In recent years the production of coal has been converted to underground mining operations and the available strip mined oil shale for retorting has decreased.
Fig. 16.2 Fushun open pit mine in mid-1940's. Source see reference 2.
Maoming

The estimated recoverable reserves at Maoming are 4.2 billion MT (4.6 billion st).

MINING

Apparently all commercial mining of oil shale in China has been by open pit excavation.

No description of the mining operations at Maoming are available, but it appears that excavation operations closely resemble those at Fushun. However, at Maoming the shale beds are near horizontal and vary from 40 to 80 m (131 to 262 ft) thick and coal is not involved.

At Fushun, a much older operation, data is available, to some extent, since the mining operation is primarily for coal, and the oil shale is a by-product of a stripping operation required to reach the coal. Fig. 16.2, is a cross-section showing how the oil shale is removed to expose the dipping coal seam. Only the higher grade shale is processed in the retorts. The lower grade shales are returned to the mine pit as backfill.(2)

Mining uses the multiple bench system with 10 m (33 ft) benches. In the early days black powder was made on site and used to loosen the shale and coal using 110 mm (4 in.) dia. blast holes drilled by mobile electric drill units. Today, the drill hole size has increased from 110 mm (4 in.) to 300 mm (about 12 in.) and the explosive used is ammonium nitrate. The bench dimension has remained the same. Blast hole spacing varies with geologic conditions.

The broken shale is loaded by 3 to 4 m$^3$ (4.25-5.25 yd$^3$) electric power shovels that load 60 MT (60 st) rail cars that are pulled by 150 and 85-MT (165 and 94 st) overhead-wire electric locomotives on a 1.43 m (4 ft 8 in.) gage railroad track.(11)

In the past mined shale was not stored and any excess was returned to the pit. Current practice is not known.

At peak operations, some 20,000 miners were employed. Current employment is unknown.(6)

Crushing

The crushing plant is located near the present bank of 24 in-use retorts. A description of the crushing equipment is not available but the oil shale is reduced to the following size ranges and fed to the retorts: 8-15 mm (0.3-0.59 in.) 26%; 15-20 mm (0.59-0.79 in.) 20%; 20-30 mm (0.79-1.18 in.) 19%; 30-50 mm (1.18-1.96 in.); 12%; 50-75 mm (1.96-2.95 in.) 18%. The minus 8 mm (-0.3 in.) raw shale fines are used (burned) directly by an on site electrical power station.

RETORTING

Fushun

It is not known what retorting system was used at Fushun in the very early, limited, pre-1923 production. The Southern Manchurian Railway Co., erected a 10 MT/day (11 st/day) retort in 1923 after having tests conducted in Scotland. This was followed almost immediately by the construction of a 50 MT/day (55 st/day) unit.

These early units were followed by retorts constructed in 1926-1928 by the
There are 4.2 billion MT (4.6 billion st) of oil shale in China, which has been extensively explored for use. However, at Maoming, oil shale is available, but it appears to be less accessible than at Fushun. Present mining methods from 30 to 80 m (100 to 262 ft) thick are available, and in some instances, the oil shale is a by-product of a salt mine. Fig. 16.2, is a cross-section of the salt mine at Maoming, showing the dipping coal seam. Only the lower grade shales are removed to form benches. In the early days, the oil shale was used for making bricks and electricity, but today, it is used as a source of oil and gas. Blast mining is employed, and the oil shale is loaded into electric shovels (5-5.25 yd³) and hauled to the site, where it is loaded onto a railroad track (11). Any excess is returned to the pit.

Current employment is at a level of 24 in-water retorts. There are at least 90 such retorts, each with a capacity of 50 MT/day (55 st/day). The original (1926-28) Fushun retorts were based on a similar technique as that used in the recovery of tar. The Fushun retorts were built by the Chinese, and the process involves the use of a retort with a reaction section where the oil shale is heated by steam and air, and the resulting gases are condensed and collected. The retort has a cylindrical reactor, and the gases are then passed through a condenser and collected as tar and oil.

Fig. 16.3 shows the Fushun retorting plant in 1928 (West Works). The retort is a cylindrical reactor lined with refractory bricks, which are superimposed and connected by a narrow section in the form of a truncated cone. The fixed carbon was burned in the lower receptacle by injection of steam and air, and the resulting gases passed through the upper section, which functioned as a distillation retort. Thus, the shale mass was heated internally.

Due to the low fixed-carbon content (about 4%), the gas produced is not sufficient to reflect complete pyrolysis of the shale. Consequently, some of the distillation gases were recycled at the base of the retort after being freed from condensable vapors and reheated. This reheating, which was accomplished by the combustion of another fraction of the distillation gas in a superheater, was consequently carried out externally.

The distillation retort had an inside diameter of 2.6 m (8.5 ft). Its volume of 20 M³ (706 ft³) corresponds to 20 MT (22 st) of shale broken to 10 to 75 mm (0.4 to 3 in.). For a production of 50 MT (55 st) per day, the shale remained 3.2 hours in
the distillation zone. The producer gas and recycled gas reach the distillation retort at a temperature of 350°F to 650°C (662 to 1,202°F), drop to 450°F to 550°C (842 to 1,022°F) in the distillation zone, and emerge from the oven at 150°C (302°F). For the pyrolysis of 1 kg (2.2 lb) of Fushun shale, 200,000 calories, of which 50% are furnished by the gas producers, are necessary. This is equivalent to approximately 720,000 Btu per short ton. The yield in oil was about 95%.(12)

The producer section had an inside diameter of 3 m (9.9 ft); its volume was 27 m³ (953 ft³). The shale remains 15 hours in the retort, when production is 50 MT (55 st) per day. The so-called "coke" from the distillation section drops into a perforated brick dome that forms the upper portion of the gas producer. It is piled against the outer walls, leaving free passage for the gases under the top of the dome. The temperature of the "coke" is 500°C (932°F). The gasification reaction is accomplished at 1,000°C (1,831°F). The Fushun shale mineral residue melts at 1,300°C (2,372°F). There is consequently a possibility, by fusion of the ash, of obstruction interference with the gasification, and difficulty of extraction of the ash (spent shale). This problem has been solved by providing the lower portion of the producer with a revolving bottom similar to that of the Mond producers. The basic heat for retorting has been coal since retorting began.

From a shale that yields 6% oil, a "coking" containing about 6% residual carbon is obtained, giving, in a producer, a gas of the following composition, in percent by volume: CO₂ = 17.5%; O₂ = 0.2%; CO = 6.0%; H₂ = 15.5%; CH₄ = 2.5%; N₂ = 58.3% = a total of 100%.(12)

The basic retort, (Fig. 16.7), although modified to increase capacity, remains in use today (1987).

In 1934 the retorts were modified and upgraded to a capacity of 100 MT/day (110 st/day), the resulting yield being about 174,881 m³ (about 1,100,000 bbl) of oil per year. Further modification in 1939 reduced the number of retorts to 60, but increased the individual retort capacity to 180 MT/day (198 st/day). This facility is known as the West Works.(6)(13)

In 1944, an additional mine pit, Fig. 16.4, was opened to supply oil shale specifically to the new facility known as the East Works, Fig. 16.5. This plant consists of 60 retorts in two rows of 30 retorts each. Each row is further divided into units of 5 retorts, each processing 200 MT (220 st) of oil shale per day. These retorts are modifications of the earlier Estonian Pintsch and Japanese Inabe retorts. The continuous increase in throughput without any change in basic dimensions was achieved only with a decrease in yield efficiency from 90% to 70%. Because the shale was "free", this was acceptable.(5)(6) It was reported in 1985 that production of shale oil was decreasing and it would appear that only 24 of these retorts were in operation.(5)(13)

The operations at Fushun in 1985 were described by Du and Nuttall(1) as follows:

The oil shale is hauled by open rail cars from the open pit mines, (Fig. 16.4), to a crusher facility close to the bank of 24 retorts. Shale fines diameter 0-8 mm (0-0.31 in.) are burned directly by an electrical power station while the raw shale 8-105 mm (0.31-4.2 in.) is fed to the retorts.

The modified Fushun retort is physically the same as previously described except capacity has been increased. The retort has a pyrolysis and gasification section and the retorting action is continuous. A screw feeder injects raw shale into the top of the retort. The shale moves slowly downward and contacts the hot gas arising up from the lower part of the retort. The shale is heated, dried, and then retorted. When the shale reaches the center part of the retort it has reached a temperature of about 550°C (1,022°F). Pyrolysis is complete and the spent shale passes from the pyrolysis section into the gasification section. As it moves downward the shale coke is further heated to 700-800°C (1,292-1,472°F); here it
recycled gas reach the distillation to 1,200°C, drop to 420°C to 550°C at emerge from the oven at 150°C of Fushun shale, 200,000 calories, of which necessary. This is equivalent. The yield in oil was about 95% (12) of 3 m (9.9 ft); its volume was 27 m³ of retort, when production is 50 MT the distillation section drops into portion of the gas producer. It is passage for the gases under the top is 560°C (932°F). The gasification retort The Fushun shale mineral residue enty a possibility, by fusion of the siflitation, and difficulty of extraction has been solved by providing the bottom similar to that of the Mond coal since retorting began.

Fig. 16.4 Fushun open pit mine - 1940's.

Reacts with the hot air and steam causing gasification and combustion of the shale coke to take place. This produces large amounts of heat and combustible gas; the shale coke becomes shale ash. The hot combustible gas moves upward to the pyrolysis section to heat the raw shale; the shale ash moves downward and heats the incoming air which contains water vapor. The ash particles are removed at the bottom of the retort by an ash disc, Fig. 16.6, and are moved to disposal areas. The gas containing oil vapors leave the top of the retort and goes to a condensing system.

The heat required for the drying and pyrolysis of the shale is supplied partly by the hot gas from the gasification section and partly by the regenerators, gas, which is heated to 700-700°C (932-1,292°F) in external heaters and then injected into the middle part of the retort.

The Fushun type retort almost completely utilizes the apparent heat of the shale raw, Fig. 16.7.

"The development of the Fushun retort may be divided into two stages; before 1945, the setting up and installing stage and after 1949 the developing and improving stage. During the latter stage we have made a series of improvements with satisfactory results."

The products obtained from 1 MT of raw shale are: shale oil = 35-65 kg/MT; ammonium sulfate = 5.5 kg/MT; gas (net gained) = 200-250 Nm³/MT (181-277) Nm³/ST.

Consumption for the production of 1 MT (4.3 bbl) of Fushun shale oil is: oil shale - 20 MT (33 ST); water - 5-6 MT (31-86 bbl); electricity - 150-170 Kwh; steam -
Fig. 16.5 Fushun East retorting plant under construction - 1940's.

2-3 Mt (1.8-2.7 st); fuel gas - 1800-2000 Nm$^3$ ($Q = 1000$ kcal/n$^3$) = (112 Btu/ft$^3$).

**IMPROVEMENTS ON FUSHUN TYPE OIL SHALE RETORT**

An article prepared in the 1980's by the Fushun Institute of Petroleum Refining (15) describes "the improvements on Fushun type oil shale retorts since the founding of the People's Republic." (September 12, 1949). It is reproduced here verbatim, including tables and figures with numbering as in original, as it adds to and supports other data presented. See Tables 16.1, 16.2, 16.3, and 16.4.

"History of Developments of Fushun Retorts"

"The development of the Fushun retort may be divided into two stages: before 1945, the setting up and installing stage and after 1949 the developing and improving stage. During the latter stage we have made a series of improvements with satisfactory results."

"Table 16.5 shows that within the 15 years from 1930 to 1945 the highest annual production of oil shale was only 257,000 Mt (1.6 million bbl), (4) while after liberation in the fifties due to the reconstruction, improvements and expansion, the annual production has reached 800,000 Mt (5 million bbl/year), which is three times higher than that of 1930-1945. Hereafter due to the extensive production of natural oil, the amount of shale oil produced gradually has decreased. In these high production years the demand of oil shale increased rapidly, the quality of raw shale got down, we even retorted a part of rejected shale, this tendency
are clearly indicated with the lowering of heating value of the raw shale. As accounted on the same quality basis of the oil shale per ton of shale at the time of the highest annual production before liberation was 34.36 MT(37.8 st) shale/ton oil. This data indicates that we have increased the utilization ratio of the oil shale, i.e. made better use of our resources and that in the meantime, we have devoted our major efforts to improve our production facilities and operation of Fushun retort and increased shale oil efficiency."

"In the early stage although we had put the Fushun retort into normal running we have found there still existed a number of problems, such as low oil shale utilization ratio, serious inclination of the combustion layer in the retort along with the mal-adjustment of heat supply, causing of shale agglomerates, resulting in a decrease of operation factor of the retort as well as in wasting a part of oil shale during starting and closing the unit, some retorts were operated in the presence of large hard agglomerates causing the increase of oil shale consumption; due to the unreasonable design and operation of the retort, there existed a certain amount of oil mud in the discharge resulting in a further decrease of oil recovery. Because of the problems mentioned above and the lack of reasonable operation and management, the actual oil yield of Fushun retort was only about 55% on Fischer assay."

"Vast research works have been carried out after the founding of New China, so that above problems have been solved one after another."

"Besides tests were made on the use of "jalousie" type retort for retorting oil shale powder and also the use of solid heat carrier for retorting oil shale particles. Trials were also made on the fluid oil shale retorting process, pellet retorting and fluid combustion process, etc. In a laboratory scale we worked on
Fig. 16.7 Diagramatic section of Fushun retort. U.S. Bureau of Mines I.C. 7348, 1946.
the basic theory of retorting and gasification of oil shale and here some results are shown in Fig. 16.A and Fig. 16.B."

"Structure and Flow Diagram of Fushun Retort"

Principal of Fushun Retort: "Fushun is of inner-heated type, having a gasification zone attached at the bottom of the pyrolysis zone, oil shale at a definite size is added at the top of the retort; it moves downward by gravity through pyrolysis section and gasification section. Ash is moved from the retort by means of the rotating ash disc. Blast air containing a definite amount of water vapor is introduced into the bottom of the retort and meets the semi-cooked oil shale, thus generator gas, is produced, this gas is further introduced to the middle section of the retort to mix with the hot recycle gas and then into lower part of the pyrolysis zone to provide heat needed for pyrolysis. The retorting product with the heat carrier (gas) evolves from the top of the retort."

"In this way the gas and the solid in retort are to be contacted with each other countercurrently so that a high heat transfer efficiency can be expected, thus resulting in a full utilization of heat by means of the simple but reliable equipment."

"Table 16.6 presents the heat balance data in pyrolysis zone when Fushun oil shale is used. It indicates that nearly 70% of the heat required comes from the gasifying zone, that is to say, heat is fully utilized and, therefore, the overall heat efficiency reaches some 70%, which is higher than other retort of the similar type."

"Development of Fushun Retort"

"The improvement of Fushun retort undergoes three important stages:

(a) 50 MT(55st)/day "narrow waist" retort in the early period. The type of retort we used during this period is a combination of Mond gas generator and Pintsch type retort. It is divided into two zones by the narrow waist at the middle of the retort, its structure is shown in Fig. 16.C."

(b) 100 MT(110 st/day) "wide waist" retort and 180 MT(200 st)/day "narrow waist" retort used during 1935-1945 successfully raised the output of the retort, but the most reasonable structure of the retort had not yet been found, by that time we simply used wide waist and narrow waist retorts alternately. The oil yield of the 180 MT(200 st)/day retort at this time was only about 50% on Fischer assay, the structural diagram is shown in Fig. 16.D."

(c) After the founding of the New China we have confirmed through vast number of tests a more reasonable structure and developed the three-zone Fushun type retort Fig. 16.D."

"Improvement on Fushun Retort"

"Utilization of Small Size Shale(6): "Since establishment of New China, shale oil industry has been reconstructed rapidly. After 1951, we began to investigate the utilization of small size oil shale 8-20 mm(0.32-0.79 in.) and put into production in 1953 and the utilization of shale was increased about 15%.

"In investigation, according to the characteristics of small size shale: retorting time is shortened greatly; the resistance against gas in the retort is increased greatly; the segregating effect of solid material in the retort is more obvious, etc. We have adjusted the height of the retort, improved material distribution
50 T/D COMMERCIAL RETORT

1. CHARGER  2. DISTRIBUTOR  3. GAS OUTLET
4. SUPPORT  5. MIXING CHAMBER  6. RECYCLE GAS
INLET  7. ARCH  8. BLAST DISTRIBUTOR
9. ASH DISH  10. WATER SEAL  11. BLAST PIPE

100 T/D "WIDE WAIST" and
180 T/D "NARROW WAIST RETORT"

180 T/D FUSHUN RETORT
100 T/D FUSHUN RETORT

Fig. 16. C

Fig. 16. D
and operations, and then used the shale fines successfully in the Fushun retort."

"In the tests for retorting small size we measured and calculated the inner resistance against the gas retort. The results are shown in Table 16.7."

"Developments of the Fushun Retort with Three Zones"

"When high moisture content shale is processed in Fushun retort, the inner resistance against gas in retort increases obviously and the height of water seal of ash disk won't be enough. So, in order to increase capacity, we have to solve the resistance problem in retort. From the pressure drop measurement and calculation we observe that: with decreasing the amount of gas added to pyrolysis section, the pressure drop can be decreased. One of the effective methods is that shale is preheated before entering into the pyrolysis section. From 1954 we began to conduct the research work on the "three zone" Fushun retort including preheating zone. In laboratory we correlated the isothermal pyrolysis temperature using different grades of Fushun and Maoming shales. The results are shown in Fig. 16.A and 16.B. It is shown that Fushun shale of low oil content begins to pyrolyze and produce oil at 350°C(662°F), and the other two at 325°C(619°F). It indicates that, the range of preheating temperature can be selected widely. The oxidation tests were carried out, the results show that, when the oxygen content of gas is 0.9%, and the shale is heated to 150°C(302°F), the oil loss of shale is 2%. While oxygen content of gas if 5.1% and the shale heated to 250°C(482°F), the oil loss of shale is 11.2%. Thereby the results are that, the oxygen content of heat carrier gas shouldn't be too high and the preheating temperature of the shale shouldn't be over 150°C(302°F), when recirculation gas is used to preheat, the results are shown in Table 16.8."

"From Table 16.8, it is shown that not only the capacity of the three zone retort can be increased by about 50% and the oil yield 5%, but the total pressure drop in the retort is lower than that of the two zone, Fushun retort with the capacity of 100 MT(110 st)/day."

"Improvements of the Construction and Operation Conditions and the Solution of the Clinker Problem." "In the early time, another problem was the clinker produced in the Fushun retort and forced operation factor down to about 80%. Some retorts were often shut down for treatment due to clinkers and also some retorts were operated in the presence of clinker, thus the oil yield was decreased."

"According to the position of the clinker produced, it can be classified as gasification clinker and carbonization clinker. The former is due to the high temp., which causes ash melting partly and clinging to each other or it is due to the inclination of the combustion layer in the retort which causes local overheating and clinking resulting in blocking up in the inner space of the generator. Both are happened when the temperature of the gasification zone reaches as high as 1100°C(2,012°F) or more, and by calculation we find that the temperature can reach that level. With the improvement of the retort construction, and the adjustment of the operation parameters, the inclination of the combustion layer can be avoided. and the clinker problem is solved gradually."

"There are also two main causes of forming clinker in the carbonization zone, one is that the position of the combustion zone tends to move upwards and the other is the inclination of the combustion layer. It is believed that the key factor is to improve the retort construction. Through a large number of cold retort and model tests, a better Fushun retort construction is developed. The distribution of shale charged and gas moving upwards and the descending rate of the shale are uniform in the retort. With adjustments of operation parameters, the clinker in the retort is basically eliminated and the operation ratio is increased from 80% to above 96%."
"Using Different Operation Conditions for Different Quality of Shales."

"Through many years operation practice, it is shown that the shale quality is often varied, and the operation parameters aren't adjusted in time, so the oil yield will be decreased. Thereby a set of methods for production and management are summarized. In accordance with the different qualities of shales the different applicable operation methods are adopted. For example, the relation between isothermic pyrolysis time and oil yield for various qualities has been investigated in laboratory. The results are shown in Figure 16.8. The pyrolysis time of the hard shale is longer. In commercial production retorting time of hard shale is prolonged and corresponding operation methods are adopted. For high moisture content shale, in order to keep heat balance, heat supply is increased in the upper section. For easily broken shale the operation experience of small size shale may be adopted. Because of mastering such a set of operation methods, the flexibility of Fushun retort can be increased."

"Decrease of Oil Mud and Increase of Oil Yield Efficiency": "There was a large amount of oil mud in the retorts of 180 MT(200 st)/day capacity from 1939 to 1951. The amount of oil mud of 60 retorts reached 80 MT(88 st)/day. By analysis the oil mud contains about 50% of water, about 25% of oil, and about 25% of ash, in which the weight per cent of the ash particles with diameter below 0.088 mm (0.0035 in.) is about 95%. In production practice, through careful observation and repeated calculation, the ratio of heat supply is adjusted and the retort construction is improved step by step, so that, the inclination of the combustion layer is avoided. The problem of forming a large amount of oil mud is basically solved. The average oil production efficiency is increased by about 10% in average. The main operation conditions and results after improvement are shown in Table 16.9."

"The amount of product for each ton of shale is as follows: shale oil 45 kg (11.89 gal); light gasoline 9 kg(2.34 gal); and by-products NH₃ as (NH₄)₃SO₃ 10 kg; gas 250 NM³. Total heat efficiency calculated by the following formula reaches 70.1%.

\[(450000 + 250000 + 16480) / 115000 = 70.1\%\]

"The main consumption is as follows for the production of each ton of Fushun shale oil:"

<table>
<thead>
<tr>
<th>Material</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>5-6 MT</td>
</tr>
<tr>
<td>electricity</td>
<td>150-170 MT</td>
</tr>
<tr>
<td>steam</td>
<td>2-3 MT</td>
</tr>
<tr>
<td>fuel gas</td>
<td>1500-2999 NM³</td>
</tr>
</tbody>
</table>

"Fushun oil shale is mined from open pit. Because of low production cost with Fushun retort the cost of shale oil is lower than crude oil price on the international market."

"The Characteristics of Fushun Retort"

"The Fushun retort has been put into production for 50 years. It is reliable in technique, the main characteristics are as follows:"

"Great flexibility for raw shale, the ability of processing low quality shales. When Fushun shale with 6% oil content is processed, the technique is reliable and the economics is profitable, and as the oil content decreases to 4-5% for a short time the heat still can be self-balanced in the retort. Research work on Huadian (Jilin Province), Eyao-Gei (Gansu Province) has been conducted with 20 MT (11 st)/day Fushun retort, and good results are obtained. It is shown that Fushun retort may be used to process the different kinds of shale of our country."
"Simple Construction and Equipment of the Retort": "The construction and equipment of Fushun retort are simple, long life, less failure, low construction cost and convenient in maintenance. These are reliable in technique."

"High Heat Efficiency": "By using of the fixed carbon of shale in gasification zone and directly using gasification gas as heat carrier in pyrolysis zone, 70% of heat required is supplied for the retorting process. The remainder 30% heat is supplemented by using self-generated gas as heat source to heat recirculation gas. In the retort, the raw shale is in counter contact with gas heat carrier and the waste residue after gasification is in counter contact with the blast air. Therefore the utilization of heat is complete and the heat efficiency is high. Though the oil content of raw shale processed in the retort is only 6%, the amount of heat can still be self-supplied and excess heat remains."

"Rich By-Products": "The oil yield of our shales processed by Fushun retort are 75-85% (including light gasoline) and each ton of oil shale can produce by-products: gas 200-250 NM³, ammonia sulfate about 10 kg(22 lb), hydrogen sulfide, pyridines, phenols and etc."

"Easy to Operate": "The operation of the Fushun retort is simple and easy to control. Only one operator is needed for the management of every 20 sets of retorts. There are also some disadvantages, such as large amount of gas at the retort exit, large recovery equipment, low heat value of gas, low by-products concentration, inconvenient to recover and so on. But in general, the Fushun retort has been put into production for many years. It is one of reliable and sophisticated retorts in technique. When it is used for retorting Fushun shale, the capacity has already reached 250 MT(275 st)/day. If further improvements and enlargements are applied to the retort, it is possible to raise to 400 MT(440 st)/day. Thus, the capacity of one unit of 32 retorts will be 12,800 MT(14,080 st)/day."

"When shale containing 6.5% oil and 6% water is processed in the retort, it is estimated that capacity is 4.2 million MT(4.6 million st) shale per year and 220,000 MT(1.38 million bbl) shale oil, 50,000 MT(55,000 st) of ammonium sulfate, and 1,000 million NM³ gas of heat value 1,000 kcal/NM³ can be obtained."

"The achievements described in this paper ahve been made by colleagues in Fushun No. 1 and No. 2 petroleum refinery, Maoming petroleum corporation and Fushun Institute of Petroleum Refining, with hard work over many years."

"Literature References:"

1. K. Ishihashi. The shale oil (1940)
Table 16.1 Physical Properties of Fushun and Maoming Oil Shale

<table>
<thead>
<tr>
<th>Oil Shale</th>
<th>Fushun</th>
<th>Maoming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>brown</td>
<td>from grey to brown</td>
</tr>
<tr>
<td>Sp. Gr.</td>
<td>2.0 - 2.3</td>
<td>1.7 - 2.1</td>
</tr>
<tr>
<td>Hardness (shopers)</td>
<td>28.0 - 34.7</td>
<td>14 - 20</td>
</tr>
<tr>
<td>Crushing strength kg.cm²</td>
<td>612</td>
<td>326</td>
</tr>
<tr>
<td>Shale ash, °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Deformation point</td>
<td>1240</td>
<td>1260</td>
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<td>1340</td>
</tr>
</tbody>
</table>

Table 16.2 Fischer Assay of Fushun and Maoming Oil Shale

<table>
<thead>
<tr>
<th>Oil Shale</th>
<th>Fushun</th>
<th>Maoming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale oil %</td>
<td>6.69</td>
<td>7.28</td>
</tr>
<tr>
<td>Water %</td>
<td>3.88</td>
<td>3.59%</td>
</tr>
<tr>
<td>Coke %</td>
<td>86.13</td>
<td>86.20</td>
</tr>
<tr>
<td>Gas + loss %</td>
<td>3.30</td>
<td>2.93</td>
</tr>
</tbody>
</table>

*In general, Maoming's raw shale contains more than 17% water.*

Table 16.3 Industrial Analysis of Fushun and Maoming Oil Shale

<table>
<thead>
<tr>
<th>Oil Shale</th>
<th>Fushun</th>
<th>Maoming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water w%</td>
<td>2.76</td>
<td>1.97</td>
</tr>
<tr>
<td>CO₂ w%</td>
<td>3.36</td>
<td>4.49</td>
</tr>
<tr>
<td>Ash A w%</td>
<td>73.60</td>
<td>73.27</td>
</tr>
<tr>
<td>Vol. matter V w%</td>
<td>20.28</td>
<td>20.27</td>
</tr>
<tr>
<td>Low Heating value Q₁</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kcal/kg</td>
<td>1081</td>
<td>1313</td>
</tr>
</tbody>
</table>

Table 16.4 Shale Ash Analysis of Fushun and Maoming Oil Shale

<table>
<thead>
<tr>
<th>Shale Ash</th>
<th>Fushun</th>
<th>Maoming</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂ w%</td>
<td>62.23</td>
<td>64.37</td>
</tr>
<tr>
<td>Al₂O₃ w%</td>
<td>23.45</td>
<td>22.37</td>
</tr>
<tr>
<td>Fe₂O₃ w%</td>
<td>9.70</td>
<td>8.17</td>
</tr>
<tr>
<td>MgO w%</td>
<td>1.41</td>
<td>1.51</td>
</tr>
<tr>
<td>CaO w%</td>
<td>1.78</td>
<td>0.85</td>
</tr>
</tbody>
</table>
### Table 16.5 Development of Fushun Shale Oil Industry

<table>
<thead>
<tr>
<th>Period</th>
<th>before 1945</th>
<th>late 1950</th>
<th>increase ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum shale oil annual production, 1000 MT</td>
<td>257</td>
<td>780</td>
<td>3.055</td>
</tr>
<tr>
<td>Maximum annual shale processed, 1000 MT</td>
<td>8830</td>
<td>20630</td>
<td>2.336</td>
</tr>
<tr>
<td>Heating value of oil shale, kcal/kg</td>
<td>1460</td>
<td>1213</td>
<td>0.831</td>
</tr>
<tr>
<td>Shale consumption, MT/MT</td>
<td>34.36</td>
<td>26.45</td>
<td>0.77</td>
</tr>
<tr>
<td>Shale consumption, MT/MT (based on the same heating value of shale)</td>
<td>34.36</td>
<td>21.98</td>
<td>0.64</td>
</tr>
</tbody>
</table>

### Table 16.6 The Heat Balance of Pyrolysis Zone in Fushun Retort (based on 1000 kg shale)

<table>
<thead>
<tr>
<th>Item</th>
<th>kcal</th>
<th>%</th>
<th>Item</th>
<th>kcal</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat for retorting shale</td>
<td>212000</td>
<td>77</td>
<td>Producer gas</td>
<td>89289</td>
<td>32</td>
</tr>
<tr>
<td>(including water evapor.)</td>
<td>50300</td>
<td>18</td>
<td>Water vapor in producer gas</td>
<td>102130</td>
<td>38</td>
</tr>
<tr>
<td>Heat carried by gas</td>
<td>12380</td>
<td>5</td>
<td>Recirculation gas</td>
<td>83270</td>
<td>30</td>
</tr>
<tr>
<td>Heat loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>274680</td>
<td>100</td>
<td>Total</td>
<td>274680</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 16.7 Pressure Drop Data in the 100T/D Test Retort mm H₂O

<table>
<thead>
<tr>
<th>Section</th>
<th>small size shale measured</th>
<th>calculated</th>
<th>large size shale measured</th>
<th>calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonized</td>
<td>175</td>
<td>+8</td>
<td>100</td>
<td>108</td>
</tr>
<tr>
<td>Gasification</td>
<td>60</td>
<td>+167</td>
<td>40</td>
<td>61</td>
</tr>
<tr>
<td>Total</td>
<td>235</td>
<td>+175</td>
<td>140</td>
<td>170</td>
</tr>
</tbody>
</table>

### Table 16.8 The Results of Preheating Test Using Recirculation Gas as Heat Carrier

<table>
<thead>
<tr>
<th>Item</th>
<th>2 zone Fushun Retort</th>
<th>3 zone Fushun Retort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity MT/D</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Oil Yield %</td>
<td>70</td>
<td>75</td>
</tr>
<tr>
<td>Gas amount at retort exit, NH³/MT shale</td>
<td>700</td>
<td>350</td>
</tr>
<tr>
<td>Total pressure drop in retort, mm H₂O</td>
<td>160</td>
<td>120</td>
</tr>
</tbody>
</table>
### Table 16.9 Operation Conditions and Material Balance of Fushun Retort

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Air consumption NM³/T</th>
<th>Air saturation point °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-200</td>
<td>220</td>
<td>83</td>
</tr>
</tbody>
</table>

#### Material Balance (basis: 1 ton shale)

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale</td>
<td>Dry gas 323 N43</td>
<td>395</td>
</tr>
<tr>
<td>(carried by shale)</td>
<td>Oil vapor</td>
<td>45</td>
</tr>
<tr>
<td>Air (dry basis)</td>
<td>Light gasoline</td>
<td>9</td>
</tr>
<tr>
<td>Steam (carried by air)</td>
<td>Ammonia</td>
<td>4</td>
</tr>
<tr>
<td>Water added to ash dish</td>
<td>Hydrogen Sulfide</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Water vapor</td>
<td>427</td>
</tr>
<tr>
<td></td>
<td>Ash (dry basis)</td>
<td>775</td>
</tr>
<tr>
<td></td>
<td>Water in ash</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Water evaporated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>from ash dish</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>1764</td>
</tr>
</tbody>
</table>

### Oil Recovery and Cleaning Section

The operation of the oil collection and gas cleanup section are important to the plants operation and are described as follows:(1)

"The rather simple system shown in Fig. 16.8 has performed well. A unique feature of the Fushun retort is the high energy value of the product gas."

<table>
<thead>
<tr>
<th>Item</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>20</td>
</tr>
<tr>
<td>CnHm</td>
<td>0.81</td>
</tr>
<tr>
<td>O₂</td>
<td>0.2-9.4</td>
</tr>
<tr>
<td>CO</td>
<td>3-4</td>
</tr>
<tr>
<td>H₂</td>
<td>9-11</td>
</tr>
<tr>
<td>CH₄</td>
<td>7-8</td>
</tr>
<tr>
<td>N₂</td>
<td>56-60</td>
</tr>
<tr>
<td>Q kcal/nm³</td>
<td>980-11000</td>
</tr>
<tr>
<td>btu/ft³</td>
<td>112</td>
</tr>
</tbody>
</table>

As shown in Fig. 16.8, the hot oil vapors from the top of the retort first enters a gas collector where a water spray removes particulates and condenses about fifty per cent of the oil vapors. The solid particles are later separated by gravity from the shale oil. The gas and vapors next enter a water-scrubbing tower where 30% of the oil is condensed. Then, the gas enters an absorbing column, where a spray stream of 1.5% H₂SO₄ solution is applied to absorb ammonia from the gas and the remaining gas enters the water cooling tower. After leaving the cooling tower, the gas is divided into two parts: one is called recirculation gas, which is heated in a recuperative furnace to 500-700°C(932-1,292°F) and sent to the retort, as a supplementary heat source for pyrolysis and another part of the gas is used as fuel to heat the recirculating gas stream.

### Maoming (1)

Maoming, located in Guandong Province, is reported to be China's largest shale oil operation. Its overall prominence is due to, in part, to the installation of a regular oil refinery and a 140 km(87 mi) pipeline from Chanchiang to bring in outside Iranian crude oil, Fig. 16.9.
Fig. 16.8 Flowsheet - Fushun retorting process. From U.S. Bureau of Mines I.C. 7348.
The Maoming oil shale operation was opened in the 1950's to utilize shale from the Gintang open pit mining operation, Fig. 16.10, but coal is not involved. The oil content of the shale is between 63 and 75 L/MT (13.6 and 16.2 gal/st).

There were initially two retort types, the Fushun retort and gas combustion retorts. The capacity of the gas combustion retorts was 180-240 MT (198-264 st)/d. However, the gas combustion retorts were soon closed down because they produced a fuel with too low a heat value. Maoming's third Fushun-type retort plant, Fig. 16.11, was completed around September 1969, and a fourth presumably, in the first half of 1970. By 1975, it was reported six plants were in operation. It was also reported in 1977 that some by-product metal of great value was also being recovered from the oil shale. (7) As at Fushun, coal supplies the basic heat for oil shale retorting.

Shale ash from the retort is successfully used as a part of the raw material for the production of cement and may be used for other purposes. (1)

In China, the procedure for making cement is as follows: (1) Raw materials consist of river sand (SiO₂), quick lime (CaO₃) and clay (Al₂O₃SiO₂). These materials are ground into fines, calcined, and then combined with mixing materials to give cement.

After the oil shale ash is further burned, the fixed arbon is completely removed and the oil shale ash can be used as a component in the production of cement. The composition of shale ash is very similar at both Fushun and Maoming and both are used to produce cement.
In 1977, the Maoming plant was reported(14) to have a new lubrication plant and five "installations for removing and recovering sulfur." In 1981 an article(10) was published reporting on the research at Maoming in fluid pyrolysis and combustion of oil shale particles. Fig. 16.12 shows the gas receiver vessels of the Maoming retorts. Fig. 16.13 shows the discharge section of the retorts and Fig. 16.14 shows the delayed coker drums originally used for shale oil and later for processing petroleum crude.

REFINING

The Fushun refinery is an example of China's "making do" philosophy. This plant was constructed over 40 years ago by the Japanese, and it at one time refined both natural crude oil and shale oil. Refining shale oil is much more expensive than refining natural crude oil and shale oil produced now is used as industrial boiler fuel and/or sold to local farmers who process it into diesel fuel for use in their tractors.(6)(1) The shale oil has not been processed by the refinery since about 1962.

Fig. 16.15 is a diagram of the crude oil refinery as of about 1938.

Both the Fushun and Maoming shale oils are a dark brown paste at room temperatures. Both area shale oils are paraffin base oils and have a C/H ratio approaching that of crude natural petroleum. The nitrogen/sulfur/oxygen content is higher than that of most natural crudes, but much lower than that of coal tar, hence the crude shale oil is suitable for processing to liquid fuels, such as
Over the years, China has tested three shale oil processing schemes. These are:

A. Thermal processing and purification by acid and bases. This scheme was used in the 1950's and was later discarded.

B. Thermal processing and hydrotreating, used briefly in the 1950's and 60's, was discontinued following the discovery of domestic crude oil in the early 1960's.

C. Hydrotreating the entire shale oil fraction. This scheme was tested on a pilot plant scale in the 1950's.
Fig. 16.12 Maoming gas receiver vessel. Courtesy
GLenn Vawter, Wash. D.C.

System A was used on an industrial scale during the 1950's and the 1960's resulting in severe oil losses.

System B has been used for many years. The shale oil is first fractionated in an atmospheric distillation tower. The light fraction is hydrogenated to produce gasoline, kerosene and diesel oil. The middle distillate is dewaxed and paraffin is recovered as a by-product. The remaining oil is subjected to thermal cracking and purification to produce gasoline and fuel oil. The residue from the atmospheric distillation tower is sent to a delayed coker to produce a light and middle fraction plus quality coke. This system was discontinued with the discovery of crude oil in the 1960's.

System C has only been tested on a pilot plant scale.
Apparentely the refining process at Maoming is similar to system A and the shale oil is refined into a number of products (see production).

![Image of discharge section Maoming retorts. Courtesy Glenn Vawter, Wash. D.C.](image)

**ENVIRONMENT**

The problem of environmental impact caused by mining, retorting and refining operations is well recognized in China. However, the solution to the problem resulting from such work were not always of concern early in the operations and while recognized were not easily resolved.

At Fushun a number of problems exist such as dust from the mining and crushing operation of a very large coal and oil shale plants. To this is added smoke from burning of coal, shale oil and oil shale. However, waste water is reported to be one of the main problems and state standards are not met. The waste water is treated to remove the pyridine, but by products are dumped into a canal that eventually flows into a river. Problems of occupational exposure to hydrogen sulfide and aromatic hydrocarbons, such as benzene, that are common to the process, exist. Overall pollution from multiple plant sources is also a major problem.

The Maoming operation also contains many of the same problems, but on a smaller scale since the total operation is smaller.

Research and control efforts by the Chinese are underway, and many of the problems
Fig. 16.14 Maoming Delayed Coker Drums—first used for shale oil—later for well crude. Courtesy Glenn Vawter, Wash. D.C.

should be eliminated in the near future.

PRODUCTION (6)(2)

Production records from Fushun and Maoming are not available. However, a 1985 report(1) states that Fushun refinery (plant) had processed a total of 452 million MT(497 million st) of oil shale, producing a total of 13.8 million m³ (about 87 million bbl) of shale oil, 2.45 million MT(2.7 million st) of ammonia sulfate, 70 million nm³ of gas with a heat value of 1000 kcal/nm³ (112 Btu ft³) and 7 million MT(7.7 million st) of cement.

Figures for Maoming were not given. However, it was estimated (1)(6) that the
Fig. 16.15 Diagram of crude oil retorting at Fushun plant about 1938. From U.S. Bureau of Mines I.C. 7348, 1946.
Oil Shales of the World

combined plants of Fushun and Maoming currently (1985) retort 8 to 10 million MT (8.8 to 11 million st) of oil shale and produce 254,372 m$^3$ (1.6 million bbl) of shale oil along with various by-products such as ammonia sulfate, high quality coke, and shale ash for making cement. An unknown valuable metal is also reported to be produced at Maoming. The shale oil is processed to produce gasoline, diesel oil, lubricants, wax, high quality coke, and even kerosene (jet fuel) for airplanes. It would appear that these products, for the most part, are only produced at Maoming since shale oil is not refined at Fushun.

Bits of information on production are found scattered throughout the literature and are presented here for record.

Sino! (6) states that the Fushun retorting system was designed specifically to maximize production of ammonium sulfate. Products produced in 1930 were: Crude oil 69,000 MT (434,000 bbl); Ammonium sulfate 18,200 MT (20,000 st); Fuel oil 53,963 m$^3$ (340,000 bbl); Pitch coke 4,800 MT (5,280 st); and White paraffin 7,000 MT (7,700 st).

By 1948, the oil was being converted to gasoline. Petroleum coke from upgraded processes was used to make carbon electrodes for dry-cell batteries. Production of wax amounted to somewhat less than 10% of all items produced from crude shale oil. The main emphasis was placed on producing gasoline which amounted to 40% of the total production. The balance consisted of kerosene, paraffin, and wax. (6)

In those days the Chinese Government was the only consumer of gasoline, which it took without payment. Therefore producers deliberately produced more wax, paraffin and kerosene—all items which they were able to sell immediately and realize a profit.

Some yearly shale oil production figures were reported as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Fushun-BBL/Day</th>
<th>Maoming-BBL/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>1,400</td>
<td>---</td>
</tr>
<tr>
<td>1934</td>
<td>2,400</td>
<td>---</td>
</tr>
<tr>
<td>1939</td>
<td>3,200</td>
<td>---</td>
</tr>
<tr>
<td>1942</td>
<td>5,500</td>
<td>---</td>
</tr>
<tr>
<td>1945</td>
<td>5,900</td>
<td>---</td>
</tr>
<tr>
<td>1963</td>
<td>6,000</td>
<td>12,000</td>
</tr>
<tr>
<td>1965</td>
<td>40,000</td>
<td>20,000</td>
</tr>
<tr>
<td>1970</td>
<td>40,000</td>
<td>40,000</td>
</tr>
<tr>
<td>1971 (est)</td>
<td>36,000</td>
<td>34,000</td>
</tr>
<tr>
<td>1977 (est)</td>
<td>16,000</td>
<td>30,000</td>
</tr>
<tr>
<td>1985 (est)</td>
<td>1,500</td>
<td>3,000</td>
</tr>
</tbody>
</table>

FUTURE PLANS

As previously stated, China apparently is committed to expanding the development of her oil shale resources.

China has worked since the 1950's to improve the Fushun retort with considerable success. China has had extensive experience in refining and utilization of the products from shale oil.

Oil shale research laboratories have been established in Fushun, Maoming, Dalian and Beijing to carry out programs in fundamentals of oil shale processing and conversion chemistry and physics.

At Maoming, a research effort is underway to evaluate rapid pyrolysis of oil shale by mixing with hot charcoal in a moving bed system. (9) Oil shale fines are burned directly at Fushun to aid in producing electric power.

There is a movement to market Chinese oil shale as a fuel in a power plant at its Fushun plant. If successful, a cooperative project with Ronol Technology that could lead to a 200 MT (220 st) plant. China will process oil shale in its Fushun plant. If successful, a cooperation project with Jordan.

With China's large oil shale sources and well lead the world in the development.

The Chinese scientists are working on the following:

1. They are using modern equipment to improve kerogen and kinetics of oil shale.
2. They are improving existing retort efficiency and oil yields from shale oil.
3. They are developing new retorting technology.

The suspension combustion and fluidized stratified. Since July 1984, a suspension operation.

REFERENCES

1. Du, Chengjun and Nuttall, H. E., 1985, University of New Mexico, Albuquerque.
7. -----, 1979, China Today, Fushun We, No. 10, p. 4.
There is a movement to market Chinese oil shale technology worldwide. There is a reported cooperative project with Romania for development of direct burning of oil shale as a fuel in a power plant.

China has signed an agreement with Jordan to develop oil shale processing technology that could lead to a 200 MT(220 st)/d oil shale plant in Jordan. To expedite this effort, China will process some 1,000 MT(1,100 st) of Jordan oil shale in its Fushun plant. If successful, a demonstration plant might be erected in Jordan.

With China's large oil shale sources and a determination to use them, China may well lead the world in the development and use of this synthetic fuel.

The Chinese scientists are working on three main problems:(2)

1. They are using modern equipment to study the fundamental properties of kerogen and kinetics of oil shale pyrolysis.
2. They are improving existing retorting technology to increase heat efficiency and oil yields from Fushun type retorts.
3. They are developing new retorting technology.

The suspension combustion and fluidized combustion of oil shale has been demonstrated. Since July 1984, a suspension combustion type power station has been in operation.

REFERENCES

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JAPAN

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INTRODUCTION

Although extensive exploration has been conducted, no oil shale resources of value have been located to date in Japan.

In spite of the fact that no indigenous oil shale resources have been found, in 1981, a decision was made to develop a technology position in oil shale recovery not only for the purpose of exporting technology but to assure from a national security standpoint that alternatives exist for production of liquid fuels.

EARLY HISTORY (2)(3)(4)

The country of Japan has a long association with the production of, and the use of, oil shale.

Japan was a prime participant in the production of the shale oils of Fushun, Manchuria, China. The oil shale industry of Fushun dated from its discovery in 1909.(2)(See Chapter on China.) For the first ten or so years the products were marketed locally. In 1924, a 10 MT(11 st)/day pilot plant proved feasibility of commercial production and a 50 MT(55 st)/day plant was soon constructed. Sometime between 1909 and 1924, The Japanese became interested in the operation and became associated with the South Manchurian Railway Co., owners of the Fushun property. About 1926, the Japanese began construction of 80, 50 MT(55 st) per day Fushun-type retorts, which were a modification of the Estonian Pintsch retort. By 1928 Japan began the first commercial oil shale production at Fushun. September 18, 1931 Japan seized the northwest Provinces (Manchuria) and set up a
puppet state called Manchukuo. In July 1937, Japan invaded China proper.

During occupation, a second plant was constructed with modified retorts of the combined Estonian Pintsch and Japanese Inabe types. These 40 retorts were capable of processing just over 200 MT (220 st) of oil shale each per day, with a recovery of about 75%. This plant and these retorts supplied as much as 874 m³ (5,500 bbl) of oil per day during World War II.

The crude oil produced at Fushun was shipped to Japan to be refined. After refining a small part was used by Japanese industry and the major portion by the Japanese Navy.

Japan ruled Manchuria from 1931 until 1945 and promoted industrialization of the region. After the defeat of the Japanese in World War II, Japan gave up all seized land. (4)

Operations at Fushun were continued by the Chinese after World War II, and have continued up to the present time.

Thus, the Japanese have a first hand knowledge of production and refining of shale oils and with the many associated problems.

CURRENT ORGANIZATION STRUCTURE (1)

The Japan Oil Shale Engineering Company Ltd., (JOSECO) was organized under guidance provided by the Ministry of International Trade and Industry (MITI) and the Japan National Oil Corporation (JNOC). Financial support is provided by 36 Japanese companies in the fields of iron and steel, heavy machinery, mining, cement, plant engineering, and oil refining.

Objective of Program (1)

JOSECO developed a five-year plan, which soon became a six year plan due to budget contraints, to achieve the following:

- Establish a data base on a cross section of oil shales in the world that are considered prime targets for development to include chemical, physical and thermal property definitions.
- Construct, operate and evaluate three retort concepts at bench scale, or approximately 3 MT (3.3 st)/day.
- Based on the bench scale tests, choose the process concept with the most potential, and construct, operate, and evaluate the performance of a 300 MT (330 st)/day pilot plant version of the concept chosen.
- Explore production related areas, e.g., mining, crushing, beneficiation, agglomeration and environmental problems.

Progress to Date (1)

JOSECO/JNOC has accomplished the following:

- Operated and evaluated (through August 1983) a shaft type retort (using U.S., Australian, Chinese, and Moroccan shale) where oil shale grain size 6 to 70 mm (0.24 to 2.76 in.) descends under gravity while being heated by a countercurrent flow of recycled off-gas 550° C (1022°F) receiving its heat from combustion of spent shale in the lower section of the retort (a seal zone is provided between the combustion and retorting section).
  - Operation was smooth.
  - Yields slightly higher than Fischer Assay were observed.

Japan
High thermal efficiency was obtained.
- Operated and evaluated (through August 1983) a circular grate retort (using U.S., Australian, Chinese, and Moroccan shale) where oil shale grain size 6 to 60 mm (0.24 to 2.76 in.) moved circumferentially on a grate passing through preheating, retorting, combustion and cooling zones while being contacted by a downward flowing recycled off-gas 700°C (1,290°F) receiving heat from combustion of the spent shale.
- Yields were approximately equal to Fischer Assay.
- Adaptability of the plant to different shale simply by changing zone length was noted.
- Operated and evaluated (through August 1983) a cross flow retort (using U.S., Australian, Chinese, and Moroccan shale) where oil shale grain size less than 6 mm (0.24 in.) flows down the inside surfaces of the louvered walls while being contacted by heat recycled off-gas 530°C (986°F) receiving heat from a separate fluidized bed combustor using spent shale as fuel.
- Low pressure loss in the retorting zone was observed.
- High carbon utilization was obtained.
- Yields were somewhat higher than Fischer Assay.
- Evaluated 85 samples from 12 districts in six countries (U.S., Australia, Brazil, Jordan, Morocco, and Sweden) including trace element analysis, heat of combustion, differential thermal analysis, diffractometry, microscopic observations, and Fischer Assays.
- Decided (in concept with JNOC) on the shaft type retort as the concept to pursue to pilot scale and initial design of a 300 MT (330 st)/day unit.
- Signed a contract with Condor (Australia) sponsors SSP/CPM to provide 20,000 MT (22,000 st) of shale for pilot plant processing.

FUTURE PLANS (1)

JOSECO/JNOC plan to do the following.
- Complete construction of the 300 MT (330 st)/day pilot plant by March 1986
- Operate the 300 MT (330 st)/day pilot plant during April 1986 to March 1988.
- Pursue research in mining, crushing, beneficiating, agglomeration, and environmental protection problems including spent shale treatment and disposal.

Another Japanese organization, the Research for Petroleum Alternatives (RAPAD), established in 1980 by 23 Japanese companies, is pursuing research in the upgrading of shale oils. A large bench scale unit is planned to further develop a two step process for hydorefining shale oil in an ebullated-bed reactor. Both U.S. (Colorado) and Chinese (Maoming) shales are targeted for testing.

JAOSCO is a joint partner with SPP/CPM of Australia in joint sponsorship of the Condor oil shale project on Queensland, (see chapter on Australia).

REFERENCES

Chapter 18
MALAYSIA

HISTORY

Little was found regarding the history of oil shales in Malaysia.

A 1983 report by Nakamura and Tominaga stated that a 1.1 million MT/year (1.2 st/year) cement plant at Rawang is using oil shale as a part of the fuel and clay components (limestone 77.2%, oil shale 20.3%, sand 2.2%, iron ore 0.3%).

The oil shale, which has a heating value of 900 to 2,150 Btu/lb (2.1 to 5.0 MJ/kg), supplies from 25 to 60% of the heat requirement for the cement manufacturing process.

REFERENCES

Chapter 19

THAILAND

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Illustrations

Figure 19.1 Major Cenozoic Basins in Thailand.(2).
Figure 19.2 Topography of Mae Tip Basin.(2).
Figure 19.3 Oil Shale Deposits in Northern and Southern Thailand (10).
Figure 19.4 Topography of Mae Sot Basin.(1).

Table 19.1 Occurrences of Oil Shale in Cenozoic Basins of Thailand.(1)
Table 19.2 Rock Types in Mae Tip Basin.(2)
Table 19.3 Rock Types Ben Huai Kalok, Mae Sot Basin.(1)

INTRODUCTION

Oil shale has been reported from at least thirteen Cenozoic basins in Thailand, Fig. 19.1 and 19.3. These are intermontane basins with steep fault-controlled margins. Basin area ranges from as small as 1 km²(0.4 mi²) to as large as 800 km² (300 mi²). Oil shale thicknesses range from 1 m to 15 m(3.3 to 49 ft). Oil content has only been noted for three of the basins and ranges from 18.2 to 341 L/Mt (4 to 74 gal/st). In many of the basins the oil shale occurs associated with coal.
Fig. 19.1 Major Cenozoic basins (stippled areas) in northern Thailand. Modified from Gibbling and Ratanasthien, 1980.

Fig. 19.2 Topography of Mae Tip Basin, northern Thailand. From Oil Shale and Coal in Intermontane Basins of Thailand,
Fig. 19.3 Oil shale deposits of Thailand. A.K. Chakrabarti, 1976.
ACKNOWLEDGEMENTS

The assistance of Martin R. Gibling, Dalhouse University, Halifax, Nova Scotia; the libraries of several U.S. Agencies; and especially The American Association of Petroleum Geologists for permission to use some of the material presented all have my grateful appreciation for their contributions.

HISTORY

While no record of historic use of oil shale in Thailand was found, it was stated that oil shale has long been of interest as a direct resource for hydrocarbons(1). Oil shale was noted by Lee(5) as early as 1927, and again during geological exploration in 1939(8). In 1956 the Mae Sot Basin was examined by Kuman Haraguchi (3), and a rather extensive geological report was prepared. However, no appreciable amounts of exploration or delineation took place until the 1970's and 1980's.

The U.S. Bureau of Mines(6) reported in 1959 that oil shale deposits existed about 8 km(5 mi) south of Maesod in extreme western Thailand, near the Burmese frontier. This deposit outcropped along a 30.6 km(19 mi) length and was estimated to contain 2 billion Mt(2.2 billion st) of shale with a 26 percent oil content.

Plans for constructing a 954 m³(6,000 bbl) per-day plant was announced in 1959. This plant was to be a joint venture of the Thai Shale & Oil Co., and the Japanese Overseas Technical Cooperation Association(6). No records were found to indicate the plant was ever constructed.

ORIGIN of OIL SHALE (2)

The oil shales of Thailand were deposited in shallow seas, large lake basins, small freshwater lakes, and bogs and lagoons. Many of the deposits are associated with coal. Most current studies have centered on the large lacustrine deposits since they are extensive and have a high oil yield. Such oil shales interbedded with coal occur in several Cenozoic Age basins in Thailand.

The Mae Tip occurrences suggest that the deposition of oil shale was controlled by the influence of ground water on the elevation and turbidity and level of the water in the deposition basins. Oil shale is likely to be deposited if inflow of sediments is low. Increase in water level results in formation of mudstone and carbonates. Formation of oil shales may result from cyclic changes in the level of the groundwater. This theory of deposition is confirmed by study of Mae Sot and other basins(1).

GEOLOGY (1)(2)(3)(4)

There are many intermontane basins in the mountain ranges of northern Thailand that have floors of non-marine Cenozoic rocks. Fig. 19.1. Sedimentation has resulted from an uplift occurring in Cretaceous to early Tertiary times.

The sedimentary rocks of these small intermontane basins show the following features:

1. Oil shale beds are thin and low to moderate grade, but can be traced for several kilometers (miles).

2. Coal seams are very thick, up to 35 m(115 ft), but laterally variable.

3. Basin margin facies are present.
4. Mudstones are abundant and thick, up to 30 m (98 ft), but coarse clastics are uncommon.

5. Carbonate rocks are common, both bedded and nodular; diatomite occurs locally.

6. Biota is terrestrial to shallow freshwater, with roots, plant fragments, gastropods, bivalves, ostracods, trace fossils, and fish.

Fig. 19.1 shows the location of the oil-shale bearing Cenozoic basins in Thailand and Table 19.1, describes the occurrences of the oil shales within these basins. The two principal oil shale bearing basins, the Mae Tip and the Mae Sot basins have been described in considerable detail(1)(2). A summary of the material presented by these two papers and by other sources(3)(4) follows.

Mae Tip Basin:

The Mae Tip basin (Cenozoic) is located in the Mae Tip township of the Ngao district, Lampang Province, Fig. 19.2. The basin is small, 30 km² (11.6 mi²). The maximum thickness of the reported oil shale unit is 1 m (3.3 ft). Elevation of the valley floor is 220 to 280 m (720 to 920 ft) above sea level and the surrounding hills rise to nearly 1,200 m (3,940 ft). The Mae Nam Tip stream runs northeastward along the axis of the basin.

The bedrock surrounding the basin consists of Permian-Triassic volcanic rocks, shale, sandstone, and limestone. Coal and oil shale were found within the basin by Piysin(7). By comparison with Tertiary coal bearing strata elsewhere in northern Thailand, they are considered to be of Tertiary age. They strike northeastward and dip eastward at about 20° at the western edge of the basin.

There are two open cut coal mines in the basin operated by Phrae Lignite Company.

The oil shale is a tough, nonlaminated, gray-brown rock with a petrolierous odor. It occurs as distinct thin beds interstratified with coal and as beds about 1 m (3.3 ft) thick which grade upward into brown mudstone. Plant fragments are rare, and fish fragments are locally abundant. Silicates are also abundant.

Samples taken from the thin oil shale beds interbedded with coal produced oil yields ranging from 19 to 122 L/MT (4.1 to 26.3 gal/st), shown as follows:

<table>
<thead>
<tr>
<th>Oil Shale Samples(27)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Yield</td>
<td>1.5 to 10%</td>
</tr>
<tr>
<td></td>
<td>18.2 to 121.8 L/MT</td>
</tr>
<tr>
<td>Water</td>
<td>1.3 to 20.9%</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.880 to 0.975</td>
</tr>
</tbody>
</table>

The oil shale beds interstratified with coal have very uniform thickness along the strike for 1.5 km (1.0 mi). The oil shale passes laterally into brown mudstone and carbonaceous mudstone (units 3 & 4, Table 19.2). Thin 8-20 cm (3-8 in.) oil shale beds interbedded with coal remain uniform in thickness for 50 m (165 ft) up dip, and pass laterally into mudstone beds of comparable thickness. The oil shale contains abundant fish material, uncommon in mudstone.

The rock types in the Mae Tip Basin are shown in Table 19.3(2), and the topography of the Mae Tip Basin is shown in Fig. 19.2(2).

Occurrences of oil shale in the Cenozoic basins of Thailand is shown in Table 19.1 (2).
<table>
<thead>
<tr>
<th>Basin</th>
<th>Approx. Area (km²)</th>
<th>Max Thickness of Oil Shale Units Reported (m)</th>
<th>Oil Yield (L/MT)</th>
<th>Geologic Notes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mae Tip</td>
<td>30</td>
<td>1</td>
<td>18.2-121.8</td>
<td>Oil shale overlies or interbedded with coal (mean 54.1)</td>
<td>Ukakimaphan et al (1981); this report</td>
</tr>
<tr>
<td>Ban Pa Kha</td>
<td>1</td>
<td>15</td>
<td>54-153</td>
<td>Oil shale overlies coal, interbedded with mudstone; gray-brown, weak laminations</td>
<td>German Geological Mission (1972); Jabaket et al (1973); Gibling and Ratanasthien (1981)</td>
</tr>
<tr>
<td>Ban Na Hong</td>
<td>12</td>
<td>10</td>
<td>-</td>
<td>Oil shale interbedded with coal sandstone, and mudstone</td>
<td>Ukakimaphan et al (1979)</td>
</tr>
<tr>
<td>Ban Huai Dua</td>
<td>3.3</td>
<td>0.5</td>
<td>-</td>
<td>Oil shale float, associated with coal, and mudstone; dark brown, nonlaminated</td>
<td>Gibling et al (1982)</td>
</tr>
<tr>
<td>Jae Hom</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>Oil shale interbedded with coal and mudstone; gray-brown</td>
<td>Ratanasthien et al (1977)</td>
</tr>
<tr>
<td>Fang</td>
<td>525</td>
<td>-</td>
<td>-</td>
<td>Oil seepages, small-scale petroleum production</td>
<td>Lee (1927); Brown (1951) et al; German Geological Mission (1972); Piaysin (1979)</td>
</tr>
<tr>
<td>Mae Sot</td>
<td>800</td>
<td>9.5</td>
<td>max. 340.8</td>
<td>Laminated, high-grade oil shale, carbonic-rich; coal not associated but occurs northward in basin</td>
<td>Gibling et al (1985)</td>
</tr>
<tr>
<td>Mae Moh</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>Oil shale interbedded with coal and mudstone</td>
<td>Chakrabarti (1976)</td>
</tr>
<tr>
<td>Krabi</td>
<td>-</td>
<td>0.3</td>
<td>-</td>
<td>Oil shale interbedded with limestone mudstone, anhydrite, sandstone, and coal</td>
<td>Brown et al (1951); Chakrabarti</td>
</tr>
<tr>
<td>Stratigraphic Units(a)</td>
<td>Rock Types</td>
<td>Lithology (b)</td>
<td>Bedding(c)</td>
<td>Fossils(g)</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------</td>
<td>--------------------------------------------</td>
<td>------------------------------------------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Brown mudstone</td>
<td>Reddish yellow to gray (7.5YR 6/3-8 to dark reddish brown (5 YR 3/4), Massive, Tough 1-cm bands, Noncalcareous; Gypsum, ferruginous vugs.</td>
<td>Very thin to very thick, Nodular bands, Slight fissility.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Marlstone</td>
<td>Pale gray-brown, Calcareous. Tough, even beds nonlaminated</td>
<td>Very thin (15 cm maximum)</td>
<td>Plants (R)</td>
<td></td>
</tr>
<tr>
<td>3=4</td>
<td>Oil shale</td>
<td>Very dark gray to dark grayish brown (10YR3/1-2), Tough, Noncalcareous; Brown mudstone fragments and bands (2 mm), Pyrite and chalcolpyrite.</td>
<td>Very thin (8 cm) to very thick, Slight fissility</td>
<td>Plants (R), fish (U-A)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Coal</td>
<td>Black, Vitrain (10-20%, 1-mm buns) and attrital coal (80-90%, lustrous), Pyrite chalcolpyrite.</td>
<td>Laminae to very thick</td>
<td>Organic material</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Carbonaceous</td>
<td>Mudstone is dark reddish brown (2.5YR3/4), carbonaceous (80-90% of rock type). Coal is black-brown (10-20%), few mm to 5 cm beds.</td>
<td>Laminae to very thick</td>
<td>Plants (A), fish (U)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Calcareous mud</td>
<td>Light gray-yellow, patchy (10YR7/1-8). Calcareous</td>
<td>Very thick</td>
<td>Roots (U), gastropods (A locally, bivalves)</td>
<td></td>
</tr>
</tbody>
</table>

(a) Stratigraphic units refer to drilling data for the mines (Table 1).
(b) Color codes (in parentheses) from Munsell Soil Color Chart.
(c) Terminology from Campbell (1967).
(d) A = abundant, U = uncommon, R = rare.
Mae Sot Basin:

The Mae Sot basin is located in southeastern Thailand about 420 km (260 mi) from Bangkok, Thailand and extends across the Moei River into Burma, Fig. 19.1 and 19.4. The existing basin is about 65 km long by 35 km wide (41 x 22 mi), but gravity data, Fig. 19.4, indicates there is a southeastern subbasin about 25 km x 10 km (15 x 6 mi). The basin is fault-bounded at least locally(1). The mountains rise to over 1500 km (4,900 ft) above the basin floor and basically run NS. Bedrock on the eastern (Tahi) margin consists mainly of Permian to Jurassic carbonate and clastic rocks (von Braun and Jordon, 1976).

Exploration 1973 to 1979 (1)(3)(4)

Geological exploration began in the Mae Sot basin over 40 years ago (Heim and Herschi, 1939)(8). Oil shale was noted by Brown et al in 1951(9), and Smith et al (6) reported technical data on some oil shale samples in 1959. Haraguchi(3) examined the basin in 1956 and prepared a rather comprehensive geological report.

The Thai Department of Mineral Resources began exploration drilling in 1973 because of the oil crisis of that date. Geologic mapping started in 1974 and drilling continued in 1974, 1975, 1976, 1977, and 1978. By the end of 1978 a total of 156 holes had been drilled for a total of over 26,211 m (86,000 ft). In 1976 the USSR, through the Ministry of Foreign Affairs, provided two oil shale experts. These experts and Thai officials explored the Mae Sot oil shales of Amphoe Mae Sot, and recommendations on sample collection, water problems of open pit mining, and pollution problems were made(4).

The results of the drilling exploration that were reported in 1978 indicated that approximately 200 km² (77 mi²) were underlain by oil shales. The area was divided into two sections, north and south of Amphoe Mae Sot. Ore reserve estimations were as follows(4):

1. Northern Section: area 24 km² (9.3 mi²), indicated reserves based upon 35 drill holes 91 to 427 m (300 to 1,400 ft) deep, totaled 7,797 million MT (8,577 million st) of shale.

2. Southern Section: area 29 km² (11.2 mi²) indicated reserves of 10,871 million MT (11,958 million st) of shale based upon 7 drill holes 457 to 610 m (1,500 to 2,000 ft) deep.

No development or production resulted from this exploration. During 1980-81, an area energy project was conducted jointly by the Electric Generating Authority of Thailand and the Department of Geological Sciences of Ching Mai University (Tantisukrit et al, 1981(1)).

The study area of 2 km² (0.78 mi²), Fig. 19.4, lies on the northern margin of the southeastern subbasin north of Ban Huai Kalok in the Mae Sot district, Tak Province. The area flanks the Moei River, which forms the border with Burma here. Topography is gently undulating at 200 m (650 ft) elevation.

The structure of the Project study area is relatively simple. A shallow syncline trends northeast-southwest, with dips averaging 15°-25°, locally up to 57°. Faults are uncommon.

Many of the fine-grained rock types at Ban Huai Kalok south of the Study area (Fig. 19.4) are laminated, but only a few are fissile, despite a flaky appearance in weathered outcrops. Hence the term "shale" is not strictly appropriate(1). The Ban Huai Kalok oil shales in general are carbonate rich. Higher grade oil shale is richer in silica, and lower grade oil shale contains more carbonate. Oil yields for oil shale A (Table 19.3) averages 168 L/MT (36.3 gal/st), decreasing to
Fig. 19.4 Topography of Mae Sot Basin. From Military Survey Division, Thailand.
17 L/MT (3.7 gal/st) for marlstone. High and low yields are not noted, but mean yields for oil shale beds B, C, and D are given in Table 19.3. Bed thickness is not included, nor are estimates of resources in place. It is noted that two types of facies sequences are interbedded in the study area: oil shale sequences and marlstone-sandstone sequences (1).

A lower and an upper oil shale sequence, respectively 8.5 m (28 ft) and 9.8 m (32 ft) thick, were studied in detail in six pits. The upper sequence contains a high proportion of oil shale, especially of oil shale A and B. The lower sequence contains a high proportion of stratified marlstone and more laminated siltstone; many beds of oil shale are noticeably more silty than in the upper sequence. Oil shale beds A and B form distinct units up to 1.5 m (5 ft) thick and can be mapped laterally for at least 2 km (1.25 mi) along the strike without significant change in thickness (1).

The Ben Huai Kalok oil shales form laterally continuous sequences up to 10 m (33 ft) thick with some units of high grade oil shales up to 1.5 m (5 ft) thick.

Other Oil Shale Deposits

Other well known Thailand oil shale deposits are Li in Lamphun Province, Ko Kha District, Lampang Province, and Krabi in the southern peninsular region, Fig. 19.3.

Krabi Shales (10): Oil shales outcrop within the tidal estuary near Krabi on the western coast of Thailand's southerly peninsula. (Fig. 19.3). The shales were deposited under coastal swamp or brackish water conditions and are relatively small in area. Intercalations of limestone, marl, and anhydrite exist in the oil shale series. A late Tertiary or possible Pleistocene age is indicated for the oil shale which lie in the upper part of the lignite-bearing Krabi formation. The shale beds in the Krabi basin have been strongly tilted and folded, but it is uncertain whether this tectonic activity was contemporary with their deposition or subsequent to it.

Li (Lamphun District) Shales (10): These Deposits lie beneath the diatomite deposits in Lamphang basin, Ko Kha District, Lampang Province, northern Thailand (Fig. 19.3). These deposits are over 9.1 m (30 ft) thick and contain fossil leaves, fish scales, and probably ostracods (Poonthai 1967) (11). Poonthai suggests that intermontane basins of northern Thailand constitute a distinctive depositional cycle and that oil shale beds similar to the Li deposits may be found beneath other diatomite deposits elsewhere in the Lamphang basin.

Ko Kha District Shales (10): Oil shales has been found in close association with lignite about 80 km (50 mi) east of the Ko Kha District at Mae Moh, on the eastern side of the Lamphang basin. Since sediments of the Mae Sot (Sot) series have been found here, a lacustrine of fluvial environment of deposits for the oil shales can probably be assumed. Oil shale in close association with lignite has also been noted from Li district, about 299 km (186 mi) southwest of the Ko Kha district, and may occupy a northern extension of the Lamphang basin.

Reserves or grades of oil shale were not noted for any of these "Other Occurrences".

RESERVES

Table 19.1. notes that the total estimated area of the Mae Sot basin containing
<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Color*</th>
<th>Lamination</th>
<th>Fracture &amp; Toughness</th>
<th>Oil Yield M/MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil shale A</td>
<td>Dark gray to dark reddish brown (5 YR 3/2)</td>
<td>Poor; minor color change</td>
<td>Conchoidal to sub-planar; tough</td>
<td>168</td>
</tr>
<tr>
<td>Oil shale B</td>
<td>Dark grayish brown (10 YR 4/2)</td>
<td>Moderate to poor; minor color change</td>
<td>Subplanar; tough</td>
<td>116</td>
</tr>
<tr>
<td>Oil shale C</td>
<td>Gray to grayish brown olive gray (5 YR 4-7/2)</td>
<td>Good to moderate; pale laminae in dark rock</td>
<td>Planar; soft to tough</td>
<td>43</td>
</tr>
<tr>
<td>Oil shale D</td>
<td>Gray to olive gray to pale yellow (5 Y6=7/2)</td>
<td>Good to moderate; dark laminae in pale rock</td>
<td>Planar to conchoidal soft to tough</td>
<td>37</td>
</tr>
<tr>
<td>Marlstone</td>
<td>Light gray to light olive gray to pale yellow</td>
<td>Moderate to absent</td>
<td>Subplanar to conchoidal soft to tough</td>
<td>47</td>
</tr>
<tr>
<td>Laminated limestone</td>
<td>Grayish brown</td>
<td>Good (parallel to cross laminae in thin beds</td>
<td>Conchoidal; tough</td>
<td>-</td>
</tr>
<tr>
<td>Sandstone</td>
<td>Pale yellow to gray</td>
<td>Good (parallel to cross laminae in thin beds</td>
<td>Conchoidal; tough</td>
<td>-</td>
</tr>
</tbody>
</table>

*Munsell Soil Color Chart (1975) designations in parentheses.
oil shale is about 800 km² (309 mi²). The maximum thickness of oil shale units is given as 9.5 m (31 ft) and the maximum grade as 340.8 L/MT (74 gal/st). It would appear that these data are insufficient for calculation of ore reserves since other oil shale beds are present and average bed oil content is not noted. Reference to mining methods or problems were not noted.

FUTURE PLANS

Information on future plans for utilization of oil shales in Thailand are unknown. The resource appears to be of sufficient size and grade that would permit use of this resource at some future time.

REFERENCES