IMPERIAL INSTITUTE

NOGRAPHS ON MINERAL RESOURCES
WITH SPECIAL REFERENCE TO THE
BRITISH EMPIRE

PREPARED UNDER THE DIRECTION OF THE MINERAL RESOURCES COMMITTEE OF THE IMPERIAL INSTITUTE WITH THE ASSISTANCE OF THE SCIENTIFIC AND TECHNICAL STAFF

OIL SHALES

BY
H. B. CRONSHAW, B.A., Ph.D., A.R.S.M.

WITH MAP

LONDON
JOHN MURRAY, ALBEMARLE STREET, W.
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PREFACE

THE Mineral Resources Committee of the Imperial Institute has arranged for the issue of this series of Monographs on Mineral Resources in amplification and extension of those which have appeared in the *Bulletin of the Imperial Institute* during the past fifteen years.

The Monographs are prepared either by members of the Scientific and Technical Staff of the Imperial Institute, or by external contributors, to whom have been available the statistical and other special information relating to mineral resources collected and arranged at the Imperial Institute.

The object of these Monographs is to give a general account of the occurrences and commercial utilization of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes.

HARCOURT,
Chairman, Mineral Resources Committee.

IMPERIAL INSTITUTE, LONDON, S.W.7.
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OIL SHALES

CHAPTER I

OIL SHALES: THEIR OCCURRENCES, CHARACTERS AND USES

Introduction

A very widespread interest is now taken in all matters which concern the application as well as the supply and demand of mineral oils, so that it is unnecessary to dilate upon the extreme importance of guarding against a shortage of mineral oils in Great Britain. The rapid expansion of the market for petroleum products has naturally led to an energetic movement for the development of new oil-fields, from which crude petroleum may be obtained by the simple and relatively cheap process of boring or drilling. The resources of mineral oil occurring in a free state have already been dealt with in *Petroleum*, one of the monographs of this series. The amount of free petroleum which still awaits exploitation is obviously limited, just as the world's supply of undeveloped coal or any other useful mineral or rock is limited; and the more rapid the exploitation, in accordance with an increasing demand, the more pressing becomes the necessity of supplementing these supplies by oil derived from other sources.

Fortunately there are in many parts of the world immense deposits of certain materials which are capable of yielding crude oil on distillation in specially constructed retorts. This artificially derived oil resembles the free petroleum of nature in that it yields, as a result of fractional distillation and refining, a number of marketable products similar in character to those obtainable in like manner from crude petroleum.

These oil-yielding materials include oil shales, carbonaceous shales, torbanites, cannel coals, coal, blackband ironstones, lignite and peat. All these are potential sources of mineral oils, but, except in a few instances, they have so far escaped development on anything like an extensive scale.

It must be remembered that, until recently, the demand for petroleum products has been met by free oil obtained from the wells of petroliferous regions. Moreover, the commercial success of an enterprise for extracting oil from any of the substances enumerated above must be initiated upon a large and generous basis, which will involve a very considerable outlay of capital to meet the heavy expenditure entailed in the erection of the necessary plant and in the equipment of the mines; and it also entails an adequately large tonnage of sufficiently rich and workable material. In addition, there are the usual questions, inseparable from all commercial enterprises, of markets, labour, transport and supplies. Each deposit will present a separate problem with regard to the constructional details of the plant and the precise nature of the processes to be adopted in order to result in the maximum and, at the same time, the most economical yield of those products, which are most in demand. A certain degree of elasticity must be introduced into the construction of the plant in order to allow for possible variations in market requirements, for, as is well known, the oil industry is one which is constantly being subjected to new influences.

Only two of the oil-producing substances mentioned above, namely, oil shales and torbanites, are included in the present monograph, although it is not easy, if at all possible, to differentiate between torbanites and cannel coals, both on account of their frequently intimate association in nature and the fact that they are connected by intermediate varieties. Strictly speaking, therefore, the distribution of cannel coal should be considered with that of the other two substances, but this unfortunately is prevented by considerations of space and on account of the priority of oil shales and torbanites with respect to their importance as sources of mineral oils.

Oil Shales

True oil shales, or "kerogen shales," are heavy laminated rocks, dark brown to black in colour. They are easily sectile, but are very tough and resistant to weathering. The specific gravity of the Scottish oil shales varies from 1·7 to 2·3, and the streak of a good oil shale is generally brown. The shales resemble hard dark wood or dry leather, and are free from grittiness.

There are various intermediate varieties which link up the true oil shales with carbonaceous shales or "blaes," a name used by Scottish miners. The latter are black laminated rocks, which are brittle and possess a gritty nature. Unlike true oil shales, they readily weather to a dark blue clay or mud.

Steuart gives [1/p. 157] the proximate composition of the Broxburn (Pentland, Scotland) seam shale, not dried, as:

	per cent.
Volatile matter	25·5
Fixed carbon	4·95
Ash	69·55
Sulphur	1·44
Nitrogen (approximate)	0·7

The nitrogen contents of four samples taken from the Broxburn seam were 0·94, 0·61, 0·52 and 0·66 per cent. respectively, corresponding to 99, 64, 55 and 70 lb. ammonium sulphate per ton.

Samples from the Dunnet seam at Pentland yielded 25·72 per cent. of volatile matter, with 74·28 per cent. of spent shale. The volatile material consisted of oils, 12·70; water, 6·47; gas and loss, 6·55 per cent. The spent shale consisted of carbon and sulphur, 8·37; and mineral ash, 65·91 per cent. The crude oil amounted to 32·27 gal. per ton. The total nitrogen was 0·49 per cent., equivalent to 51·74 lb. ammonium sulphate per ton. It was distributed in the products thus: in the water, as ammonium sulphate, 22 lb.; in the oil, equivalent to 15 lb., and in the spent shale and loss, equivalent to 14·74 lb. ammonium sulphate per ton.

Samples from the Broxburn seam yielded 24 per cent.

volatile matter with 76 per cent. spent shale. The volatile matter was made up of oil, 10·6; water, 7·5; gas and loss, 5·9 per cent. The spent shale consisted of carbon and sulphur, 5·2; and mineral ash, 70·8 per cent. The yield of crude oil was 27 gal. per ton. The total nitrogen was equivalent to 48 lb. ammonium sulphate per ton. It was distributed in the products thus: in the water, as ammonium sulphate, 23 lb.; in the oil, equivalent to 12 lb., and in the spent shale and loss, equivalent to 13 lb. ammonium sulphate per ton [1/p. 158].

TORBANITES

Torbanites are very similar in outward appearance to cannel coals, and the two are linked up by intermediate varieties. This has led to some confusion regarding the nomenclature and distribution of torbanites. Thus they have locally received the names of Torbane-hill Mineral, Boghead, White Coal, Yellow Coal, Tasmanite, Kerosene Shale, Combustible Schist and Resinous Shale. As a result of the famous lawsuit —Gillespie *v.* Russell—it was determined that torbanite should be classed as a coal. A similar dispute in Germany, however, led to its being classed with the "bituminous shales." On account of their very frequent and intimate association with cannels, and the general inability to recognize torbanites as such in the field, it is at present practically impossible to give a complete account of their distribution.

Torbanites possess the following characteristics: Colour, dark brown to nearly black; lustre, dull to satiny; streak, dull yellowish to brownish; fracture, sub-conchoidal. They are more easily split along the planes of bedding than in other directions, and a finely laminated structure is revealed on weathered surfaces, in retorted material, and in microscopic sections. Torbanites are easily sectile, curling into thin shavings, and are very tough and resistant to weathering. They burn like a candle when ignited at a flame and crackle in the fire. The specific gravity, which is relatively low, constitutes a good index to quality; for the New South Wales torbanites, it ranges from 1·008 to 1·5 or more.

The yield of oil is high, sometimes reaching 130 gal. per ton, but the yield of ammonium sulphate is low, and frequently not more than 10 lb. per ton. The ratio of hydrogen to 100 parts of carbon is about 13 for most torbanites, and the ash content varies between 13 and 30—averaging about 24 per cent.

The ultimate composition of torbanites according to various analysts is given as follows [2]:

—	Stenhouse.	Anderson.	Fyfe.	Graham.
	per cent.	per cent.	per cent.	per cent.
Carbon . .	65·72	64·02	60·25	63·0
Hydrogen . .	9·03	8·90	8·80	9·1
Nitrogen . .	0·72	0·55	1·53	} 5·5
Sulphur . .	—	0·50	0·13–0·30	
Oxygen . .	4·78	5·66	3·62	—
Ash . . .	19·75	20·32	25·60	—

Other analysts give the amount of total carbon, as 60 to 65; hydrogen, 7·5 to 9; and oxygen, 4 to 8 per cent. Determinations of ash have given variously 12·8 to 23·2, 22, 30, 21·3, 24·3, 23·9, 29·6, 29·17 and 20·6 per cent.

The average content of fixed carbon of torbanites is about 13, and that of cannels, about 40 per cent. [3/p. 69]. Steuart remarks that torbanite differs from coal in having a larger proportion of hydrogen in its composition and in not leaving a coke on distillation. In ordinary gas coal, the proportion of carbon to hydrogen is 100 to 10. With torbanite it is 100 to 14 [1/p. 160].

Torbanites, when examined under the microscope, are found to consist largely of minute yellow or orange-coloured bodies, commonly known as "kerogen globules," of a more or less rounded form, which are embedded in a small proportion of a dark amorphous matrix. These yellow bodies are also present, though to a less extent, in oil shales. In the Lothian shales, the matrix apparently consists of minute carbonized vegetable fragments. No general agreement has been arrived at concerning the nature of the yellow bodies. Bertrand and Renault (1892) regard them as microscopic algæ. Jeffrey (1910–15) regards them as macro-spores of vascular cryptogams. Cunningham Craig (1916) argues that they represent globules of inspissated petroleum, whilst Conacher (1916) takes the view that they are fragments of resin. It may be noted that the conclusions of the last named investigator are supported by the researches of Jones and Wheeler (1916), who found that coal can be resolved into cellulosic and resinic portions, the former yielding on distillation phenols almost entirely, while the latter yields paraffins, olefines and naphthenes. Conacher holds that oil shales and torbanites are derived from the same "mother-substance" as coal by the action of natural processes, which segregate the resistant resin portions and alter them dynamically [4/p. 186].

The following table gives the carbon-hydrogen ratios of oil shales, torbanites and bituminous coal:

Kerogen from Scottish oil shales . . .	6·9 : 1
Torbanite (Scottish), average	7·1 : 1
,, (Joadja Creek, N.S. Wales) . .	6·2 : 1
Bituminous coal (average)	15·2 : 1

[5/p. 5]

Mining of Oil Shales

The methods of mining oil shales closely resemble those employed for the extraction of coal. In Scotland, either the pillar and stall system, or the longwall system, is used, each having its own advantages, according to circumstances. Experience has shown that the former is better adapted for seams of average thickness, say 7 ft., whilst the latter is more suitable in the case of two seams separated by a bed of unproductive material, which can be used for packing.

In Scotland, two men working together underground, produce 8 tons of shale per day at a (pre-war) cost of 5*s*. per ton [6/p. 136]. In an open-cut system of working, the cost per ton would be considerably less than this. In the United States, an open-cut method will probably be adopted, where the overburden is small, where steam shovels can be used, and where it will pay to mine the whole of the deposit. On the contrary, where it is the intention to mine one or more rich seams only, some modification of the room and pillar (pillar and stall) system will probably be applied.

Distillation of Oil Shale.

Oil shale is distilled in retorts of special design, and the crude oil product is refined. In Scotland, the crude oil works consist of benches of retorts, condensers and ammonia house. Shale of the requisite size is charged into a hopper of 15-tons capacity. The upper (cast-iron) portion of the retort, below the hopper, is 11 ft. long and 2 ft. in diameter at the top, and somewhat wider below [5/p. 99]. The lower (brick-work) portion is 22 ft. long, and also widens towards the bottom. Near the base are two revolving toothed rollers, which keep the shale in constant movement, the spent shale being discharged into a hopper below. Steam, superheated by the spent shale and producer gas, is introduced through ports in the sides of the retort. The products are led away at the base of the charging hopper. The temperature varies from 500° C. in the upper iron portion, where probably the maximum yield of oil occurs, to 700° C. in the brick portion below, where the residual carbonaceous matter is burnt off, and the bulk of the nitrogen is expelled in the form of ammonia. From 4 to 5 tons of shale are treated per retort per day, the consumption of steam being about ¾ cwt. per ton of shale retorted.

The condensers consist of great stacks of vertical 4-in. pipes. The condensed oil and ammonia are separated from each other, and the gas, first scrubbed from ammonia, in water-towers, and from naphtha, in a heavy-oil tower, is used as fuel for the retorts. The ammonia in the liquid is expelled in the gaseous form by blowing steam through the liquid in specially constructed tower stills, and is then brought into contact with sulphuric acid, being recovered as the fertilizer, ammonium sulphate.

The process of refining is as follows: The crude oil, freed from water and sediment, is pumped into a charging tank which feeds the first still of the bench. In Henderson's system of continuous distillation there is a series of these stills, which intercommunicate and are connected with a series of condensers. The temperature of the steam, introduced into the stills, is adjusted so as to obtain distillates of the correct specific gravity. The oil of lower boiling point, left in the first still, flows continuously into the next, where a second fraction is distilled off, and so on through the series. Sometimes only naphtha is separated, and the balance being distilled as "green oil." At the end of the series is a residue still, for the production of coke, a valuable by-product, the distillate in this case consisting of heavy oil and paraffin. When full of coke, this still is disconnected and replaced by an empty one.

The once-distilled oil is first stirred up with sulphuric acid until a black viscous tar settles; the acid removes the pyridine bases, the bulk of the phenols, the sulphur compounds, etc. In a second tank, another tar is separated by treatment with caustic soda, which extracts phenols and acids. The stirring may be done by mechanical agitators or by compressed air. In order to get marketable products having the required characteristics, the once-distilled oil is subjected to a further process of fractional distillation.

Solid paraffin is extracted from the heavy oil, which is first cooled in shallow tanks and afterwards by freezing machines. The paraffin mass is squeezed in cloths by hydraulic plate presses to form "paraffin scale," which is refined by a "sweating process." The cakes are put in wire-gauze trays into a house warmed by steam-pipes. The oil and the softer paraffin sweat out, leaving the hard paraffin behind, which is decolorized with a bleaching agent. The melted paraffin is then stirred with animal charcoal, settled and filtered through paper.

In a later design of sweating plant, an upright cylinder takes the place of the tray, the operation, however, being the same. Cooling first occurs on the outer surface of the cylinder, the soft wax and oil being forced by the crystallization of the harder wax towards the inner surface, covered by a gauze or draining screen down which they flow when heat is applied. The cylinders are cooled by air or by water. The capacity of this form of stove is twice as great as that of the tray form [5/p. 195].

L. Simpson, a Canadian [7], describes and illustrates a plant designed by him to retort 2,000 tons of shale per 24 hours, which is based upon the employment of chemical principles accepted by the Scottish oil shale industrialists, but conforming to modern practice. The shale, after being crushed fine, is conveyed into and through driers, which are heated by the waste products of combustion of steam boilers, after having passed through a gas preheater. The shale is then delivered into each of the two chambers of four double retorts (forming a bench of retorts) by special feeders, so designed that the top of the shale in each chamber assumes the shape of a pile with two long sides or slopes, thereby presenting the greatest possible surface to the action of the preheated gases within the chambers. Each chamber of the double retort is rectangular in shape at the feed end, but the two form one chamber at the discharge end, where two rotating rollers keep the shale column in constant movement downwards. There are gas inlets at both ends of the chambers. The preheated gases heat the shale to the necessary temperature for eduction, and act as carriers for the oil vapours formed by pyrolysis, and also as a diluent, lowering considerably the vapour pressures and the temperature required for eduction. The gases and oil vapours are removed from the chamber through suitable apertures; the light-oil-vapour-gas mixture comes over first, and is condensed by being passed through water-cooled condensers. The heavy-oil vapours are removed and condensed separately. After being removed from the retort, the spent shale is passed into a cooling chamber, and thence taken by suitable conveyors to the by-product plant, where it is specially treated for the recovery of ammonia. The bench of retorts is enclosed between walls of steel plates, placed some inches apart, the space between being filled with a heat-insulating material (such as *Kieselguhr*).

A well-designed and well-constructed plant of commercial size can be operated at a low cost. Simpson says the cost, excluding depreciation and bond interest, need not exceed between 25 cents (with low wages) and 35 cents (with high wages) per ton of shale treated.

Composition and Properties of Shale-Oil

Crude shale-oil is similar in composition to natural petroleum, although the former is generally richer in olefines than the latter.

It is stated by Steuart [1/p. 189] that the crude oil obtained from Scottish shale is substantially a mixture of oils of the paraffin and olefine series, with a small admixture of naphthenes and benzenes. In addition to these, the crude oil contains the materials of the tars separated by acid and alkali. There are phenols, cresols, hydrocarbons with less hydrogen than olefines, pyrene, chrysene, and also members of the quinoline and pyridine series of bases.

In passing through the refinery the crude shale-oil is split up into a number of marketable products, which include naphthas, burning oils, gas oils, lubricating oils, solid paraffin, still grease and still coke, with the properties shown in the following table :

Properties of the Products obtained in Scottish Practice [8]

—	Products.	Sp. gr.	Flash point range, C°.	Boiling point range, C°.
Naphthas	Naphtha	0·735	Lowest temperatures	60–160
	Naphtha	0·740		82–193
Burning oils	Special oil, or water-white oil	0·785	41– 49	154–260
	Crystal oil	0·800	46– 52	171–302
	No. 1 burning oil	0·805	43– 57	154–304
	Lighthouse oil	0·810	63– 71	199–300
	Mineral or marine sperm	0·830	93–110	232–357
	Mineral colza	0·840	104–116	260–371
Gas oils	Gas oil	0·855	93–110	232–376
	Gas oil, grease oil, cleaning oil	0·870	135–149	260–382
Lubricating oils	Lubricating oil	0·865	135–149	302–376
	Lubricating oil	0·875	149–155	302–427
	Lubricating oil	0·885	160–171	343–466
	Lubricating oil	0·890	165–177	382–468

Distillation Tests on Crude Oil from Scottish Seams [1/p. 156]

—		Broxburn Grey.	Broxburn Curly.
Crude oil, sp. gr. . .		0·877	0·864
Crude oil, settling point .		87° F.	88° F.
Naphtha .	Sp. gr., 0·740	1·43 per cent.	1·15 per cent.
Burning oil	Sp. gr., 0·810	27·62 „	31·14 „
Medium oil	Sp. gr., 0·840	1·75 „	4·42 „
Lubricating oil	Sp. gr., 0·865	14·82 „	12·69 „
Lubricating oil	Sp. gr., 0·885	13·21 „	10·17 „
Solid paraffin . . .		10·76 „ M. Pt. 115° F.	12·28 „ M. Pt. 117½° F.
Total products . .		69·59 „	71·85 „
Loss in refining . .		30·41 „	28·15 „

Craig [5/p. 48] states that a fresh torbanite yields a good percentage of light oils, largely formed of unsaturated hydrocarbons; but as distillation proceeds the proportion of saturated hydrocarbons increases, and the heavier fractions are almost entirely paraffins containing often a good quantity of solid paraffin wax. Hydrocarbons of the benzene series, naphthalene, etc., are only present in small quantity, and the yield of ammonium sulphate is small compared with that from an oil shale. The crude oil is fairly light and mobile.

CHAPTER II

SOURCES OF SUPPLY OF OIL SHALES

(*a*) BRITISH EMPIRE

EUROPE

England

Shales capable of yielding oil on distillation occur in England interstratified with Carboniferous and Jurassic rocks. In several coal-fields there are carbonaceous shales of Carboniferous age which yield on retorting small quantities of oil, *e.g.* that of Flint in North Wales, but they are of relatively small importance.

Of much greater importance are the oil shales which occur as seams interstratified with the Kimmeridge Clay, forming the lowest division of the Upper Oolites (Jurassic). The most important beds appear to be confined to a single well-marked horizon in the upper division, although, in view of the evidence obtained at Abbotsbury in Dorset, the possible occurrence of subordinate bands lower down, must not be overlooked. In many places the upper division has been cut out, owing to the unconformable superposition of later rocks, or the oil shales, in places, have never been formed, owing to locally unfavourable conditions. In the central parts of England, the Kimmeridge Clay as a whole becomes greatly attenuated, but, in more than one area, it exhibits abnormal phases of development. Owing to the comparative scarcity of exposures and borings, precise data as to the geographical distribution, thickness and character of the formation, and of the contained-oil shales, are not yet obtainable. The formation is known to crop out at intervals in Dorset, Wiltshire, Oxfordshire, Buckinghamshire, Cambridgeshire, Norfolk, Lincolnshire and Yorkshire, and it has been penetrated by various more or less deep boreholes in Kent and Sussex. On the other hand, boring, conducted at various points in Suffolk, Essex, Hertfordshire, Middlesex, and the northern parts of Kent and Surrey, failed to meet with the Kimmeridge Clay, hence it would appear likely that an elliptical area exists, having London as its western focus, in which the formation is unrepresented. (*See* Cambridgeshire and Essex, p. 21.)

Dorsetshire

In the county of Dorsetshire the Kimmeridge Clay has been estimated to be 900 ft. in thickness, but there is no record of the occurrence of oil shales in the adjoining county, Wiltshire, although the formation is still represented there. In the southern part of Dorsetshire the oil shales are exposed at the surface in two areas, one at Kimmeridge (round about Kimmeridge Bay) and the other at Corton, some 5 miles to the north of Weymouth.

At Kimmeridge, the principal oil-bearing shale ("black-stone" or "Kimmeridge coal") is associated with several bands of shale of inferior quality, and is about 2 ft. thick and of a dark brown colour. It readily ignites, burning with a bright flame and giving off an offensive odour. It crops out on the crest of an anticlinal fold which runs east and west in Kimmeridge Bay. On the northern side of the axis it dips from 15° to 20° beneath the Portland, Purbeck and Wealden beds, whilst on the south side it dips beneath the sea. The oil shales at Kimmeridge were known in very early days, and at different times were used for local purposes. Manfield [9/p. 166] gives an interesting account of the various attempts made to exploit them. In 1848, a company was formed to work the shales, and the products, obtained by distillation at Weymouth, were naphtha, burning oil, lubricating oil, tar varnish and a fertilizer. In 1854, the reconstructed company erected works at Wareham, 10 miles from Kimmeridge, at which the shale was subjected to low-temperature retorting, the chief object being to produce a fertilizer. The yield per ton is said to have been 7½ gal. naphtha, 10 gal. lubricating oil, 1 cwt. pitch and 11½ cwt. residue, with some paraffin wax and gas. In 1858–59 a French company exported some 2,300 tons of the shale, and, during the next few years, various unsuccessful attempts were made by other companies to exploit the deposit. In 1857 shale was discovered further west, and in 1883–84, following some exposures made in a railway cutting, trial pits and boreholes were put down, and, later, "the shales were proved to extend all the way from Ringstead to beyond Portisham" [9/p. 169]. Tests made prior to this in Scotland showed that the shale could not be retorted at sufficient profit under the then prevailing conditions. In another test made in 1903 it was shown that the sulphur still remained in the oil.

During the year 1917, a series of boreholes was commenced near Kimmeridge by the Department for the Development of Mineral Resources (Ministry of Munitions). The results obtained are embodied in reports by W. T. Anderson and A. C. V. Berry to the Ministry of Munitions in February 1918. The following figures have been taken from extracts made from these reports by the Geological Survey [10/p. 23]:

Results of Sampling and Testing Kimmeridge Shales

—	Depth.	Depth to bottom of principal oil shale.	Thickness mined.	Volatile matter.	Oil.	Ammonium sulphate.
	ft.	ft.	ft. in.	per cent.	gal. per ton.	lb. per ton.
No. 1 Borehole	108½	90	—	—	—	—
Overlying shale and blackstone conjointly	—	—	4 5	24·0	26·5	20·4
Blackstone alone	—	—	2 6	34·6	40·6	22·7
No. 2 Borehole	92½	77½	—	—	—	—
Overlying shale and blackstone conjointly	—	—	3 4	32·5	32·1	27·5
Blackstone alone	—	—	2 2½	39·1	38·4	32·4
No. 3 Borehole	290	48	—	—	—	—
Overlying shale and blackstone conjointly	—	—	2 10½	27·7	22·3	28·6
Blackstone alone	—	—	2 2½	31·6	34·4	30·7

In a complete analysis by Berry, the sulphur in blackstone, Kimmeridge No. 1, amounted to 4·51 per cent.

Estimates of Oil Shale at Kimmeridge

—	Thickness.	Shale.		Oil.		Ammonium sulphate.	
		Tons per acre.	Total tons in 2,900 a.	Gal. per ton.	Total gal. in 2,900 a.	Lb. per ton.	Total lb. in 2,900 a.
	ft. in.						
Shale . .	1 11	3,913	11,000,000	8·1	92,000,000	17·6	89,030
Blackstone .	2 6	4,375	12,000,000	37·6	363,000,000	28·6	161,820
Totals .	4 5	—	23,000,000	—	455,000,000	—	250,850

The Corton Area.—An elongated area of Kimmeridge Clay stretches from Abbotsbury Station to Poxwell and Burning Cliff. On the south side of this are older rocks, whilst on the north there appear outcrops of Portland beds, Wealden and Purbeck beds, Chalk and Upper Greensand. The district is traversed by anticlinal folds with steeply inclined northern limbs. In the neighbourhood of the great Ridgeway fault, which marks off the southern boundary of the Chalk, the beds are vertical and disturbed.

The outcrop of the main oil shale has been traced from Portisham to Upway, but further to the east and as far as Poxwell and Preston, its continuation has not been demonstrated by field-sections, although there are adequate data at hand from which it can be located. Poxwell Circus is a hollow denuded area in the crest of an anticline and surrounded by an escarpment of Portland stone. It is estimated that the depth of the oil shale is from 450 to 500 ft. below the centre of the Circus. At Black Head, west of Osmington Mill, the outcrop of the oil shale can be traced for a few hundred yards, and similar beds can be seen exposed in the face of Burning Cliff, which forms the eastern side of Ringstead Bay. Oil shale is also visible at Castletown, on Portland Island.

In August 1917, several boreholes were started by the Ministry of Munitions near Corton, and the following results are recorded in the reports referred to in connection with similar investigations at Kimmeridge [10/pp. 23–4] :

Details of Boreholes at Corton

—	Depth.		Depth to bottom of principal oil shale.		Thickness of principal oil shale.	
	ft.	in.	ft.	in.	ft.	in.
Borehole No. 1 . .	65	1	54	8	2	0
Borehole No. 2 . .	116	7	102	0	2	0
Borehole No. 3a . .	42	0	24	9	1	9
Borehole No. 4 . .	104	3	100	5	2	1

Results of Sampling and Testing Corton Shales

—	Thickness mined.		Volatile matter.	Oil.	Ammonium sulphate.
	ft.	in.	per cent.	gal. per ton.	lb. per ton.
No. 1 Borehole:					
Overlying shale and main bed conjointly	6	9	16·4	15·5	11·9
Overlying shale and main bed conjointly	4	2	18·9	15·8	17·3
Main bed	2	0	29·5	25·5	28·5
No. 2 Borehole:					
Overlying shale and main bed conjointly	6	8	13·8	15·4	11·8
Overlying shale and main bed conjointly	5	3	15·4	16·3	12·0
Main bed	2	0	22·75	28·1	14·6
No. 3a Borehole:					
Overlying shale and main bed conjointly	6	0	14·5	13·9	14·6
Overlying shale and main bed conjointly	4	1	16·4	16·3	16·2
Main bed	1	9	25·9	29·9	23·3
No. 4 Borehole:					
Overlying shale and main bed conjointly	8	1	16·8	13·4	18·0
Overlying shale and main bed conjointly	5	3	19·4	15·7	18·3
Main bed	2	1	33·5	29·1	26·1
No. 1 Incline Shaft:					
Overlying shale and main bed conjointly	5	10	—	14·6	—
Overlying shale and main bed conjointly	3	10	—	16·0	—
Main bed	2	0	—	27·6	—

In a complete analysis by Berry, the sulphur in the main bed, Corton No. 2, amounted to 5·57 per cent.

Estimates of Oil Shale at Corton

—	Thickness.	Shale.		Oil yield.		Ammonium sulphate yield.	
		Tons per acre.	Total tons in 1,500 a.	Gal. per ton.	Total gal. in 1,500 a.	lb. per. ton.	Total lb. in 1,500 a.
	ft. in.						
Main bed.	2 0	3,500	5,000,000	28·0	147,000,000	26·3	61,500
Main bed with inferior shale	4 0	8,300	12,000,000	—	—	—	—
Do.	5 0	10,300	16,000,000	16·3	253,000,000	15·1	105,000
Do.	6 0	12,000	18,000,000	15·0	271,000,000	13·2	106,500
Do.	8 0	17,700	25,000,000	—	—	—	—
Do.	10 0	21,000	32,000,000	14·0	442,000,000	13·0	183,000

According to W. H. Manfield, oil from the best Kimmeridge shales, distilled in the ordinary way, contains from 5 to 8 per cent. of sulphur, and the shales richest in oil have the most sulphur. When Kimmeridge shale is heated in a retort, considerable quantities of hydrocarbons are formed, some of which take up sulphur. There is also a uniting of several hydrocarbon molecules into one by means of the sulphur. These sulphur compounds form at a very low temperature, and, when once formed, are very difficult to destroy. Endeavours have been made to remove the sulphur from the shale itself, or to prevent its association with the oil. This can be done, but the process is not commercially available, and " up to the present no system which is sufficiently economical and practical has been demonstrated " [5/p. 171] [9/p. 176].

Norfolk

The occurrence of bituminous shales at Southrey in Norfolk was recorded in 1835 [11], and at Downham Market in 1895 [12]. Recently the district round about King's Lynn has been thoroughly investigated by Forbes-Leslie, from whose paper, published in 1916 [13], the following details have been extracted :

The strata containing the oil shales (the "Wormgay Basin" of Forbes-Leslie) are concealed under various superficial deposits. The Kimmeridge Clay formation is brought up to the surface along the River Ouse, but, towards the east, it is overlaid by Lower Greensand and Gault, and by Upper Greensand and Lower Chalk. At Holkham, on the north coast, 743 ft. of chalk and greensand cover the Kimmeridge series, whilst Wealden, Hastings and Purbeck-Portland beds are apparently absent from the district.

During Cretaceous, and possibly Tertiary times, the surface of the district was deeply trenched by inter-Cretaceous, Tertiary and pre-Glacial water-channels, which cut deeply into the Kimmeridge clays, and in which a considerable amount of boulder clay was deposited by later glaciers. The Kimmeridge series has been gently folded in two directions, one trending north and south—the principal visible fold of which is one occupying the Ouse Valley—and the other south-east and north-west.

The Puny Drain section, immediately east of the River Ouse, at Setchy, exposes various superficial deposits underlaid by Upper Kimmeridge beds, which are trenched by pre-Glacial drainage-channels, but not to an extent to affect the oil shales. The upper, or Smith's series of oil shales, consists of dark brown shale included in dark blue clays, and capped by a limestone, which constitutes a commercially important datum level. The thickness of the series varies from 100 to 300 ft.; one rich seam occurs under the limestone capping, and another at the base of the series, giving a total thickness of 6 ft., and a yield of 50 gal. per ton.

Smith's series is divided from the lower, or Puny Drain series, by yellow sandstones. The oil shales are greyish-blue in colour, somewhat open in texture, and contain abundant marine fossils and fish remains. The included clays are greyish-blue to black-blue in colour, and there is evidence of one or more land-surfaces throughout the series. The thickness is given as not less than 200 ft., and the series contains one or more seams of oil shale.

Forbes-Leslie [13/p. 22] gives three percentage analyses as examples of the relative value of the two series:

—	Smith's series.	Puny Drain series.	
Moisture	9·8	8·0	4·1
Volatile organic matter	35·1	31·7	37·1 [1]
Fixed carbon	15·3	16·3	12·0
Ash	39·8	44·0	46·8

[1] Including combined water and organic sulphur.

Analyses of the inorganic contents gave, sulphur in iron pyrites, 1·46, and sulphur, unoxidized, probably in organic combinations, 2·86 per cent. The sulphur content is given as varying from 4·32 to 7·8 per cent., the oil from both series being dark golden in colour and having a specific gravity of 0·942 to 0·960.

The Norfolk oil shales are being exploited by English Oilfields, Ltd., and at an extraordinary meeting of this company held on September 1, 1919, it was stated by Forbes-Leslie that oil shale seams had been proved over an area of more than 20 sq. miles, and that the thickness of the retortable material was not less than 150 ft. It was maintained that mining operations had shown that the upper or sulphurous series is divided by a middle shale series, which is practically free from sulphur. These middle shales were estimated at 2,000 million tons, yielding on distillation in the laboratory 50 to 80 gal. of oil and 60 to 112 lb. of ammonium sulphate per ton. The estimated yield of the whole shales was given as from 45 to 55 gal. of oil, about 60 lb. of ammonium sulphate, and about 60 lb. of paraffin wax per ton.

A report by the consultants of English Oilfields, Ltd., dated December 1920, states that the upper seam (Puny Drain) is 8 ft. thick, and contains only two small bands of "blaes," a few inches thick. The overburden or cover consists of 13 ft. of glacial gravels, etc. The lower or Mines seam is also 8 ft. thick, the roof being 37 ft. from the surface. The floor consists of a hard band of pyrite. The upper half of the seam is composed of black shale, and the lower half of hard dark green shale. The shale deposits have been tested to a depth of 300 ft.

A retort for distilling Norfolk shale has been designed by

John Black, Works Manager at Setchy, and Carter White has devised the special methods of refining used.

Some free oil has been found in a few of the wells already drilled, so that it may possibly occur in commercial quantities in depth.

Mechanical diggers are to be used for removing the overburden, after which the shales will be mined, also mechanically, by the open method.

Kent

Various borings put down in search of coal in Kent have demonstrated the existence of Kimmeridge Clay beneath the covering of newer rocks. Traced in a northerly direction, the deposit does not extend beyond a line drawn from a point one mile south of Dover to another situated about five miles south of Faversham, and from there to a point four miles south of Rochester. The Dover shaft and the borings at Brabourne, Pluckley and Penshurst show that, whilst in the east the Kimmeridge Clay is only sparingly developed and interbedded with glauconitic sand, when traced westwards it progressively thickens and assumes its normal characteristics [10]. In the borings at Dover, Elham and Brabourne, Kimmeridge Clay containing bituminous seams was found exhibiting certain abnormal features. Forbes-Leslie states [13/p. 11] that boreholes have given the following results: At Dover the Kimmeridge Clay is 44 ft. thick, contains several horizons of bituminous shales, and its top lies 457 ft. beneath the surface. At Elham, a borehole reached the Kimmeridge Clay 707 ft. below the surface and proved 108 ft. without passing through it. At Brabourne, it lies at a depth of 710 ft., and is 262 ft. thick. At Penshurst, it is found at a depth of 1,245 ft., and a borehole proved 622 ft. without passing through the series. At Pluckley, a borehole reached the Kimmeridge beds at 1,261 ft. and 526 ft. of the rock was penetrated without passing through them.

Sussex

In the sub-Wealden formation in Sussex the Kimmeridge Clay was found by boring to be 1,300 ft. thick, and at a depth of 310 ft. below the top of this clay, or 600 ft. beneath the surface, a rich two-foot bed of oil shale was encountered. A boring at Battle showed that the Upper Kimmeridge Clay has approximately the same development as at Penshurst [10], and that the top of the division is only 292 ft. below the surface. According to Forbes-Leslie [13/p. 11] the borehole passed through 1,273 ft. of Kimmeridge Clay, containing apparently rich bituminous shale.

Oxfordshire and Berkshire

The thickness of the Kimmeridge Clay in Oxfordshire and Berkshire has been estimated at from 60 to 100 ft. Shale yielding a mere trace of oil was noticed by Pringle in excavations for the Great Western Railway bridge over the Thames near Abingdon [10].

Cambridgeshire and Essex

Traces of bituminous shale occur in Roslyn Hole, near Ely. When followed towards the south-east the Kimmeridge series becomes overlaid by chalk and Tertiary beds. It is stated [10] that the upper division of the Kimmeridge is known to exist with a thickness of 15 ft., whilst the lower division is estimated to be from 80 to 90 ft. thick. Forbes-Leslie includes the greater part of the counties of Cambridgeshire and Essex, and portions of Hertfordshire and Suffolk, as containing a hypothetical deposit, which he designates as the "Saffron Walden Oil Shale Basin," although in Essex the existence of bituminous shale seams has not yet been proved [13/p. 12].

Lincolnshire

The thickness of the Kimmeridge Clay in Lincolnshire is estimated at 320 ft. Although the uppermost beds are missing, thin bituminous shales have been observed at horizons ranging from a few feet to upwards of 300 ft. below the base of the Spilsby Sandstone. Bituminous shales in the Kimmeridge Clay of Lincolnshire were first met with some time prior to 1816 in a boring, about 309 ft. deep, situated near Donington

[14] [15/pp. 48, 217]. In 1904 a boring was put down near the same spot to a depth of 326½ ft., and many bands of oil shale were traversed. Two samples of shale were reported by F. W. Richardson to yield on distillation:

	No. 1.	No. 2.
Ammonia (NH_3), per cent.	0·05	0·6
Equivalent ammonium sulphate, per cent. .	0·19	0·23
Equivalent ammonium sulphate, lb. per ton	4¼	5⅐
Heavy oils, per cent.	3·00	6·1
Light oils, per cent.	7·75	3·2

Near South Willingham station several thin bands of oil shale, or "dice," were exposed in a pit. These bands occur about 150 to 200 ft. below the base of the Spilsby sandstone, and fragments broken from them are readily ignited and give off an offensive odour. Bituminous shales have also been recorded from East Keal and Driby [15/pp. 10, 155] and from the Acre House mine [16]. In 1917, the Department for the Development of Mineral Resources (Ministry of Munitions) commenced a borehole about 120 yd. north of Donnington Station, and specimens of the boring were examined by V. C. Illing, with the following results [10/p. 29]:

Sample No.	75	76	78	79–80	81	82	83
Depth from surface in feet	365·0 to 366·1	361·7 to 363·5	351·5 to 352·8	313·7 to 315·3	309·3 to 310·9	282·4 to 284·1	194·3 to 195·3
Yield of oil in gallons per ton of dry shale . .	8·7	7·0	1·3	8·8	7·0	11·8	16·4
Sp. gr. of oil at 15·5°C. .	0·990	0·990	—	0·984	0·982	0·996	0·959

Yorkshire

In 1870, Judd recorded the occurrence of bituminous bands in the Upper Kimmeridge Clay of Speeton, Yorkshire [16]. In 1889, these were described by Lamplugh [17]. It seems probable that the bituminous shales of this county are not sufficiently rich to attract commercial development.

Other Counties

In *Middlesex*, the Kimmeridge Clay is absent from all borings. In *Surrey*, it is absent from borings at Streatham and Richmond. In *Hertfordshire*, it is absent from the boring at Ware, and it has not been met with in any of the borings in the county of *London*. In *Suffolk*, it has not been found in the Culford and Lowestoft borings, whilst the record of the Little Missenden borehole in *Buckinghamshire* is too imperfect for interpretation in this respect.

SCOTLAND

The Scottish oil shale industry is mainly located in a belt of country some six miles broad, lying about eleven miles to the west of Edinburgh, which stretches from Dalmeny and Abercorn on the Firth of Forth in a S.S.W. direction for a distance of about fifteen miles. Within this region the most important industrial centres are Broxburn, Uphall, East Calder, Mid-Calder, West Calder and Addiewell.

From the Scottish oil shale deposits about 3,250,000 tons of shale are produced annually, the average yield being 19 to 20 gal. of crude oil per ton of shale, or approximately a total of 250,000 tons of crude oil. The following table gives some annual outputs of oil shale in Scotland :

Annual Outputs of Oil Shale in Scotland for various Years since 1873

Year.	Tons.	Year.	Tons.
1873 . .	524,095	1915 . .	2,992,675
1883 . .	1,130,729	1916 . .	3,009,232
1893 . .	1,947,842	1917 . .	3,116,529
1903 . .	2,009,602	1918 . .	3,080,317
1913 . .	3,279,903	1919 . .	2,763,265
1914 . .	3,268,435		

According to Ormandy [5/p. 99], an annual yield of 70 million gal. of crude oil gives a little over half a million gal. of motor spirit, 20 million gal. of illuminating oil, 12 million gal. of fuel oil, and about 10 million gal. of lubricating oil. The total yield of paraffin wax is from 20,000 to 30,000 tons, and that of ammonium sulphate approximately 50,000 tons per annum.

The shale-oil industry of Scotland was started by James Young of Kelly, who, in 1850, took out a patent (No.

13,292) for the low-temperature distillation of coal. The raw material used for about a dozen years by Young, Meldrum and Binney at the Bathgate works in Scotland was a highly bituminous mineral called Boghead coal, or Torbane-hill mineral in West Lothian, which yielded from 120 to 130 gal. of crude oil per ton. Most of this was used in Scotland, but some was exported to America and the Continent for distillation. In 1862, owing to the supply of the Torbane-hill mineral having become practically exhausted, attention was turned to the bituminous shales of the Scottish coal-measures, and they were worked in the same year by Robert Bell at Broxburn, yielding from 40 to 45 gal. of crude oil per ton. Two years later Young's patent expired, and then followed a rapid expansion of the industry. This healthy development, however, soon experienced a check owing to the importation of American oil due to the discovery, in 1859, of natural oil in Pennsylvania. Thus in 1871, 25,000,000 gal. of crude oil were produced in Scotland from 51 works, which, within two years, were reduced to 30. From 1850 to 1864, the price of burning oil ranged from 2*s.* 6*d.* to 3*s.* 6*d.* per gal., but, shortly after the expiry of Young's patent, it fell to 1*s.* 6*d.*, and for some years varied from 1*s.* 5*d.* to 1*s.* In 1890, the price fell to less than 6*d.* per gal. In 1894 only 13 oil companies existed, and, a few years later, only 5. The competition from America and other great petroliferous areas extended to other marketable products. These conditions led to the introduction of various improvements in the processes of production, and to their being put upon an economic basis—e.g. the gases and spent shale were utilized for heating, and the ammonia water, formerly allowed to run to waste, was converted into ammonium sulphate, which found a ready sale as a fertilizer. In 1880, in consequence of the falling off in the supply of Peruvian guano, the price of ammonium sulphate rose to £22, and even to £24 per ton, but, as the importation of nitrate of soda increased greatly, the price fell in 1890 below £8 per ton.

The older type of retort required a yield of 30 gal. of crude oil per ton to be remunerative; but, with the new retort, a shale furnishing 20 gal. per ton is remunerative, and from

35 to 70 lb. of ammonium sulphate is obtained, as compared with a maximum of 16 lb. with the old retort.

The methods employed in the mining and retorting of the oil shale, and the refining of the crude oil have been dealt with already (*see* pp. 6 and 7).

The five Scotch oil shale companies have recently been amalgamated and become united with the interests of the Anglo-Persian Oil Co., Ltd. The last company has made a contract, to be effective in January 1923, to supply the new company (Scottish Oils, Ltd.) with crude oil to keep its refinery going at full capacity. It is expected that extensive improved equipment will be installed at the Scotch plants at an early date [18].

The stratigraphical relationships of the Scottish oil shales are clearly summarized by R. G. Carruthers in the following statement [1/p. 3]:

The shale-measures, on which the oil industry depends, form part of the Calciferous Sandstone series of Mid- and West Lothian and the southern coast of Fife between Burntisland and Inverkeithing, the geological position of which will be readily grasped from the following statement:

> The Carboniferous system in Scotland may be arranged in descending order in four divisions as given below:
>
> 4. *Coal-measures*, comprising red sandstone, shales, and marls, with no workable coals, underlaid by white and grey sandstones and shales, with numerous valuable coal-seams and ironstones.
>
> 3. *Millstone Grit*, consisting of coarse sandstones, with beds of fireclay, a few thin coals, ironstones and thin limestones.
>
> 2. *Carboniferous Limestone Series*, embracing three subdivisions, the highest of which contains three or more limestones, with thick beds of sandstone and some coals; the middle includes several valuable seams of coal and ironstone; and the lowest is characterized by several beds of marine limestone, with sandstone, shales, some coals and ironstones.
>
> 1. *Calciferous Sandstone Series*, forming two subdivisions. The upper, known as the " oil shale " group, is over 3,000 ft.

in thickness, and contains, in its higher part, beds of coal usually of inferior quality, and farther down, about six main seams of oil shale, interstratified with beds of sandstone, shale, fireclay, marl and estuarine limestones. The lower group, in which no oil shales of economic importance have yet been found, consists of white sandstones and shales, passing downwards into grey, green and red shales, clays, marls and sandstones, with bands of argillaceous limestone or cementstone.

The upper or "oil shale" group includes the following principal seams, which occur in descending order: Raeburn, Mungle, Grey, Fells, Broxburn, "Wee Dunnet," Barrack's and Pumpherston shales. There is considerable variation in the thickness and quality of the seams in the different districts, as well as in the distance between them.

According to Carruthers [1/p. 11], the shale-measures have been thrown into a series of undulations which trend N.N.E.–S.S.W. Five important dislocations have been traced, trending E.–W. or N.E.–S.W., two of which have a downthrow to the south and three a downthrow to the north. The general effect of folding and faulting, followed by denudation, has been the production of a number of basin-like structures in which the shale seams have been preserved.

The Scottish oil shales are of two types, viz., true oil shale ("shale") and carbonaceous shale ("blaes"). These have been described above (p. 3). Carbonaceous shale sometimes contains sufficient oil to be of economic value. The seams of true oil shale may disappear and pass into "blaes," or they may become relatively thick deposits.

The seams of oil shales vary from 2½ to 16 ft. in thickness, and the deepest workings are 1,200 ft. from the surface. In 1909, the average cost of mining and treatment of one ton of shale was about 8*s*. 3*d*., the net profit on the products being about 3*s*. 4*d*. [19]. Boverton Redwood [20/p. 429] remarks that the cost (*i.e.* pre-war) of the production of shale varies between 4*s*. and 6*s*. per ton delivered at the works, and that the retorting costs amount to 1*s*. 2*d*. per ton of crude oil.

Close to and south of the village of West Calder, Midlothian, a borehole, which was put down on the summit of an anticline by H.M. Government in search of petroleum, indications of which were met with at certain horizons, reached a depth of 3,258 ft. in 1919. The borehole starts immediately below the Broxburn shale, which has been mined to the outcrop a short distance away. From 300 to 330 ft. in depth, the Dunnet seam was passed through; at 438 ft. a second oil shale (? Under Dunnet), and, at 1,128 ft. a third seam were encountered. The last proved to be very thin. The two upper seams are abnormally thick. The Burdiehouse freshwater limestone was cut at a depth of 1,290 ft., but none of the oil shale seams that lie between this and the lower Barracks limestone, such as the Pumpherston, Dalmahoy, Wardie and Coalheugh, has been identified. This was not unexpected, as in no part of the surrounding country have they proved to be workable [21].

Oil shales of Jurassic age occur in the islands of Skye and Raasay and closely resemble those of the Kimmeridge Clay. It is stated [5/p. 29] that on retorting they yield, on an average, about 13 gal. of a very sulphurous oil, though selected samples have given as much as 16 to 19 gal.

Scottish Torbanites

The Torbane-hill or Boghead coal of Armadale and Bathgate, Linlithgowshire, was the material originally used by Young for the manufacture of mineral oil. This material was, however, exhausted in about 10 years. It occurs at a higher horizon than the oil shale group, its position being near the base of the Scottish Coal Measures overlying the Millstone Grit, and it is associated with typical Coal Measure deposits of sandstone, fireclay, ironstone and common coal. The bed was about 20 in. thick, and occurred as a lenticular deposit of about 2,500 acres in area. It outcrops towards the east, and in other directions thins out or becomes replaced by ordinary bituminous coal. The yield of crude oil was 90 to 130 gal. per ton.

Ireland

The Calciferous Sandstone series (Lower Carboniferous) of the Ballycastle mineral field in the north of Ireland, is composed of massive sandstone, shales, thin beds of limestone, ironstone and coal seams. From about half a mile to the east of Ballycastle town in Colliery Bay, outcrops of seams of shale are first met with, and continue for a distance of four miles to Fair Head. The seams are eight in number, and vary in thickness from 3 to 17 ft., having a total thickness of 90 ft. of shale, 25 ft. of this being true oil shale. The total area of this district is 9,230 acres, and the shale reserves have been estimated at 189,000,000 tons.

Unfortunately, many faults and disturbances, following a more or less north-and-south course, split the field into numerous divisions. Practically the whole of the region is capped with sheet basalt, and, in one section, zones of this material are noted through the stratified rock. Specimens of Broxburn shale, taken some distance apart from localities beneath the dolerite sill—a coarse variety of basalt—near Newbygen, gave some interesting results. Two samples yielded 23 gal., but two others gave 31 gal. each of crude oil per ton, the explanation probably being that the latter were from localities further from the igneous rocks than the former.

It is said that shafts sunk in the neighbourhood of Ballyoog have cut through, at a depth of 120 ft., a seam of shale 15 ft. in thickness, and, directly over the coal seam, another seam of shale which is as much as 60 ft. in thickness [22].

AFRICA

Southern Rhodesia

Shales distinctly oil-bearing occur in Southern Rhodesia in the so-called Black Shale group, which includes the Wankie Main Coal Seam, and in the Madumabisa Shales [23].

Union of South Africa

Wagner [24/p. 140] investigated the economic aspect of South African oil shale deposits, and concluded that there is apparently no serious obstacle in the way of establishing a successful shale-oil industry. The beds hitherto discovered in South Africa are thin, in comparison with those being worked in Scotland and France, and are not very rich, but these drawbacks are, to some extent, compensated for by the absence in the country of natural petroleum and the consequent high price of mineral oils.

Oil shales have been found in the Karroo formation over a wide area extending from Middelburg (Transvaal) to Nahainkwe (Matatiele district of Griqualand East). Although the existence of oil shales in South Africa has been known for over 20 years, the north-eastern portion of the Utrecht district of Natal is the only area which has hitherto been thoroughly explored. Other areas which have attracted attention are the central portions of the Ermelo and the Wakkerstroom districts of the Transvaal—these three areas are included in the Coal Measure series—and the eastern part of Impendhle Co., Natal, which is included in the Stormberg series.

In the Ermelo district, several beds of black and gritty carbonaceous shale yield a little oil on distillation, and one thin and discontinuous layer ("top" shale) yields from 30 to 32·5 gal. crude oil, and up to 64 lb. ammonium sulphate per ton. This shale underlies a thin, but persistent, seam of coal.

The African Oil Corporation is developing a property consisting of four farms in the Wakkerstroom district. The main shale bed, belonging to the Middle Ecca series of the Karroo formation, outcrops between two sandstone cliffs at an altitude of 5,100 ft. Cuttings have exposed the outcrops for at least three miles. The sections show: Roof, solid sandstone; oil shale, grey laminated, 16 to 27 in.; black blaes (worthless), 24 in.; sandstone (often absent), 6 in.; oil shale, grey laminated, 3 to 12 in.; coal (good), 2 in.; floor, massive sandstone. Taking the observed width of 24 in., T. G. Trevor, Inspector of Mines, Pretoria, estimates that there are 3,000,000 tons of oil shale per sq. mile, and he regards the working conditions as ideal. The yield from various samples ranged from 14 to 30 gal., and a sample from 60 tons of Kromhock shale yielded 31 gal. crude oil per ton.

The Wakkerstroom Oil Co. has taken up the farm Kickvorschfontein and four other farms in the neighbourhood. A boring machine is now on the property, and definite results will shortly be available [25].

Oil shale of the sandy and carbonaceous type is found ten miles to the south of Kickvorschfontein. It is said to be from 18 in. to 5 ft. in thickness, and to yield 60 gal. crude oil per ton.

About twenty miles north-east of Wakkerstroom, a seam of rich oil shale, rarely exceeding 3 in. in thickness, underlies a thin seam of cannel coal. A company did considerable work here in 1903, but the enterprise was subsequently abandoned.

The extreme north-eastern part of the Utrecht district of Natal is the most important oil shale field of the Union. A portion of the area was extensively explored, in 1915 and 1916, by the Union Oil Co. of S. Africa.

The "main" shale, interbedded with shales and sandstones of the Coal Measures series, is about 21 ft. thick, and contains two oil-yielding shales, the "top," slightly gritty and carbonaceous, from 1 to 3 ft. thick, and the "middle," tough and dark brown in colour and up to 5 ft. in thickness. In the eastern part of the Winterplaats, 302 acres of the area occupied by the latter seam are estimated to contain about 1,500,000 tons of shale, which, over a width of 39 in., would yield 24·5 gal. crude oil per ton. The north-eastern part of Spruitfontein is believed to be underlaid by 1,000,000 tons of shale capable of yielding 20 gal. per ton. According to Wagner [24/p. 150], the shales could be worked by adits; water and timber are abundant, and coal is present.

The oil shales of Impendhle Co., Natal (Stormberg series of the Karroo formation), are exposed in the valleys of the Umkomaas, Illatimbe and Loteni rivers. The tough, dark brownish shale occurs interbedded with fire-clay and carbonaceous shales, or mudstones, in thin, apparently discontinuous layers. On the right of the Umkomaas Valley, the oil shale forms a compact layer 3 ft. thick, a sample from which is said to have yielded 27·1 gal. crude oil per ton.

According to Alexander L. du Toit [26], the oil shale belongs to the Molteno beds of the Karroo system, which are 400 ft. thick in Impendhle Co. The shale horizon is found between two sandstones, which are 60 ft. apart, the lower one—the "Indwe sandstone"—having been traced almost continuously from the Stormberg coal area. The oil shales range from 2 in. to 3 ft. in thickness.

In the Matatiele division of Griqualand East there is a deposit of oil shale of unknown extent. The bed is about 14 in. in thickness and occurs at an horizon in the Stormberg series corresponding with that occupied by the Impendhle deposits. The shale is stated to yield about 25 gal. of oil per ton. It is reported that torbanite occurs in the Stormberg beds in Basutoland, in the angle between the Great and Little Caledon rivers near Maseru.

NORTH AMERICA

Canada

British Columbia

It is reported [27/p. 364] that oil shale deposits of considerable extent occur in the vicinity of Ashcroft, and that efforts are being made to bring about their exploitation.

New Brunswick

A belt of bituminous (Albert) shales is well exposed in the counties of Albert and Westmoreland, and is continued through King's Co., but disappears between Apohaqui and Hampton. The area most explored extends as a narrow strip from Elgin to Memramcook, in the former counties. According to Map 35A of the Geological Survey of Canada, 1911, this area is occupied by a floor of pre-Cambrian gneisses and schists upon which rests the Albert series—black oil shales, calcareous shales, grits and conglomerates—of Devonian or Lower Carboniferous age. On the Albert series lie beds of gypsum, limestone, shale, sandstone and conglomerate of Lower Carboniferous age, and above these is the Millstone Grit formation, which includes grey and purple-tinted shales, sandstones and conglomerates. The oil shales are tough, break with a conchoidal fracture, and generally are dark brownish-black in colour. "Plain," "curly" and less bituminous varieties occur.

Albert County.—Shales are exposed in Albert Co. at the surface at various points along the northern edge of outcropping pre-Cambrian rocks, and, in Westmoreland, are brought to the surface as isolated exposures by anticlinal folds. The St. Joseph, Dover and Stony Creek oil- and gas-fields are situated on the southern limb of one of these anticlines. From 1859 onwards, many were drilled in the attempt to find natural oil, but hitherto with little success. The rich curly oil shales, occurring near Baltimore, in Albert Co., were opened up between 1860 and 1864, and the mined shales were retorted. The yield is said to have been 60 gal. crude oil per ton. The New Brunswick Petroleum Co., Ltd., and Martin Oilfields, Ltd., began operations in 1900 and 1908 respectively. The New Brunswick Gas and Oil-Fields, Ltd. (successors to the latter company), are the only producers of oil at present, but are concentrating their energies on gas development. The Anglo-Persian Co. is reported to have secured an option on large shale areas south of Moncton, in Albert Co., and has, or will soon have, a test plant for the experimental treatment of the shale [28].

The Albert mines area was examined by Ells in 1909, and later by Caldwell, who had test-pits put down at regular intervals to determine the depth of soil cover, and diamond drill-cores were taken from two localities on Frederick Brook; operations were then suspended. According to the Geological Survey of Canada [29], the oil shales are covered by 5 ft. of soil over an area of 1,000 by 350 yd. Several of the beds tested yielded from 27 to 52 gal. crude oil, and from 38 to 92 lb. ammonium sulphate per long ton, but the average yield obtainable from the bulk of the shale is unknown, and, if too low, the profitable mining of the rich beds will largely depend on the geological structure. The structure of the shales is said to be exceedingly complicated except at Frederick Brook, where the rich beds appear to dip at low angles. Ells [30/p. 202], however, says that the paper shales are nearly as rich as the black shales, that their thickness is not much less than 1,000 ft., and that the greater part of the deposit is well worth retorting. He also draws attention to the extensive dumps, at the old Albert mines, of rich shale mixed with albertite, which would yield over 100 gal. crude oil and more than 60 lb. ammonium sulphate per ton. The following are results of tests by the Geological Survey of Canada of samples from the five principal beds of black oil shale, both curly and plain, uncovered above Frederick Brook [30/p. 203] :

Bed.	Thickness.	Crude oil.	Sp. gr. of oil.	Ammonium sulphate.
	ft.	Imp. gal. per ton.		lb. per ton.
No. 1 . . .	6½	48·5	0·892	82.8
No. 2 . . .	3½	38·8	0·892	60·3
No. 3 . . .	5	45·5	0·891	48·0
No. 4 . . .	4½	43·5	0·896	56·8
No. 6[1] . . .	6	27·0	0·895	49·1

[1] Interbedded with thin paper shale.

Samples of paper shale taken from Frederick Brook and of oil shale from Robertson's tunnel gave the following results :

—	Crude oil.	Sp. gr. of oil.	Ammonium sulphate.
	Imp. gal. per ton.		lb. per ton.
Frederick Brook . . .	40·8	0·892	41·0
Frederick Brook . . .	18·0	0·892	40·8
Frederick Brook . . .	33·5	0·890	47·0
Robertson's Tunnel . . .	32·5	0·885	33·0

Dover.—A test of four mixed samples taken from several places along Downing Creek, Dover, gave 27·2 gal. of crude oil, of sp. gr. 0·921, and 29·5 lb. of ammonium sulphate per ton.

Taylorville.—The following table gives the results of tests made on samples of shales from four beds near Taylorville, two of 1·83 ft., one of 3 ft., and one of 5 ft. in thickness :

—	Crude oil.	Sp. gr. of oil.	Ammonium sulphate.
	Imp. gal. per ton.		lb. per ton.
Adams Farm	43·0	0·900	93·0
Taylor Farm, No. 1 . . .	48·0	0·910	98·0
Taylor Farm, No. 2 . . .	37·0	0·925	110·0
Adams Farm, No. 1 . . .	42·3	0·897	96·5
Adams Farm, No. 2 . . .	47·3	0·901	88·7
Taylor Farm, No. 1 . . .	46·8	0·902	85·0
Taylor Farm, No. 2 . . .	45·0	0·903	101·0

These oil shales were formerly mined, and several thousand tons were shipped to the United States for distillation.

Baltimore.—The results of the examinations of samples of the shales from the area of Baltimore are tabulated below:

—	Crude oil.	Sp. gr. of oil.	Ammonium sulphate.
	Imp. gal. per ton.		lb. per ton.
Baizley[1]	54·0	0·895	110·0
E. Stevens	49·0	0·892	67·0
Geo. Irving	40·0	0·895	77·0
West Branch (grey shale) . .	56·8	0·891	30·5

[30]

[1] The Baizley bed has a thickness of 6½ ft.

Prosser Brook.—A sample from the area of Prosser Brook gave 30·0 gal. crude oil of 0·895 sp. gr., and 75·0 lb. ammonium sulphate per ton.

Beyond Prosser Brook, in a south-westerly direction, and at such points as Pleasant Vale, Mapleton and Elgin, in Albert Co. and at Sussex and Norton in King's Co., the shales become much leaner in character. Samples of the Mapleton and Elgin shales yielded from 4 to 14 gal., and one sample of Goschen shale 27·5 gal. crude oil per ton.

North-West Territories

It seems quite possible that certain of the shales in the Mackenzie region will, at some time in the future, be mined and retorted for the production of oil. Manfield [9] states that shales have been reported as far north as Cape Bathurst.

Nova Scotia

Attention has been drawn by Ells and Clapp to the various deposits of carbonaceous shales in Nova Scotia. Those of the Minas Basin region, Pictou Co., Antigonish Co., and Cape Breton Island, have received preliminary examinations. The results were not, on the whole, of an encouraging character, but there appears to be need of more exhaustive investigations.

Black shales are exposed at various points on the north and south sides of the *Minas Basin*, but the rocks are carbonaceous rather than bituminous in character, and true oil shales were not met with by Ells in the region. However, a borehole put down near Hantsport to a depth of 1,500 ft. is said to have passed through from 10 to 12 ft. of black oil shale at a depth of 800 ft.

Pictou Co.—Oil shale deposits occur in Pictou Co. in a large basin or syncline, lying east of the East River, the axis of which runs north-east, covering an area of 10 sq. miles. The thickness of the shales varies, the maximum being from 80 to 100 ft., and they can be worked by open-cut methods. The continuity and uniformity of the deposits have been proved by borings from 200 to 1,000 ft. in depth. A seam of curly shale is from 5 to 6 ft. in thickness, and yields on an average 60 to 75 gal. oil and 35 lb. ammonium sulphate per ton. The ordinary cannel shale will yield from 20 to 50 gal. oil and from 30 to 70 lb. ammonium sulphate per ton. Samples of the shale-oil, which were distilled and fractionated at the Imperial Institute in 1912 yielded: Crude oil, 57·3 gal.; sp. gr., 0·873; flash point below 20° C.; and the following percentages: Light oil, 13; gas oil, 7·5; medium oil, 31; heavy oil, 35·5; still coke and tar, 13. These results were obtained by the Scottish method.

Two samples of shales from McLellan Brook, Pictou Co., yielded 42 and 14·5 gal. oil and 41 and 35 lb. ammonium sulphate per ton respectively.

It has been estimated that there are at least 500 million tons of shale in this area that can be worked profitably [31].

In 1859, torbanite was discovered at Stellarton, Pictou Co., and about 4,000 tons are reported to have been shipped for treatment abroad, a portion going to the United States [32]. The torbanitic mineral ("stellarite") gave a high yield in gas, and was evidently used in the process of gas making. Work on this area was discontinued soon after finding the native oils of Western Ontario.

Antigonish Co.—An oil shale area exists round Big Marsh or Hallowell Grant, Antigonish Co., about nine miles north of Antigonish town. Samples taken by Ells yielded from 11 to 23 gal. oil, and from 22·6 to 38 lb. ammonium sulphate per ton, and others taken by Clapp [27/p. 14], gave from 4·8 to 11 gal. oil and from 8·7 to 38 lb. ammonium sulphate per ton. Farther east, at Beaver settlement, there are large areas of very black carbonaceous shale, which yield, in the laboratory, 7·45 gal. crude oil per ton.

Cape Breton Island.—It is quite possible that in Cape Breton Island, oil-yielding shales are unconformably overlaid by lower Carboniferous limestone and gypsum. So far borings for oil shale have proved unsuccessful.

Ontario

That part of Ontario which extends in a south-westerly direction as a peninsula between Lake Huron and Lakes Ontario and Erie, i.e. south of a line drawn from Georgian Bay to Kingston, is occupied by sedimentary rocks of Palæozoic age. Within this area a series of black "bituminous" or perhaps more correctly, carbonaceous shales, some 150 to 400 ft. thick, and known as the Utica formation, overlies the Trenton limestone, which is an important petroliferous formation. It takes its name from the town of Utica, in New York, where it is typically developed. In Ontario the outcrop of the carbonaceous shales is exposed at intervals between Grand Manitoulin Island and Whitby.

In 1859, an oil shale distillation plant was erected near Collingwood in Simcoe Co. for treating Utica shale quarried in Collingwood township, Grey Co. The venture appears to have enjoyed a period of prosperity [27/p. 208].

The Ohio shales of south-western Ontario have been examined by M. Y. Williams [33]. No distillation tests were made, but the proximate analysis of samples taken indicates a yield of about 10 gal. oil per ton, and the nitrogen content is equivalent to about 10 lb. ammonium sulphate per ton.

Quebec

In 1909, Ells visited the Gaspé Basin, in order to examine the deposits of oil shales in that part of Quebec. The oil shales, which are rather of the nature of a "resinous," shaly sandstone, occur in the vicinity of the village of Gaspé and along the York and St. John rivers, which flow into Gaspé Basin. A description of the geological structure of the district, with an account of the various borings which have been put down in search of oil, is given in the Summary Report of the Geological Survey of Canada for 1902. As a result of this examination, Ells does not entertain a favourable opinion of the deposits of oil shale as regards their commercial value. It is possible, however, that careful prospecting of a detailed character may reveal more promising occurrences. So far as is known, the bituminous bands are very thin, ranging from 1 to 5 in. in thickness, and display irregularities both in thickness and in lateral extent. The following table gives the results of three tests of samples from the bituminous bands :

—	Crude oil.	Sp. gr. of oil.	Ammonium sulphate.
	Imp. gal. per ton.		lb. per ton.
No. 1 from band 14 in. wide, St. John River	30·0	0·962	42·20
No. 2 from band 5 in. wide, St. John River.	31·5	0·977	40·00
No. 3 from loose piece from York River .	36·0	0·953	59·50

Saskatchewan

Bituminous shales of Cretaceous age are known to occur in the Pasquia Hills of east-central Saskatchewan, the best exposures being found in the valley of Nabi River [27/p. 251]. A sample tested by the Mines Branch, Canada Department of Mines, gave 40·05 Imp. gal. of crude oil and 33·5 lb. of ammonium sulphate per ton. Manfield [9/p. 163] states that in the same hills near the Carrot River, oil shales of the Niobrara Cretaceous formation, 150 ft. in thickness, have been found. A chance sample of these gave 7 gal. of crude oil and 22·5 lb. ammonium sulphate per ton of shale.

Newfoundland

Large deposits of shale, covering an area of about 150 sq. miles, are reported to exist near the west coast, while, in the upper reaches of the Humber River, north of Deer Lake, on the same coast, a belt of bituminous shale, containing, here and there, veins of asphalt, is traceable for a distance of thirty miles. An English company has been formed to exploit the deposit. It is considered that much of the shale in the area is likely to yield from 20 to 30 gal. of crude oil, and from 20 to 30 lb. of ammonium sulphate per ton.

The beds are said to be from 50 to 100 ft. thick. A sample of typical shale yielded 50 gal. oil and 80 lb. ammonium sulphate per ton [6/p. 25].

At Pilier, Cape Rouge Peninsula, on the east coast, a "cannel shale" occurs, containing: Volatile matter, 36; fixed carbon, 35; and ash, 29 per cent.

AUSTRALASIA

Australia

The Federal Government of Australia pays a bounty on crude shale-oil produced in the Commonwealth, the amount paid during the twelve months ended June 30, 1919, amounting to £26,406. The whole of this bounty was earned by the firm of John Fell & Co. for oil produced at Newnes, New South Wales [34].

New South Wales

The known deposits of "kerosene shale" (torbanite) in New South Wales, according to Carne [3/p. 41], with two exceptions, lie along the shallow western margin of the Hunter River or Northern Coalfield in the Blue Mountains near Sydney. They are distributed along the margin of this area for a distance of about 200 miles, and are mostly situated close to the Mudgee railway. The two exceptions, Greta and Murrurundi, are adjacent to the eastern boundary of the Coal Measures. The occurrence of the prospected or exploited deposits close to the railway lines is explained by the greater facilities offered for exploration in these places, and by the probable lack of outcrops in the intervening rugged country owing to the dip of the measures in a north-easterly direction. Exploitation is largely in the hands of the Commonwealth Oil Corporation, Ltd.

The kerosene shale occurs in isolated and lenticular deposits at several horizons in the Upper Coal Measures of the Permo-Carboniferous System. According to David [35], its vertical range amounts to about 9,000 ft. In the Lower Coal Measures, two small patches of the shale have been found at Greta and at the head of the Clyde River. The mode of deposition of the Murrurundi deposit is exceptional and its stratigraphical position is somewhat problematical. The Coal Measures are capped by the Hawkesbury series of Triassic age, and are underlaid by the Upper Marine series of the Permo-Carboniferous age. Everywhere the strata appear to be only slightly inclined.

The kerosene shales are intimately and constantly associated with seams of coal, which are uniform and persistent over wide areas. In very many cases the shale is intercalated between thin coal seams, and at Hartley and Joadja the shale, when traced in certain directions, is found to wedge into a seam of solid coal. Moreover, the shale deposits frequently show a marginal transition into bituminous coal or coaly shale, and at other times into ordinary clay shales. Again, one often finds the shale seams horizontally divided by thin persistent bands of cannel, varying from a quarter to 6 in. in thickness.

Except for the extremely rugged nature of the country, prospecting is simplified by the fact that the shale outcrops along the sides of the deep gorges cut into the Triassic strata and Coal Measures forming the Blue Mountains. In this connection, however, the very inconstant character of the seams must be kept in mind. The shale exhibits a remarkable resistance to weathering. Inferior portions, where weathering does occur, form a grey powder, but the richer varieties yield a powder which is of a yellowish-brown colour.

The colour of kerosene shale from New South Wales varies between brownish-black and greenish-black. Its streak is yellowish to brown, and its lustre is dull to satiny in the highest grades. The texture is exceptionally fine and the fracture is conchoidal across the planes of bedding, but along these planes the shale is thinly fissile. The rock is easily sectile, and its specific gravity ranges from 1·008 to 1·5 or more. Coarseness of texture, roughness and deficiency in lustre accompany depreciating quality.

Carne states [3/p. 69] that the average analyses of five samples of the richest New South Wales kerosene shale (from Joadja) gave 88·88 per cent. of volatile hydrocarbons and 6·25 per cent. of fixed carbon. A large number of analyses of other samples from New South Wales gave average compositions ranging from 69·85 to 33·93 per cent. of volatile hydrocarbons, and from 14·10 to 12·40 per cent. of fixed carbon.

An analysis of the oil yielded gave the following results: Gasoline, 7; kerosene, 45; gas oil, 25; and residues, 9 per cent.

The following notes are taken from Carne's memoir on the kerosene shale deposits of New South Wales [3]:

Capertee Valley District.—At Blackman's Crown, near Capertee, Co. Roxburgh, the kerosene shale seam is 220 ft. above the Marangaroo conglomerate; at the Genowlan and New Hartley mines, 6 miles to the N.N.E., the shale horizon is 70 ft. lower. The two mines were controlled by separate companies. A portion of the shale was retorted at Torbane, 2½ miles from the mines, where there is a railway station. Extensive deposits are said to occur near the "Gullies" and Wolgan Valley.

Hartley Vale District.—The shale 60 ft. above the conglomerate was of exceptional thickness and richness. It was mined and exported for over thirty years, the inferior grade being retorted. The deposit is stated to be practically exhausted.

Katoomba District.—In the Megalong Valley, Co. Cook, three seams of kerosene shale occur, viz., the upper, middle and lower, which are 70, 45, and 5 ft., respectively, above the Marangaroo conglomerate. A company, working the upper seam, in a few years exported 20,000 tons of shale. The middle seam (Mort's) is purely local, and has been practically worked out. The upper (Ruined Castle seam) appears to extend over a considerable area in the southern extension of Megalong Ridge, but is of inferior quality. The lower seam is said to be of good quality.

Joadja District.—At the Joadja Creek mine, Co. Camden, kerosene shale is associated with cannel and bituminous coal, and laterally in at least one direction merges into a solid coal seam. The high-grade material is irregularly distributed, and frequently follows narrow winding channels. The deposit has been extensively worked since 1873 ; the bulk of the shale mined was exported for enrichment of coal gas, and a portion was retorted and the oil refined locally. The upper seam is 7 to 10 in., and the lower one 10 to 14 in. thick. The yield from 100 tons of kerosene shale is said to have included 10,000 gal. crude oil, or 5,000 gal. good burning oil.

Burragorang District.—A thin and inferior seam of kerosene shale outcrops in the Burragorang Valley. Some prospecting levels, driven in 1888 and 1890, appear to have met with no success.

Barigan District.—Kerosene shale, 2½ ft. thick, separating two coal seams, and 5 ft. above the conglomerate, was proved by a shaft sunk in 1898 in the Barigan Creek, Co. Phillip, but the locality is an inaccessible one. Samples yielded 60 per cent. volatile hydrocarbons, 10 to 14 per cent. fixed carbon, and 20 to 24 per cent. ash.

Marangaroo District.—A seam of kerosene shale occurs near Wallerawang, Co. Cook, 40 ft. above the conglomerate, with carbonaceous shale, associated with a coal seam, above and below it. About 1850, some levels were driven to test the deposit and a little oil was obtained from a retort erected at Kerosene Vale.

Mornington District.—In 1900, a company drove some levels in a shale seam in the Cumbermelon Range, and erected a retort, but subsequently abandoned operations. Other deposits occur at Mount Marsden, Goongal parish, and in the Ilford Range, Co. Roxburgh. Near Ilford, kerosene shale occurs in a coal seam almost at the top of the Coal Measures ; about five miles N.E. it is 50 ft. lower, a coal seam representing the Ilford horizon ; 2 miles further N.E. (Mount Marsden) the shale occurs in the lowest coal just above the Marangaroo conglomerate, which marks the base of the Freshwater Measures in this district.

Murrurundi District.—Coal Measure strata containing oil shales occur interbedded with tuffs and agglomerates in the parish of Temi, Co. Buckland. The deposit shows considerable variations ; possibly there may be an average of 9 in. of fairly good shale, associated, in places, with several feet of inferior material. The deposit has been well prospected in the past.

Mount Kembla District.—At America Creek, Mount Kembla, near Wollongong, a shale mine and retorting plant were in operation for about 10 years, the first oil being produced in 1865.

The Wolgan property, Co. Roxburgh, was the only one producing shale on a commercial scale in 1919. The results of prospecting for the mineral in other parts of the state during that year were not encouraging [36].

The following table gives sundry annual outputs and values of oil shale mined in New South Wales since 1865 :

Production of Kerosene Shale in New South Wales

Year.	Tons.	Value.	Year.	Tons.	Value.
		£			£
1865 .	570	2,350	1915 .	15,474	12,890
1875 .	6,197	15,500	1916 .	17,425	17,772
1885 .	27,462	67,239	1917 .	31,661	36,565
1895 .	59,426	75,219	1918 .	32,395	39,676
1905 .	38,226	21,247	1919 .	25,453	37,968
1914 .	50,049	27,372	1920 .	16,090 [1]	—

[1] Production of Commonwealth Oil Corporation, Ltd., for year ended September 30, 1920. Yield was 1,282,158 gal. of crude oil and naphtha, or 79·68 gal. per ton of shale.

The total production of the shale industry to the end of 1919 is valued at £2,502,813.

Queensland

Oil shale deposits in Queensland occur near Gladstone, Port Curtis province ; in the Ipswich district of Moreton province, and near Toowoomba in Darling Downs province.

Oil shales are also present in the Tertiary basin of the

Dawson River and upon the northern flank of the McPherson Range, near the border of New South Wales.

The Narrows, Port Curtis District [37].—A narrow belt of Tertiary sediments extends along the Narrows, a strait which connects Keppel Bay and Port Curtis, and separates Curtis Island from the mainland. On the mainland the deposits extend to the north-west from a point on the coast, about three miles west of the mouth of Munduran Creek, to Targinie Creek, nearly 16 miles to the south-east; they extend inland from one to two miles. The chief development on Curtis Island is between Badger and Monte Cristo creeks. The bulk of the Tertiary formation consists of shales, which sometimes pass into argillaceous sandstone, and which contain intercalated oil shales. These oil shales vary in colour from light brownish-yellow to dark brownish-green. They are somewhat sectile, exhibit a dark greasy streak, and are earthy to leathery in nature. They contain large numbers of the minute reniform bodies which are such constant features of similar shales.

The shales of Munduran Creek are associated with fireclays. A sample of darker shale from the dump of the Munduran Company's shaft gave on analysis: Fixed carbon, 6·7; volatile matter, 27·6; moisture, 5·7; and ash, 60·0 per cent. The yield of oil amounted to 28 gal., and of ammonium sulphate about 47 lb. per ton. There appears, however, a possibility that richer oil shales will be discovered elsewhere in the district.

Baffle Creek District [38].—An oil shale area is situated in the upper part of Baffle Creek valley, about midway between Gladstone and Bundaberg. In 1916, the Lowhead No. 1 borehole, situated about a quarter of a mile from the North Coast Railway, was sunk to a depth of 482 ft. Fourteen seams of oil shale were passed through without the base of the Tertiaries being reached. Fifty-four samples of various grades of oil shale were collected by Ball. Of these, 22 samples gave an average yield of 5 gal.; 18 samples, 15·1 gal.; and 14 samples, 26·5 gal. oil per ton. The following figures have been extracted from a table given by Ball; it is to be noted that the tests on the yields of oil and ammonium sulphate were carried out under laboratory conditions:

Depth.	Thickness of oil shale seam.	Oil.	Ammonium sulphate.
ft.	ft.	gal. per ton.	lbs. per ton (calculated).
73½	1	20·3	59·1
87½	1½	32·8 [1]	97·1
89	3	20·3	38·0
160½	2½	32·2 [1]	35·9
166	3	21·4	56·0
217½	1½	23·2	25·3
219¾	1½	31·0	28·5
301	2½	37·5	38·0
324	4½	31·6	28·5
341¼	4½	24·4	35·9
398¼	1½	22·0	30·6
411¾	1½	29·8	48·6
429	3	24·4	38·0
454½	1½	20·8	33·8

[1] Associated with coal seams.

The average yield of oil is 26·5 gal., and of ammonium sulphate, 42·4 lb. per ton, whilst the total thickness of oil shale is 33 ft.

The oil shales occur in Tertiary sediments which cover an area measuring 11 miles by one or two miles in width. The rocks passed through in the borehole include oil shales, barren shales, sandstones, and thin "coal seams." The so-called "coal" appears, however, to be more nearly related to one of the bituminous minerals (*see* note, p. 14 ref. [38], 1916). The dip of the strata round about the borehole averages 20°. The oil shales are pale buff to dark brown in colour, and are mostly fine-grained in texture. They are soft and sectile, and the richer bands have a tough and leathery nature. Their streak is dark brown, and they are greasy or waxy.

Tasmania

Oil shales are found in the Carboniferous strata of Table Cape, in the northern part of the Island, and in a belt extending from the Don Valley past the Mersey River to the Tamar estuary.

The area of oil-yielding shale (tasmanite or torbanite) covers 125 sq. miles, but the principal deposits are on the Mersey, between Railton and Latrobe. Exposures occur in a bank of the River Mersey, in the beds of small creeks, in the scarp faces of faults, and at the edge of beds fringing or passing below basalt lava. Where it occurs only as loose slabs, it may be referred to high country falling to the Mersey.

The property of the Tasmanian Shale and Oil Co. lies 2¼ miles south of Latrobe, and operations were commenced in 1910. Much exploration work has been carried out by shallow shafts, but the deposit does not appear to have been adequately proved. This could be most satisfactorily done by a core drill. Four retorts were erected, each with a daily capacity of 4 or 5 tons of shale, and also a plant for extracting the lighter oils from the crude oil. A little over 20 tons of oil have been produced at these works, but operations were suspended owing to lack of sufficient capital.

The leases of the Latrobe Shale and Oil Co. are situated on both banks of the Mersey. Considerable exploration work has been carried out by diamond-drilling to determine the extent and thickness of the seam. Two samples assayed by the Government analyst gave calculated yields of 50 and 29·4 gal. of oil per ton of shale respectively. The depth of the seam below the surface nowhere exceeds 200 ft.

The table on p. 46 gives some of the results obtained by Black and Esdaile in 1902 in the course of an investigation on the shales on the property of the Tasmanian Shale and Oil Syndicate of Adelaide (James's Freehold).

These trials were of shale from ground now held separately by the Tasmanian Shale and Oil Co. and the old Adelaide Co. According to Black, the oil distils over freely at a temperature lower than that required for the shales of Scotland [39]. Shale has also been found on the divide between the Mersey and Minnow rivers, south of Kimberley.

The bed is intercalated with mudstones belonging to the Permo-Carboniferous upper division. According to Twelvetrees, indications of this shale or tasmanite may be sought wherever the rocks of that division are found in comparatively undisturbed positions along the boundaries of the ancient rocks. The only other place in the island where strata of this epoch are exposed is at Porter Hill, on the Brown's River road, near Hobart. The shale is a brown or grey laminated, tough and leathery

Distillation Tests on Shale Oil from James's Freehold, Tasmania (Black and Esdaile, 1902)

—	Weight.	Fraction of gal. of product.	Temperature of steam distillation.	Sp. gr. at 20° C.	Flashing temperature.	Firing temperature.	Gal. per ton.
	oz.		C.°		C.°	C.°	
Gasolene or Heavy " Benzine " .	12·390	0·1128	Up to 115	0·779	Fires at once	Ord. temp.	6·429
Light Burning Oil (Photogene) .	13·270	0·1115	Up ,, 140	0·834	31	49	6·355
Heavy Burning or Lighthouse Oil	6·60	0·0496	140 ,, 160	0·846	60	72	2·827
No. 1 Light Lubricating Oil .	8·70	0·0642	160 ,, 180	0·870	82	107	3·659
No. 2 Light Lubricating Oil .	11·36	0·0882	180 ,, 200	0·914	121	133	5·027
No. 3 Light Lubricating Oil .	3·31	0·0230	200 ,, 220	0·900	127	139	1·311
No. 1 Medium Lubricating Oil .	11·25	0·0855	220 ,, 240	0·924	133	143	4·873
No. 2 Medium Lubricating Oil .	6·00	0·0433	240 ,, 270	0·947	155	177	2·468
No. 3 Medium Lubricating Oil .	6·00	0·0429	300	0·966	188	204	2·445
Totals	78·88	0·6210	—	—	—	—	35·394

rock, which can be cut with a knife. The outcrop weathers very slowly. The shale splits readily only along the bedding-planes. It ignites easily, producing a smoky flame, and a highly resinous odour. Church states that tasmanite is quite insoluble in resin and solvents, and he regards it as allied to "retinite," but it contains from 1·5 to 2·6 per cent. sulphur (from which retinite is almost free) partly in combination with the carbon and hydrogen. The objectionable element in the oil can be reduced to 0·6 per cent. [39]. The calorific value of the crude oil obtained from the shale is about 22,000 B.T.U.; the flash point of the fuel oil manufactured by the Tasmanian Shale and Oil Co. is given as 113° to 127° C., and the sp. gr. as 0·936 to 0·950.

Owing to the incomplete nature of the prospecting which has, so far, been carried out in the Mersey district, it is difficult to formulate an opinion on the extent of the deposits and the quantity of shale available. Taking the specific gravity of the shale at 1·6 and the average thickness of the seam at 4 ft., Twelvetrees estimates the possible total tonnage as follows:

—	Acres.	Tons.
Latrobe Shale and Oil Co.'s leases	670	4,000,000
Tasmanian Shale and Oil Co.'s leases	400	2,400,000
James's Freehold (now Adelaide block)	150	900,000
Bennett's Creek and Oliver's Farm	50	300,000
Total in Mersey District	1,270	7,600,000
At Nook Road	140	800,000
At the Minnow (possibly)	600	3,600,000
Total	2,010	12,000,000

Future discoveries may possibly be made on the Rubicon Fall and in the eastern part of Latrobe Township, as well as immediately south of it, but the productive area known at present cannot be estimated as greatly exceeding 2,000 acres in the aggregate.

In Tasmanian practice it is intended not to proceed further than the first distillation, and the rectifying of the spirit obtained during that process. The spent shale, which contains about

10 per cent. of carbon and about 82 per cent. of material insoluble in acid, finds a local sale for agricultural purposes.

The laboratory assays of numerous samples of the Mersey shale have yielded results varying from 29 to 50 gal. oil per ton. Black reported results from various outcrops as from 44 to 65 gal. of crude oil per ton. Experiments made with average quality shale showed that from 35 to 36 gal. per ton of various refined oils could be obtained by retorting and subsequent distillation processes.

Twelvetrees considered in 1911 that it would be possible to deliver the shale to the retorts from the mines at about 6*s.* per ton, and W. J. Hall, general manager of the Tasmanian Shale and Oil Co., estimated the cost of retorting a ton of the Mersey shale at 1*s.* 6*d.*, although Twelvetrees thought that 3s. would be a safer estimate. Hall takes 40 gal. per ton as a working basis for the shale at the Mersey Bend, and his estimate of the products obtainable, neglecting the values, is as follows :

Produce of 6 tons of Shale.	Gal.
Motor spirit, 11 per cent.	27
Turpentine substitute, 10 per cent.	24
Engine oil, 9 per cent.	22
Residual (fuel) oil	167
1 ton oil =	240

At Preolenna, near Wynyard, which lies considerably to the west of Devonport, on the north coast, kerosene shales are found associated with seams of coal. One of the seams contains kerosene shale from 6 to 14 in. thick. An analysis gave the following percentages: Moisture, 1·3; volatile matter, 69·56; fixed carbon, 26·54; ash, 2·88; the ratio of volatile matter to fixed carbon being as 2·70 : 1 [40].

Bangor District.—Oil shale outcrops on the top of a hill half way between Bangor and Karoola [41]. The shale is of the black, carbonaceous type, and probably exists in a few thin layers. It is sectile, but not inflammable. The yield is 19·7 gal. crude oil, 14 gal. ammoniacal water, and 2,000 cub. ft. of permanent gas per ton. The oil is dark green by reflected light and red by transmitted light. It is of a paraffin base and is semi-solid at 17° C. The sp. gr. is 0·920 at 15·5° C.

New Zealand

According to the "Mines Statement" of New Zealand for 1918, oil shale was mined from 1901 to 1903 amounting to upwards of 14,000 tons, valued at £7,236.

It is stated [42] that "bituminous shale," probably lignite, occurs to a small extent in the upper portion of the coal formation of D'Urville Island, in Cook Strait; at Mangonui and Waiapu, in Auckland; at Kaikora and Blueskin in Otago; at Orepuki in Southland, and in other localities. The following analyses of bituminous shales are given:

Locality.	Volatile matter.	Carbon.	Water.	Ash.
D'Urville Island .	81·79	7·98	0·69	9·54
Mangonui . .	75·20	9·30	1·80	13·70
Chatham Islands .	66·43	20·41	4·61	8·55
Chatham Islands .	64·67	19·87	7·13	8·33

The shale from Chatham Islands contains traces of sulphuretted hydrogen.

At Cambrian's, near St. Bathan's, there is said to be a brown, fragile "shale," probably lignite, which burns with a bright flame and which gives on analysis: Fixed carbon, 26·02; volatile hydrocarbons, 56·05; water, 12·83; and ash, 5·10 per cent. [43].

At Waimate is a light brown, fragile shale which gave on analysis: Fixed carbon, 9·81; volatile hydrocarbons, 27·99; water, 16·19; and ash, 46·01 per cent. [44].

Oil shales containing sulphur occur at Orepuki, near Invercargill. They are said closely to resemble the Scottish shales both in appearance and composition. Carne [3/p. 20] quotes a statement to the effect that the seam has a thickness of 4 ft. and is overlaid by 3 ft. of bituminous coal. The shale is said to yield 32 gal. of oil per ton and to contain from 60 to 70 per cent. of ash. A retorting plant and refinery were established at Orepuki, but operations were suspended in 1903.

There is an outcrop of oil-yielding shales about 1½ miles north-west of Pungaere Settlement on the right bank of Waiarewau stream, in the Whangaroa sub-division [45]. There are at least two beds of oil shale, the upper having a maximum thickness of 8 ft., being separated from the lower bed by 5 or 6 ft. of decomposed conglomerate. The lower bed contains several "carbonaceous streaks," and has a maximum thickness of nearly 6 ft. The following table gives the percentage analyses of three samples:

—	No. 1.	No. 2.	No. 3.
Fixed carbon	4·75	7·40	7·47
Volatile hydrocarbons . .	26·95	30·67	18·12
Water	1·50	2·16	1·11
Ash	66·80	59·77	73·30

Sample No. 1 is a picked specimen from the upper bed. Sample No. 2 is a specimen forwarded to the Colonial Analyst in 1907 by E. W. Boyd. Sample No. 3 is an average sample of the two layers of shale. On destructive distillation, sample No. 2 yielded 11·4 per cent. of crude oil, equivalent to about 28·3 gal. per ton.

An oil-yielding shale has been reported from the neighbourhood of Dunollie [46]. A sample of the shale collected near Smoke-Ho Creek, at a point close to the coal seam, gave on analysis: Fixed carbon, 31·17; volatile hydrocarbons, 33·37; water, 4·68; and ash, 30·78 per cent. On distillation an amount of oil and tar was obtained equivalent to 22·7 gal. per ton of shale. This, however, represents a rough estimate on a small sample.

The existence of a similar seam of shale is recorded as underlying the thick coal-seam worked in Stony Batter Creek, Reefton sub-division [47].

A local company has been exploring the Waikaia oil shale, which appears to be very similar to Orepuki shale. W. Donovan and G. C. Burton analysed and made distillation tests of eight representative samples received from various boreholes. A composite sample of these was analysed and gave the following percentages: Fixed carbon, 17·10; volatile hydrocarbons, 43·03; water, 10·42; ash, 29·45. An ultimate analysis yielded: Hydrogen, 5·64; carbon, 39·55; nitrogen, 0·30; sulphur, 3·05; oxygen, 22·01; ash, 29·45. On distillation the following products per ton would be obtained: Crude oil, 38 gal.; ammonium sulphate, 8 lb.; and gas, free from carbon dioxide, 3,250 cub. ft. The specific gravity of the crude oil was 0·96.

After fractional distillation and refining, the oil would give the following products per ton, allowing 10 per cent. for impurities and loss: Light oil (naphtha), 2·5 gal.; burning oil, 8·8 gal.; light lubricating oil, 6·2 gal.; heavy lubricating oil, 12·0 gal.; paraffin, 20 lb. [48]. In 1918, six out of seventeen boreholes showed seams of oil shale from 1 ft. to 17 ft. 9 in. in thickness.

CHAPTER III

SOURCES OF SUPPLY OF OIL SHALES (*continued*)

(*b*) FOREIGN COUNTRIES

EUROPE

Bulgaria

The existence of large deposits of oil shale in Bulgaria has been known for some years, and recently three concessions have been granted for their exploitation. As yet there has been no actual development.

The deposits are as follow: 1. Near Bresnik, 6 miles north of the town, where there are sandy, clayish shales and lime beds. Among the sandy deposits, there is a bed of oil shale 150 ft. in thickness. There are three grades of shale, one of which, 20 ft. in thickness, yields over 32 Imp. gal. per ton of crude oil. An estimate gives 30,000,000 tons for the surface shale only. The deposits are 15 miles from a railway. 2. Near Radomir, from 5 to 7 miles west of the railway line Sofia–Batanovtzi–Radomir, where there are also deposits of graphite extending for 12 miles. The thickness of the shale deposits has not been determined, but it appears to be even greater than the deposit near Bresnik. 3. Near Popovtzi on the Stara–Zagora–Tirnovo railway line, where the soil consists of earthy layers, in which deposits of bituminous shales are found. The latter appear to be from 9 to 90 ft. thick, and to extend for 5 miles. 4. Near Kazanlik, where there are deposits similar to those of No. 3, up to 30 ft. in thickness. 5. Near Sirbinovo, 9 miles south of Gorna Djoumaya, where the soil consists of earthy layers with bituminous shale and lignite, which are 80 ft. and 7 ft. thick respectively. The quantity of shale appears to be unlimited. The deposits are from 2 to 3 miles from the narrow-gauge railway line, Radomir–Dupnitza–Roupel.

From tests made by Glasgow analysts, 5 tons of Bresnik shales yielded 33 gal. per ton of shale. Shales near Popovtzi gave from 18 to 33 gal., and those near the village of Sirbinovo, 54 gal. per ton of shale.

The three concessions granted are in the region of Sofia-Kustendil and Vratza; in the region of Stara-Zagora; and in the region of Gorna Djoumaya and Philippopolis [49].

Esthonia

Deposits of oil shale are known to extend in Esthonia from the west coast, near Port Baltic, to the north shore of Peipus Lake, an approximate distance of 100 miles. The fields have been estimated to contain a total of 40,000 million tons of oil shale. In the eastern section the aggregate thickness of shale is 8 ft. There are 5 seams in all, varying in thickness from 8 to 30 in. Three occur together, totalling 4 ft. The overburden, soil and chalk, is 6 ft. in thickness. A ton of raw shale, with 13·7 per cent. of moisture, yielded 35 cub. ft. of gas and water, which contain acetone, methyl alcohol, acetic acid and ammonia, and about 61 gal. of crude oil, containing 19 per cent. light, and 81 per cent. heavy oils [50]. A test of Esthonian shale by Schamarin gave the following results by dry distillation:

	per cent.
Oils and tar	29·07
Gases	21·33
Coke	7·64
Ash	40·15
Water (in chemical combination)	1·81

Production at present (1921) is confined to two small works.

The Esthonian Government has been in negotiation with various companies with a view to granting concessions, but difficulties have arisen as to terms. It appears anxious to limit the grant of rights to periods not over 20 years and to prevent the forming of any monopoly.

Prospecting has been carried out along the railway from Jeve to Wesenberg.

France

In France, oil shales occur in the Permian and Upper Carboniferous Systems at Autun (Department of Saône-et-Loire); at Buxière, Saint-Hilaire, La Courolle, and La Sarcelière (Department of Allier); and at Boson (Department of Var). Of less importance are deposits at Vendée (Brittany), Menat (Puy-de-Dôme), Vagnas (Ardèche), Bastennes (Landes). Across the Channel at Boulogne, the Kimmeridge Clay is gritty and shows no development of oil shales.

The earliest attempts at the distillation of oil from shale were made in France several years earlier than in Scotland, and gave rise to an independent industry [9/p. 166]. In 1830, Laurent obtained paraffin by the distillation of oil shale, and in 1835 suggested the treatment of the Autun shale on a commercial basis; but it was left to Selligue to devise an economic process of distillation on a large scale. This was accomplished prior to 1845. Several deposits were worked, and the shale was retorted before the days of cheap American petroleum, but the majority of the enterprises were unable to withstand the competition subsequently introduced. The yield of oil is not high, but at present the heavy import duty enables several deposits to be successfully worked [51].

The Autun Deposits [52], [20/p. 90].—The Autun field has an area of 95 sq. miles, and extends for 20 miles between Epinac and Verrière, and 6 miles from Auxy to Igornay. It is said to contain 15 million tons of shale. The shale is being mined to the extent of about 100,000 tons per year, yielding about 7,400 tons of oil. Chesneau states [53/p. 621] that the Autun Basin contains two beds of oil shale, a lower bed of Carboniferous age worked at Epinac, and an upper bed of Permian age.

The shale has been mined since 1862. The deepest seams are worked by the concessions of Igornay, Lally, Saint-Léger-du-Bois, and the material is said [52] to yield crude oil to the extent of about 12 gal. per ton. The middle seam is mined in the concessions of La Comaille, Le Ruet, Le Paisot, Dracy-Saint-Loup, Saint-Forgeot, Chevigny, and Ravelon, and has received the name of the "big seam" on account of its importance. The yield per ton of shale is stated to be from 12 to 24 gal. of crude oil and about 3,800 cub. ft. of illuminating gas. The top seam includes several beds of shale and one of torbanite. A ton of the latter gives on distillation about 18,000 cub. ft. of illuminating gas. The concessions at this level are: Millery, Les Thélots, Surmoulin and Hauterive [52].

It is stated that the Autun deposits have only been developed in a superficial manner, and that the depth of the workings is nowhere more than 200 ft.

The Allier Deposits.—In the Department of Allier deposits of oil shale cover an area of 5,965 acres, the two principal centres of production being Buxière and Saint-Hilaire. The normal annual production of shale amounts to about 60,000 tons, which yield about 4,000 tons of oil. It is reported that there are more than 20 million tons of oil shale still available, capable of yielding about 1,400,000 tons of oil.

Development work was begun at Buxière in 1858, but the industry declined under pressure of American competition. Distillation is carried out in three works: that of Plamores for the concessions of Plamores and La Sarcelière; that of the Justices for those of Buxière and La Courolle; and that of Saint-Hilaire for the concession of Saint-Hilaire. The yield is stated to be from 13 to 26 gal. of crude oil of specific gravity from 0·850 to 0·900 and from 13 to 18 gal. of ammoniacal liquor per ton of shale. For Buxière, the crude oil is stated to yield from 28 to 30 per cent. lamp oil of specific gravity from 0·810 to 0·820; from 30 to 40 per cent. heavy oils of specific gravity from 0·870 to 0·925; and 29 per cent. of pitch [52].

The Boson Deposit, in the Department of Var, is situated not far from Toulon and Marseilles, and is said to be 5 sq. miles in area. It is reported to contain 14 million tons of shale, of which 3 million tons have been proved. The yield is given at from 75 to 90 gal. per ton of shale. The seam is 5 ft. thick, and dips from 30° to 40°. The oil is free from sulphur, of sp. gr. 0·86, and, when refined, gives 18 per cent. gasoline and 25 per cent. lubricants. The property is equipped with a retorting plant and a cracking plant of the Hall (English) type. This is the only French oil shale deposit that has been developed in recent years [6/p. 26].

At *Menat*, Puy-de-Dôme, the extraction of crude oil per annum is about 1,000 tons, the shales yielding about 13 gal. of oil per ton. The industry was started in 1831. At the present time a company, known as the Société des Asphaltes du Centre, operates leases at Lussat, Malintrat, Pont-du-Château, and Puy-de-la-Poix in that part of the Limagne between Allier, Riom, and Clermont-Ferrand.

According to a quotation from *Le Soir*, Paris, in the *Petroleum World* [52], oil shales were exploited at Bastennes in Chalosse, Department of Landes, and work proceeded for about twenty years. In 1845, the output was valued at £18,000.

Germany

Oil shales are known to exist in the Rhine Provinces and also in South Germany in the States of Hesse, Würtemberg, Baden and Bavaria. The shale deposits of the mountainous districts of Bavaria are stated to yield 16 gal. per ton. For some years in the past, oil was obtained from the shale, but competition with American and Russian oils ultimately ruined the industry. It is reported that the Baverische Mineraloelwerke now propose to exploit the deposits, and extensive factories are being established in the neighbourhood of Bayreuth for the purpose of utilizing the shale product, the residue of which, it is claimed, yields a nitrogenous matter, which is of great value as a fertilizer [54].

Prior to the outbreak of the Great War, shale was worked in the Rhine Provinces, and near Reutlingen, Würtemberg, but only one company was occupied in producing paraffin and mineral oils. During the war Germany paid considerable attention to the development of her shale deposits. Those at Messel, near Darmstadt, Hesse, especially, were exploited. The deposits are said to be easily worked. The bituminous shale contains 40 to 45 per cent. water, 6 to 10 per cent. tar, and 40 to 50 per cent. residue, and the yield per ton of shale is as follows: 32 gal. crude oil; 71 gal. ammonia water; and 1,900 cub. ft. of gas. The gas is burned as fuel in gas engines or under the vertical retorts [55].

Germany also obtained much oil during the war from bituminous lignites, most probably by means of low-temperature carbonization.

Italy

Deposits of easily accessible bituminous shale occur in the province of Messina, Sicily, for the working of which a concession was granted in 1915. Laboratory tests yielded 7 to 9 per cent. crude oil (sp. gr., 0·928 at 15° C.); 5 to 6 per cent. ammoniacal liquor (0·9 to 1 per cent. ammonia); and 3 to 4 per cent. gas, with traces of carbon dioxide. The crude oil contained 3·4 per cent. sulphur, and yielded 29 to 31 per cent. light oil (sp. gr., 0·820), and 12 per cent. crude paraffin [56].

Yugo-Slavia

It is stated [20/p. 413] that oil shales occur on a large scale near the station of Alexinatz, on the Serbian Railway. The principal seams appear to consist of "leaf shale" (19 ft.) and "sandy shale" (84 ft.), with bands of poorer shale above and below. In a test made by one of the Scottish companies, the shale is said to have yielded per ton, 43½ to 45½ gal. of crude oil having a solidifying point of 32·2° C. It was also shown that the crude oil would yield per 100 gal.:

	Gal.	Sp. gr.
Burning oil	30·0	0·810 to 0·820
Intermediate oil . . .	4·5	0·840 ,, 0·865
Lubricating oil . . .	15·5	0·880 ,, 0·885
Paraffin scale, hard and soft .	14·3	

Spain

Shale deposits estimated to contain about 200 million tons, yielding 9 gal. oil per ton, are said to have been found near Ferrol, province of Corunna. Large quantities of shale are stated to occur in the Ronda district, province of Malaga, and deposits also exist in Castellon de la Plana.

A company is investigating the bituminous shale deposits of the province of Teruel. Gasoline, various mineral oils and ammonium sulphate have already been obtained, and the company proposes to allocate £10,000 for the improvement of the experimental works, including the erection of 16 Anderson retorts [57].

Sweden

Large deposits of oil shale exist on the south side of Mount Kinneküllen in Östergottland, Gottland division, where there are outcrops of horizontal beds 14 ft. thick. The deposits are estimated to contain 5,260 million tons of shale, and are being worked by the A/B Svenska Skifferverken, which is receiving the support of the Swedish Government.

From tests made upon the shale oil, it is calculated that the following percentages of products will be obtained: Fuel oil, 25·5; lubricating oils, 34·5; asphaltum and tar, 18·5; ammonium sulphate, 7 to 9·5 [6/p. 28].

Switzerland

A concession of about 8,000 acres was granted in 1915 to exploit deposits of oil-sands, and of bituminous and carbonaceous shales intercalated with the sand deposits in the communes of Dardagny, Russin, and Satigny, canton of Geneva. Tests gave 14 to 15 gal. of oil per ton of shale. It is reported that the product is a typical high-grade crude oil, containing a small percentage of kerosene, but a large percentage of heavy lubricating oil. The investigations are not complete and the commercial possibilities are uncertain.

ASIA

Arabia

Oil shales are reported to occur in the interior of Arabia and in the Makalla hinterland of South Arabia, but nothing is known of their exact positions or extent. Samples of shales collected by Arabs yielded on distillation in the Government laboratories in Cairo the following results:

Volatile matter, 22·91; fixed carbon, 5·12; and ash, 71·97 per cent. Crude oil, 11·05 gal.; crude spirit from gas, 1·33 gal.; incondensible gases, 1·744 cub. ft.; and ammonia in equivalent of ammonium sulphate, 13·3 lb. per ton of shale.

The specific gravity of crude oil at 15° C. was 0·91, and its solidifying point, 21·7° C. The specific gravity of the crude spirit from the gas was 0·741 at 15° C.

China

According to Iki, oil shale occurs in large quantities at Fushun, Manchuria. The shale lies above bituminous coal of Tertiary age, which is being mined on a large scale by the Japanese. The amount of oil shale of the region has been estimated at 1,300 million tons, but what proportion of this amount could be profitably mined and treated is as yet unknown. Oil shale has also been discovered in several places in Mongolia [58].

Japan

Carne [3/p. 24] suggests, on the evidence of certain analyses by Godfrey, that there are materials similar to oil shales or torbanites in parts of Japan.

Syria

Oil shales suitable for distillation occur at Beyrout, Haidura, and Djezzin, in the Machada plain.

AFRICA

Morocco

The existence of oil shale deposits in Morocco is known, but detailed information relating to them is not available. An Anglo-French Syndicate known as the "Syndicat de Recherches" of the "Société des Tuileries," has recently been formed to exploit the shale deposits in the neighbourhood of Tangier. The capital of this company is understood to be 2,500,000 francs, and a shaft has already been sunk to prove the shales.

The laboratory tests do not appear to be encouraging, since the yield of crude oil is only about 20 gal. per ton, while the sulphate of ammonia produced is only 9 lb. as compared with some 40 lb. per ton in Scotland; also, the sulphur content is high.

It is, of course, possible that samples from a greater depth may give a higher percentage of oil, but the prospects of successful exploitation do not, on the evidence so far obtained, appear very favourable. It would probably be necessary to import fuel to fire the retorts, and this would enhance the cost of treatment.

NORTH AMERICA

United States

Owing to the abundance of free petroleum in the United States, the oil shale deposits of that country have so far received comparatively little attention. As the life of the known oil-fields has been estimated at less than 15 years, it is obvious that attempts will be made, and indeed are being made, to obtain large additional supplies of oil from the vast deposits of oil shale known to exist. Prior to the discovery of free petroleum in Pennsylvania, the Mormons distilled shale for oil near Juab, in Utah, and numerous attempts were made in the past to distil cannel coal. About 1860, various companies were in existence for the production of illuminating oil from various bituminous materials, but, as the processes were crude, the enterprises failed to survive the competition arising from the discovery of free petroleum.

Extensive deposits of oil shale occur in Utah, Colorado, Wyoming and Nevada. One large area in the first two states is known as the Uinta Basin, and lies south of the Uinta Mountains; another large area, in Wyoming, is known as the Green River Basin; a third area, in Wyoming and Colorado, is called the Southern Red Desert Basin. In addition, near Manti, in Central Utah, there is an area of 2,500 sq. miles of oil shale, and near Elko, Nevada, there is a small area upon which various discoveries have been made; also small deposits up to 100 sq. miles in extent occur, it is said, in the Rocky Mountain region [59].

Wide tracts of the Eastern States are known to be underlaid by Devonian black or bituminous shales, which yield smaller quantities of oil on distillation than the shales of the Western States.

The undeveloped deposits in Utah, Colorado and Wyoming all belong to the Green River (Eocene) formation, and their economic study was begun in 1913 by Woodruff and Day [60], and continued in 1914, 1915 and 1916 by Winchester [61], [62], for the United States Geological Survey. Winchester estimates that in Colorado alone there is sufficient shale in beds of 3 ft. or more in thickness to yield 20,000 million barrels of crude oil, and 300 million tons of ammonium sulphate, and that the crude oil is capable of yielding 2,000 million barrels of gasoline by ordinary methods of refining. In actual practice even greater yields than these might be obtained. The Green River formation occupies an area of about 1,900 sq. miles in Colorado, and an even larger area in Utah, where there is at least an equal amount of shale just as rich. Winchester points out that the material can only be profitably dealt with on a large scale, which would call for the expenditure of considerable capital for the erection of the necessary plant, etc.

A large number of samples of shale were collected and tested both in the field and in the laboratory of the Geological Survey. The tests show that the yield of crude oil ranges from less than 1 to 90 U.S. gal.[1]; that of ammonium sulphate from 0·4 to 18·3 lb. by dry distillation, or 34 lb. by steam distillation, and the yield of inflammable gases from less than 500 to 4,549 cub. ft. per short ton of shale. Samples of weathered and of unweathered material gave 32 and 55 gal. of crude oil per ton respectively. In 11 field tests of oil shales from the Uinta Basin, made by Woodruff in 1913, one sample yielded 10·4; 8 averaged 27·2; 1, 45·2; and 1, 61·2 gal. of oil per ton of shale. Of 57 samples from Colorado, tested in 1914, 17 samples yielded less than 10; 22, between 10 and 20; 11, between 20 and 30; 3, between 30 and 40; 2, of 40·6 each; 1, of 65·3; and 1, of 86·8 gal. of oil per ton of shale. Of 34 samples obtained in Utah in 1915, 6 gave less than 10; 7, between 10 and 20; 7, between 20 and 30; 9, between 30 and 40; and 5, more than 40 gal. of oil per ton of shale. From Wyoming, 41 samples yielded less than 30, whilst 4 samples yielded more than 30 gal. of oil per ton of shale. One of these represented a 2-ft. bed, which yielded 50 gal. to the ton.

Eighty-six samples of oil shale, taken by Winchester in

[1] One U.S. gal. = ⅘ Imp. gal. approximately. One barrel of oil = 42 U.S. gal. = 35 Imp. gal.

1916 from the Uinta Basin in north-eastern Utah, gave by dry distillation from 1 to 90 U.S. gal. of oil, and from a trace to 15·92 lb. of ammonium sulphate per ton; 59 samples yielded under 30 gal. and 27 samples, 30 gal. of oil or over per ton. The average yield of the whole 86 samples was 23 gal. per ton. The thickness of the beds sampled varied from 6 in. to 12½ ft., the average being over 3 ft. It is estimated that the Utah portion of the basin alone contains sufficient shale to produce 42,800 million barrels of crude shale-oil, with, perhaps, 500 million tons of ammonium sulphate as a by-product.

Most of the oils obtained on distillation of the shale are reddish-brown in colour and have specific gravities ranging from 0·8449 to 0·9496, the majority being less than 0·90.

Nine samples of crude oil were fractionated by ordinary laboratory methods in the laboratory of the Geological Survey with the following yields:

	Per cent.		Per cent.
Gasoline	. 6 to 12	Asphalt	. 0·47 to 3·62
Kerosene	. 28·5 ,, 49	Nitrogen	. 0·887 ,, 2·198
Paraffin	. 1·63 ,, 7·70	Sulphur	. 0·41 ,, 1·42

That these yields might be increased with proper treatment of the crude oil is shown by the results obtained by application of the Rittman process of refinement. Two samples of shale-oil were fractionated in the ordinary way with the following results:

Results of Fractionation of 2 Samples of Shale-Oil by Ordinary Method

Distillation temperature. C.°	Sample A. Sp. gr. 0·882; b. pt. 32° C.		Sample B. Sp. gr. 0·925; b. pt. 25° C.	
	Percentage by weight.	Sp. gr.	Percentage by weight.	Sp. gr.
To 75 . . .	3·4	0·691	2·5	0·700
75 to 100 . .	2·4	0·738	1·6	—
100 ,, 125 . .	4·8	0·754	3·6	0·772
125 ,, 150 . .	5·6	0·775	5·5	0·792
150 ,, 175 . .	6·4	0·795	5·8	0·814
175 ,, 200 . .	6·6	0·821	6·7	0·842
200 ,, 225 . .	6·8	0·844	6·1	0·862
225 ,, 250 . .	7·2	0·866	6·4	0·884
250 ,, 275 . .	9·4	0·892	7·2	0·913
275 ,, 300 . .	8·7	0·901	9·0	0·929
Residuum . .	38·5	Solid	43·0	Solid

The residuum over 175° C. of each sample was divided into two parts (A_1 and A_2, B_1 and B_2), and run in a Rittman furnace at 150 lb. pressure, with the following results:

Rittman Furnace Tests on Residuum obtained from Distillations of Shale-Oil at Temperatures over 175° C. Pressure 150 lb. (Gauge Reading)

—	Sample A_1.	Sample A_2.	Sample B_1.	Sample B_2.
Temperature used (C.°) .	525	550	525	600
Sp. gr. of residuum . .	0·920	0·920	0·957	0·957
Sp. gr. of recovered oil .	0·901	0·902	0·929	0·959
Percentage recovery . .	79	79	82	70

The oils recovered from the treatment in the Rittman furnace were then distilled with the following results:

Distillation of Oil recovered from Rittman Tests on Shale Oil

Distillation temperature. C.°	Percentages by weight.			
	Sample A_1.	Sample A_2.	Sample B_1.	Sample B_2.
To 75 . . .	—	4·2	—	3·8
To 100 . . .	2·2	6·2[1]	2·8	1·8[1]
100 to 125 . .	1·1	8·5	1·1	2·5
125 „ 150 . .	1·4	10·7	1·6	2·7
150 „ 175 . .	2·7	13·8	3·0	4·2
175 „ 200 . .	7·0	20·0	6·3	6·9

[1] Distillation at 75° to 100° C.

Six samples of oil shale were selected to represent a wide geographical distribution, as well as differences in richness and physical character. These were distilled first without steam, and then the operation was repeated on other portions of the same samples whilst super-heated steam was injected into the retort. The yields in oil and ammonium sulphate are tabulated below:

Comparison of Results from Steam Distillation with those from Dry Distillation

Sample No.	Oil.				Ammonium sulphate.		
	With steam.		Without steam.		Theoretical yield, equivalent of nitrogen in shale.	Yield as determined.	
	Yield.	Sp. gr.	Yield.	Sp. gr.		With steam.	Without steam.
	gal. per ton.		gal. per ton.		lb. per ton.	lb. per ton.	lb. per ton.
4	23	0·9346	16·8	0·8937	36·6	13·4	3·5
27	10	0·9135	8·4	0·8946	43·2	29·9	18·3
32	44	0·9630	40·6	0·8838	50·8	34·0	8·5
51	39	0·9234	28	0·9126	43·2	15·8	7·3
66	55	0·9286	55	0·9052	75·4	23·1	9·6
132	50	0·9109	50	0·8449	80·1	8·4	4·5

In the six samples tested, an average of 37·8 per cent. of the nitrogen in the shale was accounted for in the ammonium sulphate obtained by steam distillation, compared with an average of 15·7 per cent. recovered by dry distillation. An average yield of 6·7 lb. of ammonium sulphate was obtained by the dry distillation of 57 samples of shale that gave more than 15 gal. of oil to the ton.

Bituminous shale occurs in persistent beds ranging from a fraction of an inch up to 80 ft. in thickness. Some beds are thick and fairly uniform in quality, others are split up into thin rich and lean members; the former, being more resistant, weather to projecting ledges. The fresh fracture of the shale varies from light to dark brown or black, whilst weathered surfaces are light grey or almost white in colour. It possesses a velvety lustre, and is very tough and resistant to weathering. The streak is light brown. The shale can be ignited, and, when freshly broken, gives off an odour of petroleum. The most productive beds weather into massive beds of greyish-blue colour. All gradations exist to light brown, less productive "papery" shale, which weathers to curly forms, thin plates being remarkably flexible.

The oil-yielding shales are confined almost entirely to the middle part of the Green River (Eocene) formation. Although consisting principally of shales, beds of sandstone, oolite and conglomerate also occur. Nearly all members of the formation are very subject to lateral variation.

As previously pointed out, the shale-measures occupy several closely associated, yet isolated areas.

I. *The Uinta Basin of Colorado and Utah*

The stratigraphical relations of the Green River formation to the other formations of like age in north-western Colorado and north-eastern Utah are represented in the following table :

Formation.		Thickness in feet according to Woodruff.	General description.
Bridger formation		600–1,000	Soft sandstones, shales and a few conglomerates, with very irregular bedding. These rocks weather into bad land forms (unproductive soils).
Green River formation	Upper	500 (estimated)	Sandstones and shales. The sandstone is thickly bedded.
	Middle	100–700	Thinly and evenly bedded shales, with thin beds of calcareous sandstone. Some of the shales are bituminous and comparatively regular in thickness.
	Lower	1,000–1,425	Sandstone, shale and oolite. The shale is sandy, and locally calcareous or bituminous. Extremely varied in thickness and character.
Wasatch formation		1,000–1,400	Very irregularly bedded sandstone and sandy shale with variegated colouring. In Wyoming this formation includes valuable beds of coal.

The Wasatch formation is underlaid by the Mesaverde formation, which in Colorado and Utah is coal-bearing.

Winchester's estimates of the thickness of the sub-divisions of the Green River formation differ somewhat from those given in the above table. Near the mouth of Piceance Creek a section measured by Winchester gave the following results :

		Ft.
Green River formation	Upper	716
	Middle	1,550
	Lower	342
Total		2,608

Near Morris Station on the Book Cliffs the upper 595 ft. of the section there exposed is oil-yielding, but the underlying part, 1,487 ft. thick, includes no beds that will yield any appreciable quantity of oil.

The Green River formation occupies an area of about 1,900 sq. miles in Colorado and a much larger area in Utah, which areas taken together form the Uinta Basin. The structure of the Uinta Basin is that of a broad and shallow syncline, with very gentle dips at most places around the margin. It is divided into an eastern portion lying in Colorado, and a western portion situated in Utah by the Douglas Creek anticline, which extends in a general northerly direction along the valley of Douglas Creek. This anticline brings up the Mesaverde and Wasatch formations. Although small faults and great veins of gilsonite have been observed, the geology has not been sufficiently worked out to determine the extent to which dislocations have affected the structure of the region. Woodruff believes that in Utah the greatest depth of the shale below the surface in the centre of the basin exceeds 2,000 ft., but in Colorado it is much less.

II. *The Green River and Southern Red Desert Basins and the Fossil Syncline of Wyoming*

An examination of the Green River formation in south-western Wyoming by Winchester, in 1915, has not resulted in proving the existence of thick beds of rich shale in that region. The formation occupies a broad structural basin extending from the Uinta Mountains on the south to the Wind River Mountains on the north. This basin is separated into several smaller basins by north to south uplifts. Oil shales are present in three distinct areas, of which the central one, named the Green River Basin, is by far the largest. The Southern Red Desert Basin is situated on the eastern side, and the Fossil Syncline on the western side of the main basin. In all three cases the strata are very gently tilted.

De Beque and Grand Valley in Colorado are the centres of oil shale development. The strata are horizontal and have an aggregate thickness of from 100 to 500 ft., and they crop out from 1,000 to 2,500 ft. above the valley floors. "Massive" shale, which is fine-grained and curly in structure, is richest in oil yield (40 to 100 gal. per ton); leaner shales yield from 20 to 30 gal. and "papery" shale, 42 gal. per ton. Twelve oil shale companies are now operating in the De Beque district, and some of them are constructing reducing plants [63].

In all, 8 oil shale distillation plants were put into operation early in 1920 in the United States, viz., 5 in Colorado, 1 in Utah, and 2 in Nevada. A few of these have been in operation for over a year. One at Elko, Nevada, in several months produced 15,000 barrels of shale-oil [64].

An American company, which owns valuable oil shale land near the Colorado–Utah state line, has made several tests with an experimental plant having the Galloupin type of retort. The yield was a little over 50 gal. crude oil per ton. The company is increasing the capacity of the plant from 80 to 500 tons per day [65].

The incomplete retorting of the American oil shales has been suggested by G. R. de Beque, in order to increase the oil production [66].

Investigations on the oil shales of Colorado were begun on February 1, 1920, by the United States Bureau of Mines and the State of Colorado, for the purpose of determining, by large-scale laboratory retorting tests, those conditions which will produce maximum yields of best quality products from Colorado shales.

The following data were obtained as a result of the work:

1. Oil yield, 42·7 U.S. (35·5 Brit.) gal. per ton.
2. Specific gravity of oil, 0·905.
3. Weight per cub. foot, run of mine, 53·775 lb.
4. Apparent specific gravity of raw shale, 1·92 to 2·06.
5. Specific heat, raw De Beque shale, 0·265 mean; spent do., 0·223 mean.
6. Heat of combustion, raw De Beque shale, about 2,460 calories per grm.; spent do., 600 calories per grm.
7. Thermal conductivity, De Beque raw shale, range 25 to 75° C., 0·00382.
8. Analytical data:

De Beque Raw Shale

	Sample 1, per cent.	Sample 2, per cent.
Loss at 110° C. (moisture)	0·60	0·59
Loss on ignition	40·00	39·70
Ash or residue	59·40	59·71
Ash analysis:		
Silica . . (SiO_2)	44·70	45·10
Iron and alumina (Fe_2O_3 and Al_2O_3)	25·60	26·35
Lime . . (CaO)	17·65	18·35
Magnesia . . (MgO)	5·28	5·35
Undetermined	6·77	4·85

9. Heat of combustion of crude shale-oil, 10,215 calories per grm. [67].

Dillon-Dell Region, South-Western Montana

In the Dillon-Dell area, the Phosphoria formation (Permian) partly consists of black oil shales, which are somewhat phosphatic, interbedded with thin layers of grey and shaly brown oolitic phosphate, from 50 to 75 ft. in thickness. The richest beds of 3 ft. or more in thickness yield from 25 to 30 U.S. gal. of oil per ton, or less than half the yield of much of the Green River shale [68].

Elko County, Nevada

It was reported [69] that the Southern Pacific Railroad was about to explore and develop the oil shale deposits in Elko County, Nevada. Also, an American company has been experimenting for over three years there. The shale deposit is 6 ft. thick and dips 25°. The oil yielded has a paraffin base, and its amount averages 50 gal. per ton. An inclined shaft was put down 370 ft. and drives were made at the 100, 200 and 300 ft. levels. From 7 to 10 tons can be produced daily per man employed underground at an average cost of $1·25 per ton [6/p. 42].

The Eastern States

In 1914, samples of black shales were collected by G. H. Ashley and others of the United States Geological Survey at several places east of the Mississippi River. The yields of crude oil and ammonia on dry distillation were afterwards determined in the laboratory [70].

The black shales of the Eastern States occur mainly at one general horizon, which belongs to the Upper Devonian or possibly in part to the Lower Carboniferous, and which extends from New York to Alabama, and westward to the Mississippi River. These shale-measures are known as the Chattanooga, New Albany, or Ohio shales, and underlie the eastern coal-fields in Indiana, Ohio, Tennessee and other states.

Thick beds of dark shale are also represented in the Middle and Lower Devonian of New York, Pennsylvania, Maryland and West Virginia.

Black shale overlies beds of coal in Indiana, Illinois and Pennsylvania, but few have a thickness of more than 5 ft.

It has been found that in yield of both oil and ammonium sulphate the best results were obtained from the black shales overlying coal-seams. The Chattanooga shales are not so rich as the others, especially in nitrogen available for conversion into ammonium sulphate. These shales may be expected to yield about 12 gal. of oil to the ton, and, according to Ashley, some 2,000 cub. ft. of gas as a by-product, and one-third of a pound of ammonia (presumably by the application of steam distillation). Shales that are highly folded yield less oil or none at all.

It is stated that the New Albany black shale underlies an area of about 16,000 sq. miles. Ashley estimates that a yield of 100,000 million barrels of oil may be expected for the total area underlaid by the shale in south-west Indiana. The same authority further states that, at present, interest in the mining of the eastern black shales as a source of oil must confine itself to localities where one of three conditions is met. The shale must be utilized: (1) where it outcrops in a position to permit mining on a large scale by steam shovel at a minimum cost; (2) where coal that is overlaid by bituminous shale is being stripped; and (3) where a coal bed that is being mined has a black shale roof that comes down and must be removed from the mine in large amounts. Of these the second condition seems to offer the best opportunity for a trial plant, as the overlying black shale must be removed in mining the coal.

According to C. S. Crouse, Devonian oil shales outcrop extensively in Kentucky in a roughly semicircular formation, of an approximate radius of 50 miles, with Lexington as a centre, with smaller outcroppings in various places throughout the state. In addition, a large part of the state is underlaid with the shale at various depths with a thickness of 20 to 250 ft. Tests made by Crouse yielded on an average 17 Imp. gal. of crude oil per ton of shale, the oil being a mixture of 9 gal. of kerosene and light lubricating oils, 4 gal. of naphtha and gasoline, and 4 gal. of residue containing some lubricants and tars.

There is little or no overburden, and the conditions as regards mining, water and transportation are considered to be very favourable for low mining and distillation costs [71].

SOUTH AMERICA

Brazil

Extensive areas of oil shale exist in different parts of Brazil, some of which appear to be of considerable economic value.

State of Maranhão.—On the Rio do Inferno, a thick bed of well-laminated bituminous shale, of Permian age, is overlaid by boghead coal (torbanite). In the bed of the Rio Mearim, bituminous shales are covered by limestone, etc. Samples of oil shale from the central part of the state gave the following percentages: Bitumen, 36·5; clays, 22·6; soluble carbonates, 40·8; the yield by slow distillation was 100 gal. oil per ton.

State of Alagôas.—Shales rich in oil are found at several places along the coast. At Barreira do Boqueirão, north of the Porto das Pedras, the shale exposed is 6½ ft. thick. At Camaragibe, shale forms a wave-cut terrace about 500 ft. wide. Shales are also exposed at Barra do Santo Antonio and at Riacho Doce [72].

The following determinations of shales, from pits dug by a company at Camaragibe and at Riacho Doce are by Boverton Redwood [73]:

—	Riacho Doce.					Camaragibe.				
	(1)	(2)[1]	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Volatile constituents .	34·9	46·3	26·9	32·8	25·4	30·55	24·8	27·1	25·5	7·8
Non - volatile combustible constituents	1·1	19·5	8·1	14·6	10·5	9·45	4·3	12·2	2·2	2·9
Ash . .	64·0	34·2	65·0	52·6	64·1	60·00	70·9	60·7	72·3	89·3

[1] Contained 4·7 per cent. sulphur, and upon distillation gave 44·73 gal. crude oil and 19·58 gal. ammoniacal liquor per ton.

State of Bahia.—There are shale deposits of Cretaceous age at Marahú in the State of Bahia (east coast), in an area of 18 by 9 miles. In the beds are solid impregnations having the appearance of asphalt, and, at some points, the bitumen is viscous like pitch. A boghead coal (torbanite), known as "Turfa de Marahú," occurs in the formation. An analysis gave the following percentages: Water (at 110°), 2·75; volatile matter, 71·65; non-volatile combustible matter, 9·75; ash (SiO_2, Al_2O_3, CaO, etc.), 15·85. The bed is exposed for a thickness of about 12 ft. [72].

The material was used for some time in the Bahia gas-works for the generation of illuminating gas, but subsequently it was exploited by a company for the production of oils. Six samples subjected to low temperature distillation gave an average of 65·5 gal. crude oil per ton, but the yield of ammonium sulphate only amounted to 0·88 per cent. The crude oil yields the following finished products: Burning oil (sp. gr., 0·812), 23·70; intermediate oil (sp. gr., 0·844), 20·10; heavy oil (sp. gr., 0·955), 6·10; paraffin scale, 0·37; loss on refining, 15·23; total, 65·50 gal. per ton.

Farther south from Marahú, in the vicinity of Ilhéos [74], oil shales occur at several places which are similar to those of Alagôas.

State of São Paulo.—A Tertiary basin, 93 miles long, and from 9 to 12 miles wide, is found on the upper reaches of the Rio Parahyba, over a considerable part of which oil shales occur. Quantities of these shales have been used at the gas works at Rio and in São Paulo at various times, especially during the war, on account of the shortage of coal. At Taubaté, there is a small plant for the distillation of oil from these rocks. On slow distillation they yielded 27 gal. crude oil per ton. Deposits of asphalt occur along the Rio Tieté near Porto Martins, and, farther south, in the foothills of the Serra de Luiz Maximo, a heavy bed of bituminous sandstone is found some distance above the black shale. Recently a plant has been installed near São Gabriel, in Rio Grande do Sul, for the distillation of oil from these shales [72].

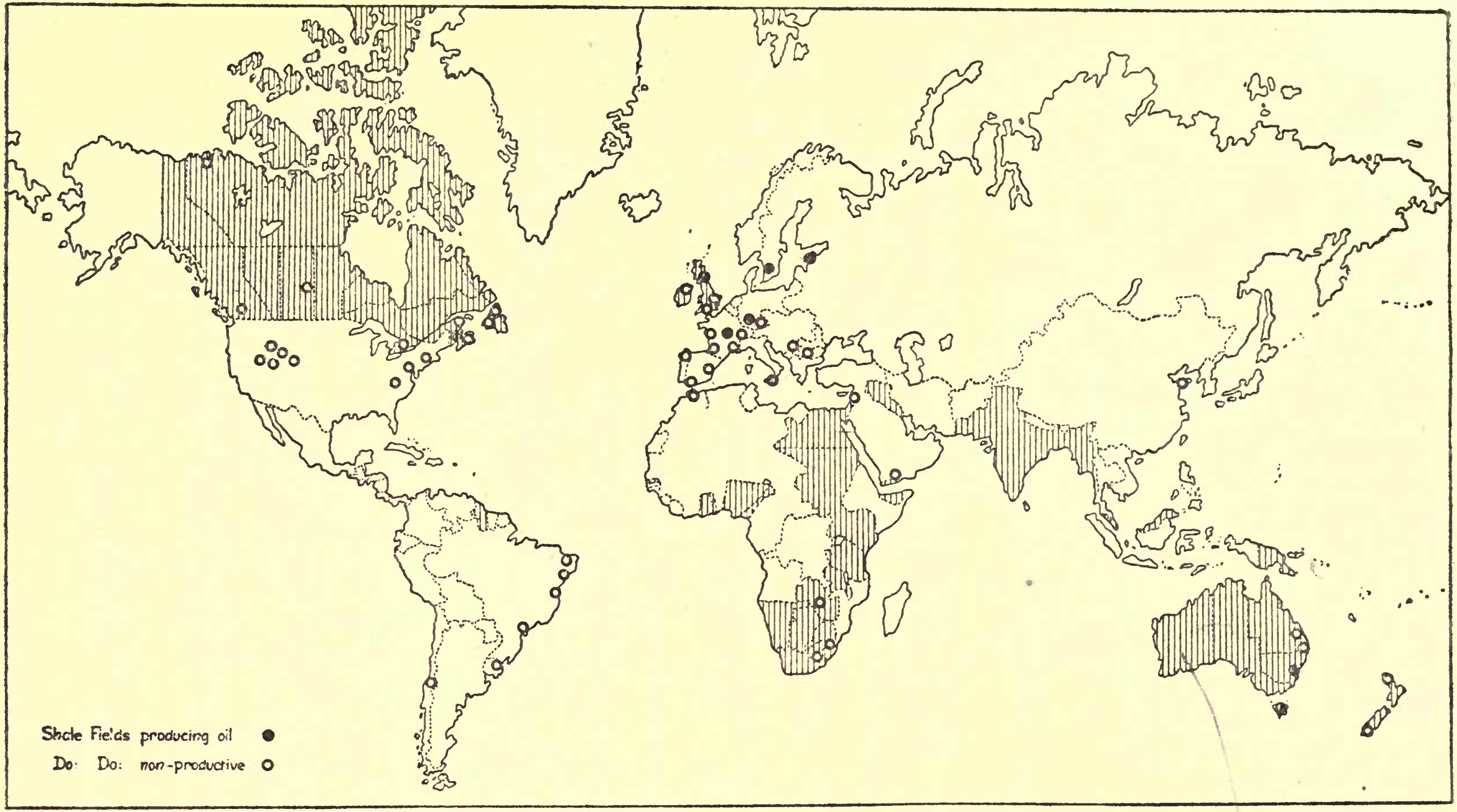
State of Espirito Santo.—Branner [75] contends that oil shales may be found within any of the Tertiary areas which skirt the north-east coast from the northern part of the State of Espirito Santo nearly to the Amazon Valley. In places this belt widens to 50 miles or more.

Chile

Oil shale deposits are reported about 620 miles south of Santiago, Chile, the yield being stated at 25 to 62 gal. of crude oil per ton of shale.

Uruguay

The discovery is reported near Melo City, in the Cerro Largo, Department of Uruguay, of a bed of bituminous shale which is believed to be large enough to supply sufficient fuel for the whole of the country. It is understood that work will be commenced on the deposits at an early date.



MAP SHOWING OIL SHALE BEARING DISTRICTS REFERRED TO IN THE TEXT.
(British Empire shaded.)

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