OIL-FIELD EXPLORATION AND DEVELOPMENT

A PRACTICAL GUIDE FOR OIL-FIELD PROSPECTORS AND OPERATORS

WITH WHICH IS INCORPORATED A DISCUSSION OF THE ORIGIN AND DISTRIBUTION OF PETROLEUM, AND NOTES ON OIL-FIELD LEGISLATION AND CUSTOMS

IN TWO VOLUMES
I. OIL-FIELD PRINCIPLES—II. OIL-FIELD PRACTICE

BY
A. BEEBY-THOMPSON
O.B.E., M.I.MECH.E., M.INST.M.M., F.G.S., M.A.I.M. AND M.E., F.INST.P., F.R.G.S.
CONSULTING PETROLEUM ENGINEER
AUTHOR OF "THE OIL-FIELDS OF RUSSIA," "PETROLEUM MINING," "OIL-FIELD DEVELOPMENT," "EMERGENCY WATER SUPPLIES"

SECOND EDITION ENLARGED
BY THE ADDITION OF NEW MATERIAL

VOL. I
OIL-FIELD PRINCIPLES

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PREFACE

No wider and more fascinating field for energy, skill and initiative can be imagined than that provided by the petroleum industry, for scarcely any branch of the sciences and crafts is excluded from participation. The search for, winning, treatment and distribution of oil necessitates the co-operation of explorers, surveyors, geologists, engineers, and chemists.

An early endeavour to revise "Oil-Field Development," when the edition was exhausted in 1922, showed how impossible that course had become in consequence of the startling rapidity of developments in all sections of the oil industry. Only when writing upon the subject of petroleum is the magnitude of the task appreciated of condensing into convenient form the advance of modern thought and technique.

The rapid growth of the industry and the surprising evolution in methods of prospecting and developing oil-fields, and in extracting and handling oils, calls for incessant contact with literature and field operations. From its genesis to its final conversion into energy, petroleum presents one long string of involved problems, upon which some of the leading scientific talent of the world is concentrating attention; but a ceaseless expansion of knowledge, following an increasing amount of research, is assisting the elucidation of problems which impeded progress, and within a few years many startling developments may be anticipated.

An unbroken and intimate professional association with oil-field operations for a period of twenty-five years, during which time most of the great oil-fields of the world have been visited, might be regarded as a fitting qualification to attack the subject, yet at times one felt how inadequate must be any one book dealing with so vast a subject.

Every endeavour has been made to give the work a practical character by the introduction of personally observed or authentic examples illustrating subjects under discussion.

During the last few years, fears have been entertained regarding the maintenance of oil supplies to meet an ever-increasing demand, and something approaching an international scramble for oil lands has, in consequence, been witnessed. This was brought about by a tardy recognition that the then existing visible supplies were within measurable sight of commercial exhaustion, and that unless large new sources of supply were discovered to compensate for natural depletion, as well as to provide for the steadily increasing demands, a serious shortage of oil would have to be faced.

Intensive, but costly, prospecting has led to some alleviation of anxiety on the score of reserves, and even caused producers painful embarrassment by excessive flush production. Producers have, however, been brought to realise that all readily accessible and obvious prospects have been acquired by far-seeing established interests, and that, as in mineral mining, it will, in the future, be necessary to explore less obvious and more risky areas. Oil companies are now compelled, under competent advice, to explore regions devoid of promising surface manifestations of oil, and where structures are very imperfectly reflected by surface geology.

Endeavours are being made to locate certain types of concealed structures mechanically by means of instruments that record slight variations of gravity, magnetism, and wave transmission caused by sound or shock. The chief difficulty is found in interpreting results in terms of geology, and calculating interference factors. So far they all aim at structure definition through differences in properties of structural cores, and do not indicate the whereabouts of oil. Aeroplane reconnaissances have proved very valuable in wild country for determining topography, locating oil seepages, and also for tracing submarine ridges and mud volcanoes.

Fortunately synchronising with this situation of alarm there were important evolutions in machinery which enabled deep sources to be more cheaply and expeditiously tested, and this compensated, to some extent, for the greater expense of pioneering.

Vol. I. of the book, under the title of "Oil-Field Principles," is mainly devoted to oil-field prospecting problems and to the description of the interesting phenomena associated with its occurrence and exploitation. An account of the geographical and geological distribution of petroleum is followed by a discussion of the vexed question of the origin of oil. Emphasis is laid upon the fact that whilst the geographical distribution of oil is defined neither by latitude, longitude, nor elevation, nor by present-day climatic conditions, the geological distribution of oil is closely allied to certain epochs connected with geosynclinal conditions. Although no generally accepted theory has yet been evolved to account for the origin of oil, accumulating data and expanding knowledge concerning the varied conditions under which oil occurs are enabling technologists to get nearer the truth. It is, however, becoming increasingly evident that oil, if only rarely concentrated into commercial supplies, is a far more commonly distributed product of nature than was generally thought, and that its genesis can be explained by no single theory. Just as carbonaceous matter is found in many stages of metamorphosis, so are the hydrocarbons discovered in infinitely more forms owing to their mobile character which encourages migratory habits. Probably under suitable yet diversified surroundings of deposition, entombment and temperature, many forms of vegetable and animal matter can provide the organic material capable of conversion into hydrocarbons through the agency of bio-chemical, geo-chemical and dynamical processes.

Whatever the origin of petroleum, it is certain that we are dealing with a wasting asset, and that there is no appreciable production and concentration of oil within measurable periods of time. For that reason, all oil technologists should combine in supporting conservation efforts. As explained in Chapter VII., there are sound reasons for believing that present methods of extraction usually result in the recovery of but a modest proportion of the oil saturating the productive strata, and this problem of increased recovery is attracting considerable attention.

A detailed description of oil manifestations, with numerous illustrations, is given in Chapter VI.; and Chapter VII. is devoted to an account of the interesting phenomena associated with oil-field development, with a description of the usual methods of calculating the oil contents of pools and predicting future yields and rates of depletion by graphic and other methods. In addition to a description with illustrations of typical oil-field structures in Chapter V., a condensed account of the geology of the chief oil-fields of the world is given in Chapters VIII. to X., supplemented by particulars of especial interest to technologists.

Vol. II. of this treatise, headed "Oil-Field Practice," deals with the development of oil-fields, and the subject is introduced by a chapter discussing the commercial aspect of the industry, leasing problems, and working customs. Drilling methods and allied subjects occupy Chapters XIII. to XVI., where many illustrations are introduced. The injuries inflicted by improperly excluded water, and the ways and means of tracing and isolating oil-field waters are explained in the last-named chapter. Chapter XII. details the methods employed for extracting oil, and the projects being tried for increasing the ratio of recovery by the application of a partial vacuum or the introduction of air, gas and water to partially exhausted oil beds. Attention is called to the urgent need of reducing oil-field losses and waste, for the elimination or serious diminution of which no adequate measures have hitherto been enforced. More rational and methodical development of new rich oil-fields appears an essential preliminary to any effective efforts aiming at preservation of resources and prevention of those excessive price fluctuations so demoralising to the industry at large. Evaporation losses are a matter of grave concern to producers now that the light products command such high prices.

In Chapter XVIII. on "Oil-Field Equipment," many hints based upon practical experience are introduced concerning the power problem and fuel economies, and a paragraph has been added concerning hygienic methods employed in tropical and other uncongenial climates, where failure to attend to the health situation results in serious loss of labour efficiency, if it does not imperil the success of the enterprise. The Author is indebted to Mr. McCarthy Jones for preparing the article on the Electrical Equipment of Oil-Fields. Producers no longer view with unconcern an expenditure of from 10 to 25 per cent. of their output as fuel for lifting their oil, and increasing use is being made of natural gas, after the extraction of its gasoline contents.

Various matters connected with pipe-line transmission of oil are dealt with in Chapter XIX., and in Chapter XX. the gas problem is discussed at some length. The utilisation or conservation of surplus gas above that required on the field is one of the most urgent problems awaiting a solution. At present, when outside the limits of economic distribution to industrial establishments or private consumers, the gas is mostly burnt either for disposal or for the production of carbon black after extraction of its gasoline contents.

Current literature has been freely drawn upon in the preparation of this work, and without the willing aid of sympathetic collaborators it would have been impossible to assemble, dissect, and abstract so much information regarding so many distant fields. Specially grateful is the Author for the ungrudging assistance of his colleagues, Messrs. Hubert May, M.I.Mech.E., M.Inst.M.M., James Romanes, M.A., F.G.S., and Arthur A. Ashworth, M.A., M.I.C.E., who, as recognised authorities in particular spheres, have contributed much of the included matter, and made many suggestions which were readily accepted. To my father, Mr. Beeby Thompson, F.C.S., F.G.S., credit is due for much of the matter connected with the origin of oil and a critical reading of much of the science matter. Valuable help was also willingly accorded by Mr. Geo. Madgwick, A.R.S.M., M.Inst.M.M., with whom a professional association has long existed.

Grateful acknowledgment is also accorded to the many sympathetic correspondents who have so willingly and patiently

answered questions, and submitted views on contentious questions.

Liberal extracts have been made from current petroleum literature, and the published magazines and journals exclusively or partially devoted to petroleum affairs. A mass of information has been collected from the valuable bulletins of the U.S.A. Geological Survey, Bureau of Mines and Bureau of Standards, as well as from State Surveys, dealing with important phases of the oil industry. Nothing but unfailing courtesy attended every request for information from the U.S.A. Geological Survey, whose director, Dr. Otis Smith, is so keenly interested in all petroleum problems. Much matter has been abstracted from publications of the Indian, Canadian, Egyptian, and Russian Governments, and from Roumanian, Polish, and German semi-official journals and papers. Amongst the sources of information most used might be mentioned the American sources, *The Oil and Gas Journal*, *National Petroleum News*, *Oil Weekly*, *Economic Geology*, *American Association of Petroleum Geologists' Journal*, *California Oil Fields Bulletin*, *Transactions of the American Institute of Mining and Metallurgical Engineers*, and the British publications, *Journal of Petroleum Technologists*, *Mining Magazine*, *Petroleum World*, *Petroleum Times*, and *Oil News*.

Thanks are likewise due to the publishers, who have spared no pains to produce a work creditable to a house of such repute.

A. BEEBY THOMPSON.

18, St. Swithin's Lane,
London, E.C.4.

PREFACE TO SECOND EDITION

OWING to the difficulties and expense of producing a new edition of Oilfield Exploration and Development, both publishers and author reluctantly agreed to re-issue at a lower price the old volumes with appendices that would bring essential data up-to-date. Little has transpired since 1925 to modify the principles enunciated relative to oilfield exploration and exploitation, although revolutionary changes in technique have taken place in almost all branches of the industry. In the province of prospecting almost unbelievable help has been rendered by aero reconnaissance and photography and by newly developed geophysical methods; but geologists have also been materially helped by a sounder acquaintance with micro-organisms and coring methods. Specialisation to-day in this, as in most industries, must necessarily preclude more than an incomplete account of the many branches of science and engineering now used in the elucidation of the innumerable complex problems that confront the modern oilfield operator.

Specialisation has reached such proportions that it is quite beyond the capacity of any single individual to have more than a superficial acquaintance with the many varied and intricate problems upon which scientists and engineers concentrate their peculiar talents. The practical application in the field of acquired knowledge lies in the hands of oilfield operators who devise ways and means of testing theories or conducting experiments on a commercial scale. Failure to appreciate the limitations of new methods sometimes causes processes to be discredited by indiscriminate and hasty application where unsuitable, for much experimentation may be necessary to develop a new process. Finality has been reached in no branch of investigation, and hundreds of carefully trained scientists are spending their whole time in the Research Laboratories of the major oil companies studying perplexing questions and seeking remedies for troubles.

Introductory to the new appendices is reference to the many remarkable innovations which since 1924 have become available to geologists when undertaking the exploration and mapping of oil territory. These new methods are particularly applicable to terrain where outcrops of rock are absent or rare due to coverings of drift, overgrowth of forest or scrub or surface creep of soft sediments. The value of air observation and photography and the several geophysical methods in general use is stressed, as also is the progress made in zoning of homogeneous sediments by a determination of micro fauna assemblages or heavy mineral aggregates.

Under the heading of Drilling Technique, attention is directed to the transformation of ideas and practice caused by Alex. Anderson's demonstration that few oil wells were as vertical as thought, and that many had drifted hundreds of feet, thereby nullifying the value of many of the sub-surface contour maps so carefully prepared on the assumption that wells were vertical. This disclosure not only impressed on operators the importance of surveying wells for verticality, but led to the design of instruments that measured both the amount of deviation and its direction. Furthermore, it opened the eyes of producers to the possibilities of directional drilling now such a common practice with the aid of oriented whipstocks. Attention is also directed to some of the principal factors which have led to the acceleration of drilling speeds and the negotiation of both hard rock and soft argillaceous sediments. These include the use of hard metallic alloys for the facings of cutting tools, and the employment of skilfully prepared and weighted colloidal muds which permit of drilling through thousands of feet of unconsolidated Tertiary formations without lining the hole. Suitably conditioned muds assure the suppression of oil, gas or water pressures until such time as they can be excluded or admitted as may be desired.

Without doubt the most valuable aid to oilfield operators since 1924 has been electric logging of wells on the Slumberger principle by which inherent properties of the strata penetrated in a well can be differentiated, and recorded data translated into geology. Not only is it possible to locate the presence of oil, gas and water horizons in an uncased well, but to correlate definite strata between wells, and so confirm or construct structural features. The invention and perfection of the gun perforator was the next great innovation, for it enabled casings to be perforated for the admission of oil or gas at any desired depth and at any time after the cementation of a single column which might have a length of several thousand feet.

The search for oil has led to deeper and deeper drilling which has only been made possible by contemporaneous discoveries by metallurgists and the ingenuity of engineers. To a remarkable increase in the strength of metallic alloys must be attributed the ability to produce casings, drill pipe and tools capable of resisting the enormous stresses to which they are subjected when drilling at depths approaching four miles. The control of well-head pressures that reach several thousand lb. per square inch has itself placed on engineers the onus of manufacturing valves and fitments that can be safely trusted in use.

No less amazing is the skill employed in arrangements for deep drilling in swamps, lakes and tidelands, subjected at times to wind of hurricane force as well as other hazards. Some idea of the magnitude of these undertakings will be gleaned from the brief description in appendix G of work on the Continental Shelf of the Gulf Coast.

Another very important change in oilfield practice has arisen from a growing disposition to depart from the time-honoured custom of capture or grab, whereby those developing a plot, however small, laid claim to all the oil or gas they could abstract, regardless of all other considerations. Some remarks are included in appendix F concerning the restrictions that are now imposed on producers in most fields by official action or mutual consent that minimise waste in its various forms, assure a more equitable distribution of oil to producers and leave the fields in a better condition for secondary methods of recovery on economic depletion by customary methods.

So complex and highly specialised are many of the operations connected with oilfield operations that all but a few of the largest oil companies employ contractors for many of the operations. This remark especially applies to aero-photography, geophysical surveys, electric well logging, shooting, cementations, acidising, casing perforation and drilling, especially directional.

Another somewhat unexpected development in the oil industry described in appendix I is the exploration of so-called Condensate or Distillate fields where high pressure dry gas is returned under pressure to the reservoirs for later use after the abstraction of its valuable gasoline content. Emphasis is also placed on the importance of the prodigious gas reserves of U.S.A., and the many long distance gas mains that now carry gas across the Continent from Texas to New York.

Appendices B, C and D describe some of the salient features which have characterised oil prospecting and oilfield development in various parts of the world since 1924. This review concerns operations in the following countries: U.S.A. Eastern, Mid-Continental group, Gulf Coast, Texas, Rocky Mountain District, California, Canada. South and Central American States: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Peru, Venezuela. West Indies: Barbados, Trinidad, Cuba. Europe: Russia, Roumania, Poland, Austria, Hungary, Italy, Greece, Portugal and Albania. Middle East: Iran

(Persia), Irak, Bahrain, Saudi Arabia, Qatar, Turkey-in-Asia. Far East: Burma, India and Pakistan, Indonesia. Australasia. Africa.

In the preparation of the contents, dependence for much of the information has been placed upon the mass of valuable material now available in the Proceedings of Institutes, Technical Journals and Government Publications, mainly of American and British origin. A second World War of long duration had its influence on oilfield operations in all producing countries, and led to a cessation of returns and a curtailed divulgence of information customarily made public. Statistical data must be regarded as approximate, as the compilations of different authorities are often at variance. It is believed that the figures given are substantially correct, as personal professional visitations to many of the areas mentioned lent support to the statements made and the views expressed. Forty years' active association with International Oilfield Exploration and Exploitation has only served to accentuate my respect and admiration for oilfield operators upon whom such a great responsibility has rested in the exercise of their onerous duties, generally under inclement conditions. The haphazard and crude methods of early days have been replaced by highly scientific approaches, and the use of plant and machinery requiring delicate and discriminating handling. Roughnecks and Roustabouts are inapplicable designations for modern derrick floor hands entrusted with intricate mechanisms of great power. To the resourcefulness, optimism and dynamic character of pioneers must be attributed the creditable achievements of those who had to rely upon plant which would to-day be regarded with suppressed amusement and scorn by youthful technologists. From small and inauspicious beginnings the oil industry in half a century has become one of the greatest in the World, and its growth shows few signs of waning in the absence of any fuel comparable in usefulness at an equal price.

I am indebted to Lawson Lomax for the brief reference to Modern Refinery Practice. Petroleum Refineries are now chemical plants, and no one can predict what other valuable products will result from treatment of oilfield liquids and gases. No words could adequately express the gratitude felt for the generous hospitality extended and the willing help given to me by oilfield executives and manufacturers of oilfield equipment during trips to U.S.A. and elsewhere. The reception accorded by Government officials at Washington and by Educational Establishments throughout the U.S.A., making Petroleum one of their subjects of study, provided a welcome opportunity of discussing problems of perplexity with those most qualified to speak with authority.

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INTRODUCTORY

(See Chapter I (1-18))

Since publication in 1925 so much has happened in almost every branch of the Petroleum industry, that it is beyond the power of any single individual to do justice to so great a subject. Although the general principles enunciated hold good to-day, extensive and intensive research in every direction has forced a modification or rather a re-adjustment of views on the subject of distribution of oil, both regionally and stratigraphically, and fully substantiated the opinion expressed previously that oil is as much a normal product of natural forces as coal and other minerals, and that given the requisite conditions for the preservation of suitable organic matter in sediments, petroleum is one of the consequences of complicated geo-chemical and bio-chemical reactions. The subsequent movement of any hydrocarbons formed is controlled by tectonic and stratigraphic conditions that lead to a separation of oil, gas and water, and their ultimate accumulation in traps where their loss is prevented or impeded by heavy overburden, cap rocks or other forms of obstruction. Anticlinal flexures in regions of terrestrial depression between or alongside mountain uplifts continue to yield some of the major oilfields of the world, although domes resulting from salt intrusions in horizontal or only slightly inclined sediments have added substantially to the oil resources of certain countries. Modern petroleum geologists show increasing reluctance to condemn territory which was formerly regarded with disfavour, for the discovery of rich oil fields in synclines and on nonoclines that were previously considered unpromising, has greatly modified deductions. Specialisation has somewhat altered the status of an oil expert who at one time was expected to be competent to advise on all phases of the industry. Under present day conditions specialists are employed in survey methods, geophysics, and many branches of geological studies, drilling and production, preparation of statistical data, refinery design, pipe line work, and civil and mechanical engineering. Firms specialising in geophysical methods, air surveys, drilling, cementing and surveying wells, contract for those duties at prices often below those which would be incurred by the principals.

The stupendous demands for gasoline as a result of developments in the internal combustion engine and its use on road transport, on farms, and in aeroplanes, caused the U.S.A. Government such grave anxiety that they encouraged and supported a world wide search for new sources of oil supply. With a full realisation that modern war weapons depended mainly upon mechanical transport, that battleships relied on oil fuel, and that aeroplanes needed vast supplies of high grade gasoline, the great oil companies were encouraged to embark on expensive exploration projects. Aided by a whole series of new methods which often gave in the early stages of their development inconclusive and even misleading clues, scientists and engineers gradually evolved geo-physical instruments and methods which recorded concealed anomalies capable of correct interpretation by experienced geologists. Ever-improving devices for detecting and delineating hidden structures led to remarkable consequences. Delicate instruments were invented that recorded magnetic or gravimetric differences, or the behaviour of terrestrial seismic waves transmitted by shocks artificially produced by firing high explosives, or the measurement of potential differences registered by applied electrical currents at terminals arranged at strategic points. Variations or combinations of the different methods best suited for local conditions have given to the geologist weapons of immense value for exploring new regions, although the limitations of all must be recognised. Interpretation of observed anomalies is, indeed, one of the principal difficulties, except in the case of salt masses or cores of igneous or hard rocks beneath a covering of lighter sediments. In the hands of skilled or discriminating geophysicists good work can be accomplished with magnetometers, gravimeters (which replaced the Torsion balance), seismographs, and electrical contrivances.

Aerial observations from planes have been found to yield data of inestimable value to oil prospectors, and this coupled with aerial photography has led to results which would at one time have been regarded as beyond the dreams of realisation. Two major wars are responsible for the unpredictable advances in aeroplane design and photographic surveys. Few geological surveys in remote regions would to-day be undertaken without a reconnaissance flight over territory when not obscured by overgrowth or sand drifts in order to observe the main structural features of a terrain and to fix areas worthy of surface examination. By selecting a day free from haze, fog or dust, and at an hour when the sunlight casts shadows, more geology can be done from the air in an hour or so than by months of foot-slogging on the ground. This particularly applies to arid, desert regions where surface travel is rough and fatiguing. But even in country clothed with forests or scrub, differences in the growth or kind of vegetation clearly denote changes of formation or lines of major faulting or disturbance, such as are invisible at ground level.

Aerial photography has reached such a high degree of perfection, as a result of improved flying technique and photographic apparatus, that accurate typographical maps can be produced from a mosaic of overlapping exposures stereoscopically showing details of relief in the most vivid form. Given a knowledge of regional geology, it is often quite easy to distinguish the different geological successions exposed on scarps or in outcropping sections.

Another aid in the location of concealed oil structures is soil analysis. Many geologists have always maintained that as the concentration of hydrocarbons in structural highs necessarily involves an interchange of the fluid contents of rocks, there is almost certain to be some escape of moist hydrocarbon gases near the crestal part of a pronounced structure. It was reasonably argued that the liberation of gases charged with moisture was likely to cause some geo-chemical changes in ground that received emanation due to adsorbtion. Delicate analyses of soil samples on known oil pools have enabled chemists to find traces of wax and of hydrocarbons in amounts that enabled lines of equal intensity to be drawn. These were found to bear a definite relationship to the shape of the pool. Further work in this direction may lead to new and important developments.

Correlation of strata by their heavy mineral content or the assemblages of micro-fauna remains has proved very valuable in those regions where considerable thicknesses of homogeneous clay or marls contain no macro fossils or identifiable breaks. Assemblages of foraminifera have proved of great value in the Mexican Gulf Coast region of U.S.A. and in Trinidad for zoning purposes. As with other methods, considerable discretion must be exercised in interpreting results, for both minerals and foraminifera have sometimes a wide range of time distribution influenced by purely local circumstances.

Oil-field Discoveries and Developments since 1925 (see Chapter VIII, pp. 354-417).—Since 1925 much has happened in the Oil World to modify all previous estimations of oil reserves and oil prospects. A second World War in 1939 not only initiated an excited scramble for oil but caused chaos, destruction and demoralisation in European, Asian and Pacific centres of oil production. The Axis powers were constrained to set about increasing indigenous supplies in the countries they occupied, and the Allies who controlled few sources of supply at home found grave difficulties in conveying to Europe oil from different countries like Iran, Irak, Burma and the East and West Indies. When Italy, and later, Japan, entered the war of aggression against the Allies, and U.S.A. joined in the fray after Pearl Harbour, it was upon the oil resources of U.S.A. that the Allies had to rely very largely for their supplies of aviation spirit and oil fuels. The invasion of Russia by German armies after they had conquered Poland and occupied Austria, led to the isolation of some of the Caucasian oil-fields, and even imperilled the supplies of Baku and Trans-Caspia.

War-time demands so depleted stocks of oil products and so endangered reserves in U.S.A. that a spirited search for new oil-fields was prompted if not sponsored by the Authorities. The final rout of the enemies and their eventual surrender induced American interests to proceed on a world-wide exploration for oil in addition to accelerated efforts at home. Results have far exceeded the most sanguine expectations, due mainly to the employment of improved methods of search and developments in oil-well drilling equipment.

Pessimistic forecasts of proved petroleum reserves have so often been falsified by events that, however authoritative, they must be accepted with caution. They were at their best only calculations of the assumed extractable quantity of oil from pools more or less defined in extent by drilled wells. In 1948 the World's proved oil reserves were estimated to be around 77,000,000,000 barrels of which the U.S.A. was responsible for 28.6 per cent. of the whole, but since that date additional reserves have been proved in Iran, Irak, the Persian Gulf Area, Venezuela, Canada and Egypt, in addition to unexpected discoveries in U.S.A., particularly in Texas and California. The American Petro leum Institute estimated the known U.S.A. oil reserves in December, 1948, at 23,280,400,000 barrels in addition to extractable natural gas liquids of 3,540,000,000 barrels; but those of the Middle East showed promise of recoverable reserves exceeding anything hitherto predicted in oil-field history. Undismayed by the disturbing climatic and physiographic conditions, the major oil interests embarked on a scale of exploration never before attempted in oil-field history, and the results transferred the centre of oil activity to an entirely new and little-known sphere where arid wastes and low rainfall had been unable to do more than provide a bare livelihood for a small population of wild tribes mostly nomadic in their habits.

Table 1, on p. 7, gives the annual production of petroleum from some 22 countries then producing oil in economical quantities, since when astonishing developments in a number of countries have entirely changed the priority of importance then attached to State values. The attached figures bring Table 1, p. 7, up to date so far as circumstances permit under conditions of disturbed world peace and international relations. Perhaps the most striking swerve from orthodox views expressed by the author has been the revealing character of limestone oils. Hitherto it could not be denied that oil-fields drawing petroleum from Tertiary semi-consolidated sediments gave a higher yield per unit of area and at a more rapid rate than those of Mesozoic or Palaeozoic age regardless of whether they were from sands, sandstones or limestones, but Mexico, where the limestones of the Golden Lane are sharply inflected into a narrow fold, and Iran (Persia) with broad flat arches of limestone gave promise of both sustained and large yields. Both were regarded as freakish features at the time, but the discovery of vast accumulations of oil in limestones of great thickness in Irak, Venezuela, and Canada, have shaken faith in past conclusions. Certainly our knowledge of these fields is far too meagre to draw sweeping deductions, for the output of wells on limestone structures has been regulated not by capacity to produce but by factors of conservation and facilities for disposal. In some cases a few strategically placed wells would suffice to drain a whole limestone pool without endangering its ultimate recovery by unequal invasion of edge water.

Maintenance of reserves not merely to sustain supplies but to provide for the increased demands which annually arise compels producers to pursue a relentless policy of prospecting. Progressive Oil Corporations devote a substantial portion of their earnings to the search for new oil sources, and the increasing costs of exploring deeper and more remote territory with its attendant greater hazards yearly place a heavier burden on producers. In 1947 only 15 per cent. of wild-cats (exploratory) wells in U.S.A. struck payable oil or gas, and such tests in outlandish spots may cost as much as $1,000,000. Drilling costs vary considerably and the daily running charge of a modern rig may fluctuate between $1,000 and $4,000, representing between $5 and $25 a foot of hole. The expense of maintaining a reserve in U.S.A. at a ratio of output to reserves of between 11 and 13 was estimated in 1948 to represent 57 c. per barrel of production, whereas some years ago it was nearer 15 c. per barrel.

One of the least understood factors in the production of future oil supplies is the evaluation of salt dome structures. No means have yet been evolved for determining the position and contents of any oil measures which in a distorted and disrupted condition flank or override the intrusive salt. Experience has shown that unconsolidated Tertiary sediments have suffered less disturbance than the consolidated strata of Mesozoic or Palaeozoic age, such as have been met with in Germany and in the Ural-Emba district of Russia. More than 200 salt domes have been located in the Southern States of U.S.A., and in the gently dipping sediments in the Gulf of Mexico ; and many more are likely to be discovered.

United States of America (see Chapter VIII, pp. 354-427).—Since 1923 extensive and intensive exploration of all the States of the Union offering reasonable prospects of oil have been conducted by oil interests, and this has resulted in many remarkable discoveries. Oklahoma attracted main interest for some years before California, and later Texas jumped into prominence and robbed her of that distinction. The Mid-Continental States of Kansas, Oklahoma and Arkansas, well repaid development with the discovery of scores of oil pools, and the San Joachin Valley and the Los Angeles basins of California disclosed surprise after surprise. Although yielding less spectacular results, the States of Colorado, New Mexico, Utah, Wyoming and Montana in the Rocky Mountain District, all revealed payable oil pools. Texas has, however, provided the most sensational oil discoveries under variable conditions. The West Texas field occupies part of the Permian Basin: North Texas, North Central Texas and Eastern Texas fields are associated with the Mid-Continental Group of Oklahoma: and the Gulf Coast District is the zone of salt domes which extends into Louisiana on the East. Michigan and Illinois have furnished their quota of oil pools of modest yield.

Eighteen States in 1938 produced 1,213,000,000 barrels of oil, of which Texas, California and Oklahoma yielded 74 per cent., equal to 45 per cent. of the World's production of 1,978,340,000 barrels.

In 1948 the production of the U.S.A. was 2,051,433,000 barrels, an average of 5,605,000 barrels a day from 430,000 wells, but in addition 123,000,000 barrels a day of foreign oil was imported. 39,778 wells with a total footage of 137,392,000 ft. were drilled in that year. Oil wells numbered 22,585, gas wells 2,897, and dry holes 14,296. 6,877 wild cat or test wells were sunk of which 81.4 per cent. were failures. The proved crude oil and condensate reserves were estimated to be 24,834,000,000 barrels in 1948. Gas reserves were calculated to be 175,000,000,000 million cu. ft. and gas lines exceeded 250,000 miles in length. Of particular interest to explorers is the fact that 60 per cent. of the oil so far found in U.S.A. is confined to 130 major fields of which the three states of Texas, California and Oklahoma account for 98 or about 75 per cent. of the total. The several thousand minor fields have individually played quite a subsidiary part in the location of refineries and of pipe lines.

Secondary recovery methods depend for their economic success on the price of crude oil, as well as upon such factors as the availability of water or cheap gas for water or gas drives. The high quality Pennsylvanian crudes enable such methods of recovery to be continued even when oil prices fall very considerably. An official tendency in some

States to relieve stripper wells from pro-rationing restrictions also serves to assist such methods.

Eastern Oil-fields.—Little new of importance has been reported from the Appalachian oil-fields where operators are mainly concerned with the recovery of the dregs of old fields by secondary methods. Owing to the sustained high price of the superior grade paraffinous oils, there are still thousands of wells being intermittently pumped at a profit, although the output is no more than half a barrel a day. In 1938 the old Bradford field of Pennsylvania, discovered in 1871, yielded mainly by water drive 15,000,000 barrels of oil to the manifest satisfaction of royalty holders. It was claimed, not without justification, that more oil would be recovered by water drive than was originally obtained by flowing and pumping. *Indiana* became a modest producer in 1944 when the output reached nearly 5,000,000 barrels. In 1948 the production was 8,008,000 barrels, and output to that date 1,883,781,000 barrels. *Illinois* gave its peak production of 148,000,000 barrels in 1940 from 3,000 wells, and in 1945 output was 75,000,000 barrels from 1,100 wells, all from strata of Palaeozoic age. Production up to 1949 had reached 1,366,769,000 barrels. The State of *Michigan* came into the picture in 1925, and in 1942 attained an output of 21,754,000 barrels. The terrain between Lakes Michigan and Huron, where the oil-fields are located, is covered with glacial drift which conceals the underlying Palaeozoic rocks yielding the oil. Up till the end of 1945, Michigan had produced approximately 240,000,000 barrels of oil from 7,400 wells in nearly 100 pools. In 1948 the cumulative production had reached 289,500,000 barrels.

Mid-Continental District.—This oil province covers parts of the States of Kansas, Missouri, Oklahoma, Arkansas and Northern Texas, as well as the Permian basin of New Mexico and West Texas. More than 300 oil and gas pools had been operated in the State of *Kansas* up to 1946 when the output was 97,560,000 barrels. By 1949 cumulative production had reached 1,884,000,000 barrels. Oil is drawn from Palaeozoic rocks and some benefit has been derived from acidising the wells. One well drilled in Rush County yielded 1,300,000 cu. ft. of gas containing 7.7 per cent. of helium at 3,548 ft. Although high initial flows are obtained in most fields the flush production rapidly falls. *Arkansas* was credited with a production of 31,622,000 barrels in 1948. In 1946, 49 separate pools in South Arkansas and the Gulf Coastal plain were designated gas and condensate fields in Cretaceous and Jurassic beds: and in North-West Arkansas, 21 gas fields had been proved in Palaeozoic beds. Up to the end of 1944, South Arkansas was credited with a cumulative output of 665,000,000 barrels of oil and 291,300,000,000 cu. ft. of gas. By far the most prolific pool discovered has been Smackover which between 1922 and 1946 gave 406,800,000 barrels of oil from 29,500 acres and yielded in 1945, 4,143,000 barrels. *Oklahoma* in 1948 produced 154,700,000 barrels of oil from somewhere around 700 pools. Up to the end of 1948, the State had to its credit a production of 5,883,000,000 barrels of oil. Particulars of some of the most spectacular fields are given below where oil is obtained from Palaeozoic rocks exhibiting their usual characteristic of high flush yields and rather steep depletion curves. Laws have been enacted that enforce spacings for oil and gas wells and also unitisation of fields where secondary measures of recovery were projected.

Field.	*Year Dis-covered.*	*Proved Acreage.*	*Cumulative Production (Barrels).*	*Output 1946 (Barrels).*
Glenn Pool	1905	16,000	228,300,000	2,356,000
Healdon	1913	7,550	200,900,000	2,416,000
Burbank	1920	24,660	218,000,000	3,121,000
Tonkawa	1921	3,700	123,300,000	393,500
Bowlegs	1926	4,000	125,500,000	1,271,300
Earlsboro	1926	5,235	129,260,000	784,400
Seminole City	1926	4,635	135,600,000	1,343,000
St. Louis	1927	20,000	167,370,000	1,728,000
Oklahoma City	1928	15,500	632,000,000	12,938,000

Texas.—This State can boast of giving more surprises to the Oil World than any other in the Union, and in 1929 it became the largest producer of both oil and gas. The discovery of unusually large oil and gas fields in East Texas was followed by the phenomenal development of salt domes on the Gulf Coast. Judging by appearances this State seems destined to maintain its proud lead for many years unless restrictions on output are imposed. The staggering speed with which developments have proceeded is due in large part to the improvements in geophysical research, for salt is one of the most easily detected deposits owing to its low density in relation to bordering sedimentaries, but it is also due to accelerated prospecting that followed the scare of dwindling reserves. Restriction of output prevents any trustworthy estimates of potentialities being assessed, but based on such knowledge as is available the reserves of oil and gas reach staggering proportions. By the end of 1948 the State had produced 12,322,000,000 barrels of oil and contained 1,400 proved oil and gas pools.

The famous East Texas field with a proved area of 136,000 acres gave between 1930, when it was opened, and 1945, 2,226,300,000 barrels of oil, and was still yielding at the rate of 131,100,000 barrels a year after 27,387 producing wells had been drilled. The initial reservoir pressure was 1,620 lb. per sq. in., and the productive sands were of Cretaceous age. The structure of this strange field is described as a truncated pinch-out of a monoclinal shore line sand : in reality a sand bar into which oil from neighbouring shales migrated and got preserved. The other unusual disclosure was the Carthage wet gas field having a proved area of approximately 212,000 acres, with a rock pressure of 3,000 p.s.i. A 24-in. pipe line was laid from Carthage to Monroe for transmission of gas.

The Upper (Inland) Gulf Coast region gave in 1944 no less than 178,500,000 barrels of oil drawn mainly from wells sunk into beds of Cretaceous age yielding light oils and gas distillate. Spindle Top, the original salt dome field that created excitement in 1901, came into prominence a second time in 1920 and the same wild orgy of ill-considered drilling was witnessed as in the first boom when new fringing rich sands were picked up by an enterprising prospector. By the end of 1925 this dome had given 128,000,000 barrels of oil. In 1948 19 major fields gave under restricted output 185,100,000 barrels of oil and were credited with an ultimate yield of 5,365,000,000 barrels.

South Texas.—Practically all oil from this coastal region of Texas is drawn from Tertiary sands of Miocene, Oligocene and Eocene age. In 1945, some 289 fields were being operated and production reached 127,700,000 barrels.

The Tom O'Connor which had already given 83,000,000 barrels of oil, produced 17,730,000 barrels in 1945, and tops the list for productivity, even with restricted output.

South Central Texas.—From a group of 75 pools with a total area of 39,400 acres in this sector, nearly 7,500,000 barrels of oil were abstracted in 1945, raising the cumulative production to 249,000,000 barrels from banded limestones and sands of Eocene and Cretaceous age.

North Texas.—A group of nearly 150 fields in the region, deriving their oil from limestones and sandstones of Palaeozoic age, gave in 1945, 44,200,000 barrels of oil, and had yielded altogether 901,000,000 barrels from some 258,000 acres.

North Central Texas.—Here a number of pools were credited with an output of 410,500,000 barrels up to the end of 1945, as the result of drilling 16,760 oil and gas wells on 143,526 acres of land. All the oil comes from indurated limestones and sandstones of Palaeozoic age.

Texas Panhandle.—In the extreme North East of the State a number of rich oil and gas pools were located and developed to the extent of giving between 1919 and 1945, 534,000,000 barrels of oil, and in the last named year they produced 31,700,000 barrels from

9,500 wells spread over 154,000 acres. The Palaeozoic strata are too compacted and indurated to yield freely. In 1945, 32 carbon-black plants were in operation utilising 307,250,000,000 cu. ft. of gas to produce 490,000,000 lb. of carbon-black. No less than 39 gas-gasoline plants were in operation, with a combined recovery of 9,003,000 barrels of gasoline from 741,172,000,000 cu. ft. of gas. Nine major pipe lines transported 341,604,000,000 cu. ft. of gas to points of consumption. This represents the equivalent of about 50,000,000 barrels of oil in heat value.

West Texas.—A province known as the Permian Basin that extends into New Mexico yielded in 1945, 175,274,000 barrels of oil from limestones and sands of Permian age, but it was anticipated that deeper drilling would disclose other productive horizons in the underlying Palaeozoic rocks. Output was derived from 17,830 wells distributed over 198 pools. The Yates field with a yield of 13,330,000 barrels in 1945 from 517 wells, and a cumulative output of 301,000,000 barrels from 22,400 wells since 1926 holds premier place in this sector. The ultimate production of this field is estimated at 800,000,000 barrels.

Louisiana.—The State oil production in 1945 was about 139,000,000 barrels of crude oil and distillate, but enormous reserves of gas had been developed. No less than 796,145,365,000,000 cu. ft. of produced gas was recorded for 1945, of which rather more than one-third was processed for gas-gasoline extraction. Gas reserves of the State were estimated at 17,000,000,000,000 cu. ft., equal in heat value to nearly 3,000,000,000 barrels of oil. In Northern Louisiana oil is chiefly derived from sands of Cretaceous age, but in the Southern Gulf coastal sector oil and gas are struck in unconsolidated sediments of Tertiary age (Miocene generally) inflected by salt intrusions. The Caddo field in the North discovered in 1905 with an area of 6,500 acres had given up to 1948 the largest output of 179,200,000 barrels of oil.

Without doubt many important discoveries will be announced when the swamps and tide lands have been fully explored and tested by drilling. A production of 190,000,000 barrels was reported for 1948 and a cumulated output to date of 2,210,000,000.

Mississippi.—Commercial oil was first produced in this State in 1939, and in 1945, 659 wells were reported to have produced oil and gas on 23 distinct fields with an output of 19,100,000 barrels of crude and distillate oil. Gas production was given as 8,353,719,000 cu. ft. On January 1st, 1946, the recoverable oil and condensate reserves was estimated at 325,000,000 barrels, and gas reserves at 2,000,000,000,000 cu. ft., the equivalent of well over 300,000,000 barrels of oil.

Twenty-seven (27) salt domes had been located and drilled between 1937 and 1945, of which 19 encountered salt. The Tindsley pool credited with 9,332,000 barrels in 1945, had given altogether between 1939 and 1948 over 107,000,000 barrels from 12,160 acres of Cretaceous sands.

Rocky Mountain District.—The vast area included under the title incorporates six States of the Union, and runs into the States of Alberta and Saskatchewan in Canada. The attached table gives particulars of some of the States in 1945.

	No. of Fields.	*Acres Proved.*	*Production 1948. (Barrels)*	*Total to 1948 since Discovery. (Barrels)*
Colorado . .	34	38,000	17,300,000	100,000,000
Montana . .	21	70,000	9,404,000	151,000,000
Utah . . .	3	7,000	20,200	352,200
Wyoming . .	88	80,000	55,000,000	807,000,000
Nebraska . .	4	2,420	314,000	4,880,000
New Mexico . .	70	180,000	48,000,000	586,000,000

Wyoming has so far responded most favourably to development, and Salt Creek has been the one really outstanding field yielding since discovery in 1906 314,771,000 barrels of light oil from 21,450 acres, and still giving in 1948 over 4,600,000 barrels. The adjoining famous Teapot dome Naval Reserve around which such scandals centred during the Harding regime gave only disappointing results when worked: oil was drawn from sands of Cretaceous and Jurassic age. The old Florence and Canon City field has so far given the most oil in *Colorado* with 13,900,000 barrels from sandy shales of Cretaceous age. Only two fields in *Montana* had up to 1945 given substantial outputs, namely the Kevin-Sunburst with 46,500,000 barrels extracted since 1922 from 23,000 acres, and Cut-Bank with 47,289,000 barrels cumulative output to 1945 when nearly 5,000,000 barrels were given from 42,280 acres. Until the end of 1948 the State had given 151,000,000 barrels of oil.

Two noteworthy oil-fields had been proved by the end of 1945 in *New Mexico.* These were the Eunica-Monument field of 39,000 acres which had produced between 1928 and 1945, 151,000,000 barrels, and gave in the latter year 12,728,000 barrels; and the Hobbs field of 10,320 acres which had yielded since 1928 up to 1945, 112,377,000 barrels, and in 1948 produced 3,800,000 barrels, both from Permian fissured dolomites. The cumulative production of the State had reached 586,000,000 barrels by the end of 1948.

Active geophysical exploration of the Rocky Mountain area has been undertaken by major oil companies who extended their investigations into the adjoining States of Nevada, Idaho and Arizona. Many new pools are likely to be discovered as a result.

California.—Although California is such a large State, oil developments have been confined to the strip of folded sedimentaries lying West of the Sierra Nevada Mountains, and fringing the Pacific ocean. Nothing of importance has, so far, been located north of San Francisco or far south of Los Angeles. Since 1923 many new oil-fields have been discovered on the San Joachin Valley that lies between the Main Mountain range and the Coastal range, as well as in the Los Angeles and Santa Maria basins. Kettleman Hill was one of the great Californian discoveries in 1928, for after the drilling of many abortive test wells on this well-known and clearly-defined structure a much deeper test succeeded in tapping wet gas under high pressure. Carried to even greater depths light oil was encountered, and by 1948 this field had given 310,000,000 barrels of oil whilst still producing at a rate of 14,000,000 barrels a year from 16,000 acres. At the fall of 1945, the Conservation Committee reported that the maximum efficient rate of production in California from 306 pools was 808,500 barrels a day, plus 56,000 barrels of gas-gasoline and condensate from 23,700 wells; that is 327,760,000 barrels a year or 19 per cent. of that of the U.S.A. at that time. The State's oil reserves were estimated at 3,860,272,000 barrels. One well had been carried to a depth of 16,246 ft., and no less than 71 wells exceed 12,000 ft., but still deeper tests are contemplated. In 1948 the State produced 345,000,000 barrels and the cumulative output to the end of that year was given as 8,000,000,000 barrels.

Practically all the oil is drawn from semi-compacted but not indurated sands of Tertiary age, hence the high yield per acre and per well compared with oil-fields of Mesozoic or Palaeozoic age excepting only the massive fissured limestones found in so few localities. No major field of California has yet been commercially depleted so that their eventual economic recovery is unknown. Water constitutes an increasing proportion of the fluid mechanically produced, and in many fields exceeds 50 per cent. of that raised, but it may be that this natural water drive is more beneficial than detrimental to recovery. Rarely does the influx of water in sand fields keep pace with the rate of fluid abstraction, and in most cases both oil and water heads fall in unison until the mingled dregs are being extracted.

Ocean drilling has been successfully undertaken at a number of localities where structures were traced into the Pacific. Improvements in the technique of directional drilling had led to land wells being given a drift to strike deep-seated designed locations far out at sea, instead of building piers and stagings from which wells were originally drilled.

The following data relates to some of the important oil-fields.

Field.	*Year Dis-covered.*	*Proved Acreage.*	*Cumulative Production. to* 1945. *(Barrels)*	*Output* 1945. *(Barrels)*
Huntington Beach	1920	3,400	361,000,000	17,600,000
Long Beach	1921	1,600	708,800,000	9,800,000
Santa Fe Springs	1919	1,400	505,300,000	6,280,000
Wilmington	1935	5,460	280,700,000	36,100,000
Ventura Avenue	1916	2,590	303,200,000	17,700,000
Buena Vista	1909	12,500	302,800,000	4,900,000
Coalinga East	1896	6,100	249,000,000	7,600,000
Kern River	1899	7,800	240,000,000	3,500,000
Kettleman	1920	13,400	310,000,000	14,400,000
Medway Maricopa	1901	17,500	690,000,000	14,000,000

Cumulative Production to 1945	Los Angeles Basin	3,236,456,000 barrels.
Cumulative Production to 1945	Coastal Fields	747,525,000 barrels.
Cumulative Production to 1945	San Joachin Valley	3,011,665,000 barrels.

In 1949 a second discovery of oil in the Cuyama valley lying parallel to and between the San Joachin and Coastal oil regions offers prospects of major developments. At a depth of 4,392 ft. a yield of 5,000 barrels was obtained of 34° gravity oil from an unusually thick sand in Lower Miocene strata.

Especially noteworthy is the fact that up till 1948 California had been responsible for 8 out of the 15 oilfields of U.S.A. which have yielded an output in excess of 300,000,000 barrels, and that only the East Texas field with 2,460,000 barrels had exceeded the largest California producer of Long Beach, which had given 726,000,000 barrels. This latter field also holds the record for yield per acre at 568,000 barrels up to 1948. The Wilmington field, which has been found to extend beneath the Long Beach Harbour, the Naval Yard, the town of Long Beach, and the ocean, is yielding a handsome revenue to the various implicated authorities as the result of directional drilling from accessible sites on the quayside or distant from buildings. The unusual spectacle of rows of pumping wells only 18 to 25 feet apart along the quayside or land boundaries is a revelation of what can be accomplished by directional drilling. Each well had been oriented to strike oil sands on a pre-determined pattern at depths up to 6,000 feet at angles up to 70° from vertical—a truly remarkable performance.

Canada.—Not until 1924 were the Petroleum prospects of Western Canada generally appreciated when large gas wells were struck in Palaeozoic limestones on the Turner Valley, 40 miles from Calgary in Alberta. After various showings of wet gas under high pressure crude oil was obtained from two zones in the upper 450 ft. of the Madison limestone in 1936 at 6,800 ft. The discovery first of wet gas and later of crude oil led to a wild scramble for concessions in Alberta, followed by the customary reactions and recriminations when fantastic forecasts failed to be realised. Distance from markets for oil and gas led to official restrictions of output which rather discouraged activity: nevertheless, in 1939 the yield of the Turner Valley pool reached 7,600,000 barrels. Those most familiar with Albertan geology, like G. S. Hume, fully apprehended the hazards of drilling on the pinched and faulted structures in the Eastern Rocky Mountains' foothills, and saw possibilities on the plains lying further eastwards into Saskatchewan; but it was not until 1947 that the first important oil-field was disclosed by the Imperial Oil Company of Canada at Leduc, south-west of Edmonton. This find by geophysical methods in terrain where the subsoil structure was completely masked by alluvial or other recent deposits led to an incursion of major oil companies with almost unlimited financial resources, for it was clear that on the vast plains east of the Rockies other prospects were almost a certainty. After the experiences of World War II, both the U.S.A. and Canadian Governments were alive to the importance of developing new sources of oil further removed from the dangers of bombing and sabotage, and nearer to the very important strategic State of Alaska, so vulnerable to air invasion of North America.

The Leduc field was soon fairly closely delineated by wells and was estimated to hold reserves of 200,000,000 barrels of oil on the 20,000 acres proved, but production was rigidly restricted by facilities for disposal of oil. The producing formation is Devonian limestone at a depth of around 5,000 ft., and the oil is under water drive. In March, 1948, a well of the Atlantic Company blew out, cratered, and before being choked gave over 1,000,000 barrels of oil in six months with a loss of gas estimated at 50,000,000 cu. ft. a day.

Another important discovery in 1948 was the Redwater field, 40 miles north-east of Edmonton, where oil was struck in Devonian limestone at 3,200 ft., and subsequent incomplete developments indicated the presence of a major oil-field with reserves that may exceed those of the Leduc field. Discoveries of oil and wet gas in the Hanna region indicated the presence of another important tract for prospecting. Expansion of operations on the Lloyd Minster field in both Alberta and Saskatchewan, suggest prospects of major developments. More is likely to be heard about fields near the Montana border of U.S.A. where oil is now being produced from the Taber Conrad and Pincher Creek pools. Until facilities have been provided for the treatment and disposal of oil and gas, the immense potentialities of the Alberta plains can only be guesswork. Pipe lines are envisaged to the Great Lakes, and to the Pacific, both involving an enormous capital outlay; and in 1949 a 16-in. line was being laid to Regina, a distance of 450 miles, and would be extended to Lake Superior, a distance of 1,150 miles, at a cost of $90,000,000.

Considerable publicity has been given to the Athabasca Rive bituminous (Tar) sand deposits by the reports of S. E. Ells of the Dominion Mines Department at Ottawa, and those of K. A. Clark of Alberta University, and others who had visited the district. For a distance of about a hundred miles bituminous sands are exposed on the banks of the Athabasca River, north of Fort McMurray (Waterways), and they are known to extend further southwards and far inland from the river. Fantastic estimation of oil contents have been made of the 200 to 250 ft. thick seam variously calculated to cover an area of from 10,000 to 30,000 sq. miles. Between 100,000,000,000 and 250,000,000,000 barrels of oil are some of the calculated contents of the Athabasca Sands, and an oil content of 100,000 to 125,000 barrels per acre have been mentioned. At the request of the Prime Minister of Alberta, the region was inspected by the author in 1930, and some of the many sections were inspected in company with Government officials, but although impressed, like others, with the extent and richness of the sands, great difficulties were foreseen in the profitable separation of the oil from the sands, and in the economic disposal of products from so remote a region where climatic and transport conditions were extremely difficult.

Oil extracted from the sands by solvents is of good quality and capable of conversion into marketable products; and it may be that by other methods than distillation useful materials besides asphalt may be produced. The various methods being tested in pilot plants by the Government and private interests did not appeal to the author as very promising.

South and Central America.—Oil in commercial quantities has been proved in no less than nine Latin American States: namely, Argentina, Bolivia, Brazil, Chili, Colombia, Ecuador, Mexico, Peru and Venezuela, although only four are substantial producers. Venezuela seems destined to yield the most important supplies of readily accessible oil, although Colombia and Mexico might if more actively prospected rapidly repay exploration. The oil potentialities of Brazil await expensive exploration, but the Amazon and Parana Basins would appear to deserve attention.

Argentina.—No striking oil developments have taken place in this vast country of 1,113,000 sq. miles. The Commodore Rivadavia, Chubat, field of Patagonia was still giving in 1948 about 16,000,000 barrels a year with over 3,300 wells, and had until that date produced 317,000,000 barrels of oil since 1907 from six zones, with reserves estimated at 440,000,000 barrels. Operations in other fields had disclosed nothing exciting. Nequen (Plaza Haincul) was giving about 3,300,000 barrels of oil in 1948, and had produced altogether since 1917, 33,600,000 barrels. Salta was producing at a rate of around 130,000 barrels a year, and was credited with an output of about 29,000,000 barrels since 1926; and Mendoza was giving 3,000,000 barrels a year, and had yielded since 1925, 17,000,000 barrels of oil. The oils vary in density from .764 to .925.

Bolivia.—A strip of interesting foothill country east of the Andes described on pp. 414-417 was subjected to systematic exploration by powerful oil interests, and this led to the discovery of several oil-fields of considerable promise. Somewhat ambitious development plans in this remote mountainous region were abruptly frustrated by a decision of the Government to nationalise petroleum in 1937. Three fields are being worked, and a fourth was opened in 1947. In the year 1947 the oilfields of Camiri, Sanandita and Bermejo were reported to have given outputs of 565, 440 and 335 barrels daily of light oil. The Camiri was said to be good for 5,000 barrels a day in 1949 and was reputed to have reserves of 21,000,000 barrels of 50° A.P.I. gravity oil at around 3,000 ft. The piping of oil over rugged mountain country to Tintin and Cochabamba is proving a difficult and expensive operation for the Government.

Brazil.—Four small fields in the Baia Basin produced 79,000 barrels in 1945, and between 1939 and 1945 some 210,000 barrels were raised. Reserves were estimated at 6,700,000 barrels, but in 1948 an output in excess of 140,000 barrels was reported, and arrangements were in preparation for dealing with the production. Oil is found in sands of Cretaceous age at depths up to 4,000 ft. on anticlinal folds.

Chili.—After many years of sustained effort a small oil-field has been proved at Cerro Manatiales (Spring Hill) on the straits of Magellan in Tierra del Fuego, and a 40 mile pipe line was being laid to Clarencia for shipment of oils. The oil of 40° A.P.I. gravity is obtained from sands of Cretaceous age around 7,500 ft.

Colombia.—In 1941 this Republic produced 24,700,000 barrels of oil which included 300,000 barrels of gas-gasoline mainly from the De Mares concession near the Magdalena River. The output in 1945 was somewhat less at 22,866,000 barrels of which 15,575,100 barrels came from the De Mares fields and included 400,000 barrels of gas-gasoline. Up to the end of 1948, when a yield of 24,400,000 barrels was reported, the cumulative production of the country amounted to about 455,000,000 barrels. Somewhat disappointing results have discounted the high hopes entertained by pioneers, but exploration is being actively pursued by a number of major companies in the hope of locating further worthwhile oil pools. The Barco concessions south-west of Lake Maracaibo between the rivers Oro and Zulia would appear to offer better prospects. Long distance pipe lines to the Caribbean Coast have been constructed at great expense from both De Mares and Barco areas, the former having an outlet at Corinas, the latter at Carthagena. Oil is found in sands and limestones of Lower Cretaceous and Eocene age. The main oil pools were as under :—

Field.	*Year Discovered.*	*Production Barrels.* 1948.	*Cumulative Production to* 1949. *Barrels.*
La Cira . . .	1926	6,600,000	228,000,000
Infantas . . .	1916	2,300,000	150,000,000
La Petrolea . . .	1933	2,800,000	30,000,000
Casabe . . .	1941	5,700,000	15,400,000
Tiba	1940	5,000,000	14,600,000

Ecuador.—Operations in this Republic have tended to confirm the qualified remarks expressed on p. 408 in 1925. Drilling in the Santa Elena, Ancon, peninsula have more than fulfilled anticipations, but exploratory drilling further afield has not been rewarded by encouragement. The bulk of production has been obtained by two British companies which were early in the field, and they have obtained over 34,000,000 barrels out of the 36,500,000 barrels produced until the end of 1945 from consolidated Tertiary sands resembling those of Peru. Some 13,500,000 gallons of gas-gasoline have also been produced.

Notwithstanding the almost insuperable difficulties that attended exploration of promising country east of the Andes in the Oriente, serious prospecting is now in hand. This work has been made possible by the use of aeroplanes for the transport of material and personnel over the high Andean passes from Pacific ports. By 1949 nothing important had materialised from drilling.

Mexico.—With the exhaustion of the famous Golden Lane oil-fields south of Tampico, Mexican production waned when active exploration failed to find any equivalent fields. The opening of a rich pool at Pozo Rica in the Tuxpan district served to check the dwindling output, but the expropriation of foreign oil properties by the Government in 1937 and the transference of the oil industry to the Authorities was a severe check on progress. Between 1937 and 1948 oil production has wavered between 35,000,000 and 58,000,000 barrels a year compared with a peak of 193,000,000 barrels in 1921. The Golden Lane group of pools was in 1945 credited with a total yield of over 1,000,000,000 barrels of oil. The fields of the Tehuantepec Isthmus associated with salt intrusions had given up to 1945, 135,000,000 barrels of oil; and the Pozo Rica field with an area of 16,000 acres between 1938 and 1948 gave 310,000,000 barrels from 64 wells. Some important gas and oil-fields had been proved in the north on the Texas border being an extension of a Texas oil province. This region seems destined to yield much oil when adequately explored and provided with pipe-line outlets.

The Southern Vera Cruz oil-fields had up to the end of 1948 given the largest volume of oil. In 1948 the Pozo Rica field was credited with 34,300,000 barrels out of the total of 58,000,000 barrels reported. This remarkable field yields oil from a fissured limestone of Cretaceous age at 7,000 ft. with a bottom hole pressure of 3,300 lb. The gas cap was estimated to contain originally 290,000,000,000 cu. ft. of gas and the oil reservoir was calculated to contain 3,020,000,000 barrels.

Mexico had produced up to the end of 1948, 2,352,000,000 barrels of oil.

Peru.—On the Parinas field a production of around 30,000 barrels a day has been sustained by the process of drilling down dip on the series of faulted blocks into which the Tertiary rocks are broken.

By 1948 this field had produced nearly 300,000,000 barrels of oil from 3,600 wells. The adjoining lands of Lobitos and Restin had produced to the same date 68,000,000 barrels.

Increased attention is being directed to the Montana, east of the Andes, where a field has been proved at Agua Caliente on an upper Amazon tributary. The inaccessibility of this region, and the absence of near-by markets for products, do not make developments here very attractive.

Restrictive labour laws and reservations of land by the Government have not induced foreign interests to pursue an enterprising policy. No important developments are envisaged in the narrow coastal belt separating the Pacific from the Andes.

Venezuela.—This State, so favourably located with relation to markets, has yielded more prizes and surprises than any other country in the world, excepting only the U.S.A. and the Persian Gulf region.

Active developments by major oil interests, furnished with almost boundless funds, quickly proved field after field, until in 1948 the production reached 490,000,000 barrels, and the total output of the country had risen to 4,556,000,000 barrels from more than 260,000 acres of proved ground covering some 70 pools. The Maracaibo Basin fields had by 1945 contributed the bulk of the production with 2,188,000,000 barrels to their credit. Western Venezuela had given a total of 3,610,000,000 barrels from around 6,000 wells drilled on 160,000 acres of proved territory up to the end of 1948. Lagunillas, however, contributed 1,650,000,000 of the total from 60,000 acres.

In 1928 Eastern Venezuela attracted attention with the discovery of the Quiriquiri field, which by December 31st, 1948, had given an output of 303,000,000 barrels from 12,000 acres. Up to the end of 1948 some 40 fields in Eastern Venezuela with a proved acreage of about 110,000 had yielded 946,000,000 barrels of oil from 2,100 wells in strata of Pliocene, Miocene, Eocene and Cretaceous age, and the potential was estimated at over 1,000,000 barrels a day. However, by far the most sensational event was the striking of oil in Cretaceous limestones in the La Paz and Mara fields of Zulia, north-west of Lake Maracaibo. Initial wells exhibited all the characteristics of the massive limestone fields with high and sustained yields. From 11 wells at La Paz a daily amount in excess of 100,000 barrels was being withdrawn. Those holding concessions in the Mara field had agreed to unit operation in order to check unbridled exploitation with its dangerous consequences. Should deep drilling in a number of the older fields develop the same conditions in the Cretaceous presumed to underlie the Tertiaries, Venezuela is likely to assume an importance far beyond the extragavant anticipations now made.

The exigencies of war greatly accelerated developments during 1940 to 1945 in Venezuela, so far removed from all but sporadic attacks by stray Axis submarines or raiders ; also the proximity of most fields to seaboard and to North America were factors of importance. Little has yet been done to explore the vast, inhospitable Orinoco Delta, beneath which many oilfields are likely to be discovered in the future.

Cretaceous oil has also been encountered in Eastern Venezuela in the Jusepin field at 2,500 ft., thereby heralding new prospects in that sector of the country with a 3,000 barrel well. In the year 1948 a footage of 4,350,000 ft. was made with 150 running rigs almost equally divided between Eastern and Western Venezuela. The following particulars relate to the fields which have given the major production of the Republic :—

State.	*Field.*	*Date of Dis-covery.*	*Production to Dec., 1948. Barrels.*	*Proved Area. Acres.*	*Production 1948. Barrels.*
Zulia	Lagunillas	1926	1,650,000,000	60,000	126,000,000
Zulia	Tia Juan	1928	560,000,000	43,000	66,000,000
Zulia	Cabimas	1917	591,000,000	4,500	30,000,000
Managas	Quiriquiri	1928	303,000,000	12,250	25,000,000
Anzoatigui	Oficina	1933	120,000,000	13,500	16,000,000
Zulia	Bachaquero	1938	126,000,000	19,000	40,500,000

West Indies.—Notwithstanding serious prospecting, only the island of Trinidad has yielded substantial productions of oil. Barbados continues to produce small quantities of high grade oil refined locally for home use, but geological investigations and prospect wells have failed to strike anything noteworthy in Cuba, Demerara, Surinam or the Bahamas, where the ocean bed was examined geophysically.

Trinidad.—Much has happened in this island since the account of the situation on pp. 388 to 394 was written; indeed, in 1948, oil constituted 75 per cent. of the island's exports, and contributed 26 per cent. of its revenue. Peak production was reached in 1940 when the output was 22,000,000 barrels, and the drilling effort 1,000,000 ft. Since that year production has fluctuated between 20,000,000 and 22,000,000 barrels yearly, and appears to have reached its peak. A number of factors operated in raising the production to a level that was scarcely foreseen. These included an intensive programme of wild-catting following extensive geological and geophysical studies, and pressure from the British Government to abstract the maximum amount of oil consistent with reasonable precautions during the war period. Previous to this, several surprise developments operated, one of which was the unexpected productions obtained in synclines which had been regarded unfavourably. Another surprise was the striking of oil far down the flanks of the monoclinally-dipping strata on the south coast following some very mediocre results at Palo Seco. An appreciation of the full significance of the great strike fault extending across the island from Point Ligoure proved a valuable help to explorers. Finally the discovery of a rich oil sand in the Oligocene at Penal aroused hopes that this might prove less lenticular than the usual Miocene sands and carry oil in other parts of the island.

Drilling had proved the productive oil sands in the Trinidad Miocene formations to be very inconstant, and they were usually interbedded with water sands which could not be clearly distinguished by ordinary methods of observation. It was not until the introduction of the Slumberger electric logging that water and oil sands could be differentiated, and, in consequence, methods adopted for isolating the water and admitting oil by the use of the gun-perforator. Although misinterpretations caused some confusion at first, local geologists were soon able to diagnose recorded anomalies correctly. High pressures and caving argillaceous sediments have enforced the employment of chemically prepared muds when drilling. Although Cretaceous strata are suspected to be the source of the oil, there is no general agreement concerning its genesis. The main fields being worked are as under, with approximate cumulative yields to the end of 1948:—

	Barrels.		Barrels.
Forest Reserve . .	91,000,000	Cora	15,000,000
Fyzabad . . .	83,000,000	Cruse	15,000,000
Point Fortin . .	57,000,000	Guapo	14,000,000
Palo Seco . . .	23,000,000	Quarry	14,500,000

Trinidad had up to January, 1949, given 370,400,000 barrels of oil.

The Central plain is regarded as a possible location for deep tests, but more serious attention is being given to the exploration of tide lands in the Gulf of Paria and on the Southern Caribbean shore where it is known that favourable conditions exist.

Europe, an Oilfield Developments since 1925 (see Chapter IX, pp. 418-458).

Russia.—Naturally this vast country, covering about one fifth of the land surface of the earth, holds more oil prospects than any other European State, but unfortunately since the advent of the Soviet regime few outside a certain domestic clique are in possession of data that would enable resources to be assessed. Production in 1938 was reported to be 224,700,000 barrels. Under stress of insistent demand for oil, active prospecting has been pursued for some years, with the result that the production of the Apsheron fields of the Baku region has been sustained by new discoveries at increased depth and by near-by developments in the Puta valley. The opening of a new field on the Caspian shore line east of Grozny was an event that equalled in importance the improved developments in the Maikop-Kuban region. Encouraging results have rewarded drilling on the Samarsky range skirting the Volga between Sizran and Stavropol. The Baku fields it was reported produced in 1938 about 165,000,000 barrels of oil; the Grozny region 17,500,000 barrels and the Kuban region 13,500,000 barrels. The Ural-Permian basin gave 14,500,000. The Uralsk and Emba basin region seems to have been neglected. Up to 1936 Russia was credited with a cumulative output of 3,629,800,000 barrels of oil and 44,000,000 ft. of drilling. Production in 1948 was believed to be about 235,000,000 barrels and cumulative output 6,000,000,000 bls.

Roumania.—World War II led to a second invasion of Roumania by the Germans and, in consequence, the total disorganisation of operations which had attained highly commendable proportions due to the activity of foreign oil corporations, who introduced modern methods of production and refining and invested large amounts of capital. The introduction of rotary flush drilling and the extensive employment of gas-lift in wells that ceased to flow were mainly responsible for the quickened pace of development and the consequent rise in production. Drilling speeds of 1,000 ft. a day in the soft Pliocene clays were general, and 3,000-ft. wells were often drilled in three days, where previously many months would be occupied on the same performance. With all the important oil-fields located on peasant holdings cut up into small parcels, competitive offset drilling forced the pace far beyond that which was rational, with the result that production exceeded demands, causing prices of crude and refinery products to fall to an unprofitable figure. Peak production was registered in 1936, when it rose to 65,000,000 barrels, but, due partly to some diminution of drilling activity, production fell to 49,000,000 barrels in 1937. Up to the end of 1938 Roumania had produced 848,000,000 barrels of oil from 6,200 wells spread over approximately 41,000 acres of proved territory.

In 1938, prior to the war, when the total output of Roumania attained 49,000,000 barrels the main oil-fields of the country were as under :—

Department.	Field.	Year Discovered.	Production in 1938 in Barrels.	Total Production to date in barrels.	Proved Acreage.	Wells Drilled.
Prahova .	Moreni . .	1903	15,500,000	348,000,000	4,800	1,600
	Bushtenari and Runcu . .	1844	1,600,000	105,000,000	5,250	1,641
	Campina . .	1884	225,000	33,000,000	580	281
	Baicoi and Tsintea	1861	4,840,000	39,000,000	850	484
	Boldesti . .	1922	8,400,000	73,000,000	5,000	163
	Ceptura . .	1913	5,000,000	35,400,000	2,100	224
Dambovitsa .	Gura-Ocnitsei .	1929	4,150,000	66,400,000	7,550	322
	Gorgota-Ochiuri .	1913	2,700,000	40,000,000	1,300	283
	Buscani . .	1935	7,300,000	31,500,000	3,900	16

A large proportion of the oil developed was from the Meotic sands, which yielded paraffinous oils, thereby introducing production difficulties. At one period the excess of residuum fuel oils for which there were neither storage facilities nor outlets at the Ploiesti refineries led to the destruction of vast quantities by burning.

The structures of most of the developed oil-fields were clearly expressed topographically, but so far the hopeful view held that geophysical work in the plains would disclose the presence of less complex structures of promise has not been fulfilled. Few fields undisturbed by intrusive salt have given high and sustained yields ; and the origin of the oils is still undetermined. It appears likely that a very large proportion of the oil contained in the meotic sands is not recoverable by any methods known to-day, owing to its high paraffinous content.

Following the Russian occupation and the refusal of the authorities to permit the return of representatives of foreign companies, little has been heard about oil developments. The oil-fields have been worked by or under directions of the government.

Poland (Galicia).—Amidst the Sub-Carpathian foothills no important oil-field has hitherto been disclosed in Poland, outside that of the famous Boryslav-Tustanowice pool, which in 1936 was said still to give about 2,000,000 barrels a year. A large proportion of the 240,000,000 barrels credited to Poland up to 1936 came from this one field, where later much gas-gasoline was extracted from gas. Inadequacy of funds is responsible for the small amount of serious prospecting undertaken, and much attention is being given to the repressuring of old fields and the development of gas for gas-gasoline extraction and for fuel purposes. Very considerable gas reserves have been proved, and pipelines have been led to points of consumption.

The second World War disrupted operations, and, under conditions existing in 1949 it is unlikely that much progress will be made. The many small fields continue to give production on a small scale.

Austria, Hungary and Czechoslovakia.—The Zisterdorf field of the Vienna basin had up to 1949 alone given a worth-while production of oil in Austria. Amidst faulted conditions, a number of quite good producers were struck, but, just when real success was in sight, the country was occupied by German troops and the oil-fields were worked for military purposes only, without regard to conservation or economy. In 1949 the discovery of oil was reported at Matzan, some 18 miles from Vienna, on a structure known to oil interests prior to the occupation of Austria by the Germans.

The discovery of oil by the European Gas and Electric Company, a subsidiary of the Standard Oil Corporation of New Jersey, in 1937, placed yet one more European Country (Hungary) on the oil map. As a result of pursuing an exceedingly active policy, a promising oil-field was located at Lispe on the Yugoslav border, and a company was then formed in accordance with agreements with the Hungarian Government in 1938 to develop an industry in which the Government held a substantial participation. This was followed by an even more valuable oil strike on a structure at Lovassi. Between 1937 and 1941 Maort (the Hungarian Company) produced 6,600,000 barrels of oil, and, admittedly, became one of the most important industrial undertakings in the country when pipelines were laid, refineries erected and modern methods employed.

On the entry of the U.S.A. into the war, the Hungarian Government was induced by the Germans to transfer all authority from the owners, and the fields were negligently and recklessly operated, yielding in 1942, 5,117,000 barrels, in 1943, 6,426,000 barrels, and in 1944, 6,204,000 barrels.

All profits had been ploughed back into the concern since conception, and no compensation has been received for some $20,000,000 said to be owed for sequestration of oil and property. The fields in 1948-49 were being worked for the benefit of the authorities under Russian dictation.

Czechoslovakia can boast of only two unimportant fields—one at Gbely (Egbell) in Slovakia on the Austrian border, which by 1938 was fully drilled and gave only 300 to 400 tons daily. The other, Hodonin (Göding) in Moravia, gave only a negligible output.

Germany and Netherlands.—Nothing very startling has been disclosed in Germany, notwithstanding a considerable amount of prospecting and wild-cat drilling during and following World War II, although geophysical investigations by the major International oil interests had proved the existence of many salt domes in the Rhine-Elbe basin. Production has wavered around 600,000 tons a year, and in 1947 was mainly derived from eight fields in Hanover and two in Schleswig-Holstein. The Nienhagen-Haenigsen field is far ahead of all others as a producer. Geophysical exploration has disclosed the existence of many non-piercement type salt domes in the Hanoverian plains and Elbe valley, and it is mainly around these that oil prospects lie.

A group of fields on the Netherlands-Emsland Frontier developed by the Germans during the war led to the first discovery of commercial oil in Holland, and by 1949 the Schoonebeck field had become the largest producer in Western Europe, with an output of over 11,000 barrels a day. The structure takes the form of a faulted anticline, and oil of 24.8 A.P.I. gravity with 5 per cent. to 6 per cent. paraffin is obtained from sands of Jurassic age at a depth of about 2,500 ft. The German Emsland group of fields is credited with a reserve of 25,000,000 barrels. The German fields are credited with a cumulative production to 1949 of about 75,000,000 barrels.

Italy.—Despite much prospecting, little of outstanding importance had resulted from expensive deep tests in the Po valley until 1949, when reports indicated that at Cortemaggiore, 20 kms. from Piacenza, a flow of 600 barrels of .845 gravity oil with much gas was struck at around 5,000 ft. on a large structure. This encourages hopes that still deeper drilling will result in finds of more oil. The extensive Po valley would appear to hold prospects for striking oil on any folds that could be located by geophysical methods. In the disturbed foothill country of the Apennines many of the outcropping Tertiary clays are petroliferous.

*Portugal**.—Further exploration in Portugal, after considerable detailed geological work, failed to locate oil in economic quantities. The belts of disturbance designated by Choffat as tiphonic areas were found to be allied to salt dome phenomena, and the associated flexuring is believed to be due to an up-thrust of Infra-Lias formation that consists of a confusing complex of dolomitic limestones, vari-coloured shales and anhydrite. Although no salt as such was found, highly saline waters are so frequent that its presence at some time may be surmised. Further complications arise from the frequency of volcanic

* Oil Prospects of Portugal—J. Inst. of Petroleum 1944.

intrusions into the Sedimentaries. A number of favourable structures were mapped, but as the Torres Vedras anticline appeared to offer best prospects a well was drilled to a depth of 3,820 ft. without encountering payable oil, although showings were met with from 300 ft. onwards. Upper Jurassic shales and sands were replaced at 700 ft. by Argillaceous limestones in which oil occurred in fissures, but the best showings were at 1,970 ft. in a brecciated zone of faulting.

Two clearly defined domes at Arruda and Belas in the Cintra district would appear to warrant a test, but two anticlines in the Argarve region far removed from known oil manifestations are somewhat difficult to explain and only deserve consideration if success is met with elsewhere.

France has up to 1949 failed to produce an oil-field of economic importance, although a fair amount of deep drilling on Jurassic and Cretaceous structures, following geophysical surveys, had been carried out. It has been recognised that best prospects lie on the Northern foothills of the Pyrenees, and it is in the Department of Landes, east of Bayonne, that prospecting is being concentrated. Small producing wells were struck in Jurassic beds at Audignon, and gas in some quantity was found at St. Marcet, north of St. Gaudens and on the Garlin fold.

Greece.—The most striking manifestations of oil in this country are to be seen in the bed of the Molitsa, a tributary of the Kalamos, in Epirus, where a considerable thickness of oil saturated sand is exposed on the bank of a gorge, and many live seepages of oil and gas occur in and alongside the stream. The seepages follow the crest of a faulted anticline in the Flysch along which the stream has carved a gorge, and although access to the spot is exceedingly difficult, necessitating the construction of roads, a decision was reached to test the region. Unfortunately war intervened and led to a cessation of plans in hand for testing the area with a drill.

Certain indication of oil in the Flysch of Macedonia scarcely warranted serious exploration. Some very expensive investigations undertaken in Morea near Olympia by a wealthy American of Greek descent ended in failure, although the country was geologically surveyed and some fairly deep wells sunk on structural highs.

On the near-by island of Zante a small amount of oil was developed in 1930, but the field proved to be very small and shallow and never repaid exploitation, although flows of an oil with a density exceeding that of unity were encountered.

Albania.—Although investigations on a serious scale by major oil interests have been undertaken, nothing of importance was found except at Devoli near Kucova. Here the Italian Government had succeeded in recovering from Miocene sands about 300 tons a day of .920 gravity oil from some 200 wells spaced on a fold where oil sands outcropped. Equipped with every modern appliance for economical drilling and producing, and with first-class housing for staff and workers the oilfield made a striking contrast with everything around. Wells 3,000 ft. deep were drilled in a month, and a 2000 kw. power plant supplied energy for all field purposes. Oil was piped to Valona on the Adriatic for shipment to Italy, where oil was so urgently needed.

Great Britain.—Notwithstanding extensive and exhaustive investigations of the British Isles for Petroleum preceding and during the Second World War, only one strike of oil in useful quantities was made. Following geophysical surveys and geological mappings of possible territory, wells were drilled on structures at Portsdown, Kingsclose, Henfield, Poxwell, Pevensey, Eskdale, Hardstoft, Keele, Cousland, Formby, and Eakring in Nottinghamshire. Petroleum was struck in 1939 on two small structures at the last named place at 2,000 to 2,500 ft. in the millstone grit, and an output rate of about 750,000 barrels a year was reached by drilling closely spaced wells that ensured maximum output in a minimum of time at an anxious period in the war. Water soon appeared and yields trailed off. A small shallow field was exploited in the millstone grit at Formby in Lancashire in 1939, but never justified early hopes. Britain is credited with an all time production of 4,000,000 barrels.

Middle East, Africa and Australasia (see Chapter X, pp. 459-501).—Since 1925 stupendous developments have taken place in the Middle East, Persian Gulf region, following the discovery at Bahrain of prolific oil sources in beds deeper than those which were producing in Iran and Irak. The Bahrain success was quickly followed by astounding discoveries on the Arabian mainland of Saudi-Arabia, and subsequently on territory ruled by the independent Sheikhs of Kuwait and Qatar; and it is reasonably certain that oil-fields will be found on the terrain of other Sultans and Sheikhs ruling rather ill-defined strips of country along the Trucial coast flanking the Persian Gulf. Nor do these prospects exhaust potentialities, for doubtless other structures underlie the shallow Gulf tidelands and may permit of off-shore drilling. The so-called neutral territory between Saudi-Arabia and Kuwait acquired such a high reputation that bids by outside American oil interests sound fantastic in their amount.

These unexpected and unpredictable results following the remarkable developments in Iran have suddenly transferred to the Middle East a position of prominence that was never suspected, and have transformed penniless potentates to a state of opulence that transcends Arabian Nights' stories. Money in abundance is now available to a population that for centuries lived on the verge of starvation, for it will now be possible to construct roads, develop water and irrigation schemes and build towns where nomads once roved in search of water and fodder.

Kuwait developments also transmitted an immediate value to the Euphrates-Tigris Delta, where geophysical surveys quickly detected structures which proved on being drilled to be oil-bearing. Pipelines across Arabia to the Mediterranean are in hand from Saudi-Arabia and Kuwait, as well as from Iran and Irak.

Iran (Persia).—Intensive geological studies in Iran led to a clearer understanding of the complex folding and distortion of the Fars chemical series of sediments that immediately overlie and totally obscure anticlines in the productive Asmari limestone. Surface inflections of the plastic Lower Fars formations in no way reflect the position of the underlying Asmari folds due to extensive overthrusts and distortion. Broad hog-back folds of considerable size characterise the Asmari limestone.

For many years the original Masjid-i-Sulaiman (M.I.S.) field opened in 1908 provided the A.I.P. Company with as much oil as could be handled, and the field is still producing at a controlled rate of around 60,000 barrels a day after giving nearly 1,000,000,000 barrels of oil to 1949. One famous well in that field had alone given 50,000,000 barrels of oil before being closed due to fears of corroded casing after so many years of use.

By 1949 five additional fields of major proportions had been discovered, and were in production, and the immense potentialities of the 100,000 sq. mile concession were still unproved. From the Naft Kel field opened in 1928, about 197,000 barrels a day were being taken from 23 wells, and from the Agha Jari field developed in 1937 around 144,000 barrels a day from 12 wells were being abstracted. Up to 1948 a total flowing output of 1,747,000,000 barrels of oil had been reported from Iran, and proved reserves were estimated by one authority at 6,500,000,000. The six main fields follow a general south-east direction from Lali in the north to Gach Saran in the south, and all are connected by a system of pipelines with the refinery at Abadan, said to be the largest in the world with a throughput of 500,000 barrels a day. The following particulars of the fields have been given relating to period ending December, 1947.

Field.	1st year Pro-duced.	Production Area. (Acres)	Depth in feet to Production area.	Thickness of Producing Zone.	No. of Producing Wells.	Daily Average Production. (Barrels)	Cumulative Products to end of 1947.
				Ft.			
Masjid-i-Sulaiman	1911	34,500	600	1,000	29	73,000	793,300,000
Nafti Shah .	1935	3,840	2,400	250	2	3,000	9,600,000
Naft Kel .	1928	28,800	2,000	900	23	197,000	749,500,000
Gach . .	1940	38,400	2,500	1,500	3	38,000	75,800,000
Naft Safid . (White oil Springs)	1945	6,400	3,000	900	2	17,000	12,800,000
Agha Jari .	1945	4,500	4,500	600	12	144,000	94,300,000

The gravity of the oil varies little, being .813 for Nafti Shah to .864 for Gach Saran, and so sensitive are the fields as a whole to withdrawals that it is necessary not to take oil from more than a few free-yielding wells at any one time. On the M.I.S. field where 229 wells have been drilled, and from which 3,750,000 barrels a year were being withdrawn, never more than 31 wells were on production at a time. At Naft Kel on which 42 wells had been drilled and from which 750,000,000 barrels have been recovered, never more than 18 were on tap at one time although 75,000,000 barrels were being abstracted per annum. Pressure equalisation is traceable for miles if the rate of flow of any one well does not exceed a maximum which is believed to be the limits of yield of a communicating fissure system. Considerable variation in the productive capacity of wells is thought to be attributable to the dimensions and extent of fissures. The formation of gas domes after the removal of much oil necessitates the closure of wells on high parts of the structures.

So many factors only imperfectly understood render predictions of ultimate recovery hazardous, for with a porosity of between 8 and 12 per cent., but low permeability, it is clear that much of the oil is being withdrawn from fissures which are fed by an infinite number of minor cracks or permeable layers in the limestone. Considerable volumes of gas are now burnt in open flares after leaving the separators, although from some gas 40 tons of sulphur per day is being abstracted and used for the manufacture of sulphuric acid.

Due to the difficulty of maintaining at the Abadan refinery a balanced throughput to meet market requirements of products, especially when emergencies arise as in war, a topping plant is in operation at M.I.S. This enables the unwanted distillates or residues to be either returned to the field via injection wells or to be pumped elsewhere.

Extremely difficult drilling problems have had to be surmounted in piercing the considerable thickness of Lower Fars chemical sediments which form the cover beds of the productive Asmari limestone. The Lower Fars consist of a succession of marls, anhydrite and salt which have suffered such severe deformation in the process of folding that they are liable to disintegrate, crumble, swell, heave or dissolve, when they come in contact with drilling fluid. Loss of circulation at intervals introduces an additional hazard that often occasions exasperating delays and calls for much ingenuity to master. Only by constant vigil and incessant attention can muds be prepared to deal with the changing conditions that appear and hold up progress. Owing to the presence of abnormally high pressures it has been necessary at times to resort to pressure drilling.

Oil was struck in 1923 on a fold that crosses the Irak frontier, but although 250 ft. of Asmari limestone was struck and good yields assured, the results did not justify the great expense that would be incurred in pumping oil to Abadan. When oil was struck on the same structure in Irak, the Iranian Authorities insisted upon the development of the field for local use, with the result that a pipe line was laid to Kermanshah and the oil treated in a 2,000 barrels a day capacity refinery.

Doubtless other oil pools will yet be disclosed, and it may be that sources deeper than the Asmari may yet be discovered. Northern Persia is likely to receive attention one of these days, but the natural outlet of any oil would be via the Caspian Sea. The Laristan Coast of the Persian Gulf has not escaped the notice of oil geologists, for some scores of salt domes have led to structures that favour the concentration of oil if source beds exist in the geological succession.

Irak.—Mesopotamia has fully justified the somewhat extravagant expectations long held by the oil fraternity regarding its oil prospects. As soon as the very conflicting claims based on pre-war negotiations had been appeased by sensible arrangements ensuring participation of International oil interests in the Turkish Petroleum Company, acceptable terms were in 1925 agreed with the Irak Government for the exploration of the Mosul oil-fields. Somewhat intricate and delicate transactions eventually led to an acceptable division between American, British, French and Dutch oil interests and culmination in the formation of the Irak Petroleum Company, in which the undermentioned participated, as stated below :—

British, 23.75 per cent. ; Anglo-Dutch, 23.75 per cent. ; French, 23.75 per cent. ; C. S. Gulbenkian, 5 per cent.—the latter for services rendered in connection with the Turkish Petroleum Company negotiations.

The blanket concession granted to the Turkish Petroleum Company by the Irak Government for oil prospecting in the vilayets of Mosul and Baghdad incorporated an obligation to make a selection of acreage chosen for development within a certain period, but when the prescribed date had arrived no productive oil-field had been located. Meantime, other interests had been pressing for concessions, and eventually lands east of the Tigris were allotted to the Irak Petroleum Group, and those west of the Tigris to the Group known as the British Oil Development. This latter corporation became International in character when a share was taken by the Italian, German and French Government-sponsored concerns.

The mapping of the oil-field region of Irak was greatly simplified by the fact that all structures are clearly expressed by topographical relief, and outcropping beds can be easily identified by distinct colouring and other characteristics. It was often possible to proceed by car direct to the crest maximum of a fold and observe the closure of selected beds round a dome, or to follow certain horizons for miles along an anticline.

After a number of unsuccessful wells had been drilled on several of the many favourable structures which had been mapped east of the Tigris, a rich oil source was struck unexpectedly in the Asmari limestone at 1,521 ft. at Baba Gurgur near Kirkuk, and for a time the well ran wild and reached an estimated output of between 70,000 to 90,000 barrels a day. This discovery led to the development of the great Kirkuk field which has been proved for a distance of 60 miles to beyond the Lesser Zab by widely-spaced wells. The initial well was drilled near an oil seepage which had been known for hundreds of years. Some of the previous wells drilled east of the Tigris were abandoned through drilling troubles and never reached the Asmari limestone, but some difficulty is found in attributing a reason for the failure to strike oil in the Asmari on certain folds where the succession was normal, and the structure in all respects favourable. In most cases gas and oil shows were encountered, and Asmari failures may be due to escape of the oil contents through fractured covering beds, for oil residues were frequent in the overlying formations of Lower Fars.

The next important developments by the B.O.D. were at Quayarah, west of the Tigris, where the Germans had dismally failed to develop oil in quantity during the war. A succession of highly productive wells were struck on the extension of the anticline at Najmah and later at Jawan and Qasab, but the specific gravity of the oil was 0.959, and too heavy and viscous for long-distance pumping without admixture with Kirkuk oil of a specific gravity of 0.845.

East of the Tigris a single oilfield in the so-called Transferred Territories on the Iranian frontier at Nafti-i-Shah (Naftkhanah) had proved highly productive and from this field oil has been taken for feeding a refinery at Khanaquin, designed to supply Irak with certain products. On the other side of the frontier in Iran sufficient oil is being pumped from the same structure to a refinery erected at Kermanshah, designed to satisfy the needs of that part of Iran.

Another tested structure at Chia Surkh in the same region as Naftkhanah struck such high pressure gas that work was suspended when a well-head pressure of 2,000 lb. was, it is said, measured. There seems little doubt that an important deep field awaits development, and if the Asmari is well covered and at a considerable depth, heavy yields might be anticipated. Although no less than 23 clearly defined anticlines with a total length of 280 miles have been mapped on the 45,000 sq. mile concessions west of the Tigris, only at Quayarah, Najmah and Jawan, and Qasab, was heavy oil in economic quantities struck in the Asmari, until at Ain Zalah, the furthest structure in a north-west direction, light oil of .864 specific gravity was encountered at around 5,000 feet in the Cretaceous.

With the consent of the Irak Government the B.O.D. holdings west of the Tigris were in 1935 transferred by arrangement to the I.P.C., thereby enabling the Mosul fields to be exploited as a whole to best advantage. The very marvellous development in Saudi Arabia and Kuwait led to many applications for concessions in the Euphrates-Tigris delta, and in 1938 a concession was granted to the Basra Petroleum Company, an offshoot of the I.P.C., to explore for oil. Geophysical prospecting in the delta quickly located several structural uplifts below the deltaic deposits, with the result that oil was struck on two folds, north-west and south-east of Basra, in strata more or less corresponding with those of Kuwait.

The oil potentialities of Irak are unpredictable, but obviously very great, for not only do prospects at depth await a test, but other fields than the Kirkuk are likely to give a production of light oil in the Asmari. The Kirkuk field has a proved area of about 80,000 acres and the oil-impregnated reservoir rock, about 1,000 ft. thick, is sufficiently fissured to admit of long distance movements and equalization of pressure on withdrawals from widely-spaced wells.

The oil is under a water drive that should promote a maximum degree of depletion under regulated output. Until 1949 the output of the great Kirkuk field was restricted to the capacity of the 12-in. pipe line to Haifa and Tripoli, some 90,000 barrels a day, but the completion of new 16-in. lines to Haifa and Tripoli in 1949 should enable the output to be raised to 270,000 barrels a day, say 100,000,000 barrels a year. Irak has been credited with proved oil reserves of from 5,000,000,000 to 8,000,000,000 barrels of oil. Up to January, 1949, the Kirkuk field alone had given 425,000,000 barrels of oil from a few wells. On the Mishraq structure where it extends across the river at the junction of the Tigris and Greater Zab is one of the greatest gas seepages in the world known for centuries, and the outcropping rocks on the cliffs at the edge of the river are impregnated with viscous petroleum residues. A well sunk on this structure failed to give oil although both the Asmari and the overlying Fars beds gave numerous showings of gas and oil. As at Quayara, cores taken from wells disclosed open fissures lined with crystalline sulphur.

In the Delta area one prolific producer was brought in at a depth of 8,360 ft. at Nar Umra, and another 25 miles south at Zubair after drilling to 11,000 ft.

Bahrain.—The discovery of oil in Eocene and Cretaceous limestones on the island of Bahrain in 1936 by American oil interests after its rejection by British oil companies opened the eyes of the Oil World to the prospects of the Persian Gulf and led to acquisitions on the Saudi-Arabian mainland. Conveniently located for easy exploitation on territory owned by a progressive Sheikh, who accepts British guidance, the field quickly acquired major importance. A modern refinery was built, shipping facilities provided, and in the course of a few years it attained large proportions and treated much Saudi-Arabian oil pumped from the mainland through a submarine line. On the delineation of the field by drilling and an assessment of its capacity and reserves, production was maintained at around 30,000 to 35,000 barrels a day from 66 wells, an output considered to ensure the maximum recovery and the safe control of edge water. Repressuring by surplus gas is undertaken to assist the process.

By 1949 the pool had given 85,000,000 barrels of oil. Prospects at depths are yet unknown, but high pressure gas has been struck far below present production.

The structure is clearly reflected by surface exposures in the hills around a central plateau, upon which the well-planned town of Awali has been built for the Company's personnel. A geophysical search in the gulf waters around the island may lead to the discovery of submerged structures.

Saudi-Arabia.—This Arab kingdom came into sudden prominence in 1938, when oil was struck on the Damam structure by an American group who held a 440,000 sq. mile blanket concession granted by King Ibn Saud. This not only proved to be an oilfield of major importance but it demonstrated the value of an immense strip of flat arid country lying between the Gulf and the mountains. A second field, Abu Hadriya, was proved in 1940, and in 1941 Abqaiq was discovered and later an extension at Buqqa. A fourth, Qatif, was located in 1945. Another field was proved in 1947 at Buqqa.

Geophysical methods were extensively employed to locate and define structures for the most part concealed by sand dunes and drift sand. Production is obtained from sands and limestones of Tertiary, Cretaceous and Jurassic age on broad-arched anticlines. Gas pressures are high, the oil is of good quality and the oil-bearing formations thick, and, although calculated reserves are pure guesses, it became abundantly apparent that results justified the building of townships, wharves for handling goods, the laying of pipelines to the coast and to Bahrain, and the construction of a modern refinery at Ras Tanura. Aramco, the operating company, also embarked on the construction of a 1,100-mile 30-in. pipeline from the Abqaiq field to the Mediterranean, designed to carry 300,000 barrels a day.

On the Damam field oil is obtained from several Jurassic limestones, about 400 ft. thick, at a depth of around 4,500 ft., and the field has a proved area of about 7,000 acres. The Abqaiq structure has an area of about 45,000 acres with good closure of Jurassic Dolomitic limestones that yield freely at a depth of about 6,000 ft. The Buqqa field lying further to the north-east on the same line of folding, is a free-producer from limestones at about 7,000 ft. The Qatif field with limits yet undetermined gives good productions from limestones at about 7,000 ft. From the Abu Hadriya structure, 100 miles north-west of the other group of fields oil has been struck in limestones much deeper than those in the south at 10,000 ft.

It is far too soon to make an estimate of reserves, although a figure of 5,000,000,000 barrels has been mentioned, but believed by some to be on the low side. Without doubt other pools will be located on the vast territory that awaits investigation. In 1948 50 wells in Saudi-Arabia produced 137,000,000 barrels of oil on two structures. Cumulative production to 1948 was given as 202,198,000 barrels.

Kuwait.—A 6,000 sq. mile concession was granted by the Independent Sheikh of Kuwait to an Anglo-American oil group in 1934, and in 1938 the Burghan field was discovered. Owing to the war little was done until 1946, when a number of widely-spaced wells proved the existence of what is believed to be the largest and richest oil-field in the world. Oil is found at 3,700 ft. under high pressure, and reserves have been given at 9,000,000,000 barrels. Output is limited by transport facilities, but in 1947 18,000,000 barrels were exported. Arrangements are in hand for coupling with a projected pipeline that will be run from Iran to the Mediterranean, and possibly with a second one in contemplation across Arabia.

The Burghan structure is a broad, flat, almost symmetrical anticline with a productive area of about 19,000 acres. The oil-yielding beds are sands of Middle Cretaceous age, securely capped by a succession of shales.

Qatar.—The Sheikh of Qatar in 1935 granted to a subsidiary of the Anglo-Iranian Oil Co., Ltd., a concession to explore his territory for oil, with the result that in 1939 oil was struck on the Dukhan field, near the West Coast of the Peninsula. Work was resumed after the war in 1947, when arrangements could be made for landing material, housing employees and providing for their sustenance and health. The Peninsula is an arid waterless waste devoid of any amenities that would ensure human health and comfort. Unless distilled sea water is used all water has to be carried from a distance. Oil will be piped to the East Coast for transhipment.

Turkey-in-Asia.—No significant oil pool had by 1949 been discovered in Turkey, notwithstanding a fair amount of serious drilling following competent geological advice. The area nearest to Irak would appear to offer the most tempting prospects, for from one pronounced structure near Zakho, where oil-saturated beds are exposed on a plunging anticline, a native oil industry has thrived for many years.

The Ain Zalah field is the nearest oil-field of Irak near Nisibin, the frontier post.

At Raman in this region a certain amount of oil has been struck in wells drilled to about 4,000 ft. on a structure.

Far East.—The second World War led to a wholesale destruction of oil-field equipment and refineries in the Dutch and British East Indian oil-fields. Demolition of valuable oil installations in Burma, Sarawak, Borneo, Sumatra and Java inflicted terrible losses on oil companies operating in those parts, and the restoration will be a long and costly affair, further impeded by the political troubles and the national aspirations which followed.

Burma.—Attempts to repair some of the damage inflicted by the Japanese on the Yenangyoung and Singu oil-fields on their departure were frustrated by civil disturbances after a considerable outlay on restoration work. It is yet too early to say whether the inhabitants will be sufficiently pacified to permit of rational development.

Widespread prospecting prior to 1938 had failed to disclose the presence of any important oil-field in Burma outside those of Yenangyoung and Singu. The cumulative production of Burma to the end of 1949 was 255,000,000 bls.

Borneo and Sarawak.—Prior to the invasion of the Japanese in 1941 the output of the East Indian Islands was as under :—

British North Borneo (Brunei—Sarawak)	18,800 barrels a day.
Netherlands East Indies (Borneo, Sumatra, Java and Ceram) .	170,000 barrels a day.

When the invasion of the islands by the Japanese seemed imminent, methodical demolition of wells and refineries was undertaken in order to deprive them of the much needed oil. On arrival the invaders set to work to renovate the works, and eventually succeeded, during four years of occupation, in obtaining some 12,000,000 barrels of oil from the Miri and Serai oil-fields of Sarawak. The Japanese, when forced by the Allies to abandon these fields in 1945, destroyed all they could, and set fire to a number of flowing wells. So energetic were the steps taken to restore these fields that by 1948 production had been raised to about 53,000 barrels a day ; a truly remarkable achievement in the face of enormous difficulties.

Cumulative production up to January, 1948, has been reported as 70,000,000 barrels for Miri and 70,000,000 barrels for Serai, although the latter field was only discovered in 1929.

In 1936 oil was discovered in Dutch New Guinea at Klamona after many years of search in remote forested territory, but its economic importance had not been tested until after 1945. Only in 1948 was a pipe line led to the coast at Sorong, where tankers could be loaded by a submarine pipe line. Production is given as 4,000 barrels a day.

India and Pakistan.—The retirement of Britain from India led to a partition of the country, after all efforts to compose religious and racial differences had failed. Both India and Pakistan developments have been hindered by the confusion thereby caused and the professed intention of revising concession terms.

The Khaur field of the Punjab, described on p. 482, proved a very prolific producer, although exceptionally difficult drilling problems arose when passing alternations of soft swelling clays and hard sandstones, in which abnormally high and low pressures were encountered. Increasingly steep dips with depth introduced a further complication, and, when eventually the Eocene limestone target was struck, the anticlinal crest had narrowed almost to a knife edge.

Only by mastering enormous difficulties was oil struck in the Eocene limestones on the Dhulian dome in 1934. Circulation mud at times worked its way through fissures in the Murree beds to the surface for a long distance around the derrick. When the limestone was eventually reached at 7,500 ft., production was obtained, but the results proved distinctly disappointing, and, as the oil was heavy, considerable changes were enforced in the Rawalpindi refinery to deal with the crude.

Water soon caused production troubles, when the pressure fell. Up till the end of 1948 the Khaur field had given 3,428,000 barrels of oil from about 320 acres.

Other fields were proved in the Punjab at Chakwal, referred to sometimes as Joya Mair and Balkassar, near Rawalpindi, in 1944, and also at Lakra at 8,250 ft. in the Middle Sind desert.

Results appear to confirm the views expressed on p. 482 concerning the restricted thickness of suspected source beds. The author was inclined to attribute the oil found at Dhulian to secondary concentration after the loss of most of the original oil through fissures in the overlying Murree beds prior to their eventual closure by continued earth movements. The Digboi field of Assam had given to 1949 a total of 38,000,000 bls.

Africa and Sinai.—The only African oil-fields so far proved border the Gulf of Suez in Egypt, and are described elsewhere under Middle East headings.

Manifestations of oil have been reported from many parts of the Continent, and much prospecting has been undertaken, without disclosing anything of economic importance. The greater part of Africa exposes igneous or crystalline rocks unsuitable for the formation of oil, and from which most sedimentary strata have been removed by denudation, except in valleys. Mention is made on pp. 490 to 496 of most known oil indications or prospects, and more detailed studies since 1925 have confirmed the unfavourable prospects then expressed. Exploration is being continued in Ethiopia. Somaliland still remains untested by the drill, although it is certain that some oil will be obtained at Daga Shabell, described on p. 492. Drilling on the Lake Albert foreshore, where oil seepages exist, gave no results, but the wild delta of the Semliki river, where paraffinous oil seepages occur, has never been tested. Mozambique and Madagascar have been neglected, but Nigeria is being further investigated, after a detailed study of the Ivory and Gold Coast indications had led to an unfavourable conclusion. Morocco, Algiers and Tunisia are being actively prospected for oil, but, although small pools have been worked, nothing very important has been disclosed. The Congo basin would appear to warrant investigation. Drilling in Angola gave negative results although much geological work had been undertaken by an important oil company.

Egypt.—After many disappointments and much abortive drilling on both sides of the Gulf and Suez, success was attained at Ras Gharib in 1938, just as Hurghada was becoming depleted. The Hurghada field more than fulfilled its early promise by yielding in 34 years up to the end of 1947 nearly 41,000,000 barrels of oil from 104 wells, or more than 35,000 barrels per acre, and was still giving over 300,000 barrels a year. Discovered in 1937, the Ras Gharib field yielded in 1938 over 4,000,000 barrels of oil from 14 wells, and in 1948 95 wells had then given 69,000,000 barrels or over 1,000,000 barrels per acre. In this remarkable field oil was struck in sandstones of Carboniferous and Cretaceous age, as well as in limestone of Miocene age; consequently, the source of the oil was uncertain.

Prospecting operations were naturally suspended during the war period; but afterwards extensive geophysical surveys were undertaken by leading oil companies working in collaboration on both the African and Arabian sides of the Gulf of Suez. This resulted in the discovery of the Sudr field in Sinai in 1946, where oil was struck in beds of

Miocene and Eocene age at 2,700 ft. A second Sinai field, Asl, only 40 miles from Suez, was opened in 1948, and a third strike was made at Ras Matarma, situated between the Sudr and Asl fields. Complicated tectonics are reported from these fields, but large initial flows have been reported. In 1948 the Ras Gharib and Hurghaḍa fields gave 9,710,000 barrels, and the Sudr field 3,500,000 barrels.

Australasia.—The striking of some gas at Roma in Queensland and some oil at Grippsland in Victoria led to a considerable amount of injudicious wild-cat drilling and much optimistic talk concerning oil prospects in Australia. Investigations by responsible and qualified oil geologists have not been sufficiently encouraging to induce major interests to embark on a programme of drilling, notwithstanding the promises of Government subsidies and help. The geological conditions do not favour hope, except in New Guinea, where manifestations of oil are numerous and prospects favourable. Work there is seriously impeded by the wild tropical forests and an absence of roads, but serious efforts are in hand by powerful interests to locate oil pools that would repay exploitation.

New Zealand has likewise been examined by geologists skilled in the art of oil finding, but although manifestations of oil are numerous the disturbed nature of the strata discourages high hopes. At Taranaki a small production of oil was obtained.