PETROLEUM

OIL FIELDS OF THE WORLD
PETROLIFEROUS DEPOSITS MARKED RED

Frontispiece Vol. I

Petroleum deposits showo in red

London: Charles Grif8n & Co., Ltd.

PETROLEUM:

A Treatise on

THE GEOGRAPHICAL DISTRIBUTION AND GEOLOGICAL OCCURRENCE OF PETROLEUM AND NATURAL GAS; THE PHYSICAL AND CHEMICAL PROPERTIES, PRODUCTION, AND REFINING OF PETROLEUM AND OZOKERITE; THE CHARACTERS AND USES, TESTING, TRANSPORT, AND STORAGE OF PETROLEUM PRODUCTS; AND THE LEGISLATIVE ENACTMENTS RELATING THERETO; TOGETHER WITH A DESCRIPTION OF THE SHALE-OIL AND ALLIED INDUSTRIES; AND A BIBLIOGRAPHY.

BY

SIR BOVERTON REDWOOD, BART.,
D.Sc., F.R.S.E., Assoc. Inst. C.E., F.I.C., Etc.

WITH A FOREWORD

BY

SIR FREDERICK W. BLACK, K.C.B.

FOURTH EDITION, Reset Throughout

Revised and largely Rewritten by the Author, in association with many Specialists.
(See Preface.)

In Three Volumes, with Plates, Numerous Illustrations in the Text, and many New Maps specially prepared for this Edition.

LONDON:
CHARLES GRIFFIN & COMPANY, LIMITED,
EXETER STREET, STRAND, W.C. 2.
1922.

WHAT THE JOURNALS HAVE SAID:

"It is indisputably the most comprehensive and complete treatise on Petroleum, and this statement is true, no matter on what branch of the industry a test of its merits is made. It is the only book in existence which gives the oilman a clear and reliable outline of the growth and present-day condition of the entire petroleum world."—*Petroleum World.*

"A veritable encyclopædia of the Oil Industry . . . even the comprehensive title fails to do full justice to the author."—*Times Engineering Supplement.*

"Will remain, as it has been in the past, the leading authority in the English language on the Petroleum Industry."—*Oil and Colour Trades Review.*

"A treatise which contains every conceivable item of information with regard to the subject . . . it should be of immense value to everyone to whom the Oil Industry is a matter of moment."—*Syren and Shipping.*

"An invaluable storehouse of information of every description relating to Petroleum."—*Bulletin of the Imperial Institute.*

"So perfect an example of what a book of reference should be."—*Nature.*

"The most important and complete single work on Oil ever published."—*Oil News.*

Printed in Great Britain.

FOREWORD,

WITH HISTORICAL NOTES OF THE LIFE OF THE LATE SIR BOVERTON REDWOOD, BART.,

By Sir Frederick W. Black, K.C.B.,
Past President of the Institution of Petroleum Technologists.

This treatise on petroleum by Sir Boverton Redwood will always remain a monument to his very extensive expert knowledge of this wide-reaching subject. It is the recognised standard all the world over, and has become a classic in the libraries of all technical men in the petroleum industry. Each new edition as it appeared was eagerly sought for as the last authoritative word on the subject and absolutely needful to those who felt obliged to keep their knowledge up to date and have at hand the best and most reliable works of reference.

Sir Boverton Redwood was in touch with every source of information on petroleum, and collected, weighed, and sifted his gathered knowledge with diligent care, so that it is not surprising to find that at the call of his publishers he was ready with thoroughly revised "copy" for this present edition, and it was only a month before his death that he discussed with them in detail every section of the work as well as the revision of the maps.

That so valuable a life should have been so suddenly removed is sincerely lamented, and it is with feelings of deep regret, not unmixed with pride, that the present writer finds himself called upon to pen this brief tribute of admiration for his work and of high esteem for one so justly held in profound regard by all. It would savour of presumption on the part of a disciple to attempt to commend this treatise to those who for so long a time have acknowledged its immense value.

Biographical notices of the late Sir Boverton Redwood appeared in many publications shortly after his death, and notably in the *Journal of the Institution of Petroleum Technologists*, of which Institution he was the principal founder and the first and greatly honoured president.

Let this note, then, be biographical, and an expression also of the satisfaction of all his many friends that after his great pioneer work he lived into the real "oil age," when his own country had not only become a great consumer of all kinds of petroleum products and deeply interested also in petroleum production, but had emerged successfully from a world-war in which, in Lord

Curzon of Kedleston's phrase, Great Britain and her Allies had "floated to victory on a sea of oil."

That one brain could absorb, assimilate, and deal with data so varied and so complex as those which Sir Boverton Redwood handled in his daily work as a consultant, and expressed in the books and pamphlets, nearly fifty in number, which stand in his name, was a subject of wonder even to those who worked with him and knew what his powers of concentration, quick and orderly thinking, and sure methods of work were capable of accomplishing.

Into a life of seventy-three years, extending from the 26th April 1846 to the 4th June 1919, was crowded a large amount of scientific and technical research and consultative work, as well as professional literary work, of high permanent value. The son of a chemist, he took naturally to that branch of science; but from the time he began to specialise in petroleum in 1869 his active mind took for its province nothing less than as wide a knowledge as one capable man could acquire of every branch of the science and technology of petroleum, from the geology of the oil-field, through all the processes of the refinery, down to the safety of handling and transport and the most accurate and scientific testing of the qualities and utilities of the finished products. Elected at the early age of twenty a Fellow of the Chemical Society, he served twice on its council; he also became a vice-president of the Institute of Chemistry, a member of the Inst. of Civil Engineers and of the Inst. of Mining Engineers, and for two years was president of the Junior Inst. of Engineers. He was a vice-president of the Royal Society of Arts, and served his turn of office as Prime Warden of the Goldsmiths' Company.

Of technical institutional work, the great monument to his fame must ever be the Institution of Petroleum Technologists. That institution has now upwards of four hundred members. It has already accomplished much solid educational work, and is now entering upon a sphere of enlarged activity commensurate with the importance which scientific and technical education in petroleum matters has assumed to enable so essential a product to be obtained and utilised in the most efficient and economical manner.

Many committees of investigation knew the value of his services, and he found time to take a part in more than one important industrial exhibition. He travelled much in India, Russia, and America, and knew oil production, oil-fields, oil men, and oil at first hand. Few consultants were better served than he by the band of experts whom he selected for work in many fields. His magnetic personality and great charm of manner, proceeding as it did from a nature of genuine kindliness, and his great loyalty to his friends, naturally secured to him their cordial co-operation in professional work and at the same time their warm personal regard for him as a man and a friend.

Some indication of the estimation of his work outside his own country is afforded by the numerous references to his activities in such a work as Bacon and Hamor's treatise on *American Petroleum Industry*, where he is quoted some twenty times, and special mention is made of his invention and patent, worked out in conjunction with Professor Sir James Dewar, in regard to distillation under pressure—a piece of research work which is to a large extent the foundation of the modern "cracking processes" now so much used for increasing the production of gasoline or motor spirit.

Amongst the many well-known men with whom Sir Boverton Redwood co-operated may be mentioned Sir F. Abel, Professor Vivian Lewes, Lord Moulton, and Admiral Lord Fisher.

With Lord Moulton he had a long and intimate friendship, and all readers of this biographical sketch will be interested to know that but for Lord Moulton's sudden death the Foreword of this work would have come from his pen, and would undoubtedly have been both a tribute of affection and a contribution to science of some fresh suggestive thought. During the war Sir Boverton Redwood, in the Trench Warfare Department and the Petroleum section of the Ministry of Munitions, closely co-operated in more than one direction with Lord Moulton's outstanding work as head of the High Explosives Department of the Ministry. The fact that these two were associated at the very beginning of the war, in the steps taken in conjunction with Sheffield manufacturers to make "tungsten" powder in this country, is evidence of Sir Boverton's versatility.

Sir Boverton Redwood was for a long time the honoured adviser of the Home Office, and had as valued colleagues Captain J. H. Thomson and Major A. McN. Cooper-Key, C.B. He gave much assistance also on many petroleum questions to the India Office and the Colonial Office.

But there was no service that he performed and no honour that came to him that he valued so much as his advisory work for the Admiralty on the use of fuel oil in British warships. He was either a member or one of the most important advisers of every committee that considered the question of oil fuel for the Navy from about 1901 onwards. His crowning work in this connection was his membership in 1913 of the Royal Commission on Oil Fuel under the chairmanship of Admiral Lord Fisher of Kilverstone. To the work of that Commission he gave literally the best that was in him, and that best was something which only those who saw his work could truly appreciate. Redwood had been one of the earliest and most consistent advocates of the advantages of liquid fuel in warships. For other purposes oil might or might not be "*fuel de luxe*," time would show, but for the British Navy it was a necessity. Lord Fisher was no less enthusiastic.

The present writer received a letter from Lord Fisher, dated 16th June 1919, in which he says "oil is going to transform ocean traffic and coal is going to be resolved into its elementary constituents," and goes on to prophesy that submarine vessels will yet appear for commercial purposes "with a new oil engine yet in the womb of time."

It is no small testimony to Sir Boverton Redwood's knowledge and adaptability that he was able to collaborate cordially with a great lawyer and scientist like Lord Moulton and equally with an organising naval genius of so powerful a personality and driving force as Lord Fisher, and to win the high esteem of both.

There was much in common to these three distinguished men, and this in particular, that each had enthusiasm and a belief in the capacity of one individual to get things done worth the doing if only heart and soul and brain were all put into the day's work. It was this wonderful concentration on the part of Sir Boverton Redwood which consummated the thorough revision of this masterly treatise.

PREFACE TO FOURTH EDITION.

THE sudden and altogether unexpected death of Sir Boverton Redwood, just when the revised "copy" for this present edition of his treatise on Petroleum was in process of being handed to the publishers, has necessitated the preparation of this preface by other hands than his own. It was felt by all interested in this work that some personal tribute to the author was needed in addition to that which would naturally find place in a preface, and sincere thanks are tendered to Sir Frederick W. Black, K.C.B., for his graceful Foreword and valuable biographical notes.

It remains to record a few facts concerning this last wonderful effort on the part of Sir Boverton to reduce to an ordered sequence the innumerable notes made with almost meticulous care since the publication of the third edition of this work. The Great War was still raging when a friendly reminder from his publishers warned him that the edition was being rapidly exhausted. On 16th December 1916, in a personal letter to Mr. Francis J. Blight, the head of Messrs. Griffin's, he wrote :—

> "I suppose I ought to be elated by the intimation conveyed by your letter of the 13th instant, but in truth I find that with advancing years and an increasing sense of responsibility there is more cloud than silver-lining about most occurrences.
>
> "However, I can with a whole heart congratulate you, for it is very largely due to your enterprising and enlightened action that what my irreverent friends in the oil-fields call their "Bible" has been a success.
>
> "I must give careful consideration to the situation as presented in your letter, and will let you know my views. At present I can only say that I do not see how I could possibly devote the requisite personal attention to a comprehensive revision of the work during the continuance of the War, as my official duties in connection with the Ministry of Munitions and other Government Departments absorb my whole time and energies."

Several conferences between author and publisher followed, and at first it was thought desirable to reprint as soon as it became necessary and to add a Supplement, but as time went on it was found possible with the co-operation of many friends and colleagues to undertake the thorough revision of the work throughout. Steady progress was made, until at the date of the signing of the Armistice, 11th November 1918, the revision was so far advanced that a few months later Sir Boverton was able to hand personally to the publishers the revised maps and a very considerable portion of " copy " ready for the printer. The remainder was also revised but needed his final touches, and to this he was giving constant attention; indeed it is pathetic to record that only a few days before his death " The Shale-Oil " section, one of the most complicated, was initialled as ready for press.

With tragic suddenness Sir Boverton died on 4th June 1919, and some time elapsed before it was possible to take in hand and finish his almost completed task. A loyal band of friends, whose delight it was to co-operate with Sir Boverton in his literary work, gladly gave every assistance in finishing this fourth edition of his monumental treatise.

We are well assured that Sir Boverton would have wished to express his heartfelt thanks to all who have assisted, and that their names should be mentioned in relation to the valuable services they have so kindly rendered.

Sections I. and II. (" Historical " and " Geological and Geographical Distribution ") were revised and enlarged by the author with the help of Mr. R. J. Ward and Mr. George Tweedy (Russia); Mr. Lewis Hamilton (Rumania); Mr. A. Beeby Thompson (Egypt); and Mrs. A. Lloyd Eastlake. Thanks are due to Mr. A. Beeby Thompson for a new and valuable map of Egypt, and to Dr. W. F. Hume, Director of Geological Survey, Egypt, who furnished an excellent report. Thanks are also due to Lord Bearsted of Maidstone and the Asiatic Petroleum Company for information regarding the production of petroleum in Egypt, Kutei, Sarawak, and Venezuela. Through the courtesy of Sir Charles Greenway, Bart., and Mr. Duncan Garrow, the author was able largely to add to what had previously been written in connection with the development of Persia and Mesopotamia. Mr. S. Maclean Jack kindly gave useful information regarding Assam, and Mr. R. I. Watson went through the papers relating to Burma. Very full details relating to the petroleum and natural-gas industry of New Brunswick were supplied by Dr. J. A. L. Henderson and his brother, Dr. William Hope Henderson, and the latter kindly provided an excellent new map of California. The section on Mexico was enlarged through the courtesy of Lord Cowdray. Mr. E. H. Cunningham-Craig, Mr. A. Beeby Thompson, and Mr. A. W. Rogers supplied information in connection with Trinidad, and the Lobitos Oil-fields, Limited, in connection with Peru.

Through the courtesy of Mr. George Otis T. Smith, Director of the United States Geological Survey, and with special attention from Mr. O. B. Hopkins and other oil and gas geologists of the Survey, that part of Section II. dealing with the geology of the United States has been largely re-written and brought up to date. To Mr. George Otis T. Smith the author is also indebted for a

most useful map (Plate 12) showing the oil and gas fields of the United States, and for his interesting and valuable report on "The Unmined Supply of Petroleum in the United States," which has been added to Section I.

Professor J. S. S. Brame and Dr. A. E. Dunstan have practically re-written and largely added to Sections III. and IV. ("Physical and Chemical Properties" and "Origin").

Mr. Ashley Carter, in consultation with Mr. William Sutton, was chiefly responsible for the revision of Section V. ("Production"), and Mr. A. Beeby Thompson kindly went through this section and supplied additional information.

A great deal of Section VI. ("Refining") has been re-written and added to by Mr. Andrew Campbell, with the help of Dr. A. E. Dunstan and Mr. E. Lawson Lomax.

Section VII. ("Shale-Oil") was revised by the author with, once again, the help of Mr. John Wishart, together with Mr. Thompson of the Oakbank Oil Company, to whom special thanks are due for the new plates of the Oakbank Retort and the Thompson Cooler. Mr. William A. Hall and Mr. E. Lawson Lomax also supplied information in connection with new developments on the Continent.

Section VIII. ("Transport, Storage, and Distribution") has been revised by Mr. Herbert Barringer, in conjunction with Mr. William Sutton, and Appendix B of the last edition now forms part of this section. The author received very useful information in connection with the United States Pipe-Lines from the Interstate Commerce Commission, Washington.

Section IX. ("Testing") has been corrected and added to by Mr. A. G. V. Berry and Mr. Arthur W. Cox.

Professor J. S. S. Brame is responsible for the revision of Section X. ("Uses"), including most important additions and a new chapter on the Natural Gas Industry. Mr. Worby-Beaumont is responsible for that part dealing with Petroleum Engines, and Mr. Pollard Digby for a valuable contribution on Transformer Oils.

Major A. Cooper-Key, C.B., has once more kindly revised and brought up to date Section XI. ("Regulations"), whilst Mr. F. E. Powell, of the Anglo-American Oil Company, has dealt with the United States part of this section.

Thanks are due to Mr. George Sell for valuable services rendered in connection with the compilation of the Statistics given in Appendix A, and for work carried out with regard to the revision of Appendix B ("Import Duties").

The Bibliography has been revised by Mr. W. H. Dalton, and but for the high cost of type-setting would have been greatly extended; whilst the laborious task of preparing the complete Index has been accomplished by Sir D. Wilson-Barker, R.D., R.N.R.

The proof correcting has been left practically in the hands of those responsible for the revision and additions, with the help of Mrs. A. Lloyd Eastlake, who also for the third time assisted in preparing the "copy" for the printer.

It was due to the enterprise of Messrs. Charles Griffin & Company that this work was first written, and to each succeeding edition they have given ungrudging support. Sir Boverton's appreciation of their encouragement and of the generous manner in which they have entered into his proposals was unbounded, and he admired their courage in facing the resetting of this great work and preparing new maps during the unprecedented times following the War. The warmest thanks of the petroleum industry are due to them.

The undersigned have been intimately associated with the author in business life for more years than they care to record, and it has been their sad privilege to take some oversight of the work whilst at press and upon them has devolved the duty of writing this preface.

Sir Boverton Redwood was the pioneer of Petroleum Technology and had always the greatest faith that the use of petroleum would extend immensely, a faith which he lived to see realised to a greater degree than even in his most optimistic moods he ever anticipated. Undoubtedly this treatise contributed more than any other influence to this unbounded extension.

ARTHUR W. EASTLAKE.
ROBERT REDWOOD.

LONDON, *September* 1921.

CONTENTS.

VOL. I.

Section I.—Historical Account of the Petroleum Industry.

	PAGE
Earliest references,	1
Russia,	3
Carpathian fields,	19
Rumania,	25
Italy,	31
Zante,	36
Germany,	37
Great Britain,	38
France and Switzerland,	43
Spain,	47
Algeria,	48
Egypt,	49
Persia,	51
Turkey,	54
India :	
Baluchistan,	55
Punjab,	58
Assam,	59
Burma,	61
The Eastern Archipelago :	
Java,	68
Sumatra,	68
Borneo,	70
Timor,	71
Philippine Islands,	72
China,	72
Japan,	74
Formosa,	76
Canada :	
Ontario,	79
Alberta and Mackenzie,	79
Calgary,	80
British Columbia,	80
Nova Scotia,	81
New Brunswick,	81
Newfoundland,	84
United States, early history,	85
United States (unmined petroleum),	92
Pennsylvania and New York,	99
West Virginia,	103
Kentucky and Tennessee,	104
Ohio and Indiana,	105
Illinois,	110
Kansas and Oklahoma,	111
Texas and Louisiana,	113
Colorado,	115
California,	116
Wyoming,	126
Minor fields,	127
Mexico,	132
West Indies :	
Cuba,	140
Hayti,	141
Barbados,	142
Trinidad,	142
South America :	
Venezuela,	146
Brazil,	147
Colombia,	147
Ecuador,	148
Argentina,	149
Peru,	151
Central America,	154
New Zealand,	155
Australia,	157
Queensland,	158
Papua,	158
Africa :	
Gold Coast Colony,	159
Nigeria,	160
Cape Colony,	160
Somaliland,	160
Madagascar,	160

Section II.—The Geological and Geographical Distribution of Petroleum and Natural Gas.

Range of bitumen,	160B
Natural gas,	160B
Oil and gas reservoir-rocks,	161
Conditions affecting accumulation,	164
Oil lines,	166
Oil in fissures and pockets,	167
Association of salt with petroleum,	168
Pressure in wells,	169
Association of mud-volcanos with petroleum,	172
Duration of oil and gas supplies,	172
Affinity of clay for petroleum,	173
Ozokerite,	174
Asphalt rock,	174
British Islands,	175
Portugal,	177

	PAGE
Spain,	177
France,	178
Alsace,	180
Belgium,	182
Holland,	182
Switzerland,	182
Italy,	183
Algeria,	184
Tunis,	185
Egypt,	185
Arabia,	186
Turkish Empire, Asiatic,	187
Turkish Empire, European,	188
Greece,	188
Montenegro,	189
Bosnia and Herzegovina,	189
Serbia,	189
Rumania,	189
Carpathian fields,	190
Dalmatia,	190
Istria, Carniola, Styria, Croatia, Slavonia,	191
Hungary,	191
The Banat, Transylvania, Bukowina,	192
Galicia,	192
Silesia and Moravia,	194
Bohemia,	194
Lower and Upper Austria, Tyrol,	195
German Empire :	
Bavaria,	195
Württemberg, Baden,	196
Rhenish Bavaria,	196
Rhenish Prussia, Hesse,' Hesse-Nassau,	196
Westphalia, Hanover and Brunswick,	197
Schleswig-Holstein, Saxony and Thuringia,	198
North-eastern Provinces,	198
Denmark,	199
Norway,	199
Sweden,	199
Spitzbergen,	200
Russian Empire :	
Finland, Northern and Central Provinces, Ural Mountains,	200
Southern Provinces, Crimea, Taman,	201
Kuban and Terek Territories,	202
Daghestan, Kutais,	203
Tiflis, Elizabetpol, Erivan, Baku,	204
Uralsk, Siberia, Turkestan,	207
Transcaspia,	208
Persia,	208
India :	
Baluchistan, Afghanistan, Punjab,	212
Assam, Burma,	213
Siam, Malay Peninsula,	214
Annam, Thibet, China, Japan,	214
The Eastern Archipelago :	
Philippine Islands, Borneo,	215
Sumatra, Java,	215
Samaauw, Timor, Celebes,	216
Moluccas, New Guinea, and Ladrone Islands,	217
British America :	
Yukon, British Columbia, Alberta,	217
Athabasca, Mackenzie, Manitoba, Ontario,	218
Quebec, New Brunswick and Nova Scotia,	220
Newfoundland,	221
Greenland,	221
United States,	221
Connecticut and New Jersey, New York,	223
Pennsylvania and West Virginia,	223
Maryland, Virginia and North Carolina, Georgia,	226
Florida, Alabama, Tennessee,	227
Kentucky,	228
Ohio,	229
Indiana,	231
Michigan, Illinois,	232
Wisconsin, Minnesota, Iowa, Missouri,	233
Arkansas, Louisiana,	234
Texas, Oklahoma,	235
Kansas,	237
Nebraska, South Dakota, North Dakota,	238
Montana, Wyoming,	239
Colorado, New Mexico,	240
Arizona, Utah,	241
Nevada, California,	242
Idaho, Washington,	243
Oregon, Alaska,	244
Mexico,	245
Honduras,	246
West Indies :	
Cuba,	246
Hayti, Porto Rico, Barbados, Grenada, Trinidad,	247
South America :	
Guiana, Venezuela, Colombia,	249
Ecuador, Peru, Bolivia, Chile,	250
Argentina, Brazil,	251
West, South, and East Africa, Somaliland, Madagascar,	252
Australia,	253
New South Wales,	253
New Guinea, Papua,	254
New Caledonia, New Zealand,	254

Section III.—The Physical and Chemical Properties of Petroleum and Natural Gas.

Early views as to the nature of petroleum,	255
Physical properties of petroleum :	
Colour, odour, and specific gravity,	257
Coefficient of expansion,	260
Calorific value,	273
Specific heats,	277
Fractional distillation,	281

	PAGE
Physical properties of petroleum :	
Various crude oils,	291
Capillary power,	293
Viscosity,	295
Refractive index,	297
Chemical composition,	299
Sulphur derivatives,	301
Hydrocarbons,	303
Ethylenic hydrocarbons,	305
Cycloparaffinoid hydrocarbons,	307
Aromatic hydrocarbons,	309
Paraffin hydrocarbons,	311
Hydrocarbons,	315
Oxygen derivatives,	323
Synthetic acids,	325
Solid hydrocarbons,	327
Asphaltic compounds,	329
Asphalt,	331
Methods of examination of petroleum,	339
Action of reagents on petroleum,	341
Natural gas,	342
Composition of natural gas,	343–346

Section IV.—The Origin of Petroleum and Natural Gas.

Inorganic origin,	348
Organic origin,	351

VOL. II.

Section V.—The Production of Petroleum, Natural Gas, and Ozokerite.

Early methods :	
Japan and China,	365
Burma,	369
Italy,	371
The United States :	
Introduction,	371
Typical oil and gas lease,	373
Drilling plant,	375
Derrick,	376
Boilers,	376
Engines,	377
Drilling tools,	377
Drilling bits,	378
Specification,	379
Sand pumps,	381
Fishing tools,	381
Drilling the well,	384
Well record,	391
Oil saver,	392
Control casing head,	392
Evolution of present system of drilling in Pennsylvania,	393
Depth of wells,	394
Drilling contract,	395
Rate of progress in boring	397
Rotary system of drilling,	397
Log of Lucas well,	403
Combination system,	404
Circulating system,	404
Portable well-drilling machines,	404
Drilling in California,	405
Cementing wells,	406
Electrical treatment of emulsified crude petroleum,	413
Elevators,	414
Casing,	415
Danger of fire,	419
Yield of wells—Inducing flow—Pumping,	419
Abandonment of wells,	421
Torpedoing wells,	425
Gas wells, pressure,	428
Gasoline from natural gas,	431
Canada :	
General description,	432
Bounties on crude petroleum,	436
Russia :	
General description,	437
Dimension of wells,	438
Drilling tools,	439
Casing,	442
Pressure in wells—Controlling outflow,	443
Yield of wells,	443
Present practice,	444
Fountains,	445
Bailing wells,	446
Raising oil by compressed air,	446
Galicia :	
Introductory remarks,	448
Hand drilling,	448
Modern methods of drilling,	449
Kind's free-fall system,	453
Fauck system,	455
" Rapid " system,	458
" Express " system,	460
Fauvelle water-flush system,	460
Fauck's water-flush system,	461
Raky system,	461
Davis-Calyx drill,	466
Diamond-boring system,	466
Pumping,	468
Swabbing,	470
The ozokerite industry :	
Separating ozokerite from the matrix,	472
Conditions and cost of working,	472
France,	473
The organisation of petroleum fields,	474
Concluding remarks: comparison of drilling systems,	474

Section VI.—Refining of Petroleum.

	PAGE
General description,	476
Cracking still,	478
Cylindrical stills,	479
Cheese-box still,	480
Waggon still,	481
Russian stills,	482
Russian horizontal cylindrical still,	483
Dephlegmators,	483
Continuous distillation,	484
Continuous still (Tait and Avis),	488
Large cylindrical stills,	490
Continuous distillation (Nobel Bros.),	491
Continuous distillation (crude petroleum),	494
Alexeeff's distillation plant,	495
Ostatki still,	497
Trumble's still,	499
Crude oil topping plant,	501
Naphtha still,	503
Lubricating-oil stills,	507
Condensers,	509
Purification,	512
Desulphurisation,	514
Lubricating oil distillates,	519
Manufacture of lubricating oils,	520
Other refining methods,	525
Use of colloidal earths,	526
Transformer oils,	529
Paraffinum liquidum,	531
Vaseline,	532
Refining in the United States,	538
Delivery of crude oil,	539
Description of a refinery, typical methods of treatment, descriptions of products,	539-542
Separating and refining paraffin,	544
"Sunning" and "reducing" oils	547
Refineries in the United States,	547-554
Refining in Canada,	554
Removing sulphur compounds,	555
Bleaching the oil,	556
Refining in Russia,	556-559
Refining of petroleum and ozokerite,	559
Ozokerite picking and extracting,	560
Chemical treatment,	561
Filter-presses and extractors,	562-564
Manufacture of ceresine,	565
Refining in Rumania,	569
Refining in Alsace,	571
Refining in France,	576
Refining in Spain,	577
Cracking,	577
Mechanism of cracking,	578
Chemical nature of cracked spirit,	578
Various cracking processes,	579-586
Action of aluminium chloride on petroleum,	586
Production of gasoline from natural gas,	587

Section VII.—The Shale-Oil and Allied Industries.

Early history,	589
Particulars of Scottish oil companies,	590
Analyses of crude oils from various shales,	592-595
French shale-oil industry,	595-600
Kimmeridge shale,	600-601
Bovey Tracy lignite,	602
Cannel coals,	603
Peat industry,	603
Shales of New South Wales,	604
New Zealand,	605
New Brunswick,	606
Nova Scotia,	606
Newfoundland,	606
American shales,	607
Spain and Serbia,	607
Sweden, Finland, and Bulgaria,	608
The Scottish shale-oil industry,	608
Geological formation,	609
Mining or winning oil-shale,	610
Distilling shale:	
Early systems,	611
Bathgate retort,	613
Intermittent retort of Young and Brash,	613
Henderson retort (earlier form),	613
Pentland retort,	616
Henderson retort,	617
Type of retort employed in Scottish oil-works,	617-618
Bryson-Jones-Fraser retort,	619
Improved Young and Fife retort,	621
Oakbank retort,	622
Condensation,	622
Scrubbing process,	623
Compression process,	623
Henderson continuous still,	623-624
Shale-oil distillation,	625
Intermittent refining still,	628
Henderson refining still,	629-631
Oil-cooling apparatus	633
Oil refrigerator,	634
Henderson cooler,	635
Thompson's paraffin cooler,	636
Sweating process,	637-641
Lignite or brown-coal tar industry,	641-643
Composition and constituents of brown coal,	645-649
Lignite tar-oil fractions,	650
Acid treatment of lignite tar oils,	651
Methods of paraffin oxidation,	653
Saturated hydrocarbons in lignite tar oil,	654

Section VIII.—The Transport, Storage, and Distribution of Petroleum.

	PAGE
Early methods, Burma and Russia,	655
The United States :	
Early history,	655
Pipe-lines,	656-665
Pumping oil through pipe-lines,	665
Storage-tanks for crude oil,	667
Railway tank-cars,	668
Tank barges,	671
Barrels, manufacture of,	672
Tins and cases, manufacture of,	673
Mexico, transport,	673
Canada, storage tanks,	673
Russia, transport and storage,	675
France, pipe-line,	678
Rumania, and United Kingdom pipe-lines,	679
Tank steamers :	
Early history,	679
Construction,	680
Description of motor oil-carrying vessel *Elbruz*	681
Chinese Newchwang junk for carrying oil in bulk,	682
Variations in deadweight capacity, cubical capacity, etc., due to respective types,	683
Ventilation,	684
Pressure and vacuum relief valve,	685
Description of the *Narragansett*,	686
American tank steamers,	688
Carriage of fuel oil in double bottoms of vessels,	689
Board of Trade Regulations,	689
Regulations for transport through the Suez Canal,	689-693
Construction of steamers for the Suez Canal traffic,	693
Cleaning of bulk-oil steamers,	694
Explosions due to ignition of petroleum vapour,	696
Experiments on the formation of an explosive atmosphere,	702
Conditions regulating the formation and ignition of an explosive atmosphere,	709
Precautions for preventing explosions,	712
Foamite system for fire extinguishing,	713
Oil storage tanks :	
Lightning conductors,	713
Protection of explosives from lightning,	714
Transport, storage, and distribution in the United Kingdom :	
London,	715
Liverpool and Manchester,	716
Barrow and Hull,	716
Bristol and Skewen,	716
European Continent :	
Antwerp and Rotterdam,	716
Hamburg, Bremen, Amsterdam, and Stettin,	716
Storage installations,	718-719
Water finders,	720
Road waggons,	721
Barrel-cleaning, glueing, drying, and filling,	722
Steel barrels,	723
Tanks for domestic storage,	724
Lloyd's 1920-1921 list of vessels carrying petroleum in bulk :	
Steamers,	725-738
Sailing vessels,	739-740

VOL. III.

Section IX.—The Testing of Crude Petroleum, Petroleum and Shale-Oil Products, Ozokerite and Asphalt.

General remarks :	
Crude petroleum, petroleum spirit and shale spirit, kerosene and paraffin oil,	741
Lighthouse oil, mineral colza (or sperm) oil, lubricating oils,	742
Paraffin, vaseline, petroleum residuum, fuel oil, gas oil, crude shale-oil, ozokerite, asphalt,	743
Crude petroleum :	
Qualities required by New York Produce Exchange, etc.,	744
Specific gravity,	745
Fractional-distillation test,	746
Dephlegmators,	747
Engler's distillation test,	748
Regnault's distillation test,	750
Other distillation tests,	750
Calorific value of crude petroleum, petroleum residuum, and oil fuel,	750
Petroleum spirit and shale spirit :	
Fractional-distillation tests,	751–752
Volatility test,	753
"White spirit" or distillate,	755
Kerosene and paraffin oil :	
Qualities required in America, Canada, and Russia,	755–756
Distillation test for burning oil,	757
Burning quality test,	759
Saybolt's testing lamp,	759
Canadian lamp test,	759
Redwood's apparatus for testing wicks and oils,	759–760
Illuminating power,	760
Determination of colour, chromometers,	761–762

PAGE

Kerosene and paraffin oil:
Odour, ... 762
Flashing-point and fire-test:
Tagliabue's open tester, . . 763
Early legislation in the United Kingdom, ... 763
Early legislation in France and the United States, . . 764
Squire's open test, . . . 764
Arnaboldi's tester, . . . 765
Saybolt's electric tester, . . 765
Indiana State tester, . . 766
Minnesota State tester, . . 766
Danish tester, ... 767
Defects in English test of 1868, 767
Keates's close tester, . . 767
English Act of 1871—Select Committee of 1872—Reference to Sir Frederick Abel, . . 767
Abel tester—Construction and use, 769
Abel test apparatus, . . . 770
Directions for applying the Abel test, ... 771–774
Testing petroleum mixtures, . 774
Modified Abel's cup with stirrer, . 775
Effects of variations in barometric pressure, . . . 776
Experiments at different altitudes in Switzerland, . . . 777
Effect of tropical climate, . 777
Abel tester, directions for use in temperate climate, . . 778
Abel tester, employment in India and other countries, . . 779
Testing-schedule of Indian Petroleum Act, . . . 781–785
Directions for use of Abel-Pensky instrument, . . . 785–790
Standardising the Abel-Pensky instrument, ... 791
Braun's modification of the Abel-Pensky tester, . . . 793
The use of a stirrer in flashing-point testers, . . . 793
Letheby's electric tester, . . 794
Pease's electric tester, . . 794
Engler's electric tester, . . 794
Directions for use of electric testers, ... 794
Heumann's modification of Engler's tester, . . . 796
Victor Meyer's tester, . . 796
Haass's modification of the Victor Meyer tester, . . 796
Tagliabue's closed tester, . . 797
Wisconsin tester, . . . 798
Elliott tester, ... 798
Granier's tester, . . . 800
Luchaire tester, . . . 801
Parrish's "naphthometer," . 801
Parrish-Engler "naphthometer," 801
"Phlog-elaio-mètre," . . 802
Foster's automatic tester, . . 802
Bernstein's tester, . . . 803
Ehrenberg's tester, . . . 804
Braun's tester, . . . 804
Beilstein's, Liebermann's, and Stoddard's methods, . . 805
Beilstein's tester, . . . 805
Millspaugh's tester, . . . 805
Mann's tester, . . . 806
Vette's tester, ... 806
Gawalowski's tester, . . . 806
Salleron-Urbain tester, . . 807
Rosenbladt's tester, . . . 808
Test-tube method, . . . 809
Comparison of various testers, . 809
Testing for petroleum vapour (Redwood's apparatus), . 809-813
Philip and Steele's apparatus, . 813
Lubricating oils:
Specific gravity, ... 813
Lovibond's tintometer, . . 813
Flashing-point and fire-test:
Pensky's tester, ... 814
Pensky-Martens tester, . 814–816
Gray's tester, ... 816
Treumann's tester, . . . 817
United States fire-test, . . 818
Volatility test, ... 818
"Carbonisation constant," . . 818
Lubricating value, ... 819
Fluidity or viscosity testers:
Nasmyth's, ... 819
Albrecht's and Phillips's, . . 819
Viscometers:
Pipette (Veitch-Wilson's, M'Ivor's, Sacker's), ... 821
Coleman-Archbutt's, . . . 822
Napier's and Mason's, . . . 822
Redwood's, . . . 823–824
Redwood-Admiralty pattern, . 825
Engler's, ... 826
Lamansky-Nobel, . . . 827
Saybolt's, ... 828
Saybolt's universal, . . 828–829
Comparison of results, . . 831
Absolute viscosity, . . 831–832
Engler-Künkler's, . . . 832
Engler-Künkler-Martens, . . 834
Künkler's for low temperatures, . 834
Künkler's grease-viscometer, . 835
Künkler's viscometer for small samples, ... 836
Comparison of Künkler's and Engler's viscometers, . . 838
Arvine's viscometer, . . . 838
Barbey's ixomètre, . . . 839
Lepenau's "leptometer," . . 839
Gibbs' viscometer, . . . 840
Bubble viscometer, . . . 840
Napier's and Cockrell's paddle viscometers, ... 840
Doolittle's viscometer, . . . 841
Value of viscosity test: friction-testing machines:
Prof. H. Thurston's views, . . 843
Investigations of Prof. Ordway and and Messrs. C. J. H. Woodbury and Beauchamp Tower, . . 845
Studies of Dr. C. B. Dudley and Mr. Waite, ... 846

	PAGE
Value of viscosity test: friction-testing machines:	
MacNaught's tester,	847
Duske's modification,	847
Woodbury's tester,	847
Deprez and Napoli's tester,	848
Bailey's tester,	849
Thurston's tester,	849
French railway tester,	850
Ingram and Stapfer's tester,	851
Boult's tester,	851
Cold test:	853
Tagliabue's cold-test apparatus,	855
Schultze's cold-test apparatus,	855
Philip's demulsification tester,	855–856
Conditions of lubricating oil tests imposed by the German railways,	857–859
Fuel oil:	
General specification,	860
Sampling,	861
Cause for rejection,	861
Gas oil,	861
Paraffin testing:	
Melting-point (English test, American test, capillary tube method, Tagliabue's tester),	862
Estimation of oil—Presses,	863
Hydraulic press,	864
Estimation of water,	864
Estimation of dirt,	864
Scottish methods of testing,	864
Petroleum residuum,	867
Chemical examination,	867
Bromine test,	868
Determining source of oil,	869
Estimation of ash,	870
Alkali test (Russian),	870–871
Sulphur compounds, estimation of,	872–873
Compound oils, estimation of fixed oils,	874–875
Acidity, estimation of,	875
Rosin oil,	876
General tests for mineral lubricating oils,	877
Vaseline and ozokerite,	877
Crude shale oil,	877–879
Solid hydrocarbons in oil,	879
Asphalt and asphalt rock,	880
Dow penetration test,	880
Bitumen of Trinidad and Venezuela,	880
Methods of analysing asphalt,	881

Section X.—The Uses of Petroleum and its Products.

General review of uses of petroleum products (pharmacy, illumination, fuel, power, lubrication, ore-concentration, waterproofing, glazing, laundry-work, perfumery, electric insulation, photometry, dyeing, solid and soluble preparations, westrumite, paint-solvent, dry-cleaning, purification of alcohol),	883
Switch and transformer oils,	887
Mineral-oil lamps:	
Early forms,	889
Hinks's duplex,	890
Rowatt's "Anucapnic," Defrie's (Sepulchre's), "Lampe Belge,"	892
"Mitrailleuse" lamp, "Lampe Veritas," and "Rochester" lamp,	893-894
"Wanzer," Aria's, and "Sunlight" lamps,	895
German and Russian lamps,	896-897
Illuminating power and oil consumption,	897
Comparison of cost of lighting by mineral oils and coal-gas,	898-900
Kerosene-vapour lamps,	900
Kitson incandescent lamp,	900
Globes,	901
Extinguishers,	901
Safety appliances, wicks, incombustible wicks,	903-904
Lamp accidents,	904
Ship's lights,	907
Spray or blast lamps, "Lucigen" and Wells,	907
Mineral-spirit lamps,	909
Lamps for solid paraffin,	910
Heating stoves,	911
Air-gas,	912
Carburetting coal-gas, with gasoline, etc.,	915
Air-gas machines and carburettors:	
General considerations,	915
Müller's "Alpha," Weston's,	915
Maxim's,	916
Maxim and Sedgwick's,	916-917
"Simplex,"	919
"Aerogene,"	919
Legge incandescent table lamp,	920
Oil-gas:	
General description,	921
Pintsch plant,	922
Keith plant,	923
Mansfield plant,	923
Thwaite plant,	924
Tocher's experiments,	925
Carburetted water gas,	927
Lowe process,	928
Thwaite plant,	929
Peebles process,	930
Tocher's experiments with coal-gas and oil-gas,	931-932
Ross and Leather's experiments,	932
Natural gas,	933
Westinghouse regulator,	933
Gasoline from natural gas:	
Casing-head gasoline,	935

	PAGE
Gasoline from natural gas :	
Methods of extraction,	935
Compression systems,	935-937
Absorption systems,	937-938
Lamp-black from natural gas,	939
Petroleum as fuel,	940
Qualities of fuel,	940-941
Advantage of,	943-947
Types of burners :	
Holden's,	949-951
Urquhart's, Rusden-Eeles, Oil City Boiler Works', W. N. Best's,	952-954
Curle's "carbogen,"	955
Kermode's air and steam,	955
Swensson's,	956
Körting's,	957
Kermode, pressure,	957
Thornycroft's,	958
Gordejeff's,	959
Wallsend,	960
Wallsend-Howden system,	960-961
General remarks on the combustion of liquid fuel,	961
Brünler system,	963
Petroleum engines :	
General account,	965
Hock, Brayton, Priestman,	967
Hornsby-Akroyd, Trusty,	971
Tangye,	972
Diesel,	972
Semi-Diesel,	973-974
Petter's,	974-976
Road carriages, Daimler motor for,	977
Aeroplane engines,	977
Launches, "Zephyr" vapour engine for,	977

Section XI.—Statutory, Municipal, and Other Regulations Relating to the Testing, Storage, Transport, and Use of Petroleum and Its Products.

British :	
General remarks (Acts of 1862, 1868, and 1871),	979-984
Abel test (Acts of 1879),	985
Hawking petroleum, etc., Act of 1881	986
Standardising testing apparatus,	987
Keeping petroleum for use in motor-cars,	988
Municipal regulations :	
London County Council, report on use of petroleum in various trades,	991-993
London County Council, abstract of regulations,	994-998
London County Council, licenses,	998-1002
Thames Conservancy (Port of London Authority),	1002
Specification for tank barges,	1005
Thames motor launch byelaws,	1005
Mersey Docks and Harbour Board,	1006
Bristol Docks Committee,	1006
Model Harbour Code, Acts of 1871–1881,	1007
Home Office, suggestions for management of lamps,	1008
Foreign and Colonial :	
Antigua,	1009
Australian Commonwealth,	1010
New South Wales,	1010
Queensland,	1010
South Australia,	1011
Tasmania,	1011
Austria,	1012
Trieste,	1012
Bahamas,	1013
Barbados,	1014
Belgium,	1014
Antwerp,	1014
Bermuda,	1014
British Baluchistan, Burma, Guiana, and Honduras,	1015
Canada,	1016
Cape Colony,	1016
Ceylon,	1016
China,	1017
Cyprus,	1017
Denmark,	1017
Copenhagen,	1018
Dominica,	1018
Falkland Islands,	1018
Fiji,	1018
France,	1019-1022
Gambia,	1023
Germany :	
Berlin,	1023
Bremen,	1025
Bremerhaven,	1027
Hamburg,	1028
Hanover,	1029
Gibraltar,	1029
Gold Coast,	1029
Greece,	1029
Grenada,	1030
Guernsey,	1030
Holland,	1031
Amsterdam,	1031
Rotterdam,	1032
Hong Kong,	1032
India,	1032
Isle of Man,	1033
Italy,	1034
Genoa,	1034
Naples,	1034
Rome,	1035
Jamaica,	1035
Japan,	1035
Tokyo,	1037
Jersey,	1037
Labuan,	1037
Malay States,	1037
Malta,	1038
Mauritius,	1038
Montserrat,	1038
Natal,	1038

	PAGE
Foreign and Colonial:	
Newfoundland,	1039
New Brunswick,	1039
New Zealand,	1040
Nigeria,	1040
North Borneo,	1040
Norway,	1041
Portugal,	1042
Rumania,	1042
Russia,	1042
St. Christopher and Nevis,	1043
St. Lucia,	1044
St. Vincent,	1044
Sierra Leone,	1045
Spain,	1045
Straits Settlements,	1045
Sweden,	1046
Switzerland,	1047
Appenzell,	1047
Canton of Berne,	1048
Geneva,	1049
Lucerne,	1049
Zurich,	1049
Trinidad and Tobago,	1049
Turkey,	1050
United States:	
Alabama, Arizona, Arkansas, California, Colorado,	1050
Connecticut, Delaware, Florida, Georgia, Idaho, and Illinois,	1051
Indiana, Indian Territory, Iowa, Kansas, and Kentucky,	1052
Louisiana, Maine, Maryland, and Massachusetts,	1053
Michigan, Minnesota, Mississippi, Missouri, Montana, and Nebraska,	1054
Nevada, New Hampshire, New Jersey, New Mexico, New York State,	1055
North Carolina, North Dakota, and Ohio,	1056
Oklahoma Territory, Oregon and Pennsylvania,	1057
Rhode Island, South Carolina, South Dakota, and Tennessee,	1059
Texas, Utah, Vermont, Virginia, and Wisconsin,	1060
Wyoming,	1061
Zanzibar,	1061
Table of standard flash-points and methods of testing,	1061-1063
Concluding remarks,	1063

Appendix A.—Statistics.

Introduction,	1065
United States:	
Production of crude petroleum, 1875 to 1918,	1066
Production of crude petroleum, 1919 and 1920,	1067
Position of petroleum-producing States in 1917 and 1918,	1068
Quantities and values of petroleum products exported, 1879 to 1918	1069
Average price per barrel of crude petroleum marketed in 1917 and 1918,	1070
Production of crude petroleum in Pennsylvania and New York, 1905 to 1918,	1071
Pipe-line runs by the principal pipe-line Companies in the Appalachian oil-field, 1905 to 1918,	1072
Amount and value of crude petroleum produced in Ohio, 1889 to 1918,	1073
Amount and value of crude petroleum produced in West Virginia, 1889 to 1918,	1074
Exports of crude petroleum and petroleum products, 1903 to 1918,	1075-1078
Consumption of fuel oil by the railroads, 1907 to 1918,	1079
Natural gas:	
Values, 1905 to 1918,	1099-1100
Record of natural gas wells, 1917 and 1918,	1101
Records, 1897 to 1918, for Pennsylvania, Indiana, West Virginia, Ohio, New York, and Kansas,	1102-1107
Records, 1906 to 1918, for Oklahoma, Kentucky, and Illinois,	1108-1110
Natural-gas gasoline:	
Quantity and value of gasoline marketed, 1911 to 1918,	1113
Production, by principal methods of manufacture, in 1916, 1917, and 1918,	1114-1116
Records, 1911 to 1918, for Oklahoma, West Virginia, Ohio, and Pennsylvania,	1117-1118
Records, 1912 to 1918, for California,	1119
Records, 1914 to 1918, for Illinois,	1119
Records, 1916 to 1918, for Louisiana, Texas, Kentucky, and Kansas,	1120
Russia:	
Production of crude oil in the Baku field, 1905 to 1919,	1079
Production of crude petroleum in Russia, 1905 to 1918,	1079
Condition of wells in the Baku field in 1915 and 1916,	1080
Production by fountains in Grozni, 1899 to 1915,	1081
Production of crude oil in Grozni, 1896 to 1918,	1081

PAGE

Russia :
Particulars of wells in the Grozni field, 1907 to 1916, . . 1081
Austria :
Production of petroleum in Galicia, 1886 to 1918, . . . 1081
Output of various fields in 1917 and 1918, ... 1082
Imports and exports, 1907 to 1913, 1082
Deliveries to refineries, 1907 to 1910, 1083
Bukowina, ... 1083
Eastern Archipelago :
Production of petroleum in Sumatra, Java, and Borneo, 1900 to 1918, 1083
Production of natural gas in Sumatra, Java, and Borneo, 1916 and 1917, . . . 1112
Rumania :
Production of crude oil, 1890 to 1919, ... 1084
Records of the petroleum industry, 1905 to 1916, . . . 1084
Output of the various fields, 1900 to 1918, . . . 1085-1086
Condition of the wells, 1916, . 1086
British India :
Production and value of crude petroleum, 1891 to 1919, . 1087
Mexico :
Production of petroleum, 1901 to 1918, ... 1088
Imports from United States, 1900 to 1918, ... 1088
Japan :
Production of petroleum, 1875 to 1918, ... 1089
Formosa :
Production of petroleum, 1906 to 1918, ... 1089
Peru :
Production of petroleum, 1905 to 1919, ... 1090
Production in the Zorritos field, 1896 to 1918, . . . 1090
Germany :
Production and value of crude oil, 1880 to 1919, . . . 1091

PAGE

Canada :
Production and value of crude petroleum, 1901 to 1920, . 1092
Natural Gas :
Values, 1892 to 1919, . . 1111
Production in Ontario, 1902 to 1918, 1111
Italy :
Production and value of petroleum, 1869 to 1918, . . 1093
Natural gas production, 1903 to 1915, 1112
Hungary :
Production and value of crude petroleum, 1898 to 1913, . 1094
Production of natural gas in 1915, . 1111
United Kingdom :
Production and value of crude petroleum, 1866 to 1920, . 1094
Production and value of natural gas, 1900 to 1919, . . . 1112
Barbados, ... 1094
Trinidad :
Production of petroleum, 1908 to 1918, ... 1095
Persia :
Production of crude petroleum, 1912 to 1920, . . . 1095
Argentina :
Production of petroleum, 1907 to 1918, ... 1095
Egypt :
Production of petroleum, 1911 to 1919, ... 1095
Venezuela :
Production of petroleum, 1917 to 1919, ... 1096
Newfoundland, ... 1096
World's production of petroleum, 1916, 1917, and 1918, . . 1096–1098
Ozokerite (Austria, Russia), . . 1121
Asphalt (Austria, Barbados, Colombia, Cuba, France, German Empire, Hungary, Italy, Japan, Mexico, United States of America, Russia, Spain, Switzerland, Trinidad, Turkey, Venezuela), . . . 1121–1127
Oil-shale (United Kingdom, France, New South Wales, New Zealand, Spain), . . . 1127–1131

Appendix B.—Import Duties Levied on Petroleum.

Abyssinia, ... 1132
Algeria, ... 1132
Antigua, ... 1132
Argentine Republic, . . . 1132
Aruba, ... 1133
Australian Commonwealth, . . 1133
Austria, ... 1133
Bahamas, ... 1133
Barbados, ... 1133
Belgium, ... 1133
Bermuda, ... 1133
Bolivia, ... 1134
Bonaire, ... 1134
Brazil, ... 1134
British Central Africa Protectorate, . 1134
British East African Protectorate, . 1134
British Guiana, ... 1134
British Honduras, ... 1134
British India, ... 1135
British North Borneo, . . . 1135
Cameroons, ... 1135
Canada, ... 1135
Cape Verde Islands, . . . 1136
Ceylon, ... 1136
Chile, ... 1136
China, ... 1136
Colombia, ... 1136
Comoro Islands, ... 1137

	PAGE
Costa Rica,	1137
Cuba	1137
Curacao,	1137
Cyprus,	1137
Denmark,	1137
Dominica,	1138
Dominican Republic,	1138
Dutch East Indies,	1138
Dutch Guiana,	1138
Ecuador,	1138
Egypt,	1138
Erythrea (Massowah),	1138
Ethiopia,	1138
Falkland Islands,	1139
Faroe Islands,	1139
Fiji Islands,	1139
Finland,	1139
France,	1139
French Congo,	1139
French Guiana,	1139
French Indies,	1139
French Oceania,	1140
French Somali Coast,	1140
Gambia,	1140
Germany,	1140
Gibraltar,	1140
Gold Coast Colony,	1140
Greece,	1141
Grenada,	1141
Guadeloupe,	1141
Guatemala,	1141
Guernsey	1141
Haiti,	1141
Honduras, Republic of,	1141
Hong-Kong,	1142
Hungary,	1142
Iceland,	1142
Indo-China,	1142
Italy,	1142
Jamaica,	1142
Japan,	1142
Jersey,	1142
Labuan,	1142
Lagos,	1142
Liberia,	1143
Loanda, Benguela, and Mossamedes,	1143
Macao	1143
Madagascar	1143
Malay Protected States, British,	1143
Malta,	1143
Martinique	1143
Maskat	1143
Mauritius,	1143
Mayotte and Comoros,	1143
Mexico,	1144
Montserrat,	1144
Morocco,	1144
Mozambique,	1144
Nevis Island,	1144
Newfoundland,	1144
New Caledonia,	1145
New Zealand,	1145
Nicaragua,	1145
Niger Territories,	1145
Norfolk Island,	1145
Norway,	1145
Panama,	1145
Papua,	1145
Paraguay,	1145
Persia,	1146
Peru,	1146
Philippine Islands,	1146
Portugal,	1146
Portuguese Congo,	1146
Portuguese Guinea,	1146
Portuguese India,	1146
Reunion Island,	1146
Rumania,	1147
Russia,	1147
Saba,	1147
Salvador,	1147
Sarawak,	1147
Servia, Croatia, and Slavonia (Yugo-Slavia),	1147
Seychelles,	1148
Siam,	1148
Sierra Leone,	1148
Somaliland Protectorate,	1148
Southern Nigeria Protectorate,	1148
South African Customs Union,	1148
Spain,	1148
Straits Settlements,	1149
St. Christopher,	1149
St. Croix,	1149
St. Eustache,	1149
St. Helena,	1149
St. Lucia,	1149
St. Martin,	1149
St. Pierre and Miquelon,	1149
St. Thomas' and Princes' Islands,	1150
St. Vincent,	1150
Surinam,	1150
Sweden,	1150
Switzerland,	1150
Togoland,	1150
The Netherlands,	1150
Trinidad and Tobago,	1150
Tunis,	1151
Turkey,	1151
Turks and Caicos Islands.	1151
Uganda Protectorate,	1151
United States,	1151
Uruguay,	1151
Venezuela,	1151
Virgin Islands,	1151
Zanzibar Protectorate,	1151

Appendix C.—Thames Conservancy.

Byelaws for the regulation of petrol motor launches on the River Thames, . . . 1152–1154

BIBLIOGRAPHY, ... 1155–1317
ADDENDUM, ... 1318
INDEX, ... 1319–1353

LIST OF TABLES.

VOL. I.

TABLE PAGE

1. Rumanian Oil Production, 1900, 27
2. Rumanian Oil Production, 1908–1910, 27
3. Well Section at Khátan, Baluchistan, 57
4. Crude Oils of Bemé, Burma, 64
5. Gas-Well Section, Welland County, Ontario, 83
6. Principal Oil-fields of the United States, 99

7*a*. Specific Gravity of Crude Petroleum from Campina, Rumania, 258

7*b*. Specific Gravity of Crude Petroleum from Bustenari, Rumania, 258

7*c*. Specific Gravity of Crude Petroleum from Hand-dug Shafts at Bustenari, Rumania, 258

8. Physical Properties of Crude Petroleums, 259–267
9. Physical Properties of Commercial Products from Petroleum, 267
10. Coefficients of Expansion of Crude Petroleum, 268
11. Relation of Coefficient of Expansion to Specific Gravity, 269
12. Coefficients of Expansion of Petroleum Fractions, 269
13. Effects of Instrumental Errors in the Determination of the Coefficient of Expansion, 270
14. Calorific Values of Texas Crude Oils, 273

15*a*. Calorific Value of Crude Oils, 274

15*b*. Calorific Value of Heavy Fuel Oils, 274

15*c*. Calorific Value of Diesel Engine Oils, 275

15*d*. Calorific Value of Kerosenes, 275

15*e*. Calorific Value of Petrols, 275

16. Calorific Power of Various Descriptions of Petroleum, etc., 276

17*a*. Specific Heat of Hydrocarbons, 277, 278

17*b*. Specific Heat of Crude Oils, etc., 278

17*c*. Specific Heats between 12° and 25° C., 279

18*a*. Heat of Vaporisation, 280

18*b*. Determinations for Certain Methylene Hydrocarbons, 280

19. Boiling-points of Crude Petroleum, and Amounts of Distillate at Various Temperatures, 281, 282
20. Results of Fractional Distillation of Galician Crude Petroleum, 282–284
21. Commercial Products of Crude Petroleum, 284–286
22. Composition, Physical Properties, etc., of Various Descriptions of Petroleum, *facing* 286
23. Physical Properties, etc., of Petroleum from the Apscheron District, 287–288
24. Physical Properties, etc., of Russian Petroleum, 289, 290
25. Products from the Crude Petroleum of Sumatra and Cebu, 291
26. Physical Properties of Galician Crude Oils, 292
27. Particulars of Lubricating Oils, *facing* 293
28. Particulars of Lubricating Oils made at the Bucharest Refinery, Rumania, 294
29. Viscosity—Seconds for 50 c.c., 295
30. Properties of Burma Lubricating Oils, 296
31. Refractive Indices of Petroleum Distillates, 297
32. Refractive Indices of Petroleum Distillates, 297
33. Composition of American Petroleum, 299

34*a*. Paraffins, C_nH_{2n+2}, 303, 304

34*b*. Melting-points of the Aliphatic Hydrocarbons, 304

35. Ethylenes, C_nH_{2n}, 305
36. Diolefines, C_nH_{2n-2}, 306
37. Acetylenes, C_nH_{2n-2}, 306
38. Polymethylenes, C_nH_{2n} (or $C_nH_{2n-6}.6H$), 307
39. Aromatic Hydrocarbons, 309
40. Paraffins from Pennsylvanian Petroleum, 311
41. Paraffins from Pennsylvanian Petroleum, 312
42. Pennsylvanian Hydrocarbons, 313
43. Ohio (Trenton Limestone) Hydrocarbons, 313
44. Canadian Hydrocarbons, 313
45. Californian Hydrocarbons, 314
46. C_nH_{2n+2} Hydrocarbons, 317–318

TABLE	PAGE
47. Solid Hydrocarbons (Pennsylvanian),	327
48. Hydrocarbons in Commercial Paraffin,	328
49. Specific Gravity of Paraffins from Boghead Coal,	328
50. Relation of Specific Gravity to Melting-point of Paraffins,	328
51. Solubility of Ceresin and Paraffin Wax,	330
52. Composition of Trinidad and Cuba Asphalt,	331
53. Comparison of Trinidad and Cuba Asphalt,	332
54. Comparison of Trinidad with Bermudez Asphalt,	332
55. Composition of Asphalt-Rocks,	334
56. Composition of French and German Asphalt-Rocks,	334
57. Analysis of Grahamite and Allied Materials,	336
58. Comparison of Solubility of Asphalts,	337
59. Comparison of Gilsonite and Grahamite,	337, 338
60. Bromine Absorption of Crude Petroleums,	339
61. Iodine Absorption of Lubricating Oils,	340
62*a*. Composition of Natural Gas used in the United States,	343
62*b*. Composition of Natural Gases of Ontario,	344
63. Composition of Natural Gas, Ohio,	345
64. Composition of Natural Gas Russia and England,	345
65. Composition of Natural Gas, Russia,	345
66. Composition of Natural Gas, Pechelbronn,	346

VOL. II.

67. Wages of Burmese Well-Diggers,	370
68. Daily Yield of Burmese Pit-Wells, 1895,	371
69. Log of Lucas Well, Spindle Top, Texas,	403, 404
70. Drive-Pipe,	415, 416
71. Oil-Well Casing,	416, 417
72. California Casing,	417, 418
73. Inserted Joint-Casing,	418
74. Riveted Pipe,	418
75. Average Daily Initial Production per New Well in Barrels of 42 U.S. Gallons,	420
76. Diameter of Wells in the Baku District, Russia,	438, 439
77. Relative Costs of Different Forms of Power in Baku, Russia,	445
78. Cost of Working one Shaft per Day of Twenty-four Hours in Galicia	473
79. Results Obtained in the Continuous Distillation of Crude Petroleum,	494
80. Fractions of Russian Oil,	520
81. Proportions of Distillates,	520
82. Proportions of Distillates,	520
83. Comparison of Candle-power of Distillates,	526
84. Vaseline Oils, Galicia,	532
85. Vaseline from Galician Oils,	533
86. Composition of Galician Vaselines,	533
87. Melting-points of Vaseline Distillates,	533
88. Paraffins in Vaseline Distillates,	534
89. Viscosity of Vaseline,	536
90. Oxidation of Vaseline,	537
91. Petroleum Products,	541
92. Petroleum Products,	541
93. Petroleum Products, Eastern United States,	546
94. Petroleum Products, Canada,	555
95. Petroleum Products, Baku,	556
96. Products of Baku Oil,	556, 557
97. Yield from Various Crude Oils, Baku,	557
98. Products of Galician Oil,	560
99. Rumanian Products,	569
100. Quantities of Crude Oil Manufactured into Products in Rumania in 1914 and 1915,	570
101. Alsace Products,	571
102 (1). Products from Residuum, Hanover,	571
102 (2). Properties of Products, Hanover,	572
102 (3). Yield of Products, Hanover,	572
102 (4). Properties of Spindle Oil, Hanover,	573
102 (5). Yield of Spindle Oil, Hanover,	573
102 (6). Yield of Lubricating Oil, Hanover,	573
102 (7). Properties of Distillates after Refining, Hanover,	574
102 (8). Yield of Distilled Oil, Hanover,	574
103. Lubricants from Alsace Residuum,	575
104. Action of Aluminium Chloride on Various Oils .	587
105. Particulars of Scottish Oil Companies,	590
106*a*. Analyses of Crude Oils from Various Shales, Scotland	592
106*b*. Losses on Distillation of Torbanehill Mineral Crude Oil,	593
106*c*. Analyses of Crude Oil from Different Seams, Scotland,	594
106*d*. Analyses of Crude Oil from Different Seams, Scotland,	595
107. Oil-Shale Workings, France,	596
108. Shale-Oil Production, France,	597

TABLE PAGE

109. Yield per Hectolitre of Crude Oil, France, ... 598
110. Yield of Dorsetshire Shale, . 601
111. Comparison of Bovey Tracey, Devonshire, Lignite with Peat and Coal, ... 602
112. Analyses of Kerosene Shales of New South Wales, . . 605
113. Composition of New Zealand Shales, ... 605
114. Yield from Scottish Crude Shale-Oil, ... 641
115. Composition of Brown Coals, . 644
116. Ash-Constituents of Various Brown Coals, . . . 645
117. Products of Distillation of Brown Coal, ... 646, 647
118. Yield of Tar, etc., from Brown Coal, ... 647, 648
119. Leaf-Shale Products, . . 648
120. Products of Distillation of Bentheim Jet Tar, . . . 649
121. Lignite-Tar-Oil Fractions, . 650
122. Saturated Hydrocarbons in Lignite-Tar-Oil, . . . 654
123. Pennsylvanian Pipe-Lines, 658, 659
123*a*. Appalachian Pipe-Lines in Indiana, Ohio, Pennsylvania, West Virginia, and Kentucky, connecting with the National Transit Company's Lines, . 661
124. Specifications of Storage Tanks, 669
125. Comparison of Tank Steamers, . 683
126. Experiments with Petroleum Spirit, ... 706, 707
127. Experiments with Crude American Petroleum Air-Gas, . . 707
128. Experiments with Pentane and Gasoline evaporated in Explosion Chamber, . . . 708

VOL. III.

129. Baumé and Specific Gravity Equivalents, . . . 746
130. Fractions of Benzine, . . 754
131. Fractions of Kerosene and Solar Oil (Biel), ... 757
132. Fractions of American and Russian Oils (Biel), . . 758
133. Fractions of American and Russian Kerosene (Redwood), 758
134. Photometric Comparison of Kerosenes, ... 760
135. Relation of Flashing-Point to Barometric Pressure, . . 777
136. Correction of Flashing-Points indicated by the Test, for Variations in Barometric Pressure on either side of Thirty Inches, . . . 780
137. Initial Test-Point for Various Barometric Pressures, . . 788
138. Correction of Apparent Flashing-Points to the Normal Barometric Pressure of 760 Millimetres, ... 789
139. Salleron-Urbain Tester, . . 807
140. Relation of Density to Vapour-Tension, ... 808
141. Flashing-Points in Rosenbladt's Test, ... 808
142. Comparison of Systems for Testing Flashing-Point, . . 809
143. Phillips's Fluidimeter, . . 821
144. Conversion Table for Saybolt Universal and Redwood Viscometers, ... 830
145. Ratio between Efflux Times by Different Viscometers at the same Temperature, . . 831
146. Comparison of Künkler and Engler Viscometers, . . 838
147. Comparison of Redwood Viscometer and Barbey Ixomètre, . 839
148. Bromination of Oils, . . 869
149. Bitumens of Trinidad and Venezuela, ... 880
150. Properties of Transformer Oils, ... 889
151. Comparison of Lamps and Oils, 898
152. Pentane, ... 913
153. Gasoline (Specific Gravity 0·639), 913
154. Petroleum Spirit (Specific Gravity 0·679), . . . 914
155. Petroleum Spirit (Specific Gravity 0·700), . . . 914
156. Petroleum Spirit (Specific Gravity 0·801), . . . 914
157. Products Yielded by Various Oils, ... 925
158. Products Yielded by Various Hydrocarbons, . . . 926
159. Oil-Gas and Coal-Gas in Various Proportions, ... 931
160. Comparison between Laboratory and Works Tests, . . . 932
161. Production of Gasoline from Natural Gas in the United States, ... 935
162. Boiling-Point, Critical Temperature and Pressure of Lower Paraffin Hydrocarbons, . . 936
163. Blended Casing-Head Gasolines, ... 939
164. Monthly Averages of Oil-Burning Locomotives, . . . 945
165. Standard Flash-Points and Methods of Testing, . 1061-1063

LIST OF ILLUSTRATIONS.

VOLS. I. AND II.

Frontispiece, vol. i.—Oil-Fields of the World.

PLATE		TO FACE PAGE
1.	Egypt,	185
2.	Rumania,	189
3.	Carpathian District,	194
4.	North Germany,	195
5.	The Caucasus,	200
6.	Cross-Sections in the Baku District,	200
7.	Persia,	208
8.	Assam,	213
9.	Japan,	214
10.	Eastern Archipelago,	214
11.	Canada,	217
12.	United States (four sheets),	224
13.	California,	242
14.	South Mexico,	245
15.	Trinidad,	247
16.	South America,	250
17.	Derrick or Carpenter's Rig,	376
18.	Drilling Rig,	376

Frontispiece, vol. iii.—Petroleum Vapour Flame-Caps.

PLATE		TO FACE PAGE
19.	Principal Drilling Tools, Pennsylvania (H. M. Chance),	379
20.	Sections of Three Oil-Wells, showing Variations of Style of Drilling,	387
21.	Russian Drilling Tools,	439
22.	Galician Drilling Plant,	450
23.	Tools used for "Rapid" System of Boring,	460
24.	"Rapid" Drilling,	460
25.	Design for Standardising Oil-Field Buildings,	474
26.	Allan's Atmospheric Condenser,	485
27.	Battery of Galician Stills,	560
28.	Henderson's Shale-Retort (New Form),	617
29.	Oakbank Retort,	622
30.	Oakbank Cooler,	635
31.	Motor Tank Vessel,	681

VOL. I.

FIG.		PAGE
1.	Petroleum Zone of Emilia, North Italy,	33
2.	Oil-Fields of Alsace,	44, 45
3.	Yenangyaung Oil-Fields, Burma,	62
4.	Irawadi Oil-Fields, Burma,	66
5.	Arakan Islands, Burma,	66
6.	Chart showing Relations between Production and Consumption of Petroleum in the United States, 1890 to 1918,	97
7.	Oil Regions of Pennsylvania and New York,	100
8.	Schodnica-Boryslaw Section,	194
9.	Generalised Section in Woodsfield District, Ohio,	231
10.	Dilatometer,	272

VOL. II.

FIG.			PAGE
11.	Chinese Drilling Tools,		368
12.	Winged Substitute,		377
13.	Sand-Pumps,		382
14.	Horn Socket,	Fishing Tools.	382
15.	Slip Socket,	Fishing Tools.	382
16.	Pin Socket,	Fishing Tools.	382
17.	Jar Latch or Boot-Jack,	Fishing Tools.	383
18.	Spud,	Fishing Tools.	383
19.	Mandrel Socket,	Fishing Tools.	383
20.	Casing-Spear,	Fishing Tools.	383
21.	Rope-Grab,	Fishing Tools.	383
22.	Rope-Spear,	Fishing Tools.	383
23.	Casing-Cutter,	Fishing Tools.	383
24.	Valve-Rope Knife,	Fishing Tools.	384
25.	Sucker-Rod Spear,	Fishing Tools.	384
26.	Mouse Trap; Hollow Reamer; Grab; Bailer-Grab; Tubing Spear and Socket; Combination Tubing and Sucker Rod Socket; Jar Socket,	Fishing Tools.	385
27.	Grab for Rubber; Hook for Bit; Alligator Grab; Rasp; Casing Perforator; Grab for Valve-Cap; Rope Worm,	Fishing Tools.	386

FIG. PAGE

28. Sinking Drive-Pipe, . . . 388
29. Barrett Patent Oil-Well Jack, . 390
30. Oil Saver, ... 393
31. Control Casing Head, . . 394
32. Derrick for Rotary System, . 398
33. Rotary Table, ... 399
34. Rotary Draw-Works, . . 399
35. Rock Drill-Bit, ... 400
36. Mud Mixer, ... 401
37. Back-Pressure Valve, . . 402
38. Combination Rig, . . . 405
39. All-Steel Californian Rig, . . 406
40. Graham's Perforator, California, 407
40*a*. Cement Plug, ... 413
41. Californian Casing Elevator, . 414
42. Pump-Valves, ... 421
43. Pumping Power, ... 422
44. Iron-Frame Pumping Power, . 423
45. Rivet-Catcher, ... 424
46. Sucker-Rod Elevator, . . 424
47. Pumping a Well, . . . 426
48. Oil-Well Torpedoes, . . . 428
49. Canadian Derrick and Transmission, ... 433
50. Clay Auger-Rod, ... 434
51. Bits, ...
52. Under-Reamers, . .
53. Auger-Stem or Sinker-Bar, .
54. Jars, ...
55. Temper-Screw, . . .
56. Boring-Rods, . . .
57. Rod-Connection, . .
58. Rod-Guide, . . .
59. Substitute-Connection, .
60. Wrenches for Tool-Joints, .
61. Fork to Hold-up Tools, .
62. Screw-Jack, . . .
63. Casing-Clamps, . . .
64, 65. Swedges, . . .
66. Mud-Augers, . . .
67, 68. Sand-Pumps, . .
69. Bailer, ...
(51–69) Russian Drilling Tools: Plate 21. *Facing page* 439.
70. Lentz Riveting Anvil, . . 442
71. Boiler Installation, Baku, . . 444
72. Galician Hand-Drilling System, . 449
73. Under-Reamer, Galicia, . . 451
74. Improved Under-Reamer, Galicia, ... 451
75, 76. Eccentric Bit, . . . 453
77. Galician-Canadian Drilling Plant, 454
78. Kind's Free-Fall Borer, . . 455
79. Fauck's Under-Reamer, . . 456
80. Fauck's Under-Reamer, secured for Introduction to Casing, . 456
81. Fauck's Under-Reamer, Section, . 456
82–84, Fauck's Free-Fall Borer, . 457
85. Fauck's Self-acting Free-Fall Borer, ... 457
86. Fauck's Boring-Rod, . . . 457
87, 88. Transmission, Fauck System, 457
89. "Rapid" Boring System, . . 459
90. Crown for Core-Boring, . . 460
91. Express Drilling Gear, . . 461
92. Express Under-Reamer, . . 461
93. Fauck's Water-Flush, . . 462
94. Raky Derrick, ... 462

FIG. PAGE

95. Raky Rig (Side View), . . 463
96. Raky Rig (End View), . . 463
97, 98. Slipping-out Devices, . . 465
99. Davis-Calyx Drill, . . . 467
100. Davis-Calyx Drill: Section, . 467
101. Davis-Calyx Bit or Cutter, . 468
102. Davis-Calyx Drill, Gripping the Core, ... 468
103. Pumping-Rig, Galicia, . . 469
104. Old System of Ozokerite Mining in Galicia, ... 471
105. Cracking Still, Russia, . . 478
106. American Horizontal Cylindrical Stills, ... 479
107. Cheese-Box Still, . . . 480
108. Waggon Still, ... 481
109, 110. Russian Still, . . . 482
111. Dephlegmator, . . . 483
112. Separator, ... 483
113. Russian Horizontal Cylindrical Still, ... 483
114. Allan's Atmospheric Condenser, *facing* 485
115–117. Continuous Still (Tait and Avis), ... 488
118, 119. Continuous Still (Hill and Thumm), ... 490
120. Continuous Distillation (Nobel Brothers), ... 491
121. Alexéeff's Continuous Still, . 495
122. Ostatki Still and Dephlegmator, 497
123. Trumble's Still (Perspective View), ... 498
124. Trumble's Still (Vertical Section), 499
125. Trumble's Still (Horizontal Section), ... 499
126. Wilton's Oil Topping Plant, . 501
127. Heckmann Still (Horizontal), . 503
128. Heckmann Still (Vertical), . 504
129. Heckmann Still Gauge, . . 505
130–133. Lubricating-Oil Stills, . 506
134. Vacuum Still, ... 507
135. Russian Distilling System, . 508
136. Worm Condenser, . . . 510
137. Parallel-Tube Condenser, . . 511
138–140. Continuous Still (Stombs and Brace), ... 511
141. Agitator, ... 522
142. Gas Trap, ... 539
143. Inspection Box, . . . 540
144. Ramdohr Paraffin Mixer, . 544
145. Ramdohr Paraffin Filter, . . 544
146. Galician Distilling Apparatus, . 561
147. Dehne Ozokerite Filter-Press, . 562
148. Thorn's Extractor, . . . 563
149. Wegelin-Hübner Extractor, . 564
150–153. Merz Universal Extractor, . 566
154. Engler's Fractionating Apparatus, 576
155. Benton Still, ... 580
156. Dewar-Redwood Still, . . 581
157. Burton's Cracking Plant, . 583
157*a*. Rittman's Cracking Process, . 583
158, 159. Hall's Cracking Plant, . 585
160. Continuous Shale-Retorts, . 612
161. Intermittent Shale-Retort (Young and Brash), . . 614

FIG. PAGE
162. Henderson Retort (1873), . 615
163. Pentland Composite Retort (1882), ... 616
164. Pentland Gas-Producer, . . 616
165. Shale Retort, Bryson and others (1894), ... 619
166. Shale Retort, etc., Young and Fyfe (1897), ... 620
167. Young's Improved Retort (1899), 621
168. Henderson Improved Retort-Gear (1901), ... 622
169. Henderson Ammonia Still (1885), 624
170–172. Henderson Continuous Still, (1885), ... 624, 626
173. Intermittent Refining Still, . 628
174–178. Henderson Refining Still (1883), ... 629–631
179. Oil-Cooling Apparatus, . . 633
180. Oil Refrigerator, . . . 634
180*a*. Thompson's Paraffin Cooler, . 636
181, 182. Henderson Cooler (1884), . 638
183. Henderson Cooler Scrapers, . 638
184, 185. Henderson Sweating Process, ... 640, 641
186. Profile of Country along New York Pipe-Line, . . . 657
187. Tank-Cars in Railway Siding, . 670
188. Tank-Car Loading-Rack, . . 671
189. Baku District Pipe-Lines, . 675
190. Nobel System of Storage of Oil in Russia, ... 676
191. Clay-lined Oil Reservoir, . . 677
192. Timber-lined Oil Reservoir, . 677
193. Manhole Fittings, . . . 678
194. Water-Level Gauge,. . . 678
195. Water Extractor, . . . 678
196. Clack-Valve, ... 678
197. Chinese Newchwang Junk for carrying Oil in Bulk, . . 682
198. Ventilation of Screw-Shaft Tunnel of Tank-Steamer, . 684
199. Pressure and Vacuum Relief Valve, ... 685
200. Air-Trunk for Tank-Steamer, . 696
201. Dirt-Tank for Settlement of Water, etc., ... 717
202. Delivery to Storage-Tank, . 718
203. Horley-Sedgley Water-Finder, . 720
204. Redwood-Barringer Registering Water-Finder, . . . 720
205. Glue-lining Barrels, . . . 721
206. Barrel-cleaning Plant, . . 722
207. Barrel-cleaning and Glueing House: Plan, . . . 722
208. Barrel-cleaning and Glueing House: Section, . . . 723
209. Barrel-filling Arrangement, . 723
210. Automatic Filling Cock, . . 724

VOL. III.

211. Tervet's Dephlegmator, . . 747
212. Young's Dephlegmator, . . 747
213, 214. Young's Evaporator Column, 747
215. Engler's Fractionating Flask, . 748
216. Regnault's Fractionating Instrument, ... 750
217. Saybolt Testing Lamp, . . 759
218. Redwood Wick-Tester, . . 760
219. Redwood Camera for Variations of Flame, ... 760
220. Wilson Chromometer, . . 761
221. Stammer Chromometer, . . 762
222. Tagliabue Open-Test Instrument, 763
223. Saybolt Electric Tester, . . 765
224. Keates's Close Test, . . 767
225. Abel Test Apparatus, . . 770
226. Modified Abel's Cup with Stirrer, 775
227, 228. Abel-Pensky Testing Apparatus, ... 786, 787
229. Pease's Electric Tester, . . 795
230, 231. Engler's Electric Tester, . 795
232. Heumann's Modification of the Engler Instrument, . . 796
233, 234. Tagliabue's Closed Tester, . 797
235. Foster Automatic Tester, . . 802
236 Bernstein Tester, . . . 804
237. Braun Tester, . . . 804
238. Beilstein Tester, . . . 804
239. Millspaugh Tester, . . . 805
240. Mann Tester, ... 805
241. Gawalowski Tester, . . . 806
242. Salleron-Urbain Tester, . . 806
243. Redwood Vapour-testing Instrument, ... 811
244. Testing-Lamp and Collecting-Cylinder (Redwood), . . 811
245. Lovibond Tintometer, . . 814
246. Pensky Tester, . . . 815
247. Pensky-Martens Tester, . . 815
248, 249. Gray's Tester, . . . 816
250. Truemann Tester, . . . 817
251. Albrecht Tester, . . . 820
252. Coleman-Archbutt Viscometer, . 822
253, 254. Redwood Viscometer, . 824
255. Redwood Viscometer, Admiralty Pattern, ... 825
256. Engler Viscometer, . . . 827
257. Saybolt Viscometer, . . 829
258. Saybolt Standard Universal Viscosimeter, . . . 829
259–261. Engler-Künkler Viscometer, 833
262. Martens Viscometer, . . 834
263. Künkler Grease-Viscometer, . 835
264. Künkler Small-Sample Viscometer, ... 837
265. Lepenau Leptometer, . . 840
266, 267. Napier Viscometer, . . 841
268. Doolittle Viscometer, . . 841
269. MacNaught Lubricant Tester, . 847
270. Deprez-Napoli Tester, . . 848
271. Bailey Tester, ... 849
272, 273. Thurston Tester, . . 850
274. Thurston Recording Tester, . 851
275, 276. French Lubricant Tester, . 852
277. Ingram-Stapfer Tester, . . 853

FIG.		PAGE
278, 279.	Boult Lubricant Tester,	854
280.	Tagliabue Cold Tester,	855
281.	Philip's Demulsification Tester,	856
282.	Screw Press for Testing Paraffin,	863
283.	Lever Press,	863
284, 285.	M'Cutchon Press,	864
286.	Hydraulic Press,	864
287.	Distillation Flask for Scale Analysis,	865
288–291.	Hinks's Duplex Burner,	890–892
292.	Anucapnic Burner,	893
293.	Lorne Burner,	893
294.	Sepulchre Burner,	893
295.	Mitrailleuse Burner,	893
296.	Lampe Veritas,	894
297.	Rochester Lamp,	895
298.	Aria Lamp,	895
299, 300.	Sunlight Lamp,	895, 896
301.	Victoria Lamp,	902
302.	Victoria Lamp (Extinguisher),	902
303.	Postlethwaite Extinguisher,	903
304, 305.	Lucigen Lamp,	908
306, 307.	Wells Lamp,	909, 910
308.	Section of "Aetna" Blow-Lamp,	911
309.	Section of Roarer Primus Stove,	911
310.	Evaporation of Hydrocarbons,	912
311.	Weston's Carburettor,	916
312.	Maxim's Carburettor,	917
313.	Coal-Gas Carburettor,	918
314.	Simplex Carburettor,	919
315.	Pintsch's Oil-Gas Plant,	922
316.	Keith Oil-Gas Plant,	923
317.	Mansfield Oil-Gas Producer,	923
318.	Thwaite Oil-Gas Plant,	924
319.	Thwaite Gas Plant,	929
320.	Peebles Gas Plant,	930
321.	Westinghouse Gas Regulator,	933
322.	Liquid Fuel Firing,	946
323.	General Vertical View of Holden Burner,	949
324.	Sectional Plan of Holden Burner,	950
325.	Oil-fired Locomotive (Holden System),	950
326.	Holden Burner,	951
327–330.	Urquhart's Ostatki Burner,	952
331.	Rusden-Eeles Burner,	953
332.	Orde Burner,	953
333.	Oil City Boiler Works' Burner,	954
334.	Best Burner,	954
335.	Curle's Burner ("Carbogen"),	955
336.	Kermode Hot-Air Burner,	955
337.	Kermode Steam and Induced Air Burner,	956
338.	Swensson Burner,	957
339.	Körting Burner,	957
340.	Kermode Pressure Jet Burner,	958
341.	Thornycroft Burner,	958
342.	Gordejeff Burner,	959
343.	Wallsend Pressure Atomiser,	959
344.	Wallsend-Howden System for Natural Draught,	960
345.	Wallsend-Howden System for Forced Draught,	960
346.	Oil Pumping, Heating, and Straining Unit installed in the Wallsend-Howden Oil Fuel System,	961
347.	Brünler System,	964
348.	Brayton Oil-Engine,	967
349, 350.	Priestman Oil-Engine,	968, 969
351.	Priestman Spray-Maker,	969
352.	Priestman Vaporiser,	969
353.	Hornsby-Akroyd Oil-Engine,	970
354.	Trusty Oil-Engine,	971
355.	Single-Cylinder Two-Stroke Cycle Heavy-Oil Engine by Messrs. Petter's, Ltd.,	975
356, 357.	Sections of Petter Semi-Diesel Oil-Engine,	976
358.	Brick Intercepting Tank for retaining Petroleum,	996
359.	Diagram of Petroleum Store,	996

A TREATISE ON PETROLEUM.

SECTION I.

HISTORICAL ACCOUNT OF THE PETROLEUM INDUSTRY.

GENERAL.

THE natural product referred to under the names of petroleum, rock oil, earth balsam, earth oil, mineral oil, bitumen, maltha, asphaltum, pissasphaltum, pisselæum, mumia, carabe, brea, oleum Medeæ, St Quirinus's oil, Seneca oil, Rangoon oil, Persian naphtha, Trinidad pitch, Barbados tar, etc., and equivalent terms in other languages, has been known from very remote times.

Of the two general terms used to denote these substances, *bitumen* is older than *petroleum*, the latter not being found in classical Latin. At the present time petroleum, in its widest sense, may be considered to embrace all the hydrocarbons, gaseous, liquid, or solid, occurring in nature, a list of the modern names of which will be found at the beginning of Section II.

Earliest References.—In the Scriptures this product is frequently mentioned, the word translated " salt " having been used indiscriminately for common salt, nitre, and bitumen. The following passages are of especial interest :—In *Genesis* ix, 3, in the description of the building of the tower of Babel, we are told that " slime had they for mortar," a statement which receives an interesting confirmation by the historian Herodotus, who, writing about the year 450 B.C., refers to the use of the bitumen brought down by the Is, a tributary of the Euphrates, as mortar in building the walls of Babylon (*Hist.*, i, 179). Diodorus, Curtius, Josephus, Bochart, and others also speak of this use of bitumen, and Vitruvius tells us that it was employed in admixture with clay. " The Vale of Siddim was full of slime-pits " (*Gen.* xiv, 10) ; here the word which is translated *slime* in our version appears as *bitumen* in the Vulgate. In *Job* xxix, 6, we find, " and the rock poured me out rivers of oil," and in *Deut.* xxxii, 13, " oil out of the flinty rock " ; though both of these expressions may be merely oriental hyperbole for olive oil, produced in the most sterile regions. In *Maccabees II*, i, 18–36, it is stated that the priests hid the fire which they took from the altar in a deep pit without water. After many years, Nehemiah sent some of the posterity of the priests who had hidden it, and " they found no fire but thick water." This was poured by Nehemiah upon the sacrifices and upon the wood and the altar, and when the sun appeared from behind a cloud it burst into flame, and there was " a great fire kindled." " And Nehemiah called this thing Nephthar, which is as much as to say, a cleansing ; but many call it Nephai." In the New Testament the expression (*Matt.* v, 13) referring to salt losing its savour is supposed by some to relate to petroleum, which, on exposure, loses its volatile parts, and leaves asphalt, good only to be " trodden under foot of men." Herodotus (vi, 119) thus describes operations which were carried on at the pits of Kir ab ur Susiana (Kirab, 57 miles N.W. of Shuster) : "Near Ardericca is a well which produces three different substances, for asphalt, salt, and oil are drawn up from it in the following manner :—It is raised by a swipe [balance-beam], to which, instead of a bucket, half a wine-skin is attached. Having dipped down with this, a man raises it and pours the contents into a reservoir ; it is then poured from this into another, and assumes these different forms ; the asphalt and the salt immediately become solid, but the oil they collect, and the Persians call it Rhadinance ; it is black and emits a strong odour." He also describes (iv, 195) the collection, in the island of Zante, of bitumen having the smell of asphalt, but, in other respects, "better than the pitch of Pieria." As the district of Pieria in Macedonia does not furnish mineral bitumen, the alternative reading "pine-pitch," which appears in one Codex, is probably the more correct. For a modern description of the pitch spring in Zante to which he here refers, see *post.*

Vitruvius, Strabo, and others refer to the working of extensive asphalt-deposits, which are not yet exhausted, in the vicinity of Selenitza in Albania. These have been described in some detail by M. Coquand, who has collected many references to them from ancient authors (*Bull. Soc. Géol. France*, 2, xxv. 20). Dioscorides (i, 100) describes a pissasphaltum obtained at Apollonia near Epidamnos, in Albania, which was thrown up by the river, and was found concreted into pitchy masses on the banks.

The last-named, Strabo, Pliny, and other authors also mention the use of "Sicilian oil" from Agrigentum for illuminating purposes. Plutarch, in his Life of Alexander, describes how, in the district of Ecbatana (Kerkuk), Alexander was particularly struck with "a gulf of fire, which streamed continually as from an inexhaustible source. He admired also a flood of naphtha not far from the gulf, which flowed in such abundance that it formed a lake. The naphtha in many respects resembles the bitumen, but it is much more inflammable. Before any fire reaches it, it catches light from a flame at some distance, and often kindles all the intermediate air. The barbarians, to show the king its force and the subtilty of its nature, scattered some drops of it in the street which led to his lodgings, and standing at one end they applied their torches to some of the first drops, for it was night. The flame communicated itself quicker than thought, and the street was instantaneously all on fire. . . . Still there remains a difficulty as to the generation of this naphtha, whether it derives its inflammable quality from [word missing in the original], or rather from the unctuous and sulphureous nature of the soil." He also mentions the discovery of petroleum "having the gloss and fatness of natural oil," by an attendant of Alexander, while digging on the banks of the Oxus.

Among other ancient authors who make interesting references to this product are Ctesias, 450 B.C. ; Aristotle (*De mirabilibus auscultationibus*) ; Pliny (*Hist. Nat.*), and Agricola.

The bitumen of the Dead Sea (anciently known as *Lacus Asphaltites*), and of the East generally, received considerable notice from the early travellers. Diodorus, a celebrated historian of the time of Julius Cæsar, says that the inhabitants of the surrounding parts collect the asphalt and sell it in Egypt for embalming purposes (*Hist.*, ii, 29). Pliny (*Hist. Mundi*, v, 15, 16), Shaw (*Travels*, 1738, p. 374), and Volney (*Travels in Egypt and Syria*, i, 310) also refer to this subject.

In the ancient records of China and Japan numerous references to petroleum are said to occur, natural gas having been employed as fuel, and for illuminating purposes, centuries before the Christian era.

As the earliest references to petroleum are chiefly connected with the western part of Asia and the eastern part of Europe, a commencement will be made with the description of the districts which border on the Caspian Sea.

RUSSIA. (Plate 5.)

Unlike the Governments of the United States and Canada, the Russian authorities have not yet caused a full survey of their oil lands to be made officially, even the Caucasus having been but incompletely explored; and although private enterprise has resulted in the acquisition of much information on the subject, the ample capacity of the Baku fields to provide for all present requirements had, until recently, acted as a discouragement to prospecting work. There exist evidences, however, in the neighbourhood of Baku and elsewhere, as pointed out by Professor Mendeléeff, of many outlying and isolated fields like that of Bibi-Eibat, which can be drawn upon when required. The total petroleum-producing area of the Russian Empire has been officially estimated at 14,000 square miles.

In respect to this estimate, Mr. Marvin (*The Region of the Eternal Fire*, 1888, p. 186) makes the following statement:—"The compiler of Spon's *Encyclopædia of the Industrial Arts*, an authoritative work of reference, speaks of the Russian official estimate of 14,000 square miles composing the area of the petroleum territory of the Russian Empire as 'obviously exaggerated.' I do not see what grounds exist for such a sweeping statement. Petroleum abounds in the Vistula province, in the Governments of Samara and Saratoff on the Volga, in the Petchora region of the distant north, and in the territory of Ferghana, on the confines of Afghanistan. But, excluding all these, and restricting ourselves entirely to the Caucasus and Caspian, we have there oil strata running direct from the Crimea, across the Caucasus and under the Caspian, to the Balkan hills beyond—a distance of 1500 miles—which, with a hypothetical breadth of 10 miles, would alone give more than the area referred to."

Although the oil of Baku has been known and worked from the earliest times, and was of more than local celebrity, there appears to be no direct evidence of its exportation from the Apscheron Peninsula prior to the tenth century.

Marco Polo, writing at the end of the thirteenth century, says of the Baku petroleum:—"On the confines towards Georgine there is a fountain from which oil springs in great abundance, inasmuch as a hundred ship-loads might be taken from it at one time. This oil is not good to use with food, but is good to burn, and is also used to anoint camels that have the mange. People come from vast distances to fetch it, for in all countries round there is no other oil" (see *The Book of Ser Marco Polo the Venetian*, ed. by Col. Yule, London, 1871, i, 4).

In an account of a journey with an embassy from Germany to Persia, published in 1656, Olearius states that he saw over thirty petroleum springs near Scamachia, in Persia. This is the modern Schemakha to the west of Baku, which was then Persian territory.

Dr. Hyde (*De Veteri Persorum, Medorum ac Parthorum religione historia*, London, 1760) has described the ceremonial of the Fire-worshippers of the district, and Kinneir (*Geog. Memoir of the Persian Empire*, London, 1813, p. 359) informs us that Baku was annually visited by thousands of pilgrims as the principal city of the Fire-worshippers, previous to the Saracenic Conquest of A.D. 636, while, according to the U.S. Consular Report for 1880, the Temple of Surakhani, on the western shore of the Caspian, at which the Sacred Fire was formerly maintained, was attended by priests from India as late as that year. The temple now standing, which resembles one in the Punjab, is considered to be of Hindu origin, and to have been erected within the last two centuries. When the author visited it in 1884, the Fire was no longer burning, but the gas was still issuing and could be readily ignited.

Jonas Hanway gives, in 1754, the following interesting account of the petroleum of Baku :—" What the Guebers, or Fire-worshippers, call the Everlasting Fire is a phenomenon of a very extraordinary nature. This object of devotion lies about 10 English miles northeast-by-east from the city of Baku, on a dry rocky land. There are several ancient temples built with stone, supposed to have been all dedicated to fire. Amongst others is a little temple at which the Indians now worship. Here are generally forty or fifty of these poor devotees, who come on a pilgrimage from their own country. A little way from the temple is a low cleft of a rock, in which there is a horizontal gap, 2 feet from the ground, nearly 6 long, and about 3 broad, out of which issues a constant flame, in colour and gentleness not unlike a lamp that burns with spirits, only more pure. When the wind blows, it rises sometimes 8 feet high, but much lower in still weather. They do not perceive that the flame makes any impression on the rock. This also the Indians worship, and say it cannot be resisted, but if extinguished will rise in another place. The earth round the place, for above 2 miles, has this surprising property, that by taking up 2 or 3 inches of the surface and applying a live coal, the part which is so uncovered immediately takes fire, almost before the coal touches the earth ; the flame makes the soil hot, but does not consume it, nor affect what is near it with any degree of heat. Any quantity of this earth carried to another place does not produce this effect. Not long since, eight horses were consumed by this fire, being under the roof where the surface of the ground was turned up, and by some accident took flame. If a cane or tube even of paper be set about 2 inches in the ground, confined and closed with earth below, and the top of it touched with a live coal, and blown upon, immediately a flame issues without hurting either the cane or paper, provided the edges be covered with clay ; and this method they use for light in their houses, which have only the earth for the floor ; three or four of these lighted canes will boil water in a pot, and thus they dress their victuals. The flame may be extinguished in the same manner as that of spirits of wine. The ground is dry and stony, and the more stony any particular part is, the stronger and clearer is the flame ; it smells sulphurous, like naphtha, but not very offensive. Lime is burnt to great perfection by means of this phenomenon, the flame communicating itself to any distance where the earth is uncovered to receive it. The stones must be laid on one another, and in three days the lime is completed. Near this place brimstone is dug, and naphtha springs are found. Baku supplies Ghilan and Mazanderan and other countries contiguous with naphtha " (*Historical Account of the British Trade over the Caspian Sea*, London, 1754, i, 263 and 381).

The natural gas is still used for burning bricks in this neighbourhood.

As regards the petroleum of the island of Wetoy (Sviatoi or Holy Island), lying a little to the north of the extremity of the Apscheron Peninsula, Hanway says :—" The Persians load it in bulk in their wretched vessels, so that sometimes the sea is covered with it for leagues together. When the weather is thick and hazy, the springs boil up the higher, and the naphtha often takes fire on the surface of the earth, and runs in a flame into the sea in great quantities, to a d stance almost incredible. In clear weather the springs do not boil up above 2 or 3 feet ; in boiling over, the oily substance makes so strong a consistency as by degrees to almost close the mouth of the spring ; sometimes it is quite closed, and forms hillocks that look as black as pitch, but the spring which is resisted in one place breaks out in another. Some of the springs which have not been long open form a mouth of 8 or 10 feet diameter. The people carry the naphtha by troughs into pits or reservoirs, drawing it off from one to another, leaving in the first reservoir the water or the heavier part with which it is mixed when it issues from the spring. It is unpleasant to the smell, and used mostly among the poorer sort of the Persians, and other neighbouring people, as we use oil in lamps, or to boil their victuals ; but it communicates a disagreeable taste. They find it burns best with a small admixture of ashes. As they obtain it in great abundance, every family is well supplied. They keep it at a small distance from their houses, in earthen vessels underground, to prevent any accident from fire, to which it is extremely susceptible."

Hanway also describes a "white" variety of naphtha, collected on the peninusla of Apscheron, as "of a much thinner consistency than black naphtha. The Russians drink it both as a cordial and medicine, but it does not intoxicate. If taken internally it is said to be good for the stone, as also for disorders of the breast, and in venereal cases, and sore heads ; to both the last the Persians are very subject. Externally applied, it is of great use in scorbutic pains, gouts, cramps, etc., but it must be put to the part affected only ; it penetrates instantaneously into the blood, and is apt for a short time to produce great pain. It has also the property of spirits of wine to take out greasy spots in silks or woollens, but the remedy is worse than the disease, for it leaves an abominable odour. They say it is carried into India as a great rarity, and, being prepared as a japan, is the most beautiful and lasting of any that has been yet found." Further notices of the Baku district will be found in John Cook's *Voyages and Travels through the Russian Empire, etc.*, ii, 382 ; in Kaempfer's *Amanitates Exoticæ*, 1712, ii, 262–286 ; in Gmelin's *Reisen durch Russland*, 1784, iii, 63–88, and in the French *Histoire des Découvertes Russes*, ii, 215.

Baku was annexed from Persia in 1723 by Peter the Great, who was aware of the value of the produce, and made arrangements for its collection and transportation up the Volga. A few years later it was restored to Persia, and although it was noted for its exports of naphtha and rock-salt at that time, the petroleum-deposits were not systematically worked until its re-annexation by Russia in 1806. A monopoly of the production was then granted to a merchant named Mirzoeff, who held it until 1872, when the monopoly was abolished, and was replaced by a Governmental tax.

The production of petroleum in the Apscheron Peninsula is confined to an area of about 12 square miles, consisting of the oil-fields of Balakhani, Sabuntchi, Romani, Zabrat, Binagadi, Surakhani, Holy Island, and Bibi-Eibat. The **Balakhani-Sabuntchi** territory has an area of about 4 square miles, and it lies on a level plateau at an elevation of 175 feet above sea-level, about 8 miles northeast of the town of Baku.

Oil is found in quantity at widely different depths even in closely adjacent wells ; but very few wells have been sunk to 700 or 800 feet without proving largely productive, and the yield usually increases with the depth. The disturbed nature of the deposits, which is described in the following section, gives rise to a large number of practically independent portions, each of which, as a rule, supplies but one well.

The neighbouring district of **Romani** (in which the deposits lie at a greater depth than those at Balakhani-Sabuntchi) also furnishes prolific wells ; and the **Bibi-Eibat** field, 2 to 3 miles south of Baku, has given some of the highest producing capacity. The oil of Bibi-Eibat is of slightly less density than that of Balakhani-Sabuntchi ; while the light amber-coloured oil found at **Surakhani,** 11 miles northeast of Baku, is of the low specific gravity of 0·780.

Colonel Yule (*The Book of Ser Marco Polo*, i, 4) estimated the yield of the Baku wells in 1819 at about 4000 tons, most of which went to Persia. According to Rees's *Cyclopædia* (1819), the revenue obtained by the Khan of Baku before the annexation of the country by Russia amounted to 40,000 roubles annually.

The following statistics show the position of the Baku petroleum industry when the monopoly was abolished :—Annual production, 24,800 tons ; number of pit wells, 415 ; number of drilled wells, 2 ; price of crude oil, about £3, 10s. per ton ; Government revenue, £17,000 ; number of refineries, 50 ; quantity of oil refined, 6450 tons. The production then rapidly advanced, until in 1877, when the Governmental tax was removed, the output was 242,000 tons. In that year there were 130 drilled wells and 150 refineries, which turned out 74,000 tons of refined oil. In 1880 Stack (*Six Months in Persia*, London, 1882, ii, 209) estimated the production at 160,000 tons. In 1884 there were about 400 drilled wells, of which about 100 were producing. The output during that year amounted to 90,000,000 poods (one pood being equal to about 36 lbs.). According to Vasilieff, the average yield of the active wells at Baku in 1885 was 32 tons per well daily. In 1890 the production reached 239,000,000 poods. In 1898 a great development took place, the production showing an increase of about 15 per cent. over that of the preceding year. The production reached its maximum in 1901, when it had increased to 671,706,147 poods, of which the Balakhani-Sabuntchi field yielded 413,000,000, Bibi-Eibat 133,600,000, Romani 124,000,000 poods. Although this rate of output was not maintained, the production in 1904 was greater than in 1900 or any of the years of the nineteenth century. At the close of 1904 began a series of disastrous riots amongst the workmen in the Apscheron peninsula, and these helped to reduce the quantity of oil raised in 1905 to 414,762,000 poods. Some increase has taken place since that time, but the figures for 1910 are still behind those of 1898.

The production in 1910 was as follows :—

Balakhani-Sabuntchi,	263,292,625 poods.	Bibi-Eibat,	118,832,040 poods.
Romani,	96,068,390 ,,	Other fields,	19,649,157 ,,

Total, 497,842,212 poods.

The earlier wells being all dug, there were at first no flowing wells ; in fact, of the 417 wells existent in 1872, only 2 were drilled. The earlier of the flowing wells were completely unmanageable, and resulted in immense waste and damage to the surrounding property. In the case of one well, 16,000,000 gallons was sold at 7d. to 8d. per ton, while 600,000 gallons from another was sold for £80. In the majority of cases, however, the oil was entirely wasted, the owners being often called upon to pay heavy compensation for damage. After a time it was found possible to cap the wells, and thus preserve their yield for future use.

Mr. Marvin (*The Region of Eternal Fire*, 1888) collected much valuable information regarding the petroleum-fountains of Baku. The first fountain was struck in July 1873, by the Khalify Company, and resulted in a fall in price from 45 to 5 copecks the pood, and in wresting from Mirzoeff his supremacy as a producer. In 1875 a great fountain, which yielded 600,000 gallons every twenty-four hours, was struck on the property of the Company of Petroleum Participators when deepening a well whose output was decreasing.

In the following year another well was completed on the same property at a depth of 280 feet. It flowed for about three months at the rate of 270,000 gallons daily, the whole of the oil being wasted.

Mirzoeff's No. 5 well, in Group IX, commenced to spout in 1877, and, having been capped, gave a continuous supply which amounted, up to the end of 1883, to about 16,000,000 gallons.

In 1881 a well belonging to Mnatsakanoff commenced to spout at a depth of 434 feet, and ejected 3,320,000 gallons of oil in less than seven weeks, after which it was capped. None of this oil was lost. In the same year the No. 9 well of Lianozoff Bros. threw up 7,200,000 gallons in three months, the greater part of this being collected and sold. The No. 2 well of Orbelovi Bros. at Shaitan Bazaar was bored to a depth of 490 feet, and resulted in a yield of 4,000,000 gallons in a week, the greater portion being wasted.

In 1883 several large fountains, including the renowned Droojba, the property of an Armenian Company, were struck. Two of these were on the Lianozoff estate, and were successfully capped. The No. 14 well of Mirzoeff spouted at a rate varying from 20,000 to 400,000 gallons daily. During the summer of 1883 it yielded about 10,000,000 gallons, none of which was lost. Nobel's No. 9 well spouted nearly 30,000,000 gallons in four weeks, while their No. 25 well yielded nearly 2,000,000 gallons daily.

Marvin thus describes the Droojba fountain, which, on the 1st September 1883, commenced flowing at the rate of 1,600,000 to 2,000,000 gallons, valued at over £11,000, daily :—" The fountain was a splendid spectacle—it was the largest ever known in Baku. When the first outburst took place, the oil knocked off the roof and part of the sides of the derrick, but there was a beam left at the top against which the oil burst with a roar in its upward course, and which served in a measure to check its velocity. The derrick itself was 70 feet high, and the oil and the sand, after bursting through the roof and sides, flowed fully three times higher, forming a greyish-black fountain, the column clearly defined on the southern side, but merging in a cloud of spray 30 yards broad on the other. A strong southerly wind enabled us to approach within a few yards of the crater on the former side, and to look down into the sandy basin formed round about the bottom of the derrick, where the oil was bubbling round the stalk of the oil shoot like a geyser. The diameter of the tube up which the oil was rushing was 10 inches. On issuing from this, the fountain formed a clearly defined stem about 18 inches thick and shot up to the top of the derrick, where, in striking against the beam, which was already worn half through by the friction, it got broadened out a little. Thence continuing its course, more than 200 feet high, it curled over and fell in a dense cloud to the ground on the north side, forming a sandbank, over which the olive-coloured oil ran in innumerable channels towards the lakes of petroleum that had been formed on the surrounding estates. Now and again the sand flowing up with the oil would obstruct the pipe, or a stone would clog the course ; then the column would sink for a few seconds lower than 200 feet, to rise directly afterwards with a burst and a roar to 300. . . . Some idea of the mass of matter thrown up from the well could be formed by a glance at the damage done on the south side in twenty-four hours—a vast shoal of sand having been formed which had buried to the roof some magazines and shops, and had blocked to the height of 6 or 7 feet all the neighbouring derricks within a distance of 50 yards. Some of the sand and oil had been carried by the wind nearly 100 yards from the fountain. . . . Standing on the top of the sand shoal we could see where the oil, after flowing through a score of channels from the ooze, formed in the distance on lower ground a whole series of oil lakes, some broad enough and deep enough to float a boat in. Beyond this the oil could be seen flowing away in a broad channel towards the sea."

The well was capped on the 29th of December 1883, after giving an amount of oil variously estimated at from 220,000 to 500,000 tons.

On 13th August 1887 a well on the Balakhani field belonging to the Baku Mining Company commenced to spout at the rate of 7000 to 8000 tons daily. The well flowed unchecked for over six weeks, the yield at the end of that period being about 2000 tons daily. It was finally capped, after about 50,000,000 gallons of oil had been wasted.

The first great well at Bibi-Eibat was struck at a depth of 714 feet on 5th October 1886, by Tagieff, and resulted in a flow which exceeded the maximum daily output of the Droojba well.

The Baku *Isviestie* thus describes this fountain :—" From the town the fountain had the appearance of a colossal pillar of smoke, from the crest of which clouds of oil-sand detached themselves and floated away a great distance without touching the ground. Owing to the prevalence of southerly winds, the oil was blowing in the direction of Bailoff Point, covering hill and dale with sand and oil, and drenching the houses of Bailoff, a mile and a half away. . . . The whole district of Bibi-Eibat was covered with oil, which filled up the cavities, formed a lake, and on the fifth day began flowing into the sea. The outflow during three days was estimated at 5000 or 6000 tons daily. . . . On the eighth day the maximum was reached, the oil then spouting at the rate of 11,000 tons, or 2,750,000 gallons a day. . . . After the tenth day it began to diminish, and by the fifteenth day the engineers had so far got it under control that the outflow was only 250,000 gallons a day. Altogether over 10,000,000 gallons of oil came to the surface, and most of this was lost for want of storage accommodation."

In the same field, on 20th March 1887, Well xv in Group XIX, known as the " Zubaloff," commenced spouting when the drill reached 679 feet, and the oil rose to a height of 350 feet above the casing. It was estimated that in ten days the flow amounted to about 2,640,000 poods, almost all of which was wasted.

In the same year Well xix in the same group proved a fountain at 735 feet, and gave about 2,000,000 poods in six days, after which it was controlled, and subsequently yielded 20,000 to 30,000 poods an hour, reaching a total outflow in 1888 of nearly 9,000,000 poods.

In 1893 another well in this group became a fountain at a depth of 1150 feet and supplied an average of 30,000 poods a day for some time, the yield amounting to 25,000,000 poods before bailing became necessary.

In 1897 Well xxxiv, from a depth of 1073 feet, supplied 250,000 poods a day, and Well xxiii spouted forth over 22,000,000 poods in two months.

These, however, have all been eclipsed by Wells xxxi and xxxii, the former of which in 1896, from a depth of 1043 feet, yielded 190,000 poods in three hours ; and the latter, from 1505 feet, sent up about 34,000,000 poods in 1898.

A very productive well was that mentioned by Mr. P. Stevens, H.M. Consul at Baku, in a communication dated 1st March 1893. This well was drilled between a quarter of a mile and half a mile eastward of the existing wells on the Apscheron Peninsula, and yielded at the rate of about a million poods (17,742 tons) daily. Much of this oil, however, ran to waste owing to the impossibility of controlling the flow.

In 1899 a fountain in the Balakhani-Sabuntchi field produced over 17,000,000 poods ; and in the Romani field one well spouted 16,000,000 poods in 1899–1900, from a depth of 1442 feet, and another 15,000,000 poods in 1900, from a depth of 1659 feet. The largest well in 1900 was struck in June, and flowed for two months, averaging over 300,000 poods a day, and another yielded about 33,000,000 poods in forty days.

A fountain started in the Romani field on 17th April 1901, from a depth of 1750 feet, erupted 500,000 to 800,000 poods per day. After several days it caught fire, but fortunately became choked, and the fire was extinguished. The well then started again, and in three days discharged 500,000 poods of oil, after which it stopped.

In June of the same year a very large well was struck, and in seven weeks produced about 17,000,000 poods, its average during July being about 30,000 poods a day. Another well in the same year yielded about 34,000,000 poods in less than six weeks.

In November a very prolific spouter was struck in the Bibi-Eibat field by the Baku Naphtha Company at a depth of 1800 feet. For a few days it gave about 1,500,000 poods a day, and continued flowing till it had produced nearly 17,000,000 poods. Shortly afterwards another large one was struck in the Romani field, which produced over 8,000,000 poods in a month.

In 1903 a well in the Bibi-Eibat field belonging to the Schibaieff Company started spouting at the rate of 1,000,000 poods daily, but after a few days moderated to about 300,000 poods a day. It then stopped for about two months, and subsequently renewed its activity for a short time at the rate of 200,000 poods a day.

In the same field a fountain of Zubaloff's in June 1903 commenced erupting about 400,000 poods a day, and in two months had furnished 16,000,000 poods. Another belonging to the Baku Naphtha Company furnished about the same time 100,000 poods a day to the extent of over 1,000,000 poods ; and one drilled by the Tiflis Company yielded 10,000 poods in ten to fifteen minutes, when it became choked. One of Asadulaieff's yielded 3,000,000 poods in May and June 1903, and one of the Shikhovo Company's 1,500,000 poods. In the Romani field two fountains were struck in January 1903 about 790 feet apart, one of which gave 400,000 poods a day, and the other 500,000 poods.

Despite the continued occurrence of flowing wells, the production from these in 1905 showed a total decrease since 1901 of 85 per cent. In 1907, however, the ill effects of the labour disturbances and Galician and Rumanian competition were to some extent counterbalanced by the completion of several spouters of phenomenal size. In 1909 there was a very considerable increase in the production from flowing wells, principally in Bibi-Eibat, but concurrently there was a decreasing activity in drilling.

In 1897 the Russian Government commenced the construction of an 8-in. pipe-line from Baku to Batoum, which was completed in 1905, with a transport capacity of a million tons of refined oil a year.

The following notes, dated 6th January 1919, on the oil-fields of the Baku region, by Mr. R. J. Ward, late engineer of the European Oilfields Corporation, Limited, are of interest as indicating the present position of the industry in that district :—

Balakhani-Sabuntchi.—The higher selling price of crude oil has enabled producers to repair old wells and to bring back into exploitation many wells that were not profitable.

The introduction of the internal-combustion engine and the electric motor has been the means of effecting great economies in fuel used in production ; furthermore, arrangements have been made in many cases for working a number of wells from one motor. Bailing still remains the chief method by which the liquid is raised, but some of the English Companies have introduced deep-well pumping with gratifying results.

Although the Russian freefall system, which may be regarded as the Canadian system modified to suit local conditions, is still in general use, yet the American method of rotary drilling with a mud flush has been successfully introduced, and will probably be more largely employed. In June 1917 this method was used in deepening a well in a section of the Balakhani district known as Fifth Group, and a flowing well was obtained at a depth of between 2100 and 2200 feet. The well shortly after sanded up, and on account of the disorder prevailing locally amongst the workpeople, little further work has been done on it. This well discloses the existence of a new source not hitherto tapped, and gives promise of renewed life to a section of the field that was gradually being abandoned owing to the flooding by water of its upper sources.

Romani.—This field has continued to produce many fountains and much new land has been taken up for drilling operations. The completion of the filling-in of the Romany Lake by the Moscow Company has opened up a very large new area for drilling operations, which were only checked by the prevailing disorder throughout Russia.

Drilling activity in this region was stimulated by the striking of a fountain in 1913, on land at the northwest extremity of the lake. The rotary system is being used in this field.

Zabrat.—Whilst new wells have continually been drilled, there has been less activity in this direction in Zabrat than in some other fields. Much valuable oil-bearing land belonging to the Government is still withheld, and this, on being released, should constitute an important addition to the area now available for drilling operations.

Surakhani.—It is in this field, which lies to the north and east of Sabuntchi, that the greatest activity has prevailed, with the completion of many fountains of large productivity. The rotary system has been largely employed here in the hands of American drillers, and the success met with has been the means of breaking down much of the local prejudice against this method of drilling. In many instances the air lift has been used, not so much for raising oil as with the object of keeping the liquid in motion and thus causing the wells to flow.

The productive formation lies fairly uniformly at depths ranging from 2100 to 2250 feet. It is interesting to note that several fountains have been obtained on land adjacent to the old "Fire Temple."

Successful operations have also extended eastward of Surakhani towards the sea.

Binagadi, Bog Bala, Mud Mountains.—These areas, which lie to the north of Baku, have been the scenes of great boring activity with successful results, the oil being obtained at depths of from 1400 to 1750 feet. The gradual growth of these fields in an easterly direction should eventually result in the junction of them with the western extremity of the Balakhani field.

Bibi Eibat.—Wells have been carried down to 3000 feet with good results. Great difficulty was experienced in drilling to such a depth owing to the upper sands having been much disturbed by fountains in the previous exploitation of this field. The filling in of Bibi Eibat Bay has reclaimed from the sea much valuable oil-producing territory, which should restore this field to its once great producing position as soon as drilling operations can be restarted.

Hand-dug Wells.—During the past few years great activity has prevailed in the sinking of hand-dug wells, which have reached in some cases a depth of over 700 feet. Land surrounding what is known as "The Eternal Fires," northwest of Baku, was productive of much heavy oil by this means. The oil was raised by hand by means of winches and wooden buckets or bailers. The outcrop on the western side of the Balakhani field was the site of many hand-dug wells, and yields of 50 poods and more were obtained from single wells, making it a very profitable undertaking, as the price of crude oil was high and the cost of digging a well not excessive.

In addition to these developments, there have been successful operations in the fields of Holy Island (Sviatoi) and Surakhani, both of which began to be prominent in 1903. On Holy Island, at the eastern end of the Apscheron Peninsula, a well, which spouted for some hours, until it was plugged, was drilled in September of that year to a depth of 1386 feet; since that time several spouters of heavy oil have been struck by the firm of Nobel Brothers.

At Surakhani gas has long been used locally in limekilns, but a great increase in production in 1903 led to its adoption as fuel on the Balakhani oil-field. In 1906 the attention of the outside world was called to the production in several wells of the so-called "white" oil, with a specific gravity ranging from 0·769 to 0·785. In a deeper well a dark-coloured oil of specific gravity 0·820 was also found at the depth of 1585 feet. A great development took place in 1909, and many new wells were drilled, one commenced at the time striking a flow of light crude oil early in 1910. The total production for 1910 is estimated at 223,706 poods of white oil, and 10,492,474 poods of the heavy variety, in addition to a large volume of gas.

Exploratory borings in the northern part of the province of Baku, at Kiliazi and Khidirzindi, have met with varied results. At Kiliazi, oil of good quality, with specific gravity of 0·850, was found at 853 feet in 1901. The Schemakha field, of such promise in the seventeenth century, has been practically ruined by repeated earthquakes, fissuring the rocks and discharging their stores of petroleum, the inflammation of which added further horrors to the scene of destruction. Recently attempts have been renewed to develop a field in this district.

The oil-fields of **Daghestan** require but a brief mention. Petroleum has been collected in the region in small quantities from very early times for local use, but practical exploitation commenced in 1898, though a few years previously the oil had been analysed and found to be of good quality, and a company had been formed. During the next two years many trial-borings were made, the results of which confirmed the opinions previously formed. In December 1902, about 4 miles from Bereke, 80 miles from Petrovsk, oil was struck at a depth of 1365 feet, and spouted to the top of the derrick. The flow was not continuous, and varied from 5000 to 15,000 poods a day. These promising results were, however, followed by the appearance of hot salt water in 1904, and later developments have so far failed to indicate more extensive stores of petroleum.

To the northwest the petroleum deposits of the **Terek Province** are more important, stretching from west to east in three parallel lines, which are called by M. Konschin the Black Mountain zone, the Sunja zone, and the Terek zone. The petroleum-bearing beds crop out between 30 and 40 versts east of the Vladikavkaz railway, and similar outcrops occur at a distance of 120 versts towards the Caspian.

The **Grozni** oil-field lies in the Sunja belt, in 43° 30′ north latitude, and 44° 45′ east longitude, 90 versts from the town of Vladikavkaz in a north-easterly direction, and 12 versts northwest of the town of Grozni. It is about 300 miles northwest of Baku. In consequence of the proximity of the town of Grozni, and of the land belonging to the Terek Cossacks, the field is known as "the Grozni Military Naphtha Springs Group"; while another petroleum-field situated in the Mamakai valley, 3 versts to the west of the Grozni field, is called "the Mamakai Military Naphtha Springs Group." The principal part of both fields is the property of the Terek Cossack Army, although there are large estates in private hands.

The deposits belong to the Tertiary system. The petroleum, which comes to the surface in small quantities in the Mamakai field, has a specific gravity of 0·950. The Grozni field has been worked by means of dug wells, from which the oil was bailed, since 1823 ; and a small refinery has been in existence for many years ; but it was not until the autumn of 1893 that the first two drilled wells were completed. The first is situated on the grounds rented from the Alkhan-Yurtov Cossack Corporation. It was commenced with a diameter of 14 inches, and at a depth of 105 feet this was reduced to 12 inches. On the 6th October 1893, at a depth of about 434 feet, a fountain was struck, which gave from 50,000 to 80,000 poods daily for the first ten days. The bore was then carried about 60 feet deeper, and another fountain struck, which, in July 1894, yielded nearly 10,000 poods per twenty-four hours, of oil of specific gravity 0·880 to 0·900. The second was drilled in the neighbourhood of the old wells on the grounds of the Terek Cossacks. It was commenced on the 19th October 1893, with a diameter of 16 inches, and work was continued day and night until, at a depth of 198 feet, on the 18th November, the oil spouted to a height of over 200 feet. On the first day the yield from 7 a.m. to 6 p.m. was estimated to have been not less than 800,000 poods, and to store the oil, a dam was constructed which formed a reservoir of 15,000,000 poods capacity. On the second day the flow decreased, but it continued at the rate of nearly 500,000 poods for five or six days. In July 1894 the yield was stated to be 30,000 poods a day. The crude oil is reported to have a specific gravity of 0·873 to 0·875, and to yield 18 per cent. of benzine and about 20 per cent. of kerosene. A sample of crude petroleum from the Grozni district, examined by the author, had a specific gravity of 0·884 at 60° F., and a flashing-point below zero F.

In 1894–95 four wells were put down in the Mamakai field, and each proved a fountain. In April 1895 the property changed hands, and the new owners put down two more wells, Nos. 6 and 7, both of which were likewise fountains. In No. 7 oil was obtained first at a depth of 294 feet, but this was shut off, and second oil was struck at 462 feet, the yield from which was estimated at about 1,000,000 poods a day for a short time.

In October 1895 one of the largest fountains ever struck was reported, the flow from which was stated to be so prolific that in a month it had formed the neighbouring valley into a vast lake, in which steamers could easily float.

In October 1902 another remarkable fountain was struck, which in three hours filled an ambar holding half a million poods ; the flow continuing, the oil formed a stream down the Neftianka, which was filled with oil for several miles, to the river Sunja, despite all efforts to stop it by erecting dams. The daily yield of oil was estimated at the enormous total of upwards of two and a half million poods.

The total production of the field had increased from 27,500,000 poods in 1897 to 34,000,000 poods in 1902, and of this quantity nearly half was due to spouters. In 1905 it was over 41,000,000 poods, but 1906 and 1907 showed a decrease, owing chiefly to the decline in the output of flowing wells. In the two following years a great development took place, at first due to fountains, but later to a large increase in the output from pumping wells. In 1910 a still greater advance was mainly due to the drilling in of several prolific spouters, but there was also an increase in the amount of oil pumped to the surface, whilst the extended use of natural gas as fuel on the field has greatly diminished the quantity of petroleum consumed as fuel in the drilling operations. Marked features in the Grozni field have been the increase in output of paraffin-base oil, and the greatly augmented depth of the borings.

As a petroleum-producing territory, Grozni is more favourably situated than Baku. The distance by rail to Novorossisk on the Black Sea coast is more than 100 versts shorter than that from Baku to Batum, and the gradients are easier. There is an 8-in. pipe-line from Grozni to Petrovsk.

About 25 versts east-northeast of Grozni, on the northern slope of the Terek Range, facing the Terek River, is the **Braguni** field, where are found considerable quantities of petroleum exuding from the soil, and forming deposits of pitch which are worked for asphalt. Boring for oil has taken place, and good results are reported to have been obtained at depths of 250 feet and 1050 feet. Other places in this district where indications of petroleum occur are mentioned in the following section.

The oil-field of **Maikop,** in which a large amount of English capital has been expended in drilling operations, is situated in the Kuban territory, about 300 miles westward of Grozni, and about 50 miles northeast of the port of Tuapse on the Black Sea.

Several companies were formed in 1909 and 1910 to exploit the Maikop oil-fields, and some exploratory work was done, but as the results obtained did not justify the anticipations which had been expressed, some of these undertakings came to an end before 1914. Others became associated with the Anglo-Maikop Corporation, and the combined efforts have resulted in a profitable production, in addition to proving to a large extent the direction in which an extension of the oil-bearing territory may be sought. Several wells drilled gave, and continue to give, a fair production of 5 tons to 50 tons per day of oil with a specific gravity of 0·820 to 0·830. During these operations fountains have been struck on several plots ; the most prolific of these was a well on Plot No. 457, which produced over 100,000 tons in one year.

Light oil was first found on Plot No. 490 in the southern part of the field where the first fountain was struck, and it was found that the petroliferous formation extended to Plots 489 and 488, and onwards to Plots 457 and 435 ; the same character of ground was found in an uncompleted well further north, on Plot No. 407.

The result of those drilling operations was to show that the direction of the extension of the light-oil sand was north to northwest.

A further exploration was carried out 4000 feet west of the line already described, where sand containing light oil was also discovered, and the drilling of many wells was projected, but operations were stopped owing to the war.

Heavy oil was discovered in this district east of the light-oil sand. So far the only plots exploited in this area are 531, 533, and 532, south to north, and further to the east of these plots successful wells have been bored to a distance of about 5000 feet.

The production from these wells has, so far, been from 5 to 15 tons of oil per day. The specific gravity of the oil is 0·870 to 0·900.

The indications to the north as well as the east point to the conclusion that this source may extend considerably in both directions.

In Neftiania and Khadijinskaya little exploration has, so far, been attempted. The wells which have been drilled have given a production of about 5 tons per day. The specific gravity of the oil is from 0·840 to 0·850.

The wells have been drilled, so far, by the Canadian and American types of rig.

Complete electric light installations and water works have been erected.

The aggregate capacity of the steel tankage in the Shirvanskaya and Apscheronskaya districts is about 55,000 tons, and of the open reservoirs or ambars is about 10,000 tons.

An 8-in. pipe-line has been laid to Ekaterinodar, about 70 miles, and a

6-in. line to Tuapse, about 75 miles; pumping stations have been erected at both Shirvanskaya and Khadijinskaya with capacity to pump 3000 tons per day to Ekaterinodar and 1500 tons to Tuapse.

The tankage at the Shirvanskaya and Apscheronskaya stations amounts to about 26,000 tons, at Khadijinskaya to about 34,000 tons, at Ekaterinodar to about 26,000 tons, and at Tuapse to about 12,000 tons.

The advantage of having two lines is that the crude oil producers are enabled to supply the refinery at Ekaterinodar, and the port of Tuapse, with a view to meeting requirements in Russia and in other countries.

Previous to 1913 all materials were shipped through Armavir or the port of Tuapse, and were carted thence to the fields by road, a distance of about 70 miles from each place. In 1913 the Armavir-Tuapse Railway was completed. It passes through the Khadijinskaya district and has a station at that place, which is about nine miles from the Apscheronskaya-Shirvanskaya fields. A well-made sandstone road was completed in 1917 from Khadijinskaya station to the village of Neftianaya, which is about four miles from the fields.

A refinery has been constructed at Ekaterinodar, a most convenient situation for carriage of the products by railway to the interior of Russia, and for transport by the Kuban River, as well as for receiving crude oil from Krimskaya and Grozni.

The developments at Maikop have caused increased attention to be directed to the other petroliferous localities of the **Kuban District,** known and worked long ago by the wandering Tcherkesses of the region. Here the earliest work in modern times was done by Colonel Novosiltzoff, who, having acquired the monopoly of the Cossack lands, commenced in 1864 to sink wells near the Black Sea Coast. In 1873 he had a number of wells drilled in the valley of the Ili, near Ilsky; but failing to make the venture a commercial success, in 1879 he leased 1,500,000 acres of the property to Dr. Tweddle. The property was ultimately acquired by the Standard Russe Company of Marseilles, by whom the work was carried on, but the oil principally obtained is comparatively viscous and of high density. Altogether over 100 wells have been drilled at Ilsky, to depths varying from 1200 feet upwards, and most have yielded petroleum. The greater number have yielded oil of about 0·985 specific gravity, at depths of from 150 to 350 feet, but some light oil has been found at from 650 to 900 feet. About 14,000,000 poods of petroleum was obtained between 1880 and 1894 from an area of about half a square mile.

In the summer of 1893 some borings were made at Glinoj Balka, about 4 miles northeast of Ilsky. From two of the bore-holes, one 110 and the other 170 feet in depth, 3000 poods of oil daily was pumped. The oil had a specific gravity of 0·970.

Important results were obtained at Kudako, near Krimskaya, where Colonel Novosiltzoff commenced drilling in 1866, and at 123 feet struck the first flowing well in the Kuban. After yielding at the rate of 5000 gallons daily for a short time, the bore became choked; but it again flowed at double that rate when the depth was increased to 242 feet, and the outflow became uncontrollable. It is stated by Mr. Peacock, British Consul, to have flowed for eighteen months, and the oil, which was wholly wasted, is said not only to have formed a large lake, but to have reached the Kuban river, 9 or 10 miles away. In 1886 another well became a fountain at 183 feet, spouting to a height of 40 feet, and giving about 25,000 poods of oil a day of a specific gravity of 0·860. The oil from one well of a depth of 600 feet resembled the light-coloured oil of low density already mentioned as being found at Surakhani, while a very heavy oil was obtained from a shallower well 40 feet distant.

It was said that no well at Kudako proved unproductive. The Paul well, sunk in 1872, with a depth of 398 feet, still yielded 150 gallons daily in 1896. Another well, sunk to a depth of 420 feet, yielded from 600 to 700 gallons daily; while a third well, 512 feet deep, yielded 200 gallons daily, of a specific gravity of 0·815. The average yield from the three wells was estimated at 12 barrels each daily. The Kudako petroleum zone covers about 5000 acres, and extends in an almost straight line running N.W. by S.E. It is 8 miles from the railway station at Krimskaya, about 35 miles distant by rail, or 22 miles in a direct line, from the Black Sea port of Novorossisk. A sample of oil from Kudako, examined by the author, had a specific gravity of 0·869 at 60° F., and freely ignited at the ordinary temperature. Mr. Rydèn informed the author that at Kudako small quantities of an exceedingly volatile description of petroleum of pale yellow colour were obtained, especially after the shallow wells had been pumped for some time. Some of this crude petroleum had a density of 0·650, and evaporated instantly on the hand.

Many other wells have been drilled in the vicinity of Kudako, and a flowing well has recently been obtained by an English company operating near Krimskaya. Trial borings have been made in the valleys of Psiph and Nepitel, which are parallel with the Kudako valley and of similar geology, and a superior quality of oil has been obtained. In 1867 wells were bored in the Tchekups valley, above Varenikov, and two flowing wells which yielded light oil were struck.

The Anapa district on the shore of the Black Sea has not yet been exploited to any great extent, though shallow wells have yielded oil on the Suvorovsk and Michaelsfeld fields. Some oil of high quality has also been obtained in borings in the Kapustina Balka and at other points on the Taman Peninsula.

In the **Crimea** the existence of petroleum has been long known. In 1864 Colonel Gowen, an American, put down several borings. In one near Kertch, at 70 feet deep he met with a considerable issue of gas, and some oil, the yield being stated to have amounted to 25 poods a day. In another boring at Tchongelek, 16 miles south of Kertch, on the shore of the Tobetchilk Salt Lake, he met with a fountain of considerable violence, which covered the lake with oil, and did much other damage. In 1883 a French Company was formed to exploit the district. One well gave for a time a yield of about 240 poods daily. This well had a depth of 910 feet, according to Mr. Chambers, or 930 feet, according to Colonel Stewart, and is said to have been the deepest which had been sunk at Tchongelek up to that time. It soon became choked and was abandoned. In 1890 another company put down a boring to the depth of 1200 feet, and were rewarded with a yield of 30,000 poods a day. In 1901 a fountain was struck at a depth of 810 feet which gave promise of considerable supply, but was spoiled by breakage of the casing.

Since 1907 drilling operations have been resumed by Anton Raky and others, but the field is still undeveloped.

The crude oil from this district is of good quality, with a specific gravity of 0·864, giving 36 per cent. of kerosene, and 30 per cent. of heavy oils.

The Guri district in **Kutais,** northward of Batum, exhibits many indications of the presence of oil, and that the existence of surface oil has long been known is demonstrated by the numerous names of streams of which "*Kupra*," the native word for petroleum, forms a part. Moreover, the peasants have been accustomed to collect the oil which oozes out into the ditches, and utilise it for lighting purposes. Trial borings have been carried out, notably near Supsa, Jacobi, and Omparete, but hitherto without much success.

In the Imeretia district, the chief sources are at Tedeleti, 6 miles from

Kvirila station, where for many years the inhabitants have been in the habit of using the oil for cart-grease. The first dug well was begun in 1882, and sunk to a depth of 30 feet, at which oil to the amount of 70 poods a day was obtained. Other wells were subsequently put down, and gave a yield of 50 to 80 poods a day.

In the **Tiflis Province** there were in 1874 fourteen wells which yielded about 124,000 poods of oil.

The Signakh field, eastward of Tiflis, produced 55,296 poods in 1889. In the summer of 1902 exploration took place in the district between the rivers Iora and Alazan, 40 to 50 miles northeast from Tiflis. One boring in Kakheti became a fountain, and another near the village of Gambori, at a depth of 140 feet, struck oil of good quality, with a specific gravity of 0·850. The quantity, however, was not great, and the drilling was continued to 345 feet, when such a strong issue of gas was met with that work was stopped until storage-accommodation could be provided. At Matau-Marelis, about 12 miles southwest from Tionet, oil was reported to have been found in the autumn of 1903. At 370 feet there was a flow of about 30 poods a day of greyish-green oil with a considerable percentage of paraffin, and a specific gravity 0·885 at 9° C.

The Tchatma field to the south of the Kur river is somewhat difficult of access. About twenty-five years ago an Armenian named Paatoff was granted leave to dig asphalt and bore for oil. He put down five-and-twenty shallow wells, from which he annually extracted about 30,000 poods. In 1903 a company was formed for the purpose of further exploitation, but neither has this nor have later ventures in the Tchatma and Eldar fields hitherto been attended with decisive results.

In the province of **Elizabetpol,** in the Geran or Naftalan district, some 35 versts southeast of the capital, oil of exceptionally high quality has for many years been collected and sold for medicinal purposes. It is reported that a well drilled recently in the district began to spout with considerable force, the flow of oil breaking the casing, so that the boring soon became choked.

The **Transcaspian Province** seems to be rich in petroleum, and has recently attracted considerable attention as a source of petroleum. **Tcheleken Island,** off the coast, "consists almost entirely of cliffs saturated with petroleum," and is hence called "Naphtonia." Of this island Captain Woodroffe (1743) says:—"We weighed, and came in close under the east side of Naphtonia, as the Russians call it. The Persians call it Cherriken. The coast is difficult of access, being high. It contains about thirty-six families, who have twenty-eight large boats, with several wells of naphtha. The people exist entirely by piracy. To remedy this evil, Nadir Shah some years ago offered to forgive all that was past, and to receive them into his favour, if they would come and settle about Astrabad Bay, where they might have lands, and sell their naphtha to the inhabitants of that quarter. This they accepted, and carried on a brisk trade for about two years, selling their naphtha to the Persians, Turkomans, etc.; but, getting tired of this way of living, returned to their trade of piracy." The island is now being actively exploited with the drill, and spouting wells have been obtained. Ozokerite is also being obtained here in commercial quantities.

On the mainland, which has long been known to yield petroleum, the oil has been used as fuel on the Transcaspian Railway since 1881. In 1883 Napthnia Gora, or "Naphtha Hill," situated about 100 miles inland of Krasnovodsk, and 16 miles southwest of the Tageer wells, which had been noticed as a promising territory by a party of engineers in 1881, was inspected by M. Konschin, who estimated the petroliferous land around the hill at 20,000 acres, and its producing-power at 1,000,000 tons annually. The value of this petroleum and of the ozokerite, which also exists there in large quantities, has been estimated at £35,000,000 (*Marvin*).

The hill, which is about 3 miles long by about a mile and a half wide, appears to be due to a short anticlinal fold. In consequence of the compression inducing this flexure, petroleum mixed with sand and ozokerite escapes at the surface. Mud-volcanos also exist, and constantly throw out mud, water, petroleum, and ozokerite. It is said that fragments, and even layers 3 inches thick, of ozokerite have been found in the mud and sand-hills surrounding these volcanos. The collection of petroleum on the hillside in olden times is proved by the existence of many abandoned wells on the northwestern slope. Trial-borings for petroleum have also been made by the Government, and these, at a "small depth," are reported to have given a daily output of from 500 to 700 poods.

In the **Uralsk Province** a large oil-field is believed to exist in the Gurieff district on the northeast shore of the Caspian, occupying several thousand square miles on the Emba, Sagis, and Uil rivers. In 1900 the Doppelmeier Company obtained a concession from the Government, and started borings at Karatchungul and Karaton. At the former place sixteen holes were put down, and oil found at 37 feet and 126 feet. Ozokerite is said to have been met with at depths of 109, 136, 148, and 210 feet. At Karaton oil was found at 38 feet and 112 feet. It is described as of dark brownish colour, full of paraffin and having a specific gravity of 0·850.

In the course of an instructive paper on the petroliferous region of the Uralsk Province, read before the Institution of Petroleum Technologists in 1915, the late Mr. F. A. Holiday gives the following information :—

The reported signs of petroleum occur between the fifty-first and the forty-sixth parallels of north latitude, and the forth-ninth and fifty-eighth meridians of east longitude. It will be seen that they are distributed over a very large part of the Uralsk Province, the area being about 60,000 square miles. Dos Sor has been the main centre of production. It was brought into prominence in 1911, when a well which had reached a depth of 732 feet began to spout with great violence. Drilling operations attended with highly promising results have been carried out in many adjacent localities, including Karaton, Karatchungul, and Novo-Bogatinsk. Some exploratory work has also been done at Mokat, Iskene, Bli-ule, Bek-Beke, and elsewhere. There are two six-inch pipe-lines transporting the oil from Dos Sor *via* Iskene, a distance of 45 miles, to Rakusha, the shipping port where the refineries are situated.

Early in the eighties some hand-dug wells were put down by Colonel Herman in the **Ferghana Province,** near Tchimion, to a depth of 70 to 80 feet, and about 100 poods of oil a day obtained from them. He also erected a small refinery, and for some years the town of New Marghilan was lighted with the kerosene produced. In 1898–1900 further exploitation took place, and oil was obtained in small quantities from a depth of 175 feet.

In 1901 trial-borings on a more extended scale were made in this district, which are stated to have resulted in 1903 in the discovery, at a depth of 1015 feet, of rich petroliferous strata, producing an oil of high quality, with a specific gravity similar to that of the oil of Bibi-Eibat. About 400 poods were produced in an hour.

In December 1903 it was announced that borings at Maili-sai had produced a fountain at 550 feet, which spouted to the height of 60 feet, and produced 20,000 poods daily. In many places where petroleum exudes from the soil, it is gradually modified into "kir," which is largely used in the district for paving, etc. In 1907 and 1908 flowing wells were obtained here, one of which is said to have produced 7000 poods daily down to the end of 1910. The production of the province during that year is estimated at over 600,000 poods.

In the provinces of **Archangel** and **Vologda,** the presence of petroleum has been long known. In the time of Peter the Great, operations were carried on at Nabatnov's refinery, mentioned by a traveller as existing on the Uchta in 1805. During the sixties, Sidoroff engaged in some explorations, but died before he had completed them. There remain tubes and pits sunk by him, at which traders fill their barrels, and the peasants on the Ijma collect oil for cart-grease and domestic use. About 12 poods is said to be thus collected annually. The trial-holes were situated on both banks of the river Uchta, separating the provinces of Archangel and Vologda, and about 400 miles east-southeast of Archangel. The district was geologically explored in 1889 by order of the Minister of Crown Domains. A boring of 40 feet 4 inches in depth penetrated a stratum of blue marl, from which petroleum flowed in a continuous stream to a height of 14 inches above the casing of the well. Another boring to a depth of 10 feet, at a point three-quarters of a verst higher up the river, gave a similar result. The oil from the bore-holes was officially analysed, and was stated to yield over 41 per cent. of kerosene. It was pronounced superior to that of the Baku district. In 1896–97 explorations were carried on by von Vangel and A. M. Galin, but without any successful results. The distance from the field to Moscow is 1553 versts, as compared with 3402 versts from Baku to the same centre. Recently further boring has been carried out, but the field is still undeveloped.

The development of the Dos Sor field in the Ural-Caspian region resulted in 1913 in the commencement of the marketing of the crude oil, but this did not suffice to make up for the decline in the output of the older fields.

In 1914 there was an increase of nearly 7 per cent. in the total petroleum production of Russia, as compared with that of 1913. Of the Baku fields the only one which gave a larger output was Balakhani, but in the Grozni district activity and drilling operations and extension of the production area gave a record production, 34 per cent. in excess of that for the previous year. At Maikop there was a slight decrease in output. In the Ural-Caspian region the production of the Dos Sor field was more than doubled. The production of the island of Tcheleken showed a moderate decline, and in the Ferghana Valley the developments were unimportant.

The production of petroleum in Russia in 1915 was very slightly in excess of that in 1914, notwithstanding the difficulty of obtaining drilling plant and the scarcity of labour. The chief event was the completion of a highly-productive flowing well in the Maikop field.

According to such statistics as are available, there was an increase in the total output of Russia for 1916 of about 6 per cent., as compared with the figures for 1915. The enhanced yield of the Baku fields of 8 per cent. was partly due to the results of drilling on land reclaimed from Bibi Gibat Bay, but principally was contributed to by the larger output of the Sarakhani field. There was a gain of 16 per cent. in the Grozni district, arising from the development of a new area thrown open by the Government in 1915. In the old Grozni area there was a decline in production. In the Maikop field the flowing well completed in 1915 ceased flowing in January 1916, and the production of this field for the latter year exhibited a considerable decline.

The relative importance of the various sources of production of petroleum in Russia in 1916 is indicated by the following tabular statement of output for that year :—

	Poods.*
Baku Fields,	464,902,000
Grozni,	102,731,246
Maikop,	2,000,000
Emba (Ural-Caspian),	15,200,000
Sviatoi,	7,000,000
Ferghana,	2,000,000
Tcheleken,	3,000,000
Hand Wells,	9,600,000
	606,433,246

* 61·05 poods=1 metric ton.

The presence of petroleum in the Russian (*i.e.* northern) half of **Sakhalin Island** has been known for over a quarter of a century, and in 1880 a concession was granted to Mr. Ivanoff to explore. Subsequently concessions were granted to other parties, and in 1889 Mr. Batsévitch was sent there to report. Several borings were said to have yielded from 20 to 30 gallons of oil daily at depths of 20 to 30 feet. In 1898 Mr. Kleye visited the Nutovo and Boatasin rivers, and obtained oil in a boring on the latter. In the Nutovo district there are several lakes covered by a more or less constant flow of oil, and a little gas in places. Mr. W. H. Dalton's investigations in 1903 confirmed and extended these observations. In company with Dr. F. Anderson, Mr. L. V. Dalton visited the island in the autumn of 1909 and found that preparations were being made by Mr. Kleye on behalf of a Tientsin group of capitalists to commence drilling, but no definite results have yet been reported.

In 1913 a lengthy investigation of the island was carried out by Mr. F. A. Holiday on behalf of Sir Boverton Redwood, and a favourable report made. Owing to the outbreak of war in 1914 the further drilling work arranged had to be abandoned.

A sample of oil analysed by the author in 1914 had a specific gravity of ·903 at 60° F., and a flash-point (close test) 208° F.

THE CARPATHIAN FIELDS. (Plate 3.)

After that of Russia, the petroleum-industry in the districts of the Carpathian range next claims attention by its importance and antiquity. On the northern slopes will be found the oil-fields of Galicia ; while on the southeastern and southern slopes of the Southern Carpathians or Transylvanian Alps lie the important deposits of Rumania, and the less-known fields of Bukowina and Hungary.

Galicia.—As far as it has yet been defined, the Galician oil-belt extends for a length of about 220 miles by 40 to 60 miles, in a general northwesterly and southeasterly direction, along the northern slopes of the Carpathian mountains. The hitherto little-worked deposits in Bukowina and in Hungary, and the important Rumanian oil-fields occupying the southeastern and southern slopes of the Southern Carpathians or Transylvanian Alps may be looked upon as forming an extension of the Galician deposits, and be considered with them.

The petroleum industry in this country is of considerable antiquity. The earliest historical records show that oil was collected in a primitive fashion and used as a cart-grease from very early times, and old timbered oil-wells still existing in Galicia and Rumania indicate that this practice prevailed to a considerable extent.

As "earth-balsam," Galician petroleum was known as far back as 1506, and in local records it is mentioned early in the seventeenth century. Mr. Nelson Boyd has pointed out that no reference is made to it in the Austrian Mining Laws of 1786—in fact, the first official notice appears in a Governmental decree of 1810 relating to the registration of mining rights. In 1810, or between that date and 1818, oil from the Drohobycz district is said to have been distilled by Hecker and Mitis at a small refinery at Kabicza, and to have been used for lighting the Alstettering in Prague. These operations, however, soon ceased, and refining does not appear to have been again practised until 1852, when a manufacturer of cart-grease, Schreiner by name, took some of the liquid condensed on the cover of a vessel in which he had heated the crude oil to an apothecary of the name of Mikolasch. His assistants, Lukasiewicz and Zeh, treated the distillate with sulphuric acid and caustic soda, and obtained a product of such excellence as a burning fluid that renewed attention was directed to the subject. The following year Galician petroleum replaced candles for lighting the station of the Emperor Ferdinand's North Railway, and in 1854 obtained a footing as an article of commerce in Vienna.

At one time the most important of the Galician oil-fields was that of Sloboda Rungurska, about 3 miles from Kolomea, with an area 1500 metres in length by 350 to 500 metres in breadth. Two brine-wells which were dug in this district in 1771 are said to have continuously yielded petroleum. One was deepened to 25 metres in 1859 and to 50 metres in 1865, giving a larger yield each time, although the production does not appear to have exceeded 7 quintals daily. The depth was increased to 150 metres in 1875, and was finally carried to 213 metres by boring in 1884, the yield then rising to 10 barrels a day.

Although exploration had been carried on since 1867, active development in this district only commenced in 1881, but by 1883 the production had increased to about 550 barrels daily. At one time it yielded as much as 1600 barrels daily, and formed the chief oil-producing district in Galicia. Since 1887, however, the production has greatly diminished, and in 1894 averaged only about 42 tons a day and in 1901 about 32 tons a day. For 1910 the total production from this field was estimated at about 4000 tons, and in 1913 at 3460 tons. Owing to the regularity of the petroleum-bearing series, the drilling of wells within the demarcated oil-zone in this district was attended with comparatively uniform success, and the wells, the depth of which usually ranged from 215 to 330 metres, but in some cases exceeded 400 metres, usually yielded from 3 to 5 tons of oil a day. The borings, which were confined to a clearing in a valley surrounded by the State forests, passed through a series of shales and sandstones of Eocene age.

Babu gives the following particulars of the strata pierced by a well drilled to a depth of 215 metres, in the Sloboda-Rungurska field:—

	Metres.
Green and red shales alternating,	85·00
Unimportant beds of shale and sandstone alternating,	35·00
Hard shale,	13·75
Hard sandstone (1st petroleum horizon),	15·00
Shale,	2·50
Hard sandstone,	10·25
Alternate layers, 1 to 10 metres in thickness, of sandstone and marl,	51·87
Sandstone (2nd and more important petroleum-horizon),	44·38

It was, however, in the Bobrka district, on the left bank of the Jasolka, between Krosno and Dukla, that the earliest systematic development of the petroleum-industry in Galicia took its rise in 1854. Here, after unsuccessful attempts to collect the petroleum by digging trenches and shallow wells, Lukasiewicz and Klobassa completed, in 1861, a well which yielded 6000 kilogrammes per hour at a depth of only 14 metres. Additional wells were soon sunk by the same proprietors and others, and in 1870 the total yield of the field was estimated at upwards of 800 tons a month. In 1885 drilling was commenced, and from that date the production rapidly increased.

The development of the Wietrzno and Rowne properties, to the southeast of Bobrka, was commenced in 1886–87, and from the commencement the first of these two districts afforded remarkable results, flowing wells with a large output of oil being struck, while Rowne became an important producing district during the second year of its development.

At Weglowka, about 7 miles north of Krosno, oil has been found in considerable quantity at no great depth, and after this field was opened up in 1888, drilling was actively carried on.

Potok, in the Krosno district, about 8 miles north-by-west from Bobrka, and 4 miles from Krosno, the development of which was not commenced until 1890, came most rapidly into prominence. When the author visited this field in 1894, he was impressed with the character of the results achieved. Somewhat deep drilling was necessary here, but oil and gas were met with under great pressure, and spouting wells of a remarkably productive character were not uncommon. One well was drilled to a depth of 2140 feet, and was at the time the deepest producing well in Europe. In 1901 the production of this field amounted to 68,000 tons, but in 1902 it had declined to 32,500 tons, and in 1913 to 12,750 tons.

At Bolerka, 7 to 8 miles south of Krosno, the production amounted to 57,280 tons in 1904, but for the year 1913 it was only 8000 tons.

Further westward, about 18 miles from Bobrka, is the Gorlice field, in which the industry began to be developed shortly after it had been commenced at Bobrka. The places where petroleum was first worked were Siary, Kryg, and Kleczany, at which latter place a small refinery was built as early as 1858. The wells were all hand-dug, and were from 100 to 180 metres deep. At Lipinki the first oil was struck in 1865, but no considerable development took place until 1882, when the Canadian drilling system was first introduced into Galicia at Kryg by Messrs. Bergheim and MacGarvey, and this field became for some years a very important centre of the industry. The production of the Gorlice field for 1913 amounted to 10,000 tons.

The Sanok-Chyrow field has made comparatively slow but steady progress, the production having increased from 13,000 tons in 1894 to 36,000 tons in 1901. None of the first forty wells drilled at Ropienka flowed, though yielding fair quantities of oil by pumping, but, subsequently, flowing wells were obtained. Three wells drilled in 1884 on the Brelikow property yielded but little oil, but a bore-hole put down in 1894 to a depth of 300 metres was reported to have furnished about six tons of oil a day. Considerable development has taken place in the neighbourhood of Ustrzyki, where the author, in 1887, found the industry already firmly and very favourably established.

In 1894 development began in the district round Schodnica. Oil had been produced here for twenty years previously, but it was only in 1894 that systematic attempts were made to develop this territory by drilling. Some of the earlier drilled wells were dry, but the position of the oil-belt was soon determined, and the district for many years occupied a very important position. Every well proved productive, and continued to yield for about seven or eight years on an average. In August 1895 the well known as the Jacob well was struck here at a depth of 985 feet, and commenced to flow at the rate of about 900 tons a day, but in a month had dropped to 150 tons a day. In 1897 a flowing well with a daily production of 120 tons was brought in at Muchowate in this district. Three oil-horizons were found at about 300, 400, and 500 metres respectively, but the uppermost one had not a large yield.

The chief centre of the petroleum industry in Galicia is the rich **Boryslaw-Tustanowice** field, which produces about 93 per cent. of the total output of Galicia. Boryslaw has had its petroleum springs, locally known as "kipiaczka," from time immemorial, and pits were dug for oil as early as 1850. In 1896 Canadian drilling was introduced, and borings to a depth of about 1500 feet were put down, which proved very successful, every well being productive. In 1902 still deeper drilling was tried, and wells of 800 and 900 metres in depth were sunk, resulting in yields of 30 to 50 tons a day. One well is said to have produced 200 to 250 tons daily for a considerable time, and another of a depth of 1000 metres was a flowing well. In 1914 there were in this field sixteen wells of a depth of over 5000 feet, and one was then yielding oil from strata which had been reached at 5873 feet. Such wells are costly to drill, but flowing wells are frequently obtained, and the production of these is so large that heavy expenditure in drilling is justified. The crude oil is of good quality, and yields all the usual commercial products, including a large percentage of paraffin wax.

Since 1911 interest has increased in the hilly district of south-east Galicia, particularly in the neighbourhood of Bitkow, west of Nadworna, where the output of crude oil, which had commenced in 1899, amounted in 1913 to 36,700 tons. In 1914 deep-drilling was in progress at Mraznica, Schodnica, and elsewhere. Among other contributing localities is Kosmacz, the output of which was 2460 tons for 1913, and a small production has been obtained from Pasieczna, Statunia, Maidan, and Dwiniacz.

The growth of the industry in Galicia may be seen from the following statistics :—The total production in 1878 is said to have been only 600 tons; in 1884 it was 38,000 tons; in 1890, 91,600 tons; in 1895, 202,000 tons; in 1898, 330,000 tons; in 1902, 576,000 tons; in 1903, 727,971 tons; in 1909, 2,076,740 tons. In 1910 the production fell to 1,762,560 tons. The specific gravity of the crude oil varies considerably, as does also the colour from very light green to dark amber and black.

According to the Annual Reports of the United States Geological Survey, production in Galicia declined continuously from 1909, at the rate of about 2,000,000 barrels a year, until 1913, when the decline was less than 1,000,000 barrels, or from 8,535,174 barrels of 42 gallons each in 1912 to 7,818,130 barrels in 1913. The decline came altogether from Tustanowice, the dominating field of Galicia. In other districts, Boryslaw and West Galicia, an increase was shown. There was a considerable decline in the amount of oil exported from Austria-Hungary and a large increase in the imports.

Oil production from hand-dug wells has entirely ceased in Galicia, the number of such wells having been reduced to 15, and on these no work has been done. Forty-three producing wells were hand-pumped, 914 were pumped with steam, 620 with gas motors, and 18 were flowing wells. There were also 861 wells which were not productive. Of the wells in the Boryslaw-Tustanowice area 252 exceeded 4000 feet in depth, the deepest having reached 5400 feet, or over one mile.

In the oil-fields of East Galicia, active drilling early in 1914 resulted in a southern extension of the Boryslaw field, which is interpreted to indicate the ultimate connection of that field with the development at Mraznica. In West Galicia no important developments were reported. Operations in all fields were greatly curtailed, and in places brought to a complete standstill during the latter part of the year, when the adjacent territory became the theatre of conflict between the Russian and Austrian armies. Owing to the unsettled conditions in the country it was impossible to procure complete statistics of petroleum output for 1914.

The petroleum industry of Galicia in 1915 was one of uncertainty and disaster, as a consequence of the enormous military importance of the areas of oil-production in that country. About the middle of September 1914, the Boryslaw-Tustanowice district was occupied by the Russian armies; during this occupation, field work, which was abruptly curtailed at the beginning of the war, was resumed to about 50 per cent. of its normal proportions, though little refining was done. As a consequence, field stocks of crude petroleum increased so that by the middle of May they were reported to have amounted to 6,000,000 barrels. In May 1915 the Russian line in southeastern Galicia was broken by the Austro-German armies, and the position of the petroleum industry there became very grave. For military reasons the retreating Russian armies set fire to a large number of oil-wells in the Tustanowice district, and burned a considerable part of the petroleum stored in the East Galician fields. According to the *Frankfort Gazette*, 229 wells out of a total of 319 were destroyed in the Tustanowice district, and about 2,300,000 barrels of crude petroleum were burned. Immediately after the Austro-German occupation of the fields in May 1915, steps were taken to restore the damaged wells and refineries, and place the petroleum industry on a sound basis. This work required considerable time, but before the end of 1915 a decided increase in the rate of oil production was recorded. Drilling activity was limited mainly to restoring damaged wells to the state of producers, and to the completion of wells that were in progress at the time of the Russian retreat, little effort being made to start new wells. In order to avoid the uncertainties of railway transportation on lines already overburdened with military transport, a pipeline 40 miles in length was constructed between Drohobycz and Chyrow to facilitate the distribution of crude petroleum from the Boryslaw-Tustanowice district to the refineries in the vicinity of Lemberg.

Although from 1912 to 1916 the production of petroleum fell to practically one-half of the original output, available statistics indicate that in 1916 substantial progress was made in that year toward restoring the Galician fields to their normal productivity. The gain in yield compared with 1915 was about 55 per cent, the production in 1916 amounting to 6,461,706 barrels of 42 gallons. In 1917 the production fell to 5,965,447 barrels.

The dependence of the German and Austrian military authorities on the Galician oil-fields until late in 1916 for the greater supply of their motor fuels and lubricating oils resulted in a high level market for crude oil in all the Galician districts that served as a decided spur to activity in drilling throughout 1916.

As regards the future of the Galician petroleum-industry, all the indications point to the conclusion that the production may not improbably be increased by the general adoption of deeper drilling. It is by no means unlikely that some of the older oil-fields of this country may be found to have been insufficiently tested, and a large amount of presumably oil-bearing territory remains undeveloped.

The principal seat of the Galician **ozokerite** industry is in and around Boryslaw, where it has been carried on since 1860. It is first mentioned in the Mining Laws in 1854. Ozokerite is also found in Dzwiniacz and Starunia, south of Stanislau, at Slanik in Moldavia, and at other points on both sides of the Carpathians. At Truskawiec, near Boryslaw, occurs a deposit of native sulphur, galena, and blende, intermingled with gypsum, ozokerite, and petroleum, in a greyish-blue clay-shale with sand and marl.

Ozokerite was at one time considered a "Crown mineral" in Austria-Hungary, but was declared free in 1865—a measure which resulted in an important increase of activity in the industry. The Boryslaw ozokerite-field was originally worked by scores of proprietors, who sank many thousands of shafts; but the majority of the owners had only a small holding, the greater part of the richer interior portion being held by a few large owners.

The district is pear-shaped, its major axis trending E. 15° S. from Boryslaw in the broader portion to Wolanka at the narrow end. The richest part of the field occupies an area of about 52 acres, with a length of 1000 metres and a maximum breadth of 350 metres; but an outer zone of less productive territory increases the workable field to about 150 acres, 1500 metres long by 550 wide.

The ozokerite occurs in well-defined veins, and is worked by the pick, as in ordinary mining. It has been largely extracted in very primitive fashion by small proprietors; but a French company some years ago commenced mining near Wolanka by a system resembling that employed in getting coal. As, however, the site selected did not lie within the most productive area, the operations were not very successful. Many accidents occur from the caving-in of the galleries, or from the influx of gas or of semi-solid ozokerite. In the case of one mine, the perforation of a thin layer of sandstone by a miner's pick resulted in the gradual appearance of a stalk of ozokerite, which for a long time was forced out as fast as it was removed. This curious appearance of growth gave the name of the "Asparagus" Mine to the shaft.

The surface of the valley-slopes is covered with drift, of clay, sand, and gravel, several metres in thickness. The shafts sunk by the early workers traversed these water-bearing deposits to the ozokerite beds, which are alternating sandstones, blue shales, and marls, with rock-salt and gypsum. They were 8 or 10 yards apart, and each worked an area of 9 to 64 square yards, drifts being carried from the shafts into the ozokerite-veins. The veins vary from extreme tenuity to a thickness of some feet, from 2 to 8 per cent. of the excavated matter being ozokerite.

The productive width of the marl rapidly diminishes as the depth increases, and at 100 metres down is but 200 metres in place of the 350 at the surface. The wax has evidently been forced up from underlying beds by lateral pressure, through fissures resulting from local yielding of the marl to the compressive strain. The pressure which still exists is attested by the viscous flow of the ozokerite in the mines, as mentioned above, and by the frequent distortion or collapse of the timbering, much enhancing the difficulties of mining-operations, which in turn tend to increase the instability of the mass of ground affected.

At the present time only two firms are mining ozokerite. Modern plant has been erected, and upcast and downcast shafts have been sunk, which are properly ventilated. The stringent regulations of the mining law of February 1901 could only be complied with by the large owners, and all the holders of small pieces of land were compelled to abandon work.

The production amounted to about 9000 tons in 1874, in 1885 to 13,000 tons, and in 1913 to about 2000 tons per annum.

In **Bukowina,** oil has been found in the Watra Moldawitza district (where several wells were drilled to depths ranging from 170 to 340 metres), and elsewhere.

The oil-fields of **Hungary** geologically resemble those of Galicia, but the petroliferous area on the Hungarian side of the Carpathian range is comparatively narrow, and has not as yet assumed any great industrial importance, though recent drilling has met with good results.

In the neighbourhood of Bereczk, in the county of Haromszek, numerous outcrops of petroliferous strata occur, and shallow wells at Sösmezö, Gelencze, and Zabola have yielded oil, those at Sösmezö dating as far back as 1774. A well sunk to a depth of 137 metres is stated to have yielded at first as much as thirty barrels of oil a day.

Westwards, in the southern part of Zala county, oil has long been known to exist, and within the last ten years over thirty wells have been drilled with encouraging results.

Natural gas has recently been discovered in considerable quantities in Eastern Hungary, during a search for sources of potash salts. In one of the borings undertaken by the Hungarian Government in 1908, near Kissármás in the county of Kolozs (Klausenburg), gas was encountered under considerable pressure at about 575 feet, and at 995 feet work had to be stopped on account of the force with which the gas was escaping. The yield was over 1,000,000 cubic feet per hour. The output of natural gas in Hungary for 1915 is reported to have been 25,108,054 cubic metres.

RUMANIA. (Plate 2.)

The petroleum-deposits of Rumania are continuous with those of Galicia ; they are also of much the same age as, and are connected under the sea with, the petroleum-bearing beds of the Caucasus. The outcrop of possibly petroliferous formations is from 15 to 20 miles in width, and runs for a distance of about 400 miles, with a few unimportant breaks, from the Iron Gates to the Galician frontier, as shown on the sketch map (Plate 2), which also indicates the principal localities wherein petroleum is produced.

The traveller Raicevich reported, in 1750, that the "liquid bitumen" of this country was used as a medicinal agent in treating the diseases of cattle, in lighting the courtyards of the "boyars" (large landowners), and as a cart-axle grease. At this time the most abundant spring appears to have been one near Pacureti in the Prahova district, and from this and neighbouring sources about 20 tons annually appears to have been obtained. Petroleum has, however, been known in Rumania from remote times, as is shown by the number of places named Pacuerti, "pacura" being the Wallachian word for this substance, and by the existence in the districts of Bacau and Prahova of numerous pits or hand-dug wells similar to those met with in Galicia ; and it may be added that in no country has the digging of wells for petroleum been more successfully conducted, surprising depths being reached in many cases. For the last forty-five years there have been refineries, more or less satisfactorily conducted, in the principal towns, where the oil collected by merchants has been treated ; while still larger quantities have passed over the frontier to be dealt with at the more complete works at Kronstadt and other places in Transylvania and Galicia. During this period, and especially shortly after the Government redistribution of land in 1866, various larger enterprises have been started with the object of extracting the petroleum in a more rational and systematic manner, and in some cases have met with very considerable success. Contrasting Rumania with Galicia, we find that in the former country the entire production was from dug shafts long after such wells had in the latter country been replaced by borings made by steam-power. It is, in fact, only within the past thirty years that drilling has superseded digging in the Rumanian oil-fields. Foremost amongst those who were prominently associated with this development was Prince Cantacuzino, who obtained the first flowing well, and carried out extensive drilling-operations at Draganeasa between 1880 and 1887. The production of the well in question was far in excess of any yield of which there had been previous experience in Rumania, and adequate provision not having been made to store the oil, great quantities ran to waste. Concurrently, similarly successful results were obtained by others at Sarata and Solonti-Moinesci, and this led to the introduction of foreign capital into the business. The attempts which were then made to develop the oil-fields of Bustenari, Baicoi, Campina, Glodeni, and Poiana were not, however, attended with encouraging results, though subsequent experience has shown that it was more the management than the territory which was at fault. Since 1890 many properties have changed hands, a number of the smaller interests have been amalgamated, modern refineries have been erected, arrangements have been made for the export of the products, and the business generally has been placed on a sound footing. The first company which sought to acquire a commanding position in the industry secured the control of the greater part of the production, which was at that time centred in Glodeni, in the district of Dambovitza ; Campina, in that of Prahova ; Sarata, in that of Buzeu ; and Solonti-Moinesci, in that of Bacau—the aggregate output being about 60,000 tons annually. The company refined this oil at Bucharest, Monteoru, Campina, and Moinesci, and possessed pipelines for its transport from Glodeni to Doicesci and from Bustenari to Doftana. In 1895 the business thus founded was acquired by the Steaua Romana, other companies were formed, and under new auspices the production was soon very greatly increased. Realising the necessity for fostering the export trade, the Steaua Romana constructed a tank-storage at Giurgiu (Giurgevo), with arrangements for conveying the oil by tank-barges thence to Ratisbon, where another installation was erected, with a view to the supply of the markets of Southern Germany and Switzerland. An installation was also provided at Constanza for the loading of tank-steamers to carry the oil to the Mediterranean ports and elsewhere. The home-consumption of the ordinary commercial products exhibited steady growth, and a beginning was made in the use of liquid fuel. In 1908 the Rumanian railways used 180,000 tons of this fuel mixed with lignite, and the number of locomotives burning petroleum had increased in 1910 to over 600, while nearly all the sugar-refineries, distilleries, breweries, engineering works, limekilns, electric generating stations, gas-works, hospitals, and other public buildings with central generating stations were using petroleum as fuel.

The estimated production of crude oil for the years 1895 to 1899 (accurate statistics not being obtainable) was as follows :—

1895,	about	76,000 tons.
1896,	,,	80,000 ,,
1897,	,,	110,000 ,,
1898,	,,	180,000 ,,
1899,	,,	250,000 ,,

In 1899 the progress of the industry was arrested by industrial depression and other causes, as is shown by the following figures, which give the production for 1900 :—

TABLE I.—Rumanian Oil Production, 1900.

District.	Locality.	Wagons (of 10 tons each).	
Prahova, ...	Campina-Poiana, . . .	9,000	
	Bustenari, Telega, . . .	11,000	
	Baicoi, Tintea, Matita, Apostolache, Poiana-Verbileu, . .	1,400	
			21,400
Dambovitza, . . .	Ocnita, Glodeni, Resca, Colibasi, .		1,400
Bacau, ...	Moinesci, Solonti, Casin, Campeni, Piatra, ...		1,400
Buzeu, ...	Sarata, Berca, Tega, . . .		800
			25,000

In 1901, however, matters improved, and subsequently there was a steady growth in the output. The following table shows the production of oil in the different districts and principal fields in 1908, 1909, and 1910:—

TABLE II.—Rumanian Oil Production, 1908–1910.

District.	Field.	1908.	1909.	1910.
		Tons.	Tons.	Tons.
Prahova, . . .	Bustenari, . . .	473,106	393,242	318,269
	Moreni, . . .	337,763	369,784	438,475
	Campina-Poiana, .	233,825	311,147	333,382
	Others, . . .	51,127	147,469	155,177
Dambovitza, . .		26,272	30,288	43,295
Bacau, . . .		14,866	19,084	23,974
Buzeu, . . .		10,768	25,389	39,717
Totals, . .	. . . . .	1,147,727	1,296,403	1,352,289

During the following four years there was a progressive increase in the output, and only a slight falling-off in 1915. Towards the end of 1916 the great war caused very serious injury to the industry, and the production of crude oil, which amounted to 1,673,145 tons in 1915, and to 1,432,296 tons (estimated) in 1916, fell to 373,000 tons (estimated) in 1917. Under German control the damage done by the military operations has been largely repaired, and it is reported that the output is being rapidly brought up to the pre-war level.

The proportions in which the various districts contributed to the output of crude oil in 1915 was as follows:—

Prahova, ...	85·54 per cent.
Dambovitza, ...	6·03 „ „
Buzeu, ...	6·70 „ „
Bacau, ...	1·73 „ „

The following statements are quoted from the Annual Reports of the United States Geological Survey:—

In spite of the Balkan War, with its depressing effect upon all industries, and of two unusually disastrous fires in the oil-fields, the Rumanian producers succeeded in increasing, though very slightly, the total production of crude petroleum in the year 1913.

Notwithstanding the mobilisation of the Rumanian army in June 1913, and the consequent loss of workmen and drillers, exploitation increased as to both drilled and hand-dug wells. A gusher drilled in January 1913, known as well No. 79 of the Columbia Company, at Gropi, opened new territory connected with Chiciura. In February the Astra-Romana Company struck a gusher at Staropoleos-Moreni which added new territory west of previous developments in the Moreni field. In March the Romano-Americana Company's well No. 22, Fierbatori (Baicoi), proved a violent gusher, opening new territory, and the Steaua Romana obtained in this month its first well at Runcu, opening up territory between Bordeni and the Chiciura pools. The conclusion of peace in the Balkan States and the demobilisation of the army in August caused considerable increase in oil operations. Several wells were drilled to the north of Mislishoara, adding new territory to that important region, but the industry received a serious set-back in October by a well-explosion and fire lasting 14 days, in which 17 wells were destroyed, among them the great gusher Columbia No. 1, which had yielded in all about 2,600,000 barrels of oil. Important progress was made in the construction of the pipe-line from the oil-fields to Constantza on the Black Sea.

Considering the handicap of a greatly restricted market during the latter half of the year 1914, following the closing of the Dardanelles and the declaration by the Government of an embargo on many petroleum products, the decline of less than a million barrels in the output of petroleum in Rumania in 1914 is remarkable. That the falling off was not greater was due to the success that attended active drilling operations during the first half of the year, which proved the presence of vast stores of petroleum in previously untested areas. Substantial additions were made both on the east and on the west of the productive area at Bana-Moreni, on the south at Tzuicani, and on the northwest (Ferbatori) at Baicoi. A new field was opened up by the Astra-Romana Company at Ochiuri, in Dambovitza, and test wells at Ceptura, Valea Telegei, and Cricov furnished results which warranted the projection of additional work in those localities for 1915. The increasing use of the rotary system of drilling in the Rumanian fields during the previous three years contributed in no small degree to the success of the operations.

Notwithstanding the great difficulties encountered by the petroleum industry of Rumania since the beginning of the European war, including scarcity of labour, shortage of drilling materials, partial cessation of exports, and accumulating stocks, the output of petroleum from the oil-fields of Rumania in 1915 declined very little from the output in 1914. In Prahova and Dambovitza, the districts most favourably situated with regard to refining, conditions of production were practically normal, because kerosene, lubricating oils, and gas oils were free for exportation, though crude oil, benzine, and residuals were prohibited from exportation. In the Buzeu and Bacau districts, however, from which it is necessary to transport the crude petroleum to the refineries in tank wagons, a notable decrease in production was recorded.

The relatively slight decrease in production in 1915 is ascribed to the ability of the Rumanian industry to adapt itself readily to new and unforeseen circumstances, and to its perfect organisation, enabling it to overcome quickly the extraordinary difficulties resulting from the great war.

Owing to the high cost of drilling materials and to the general depression in the petroleum industry, drilling activity in the Rumanian fields was below the normal in 1915. Nevertheless considerable exploratory work was accomplished. Substantial additions were made to the productive area of the Stavropoleos field at its northern end, and the new deep-sand sections of the

Bana-Moreni field received considerable attention. Exploration in the new field at Ochiuri, in the Department of Dambovitza, discovered by the Astra-Romana (Dutch-Shell Syndicate) in 1914 resulted in the completion of a number of good wells, and demonstrated the opening up of a profitable field; it also added materially to the output credited to this Department. The decline in output in the Bustenari field is ascribed, on the one hand, to the natural exhaustion of the old wells, and on the other to the fact that a very slight amount of new drilling was undertaken during the year. In the south-west part of this field exploratory work has revealed the presence of rich oil-sands, the ultimate development of which will doubtless greatly increase the output of this field. In the Baicoi division of the Bana-Moreni field production greatly increased as a consequence of drilling activity in the Ferbatori extension. Important tests were reported in progress at the close of 1915 at Floresti; at Ocnitza-Copatshishi, west of Moreni; at Piscuri, northwest of Moreni; and at Scaioshi, Cosminele, and Pacuretzi.

The year 1916 brought disaster to the petroleum industry of Rumania. This came as a consequence of the entrance of Rumania into the great war on the side of the Entente Allies in September, and the subsequent defeat of her armies on the Austrian and Bulgarian frontiers, followed by invasion of her territory by the armies of the Central Powers. With the evacuation of Bucharest at the end of November, it became very clear that the capture of the Rumanian oil-fields was one of the chief objectives of the invasion; and drastic steps were taken to prevent a repetition of the success that had attended the fall in October of Constantza, with its enormous stocks of crude oil and of refinery products awaiting export *via* the Black Sea, a systematic campaign of oil-field destruction being carried out under the direction of Colonel Sir J. Norton-Griffiths of the British Army.

An important development that took place a few days before the entry of Rumania into the war was the completion of a Government-owned pipe-line, 140 miles long, from Baicoi to Constantza, through which it was intended to transport oil direct from the field to the Black Sea. The total length of the three pipe-lines in the Dobrudga, between Cernavoda and Constantza, is $56\frac{3}{4}$ kiloms. ($35\frac{1}{2}$ miles). There are pumping-stations at Cernavoda and Palas, 3 miles from Constantza port.

Three routes were open to the Central Powers for the export of petroleum and its products, viz.:—(1) By rail, *via* Predeal, this route giving practically a direct connection between all the more important oil-fields (Moreni, Baicoi, Campina, and Bustenari) and the largest refineries at and near Ploesti and Campina on the one hand, and the great central European distributing centres at Buda Pest, Pressburg, Vienna, etc. (2) By rail to Giurgevo, on the Danube, 62 kiloms. (39 miles) south of Bucharest, and thence by barge up the Danube to Buda Pest, Pressburg, Vienna, and Regensburg, where there is a large storage depot. (3) By rail, *via* Verciorova, to the refineries at Orsova, Buda Pest, Pressburg, etc. Most of the railway lines in Rumania consist of a single track, but there are double lines between Bucharest, Ploesti, and Campina, at which latter place they again become single as far as the frontier station, Predeal. From Predeal, and all through Transylvania, there are only single-line tracks. Campina is 49 kiloms. (31 miles) from Predeal.

The aggregate capacity of the storage tanks on the oil-fields, at the refineries, and at the ports of exportation is about 1,411,000 tons. The total oil-storage capacity of the country is estimated at about 1,723,000 tons.

The initial transport of oil in Rumania, on the oil-fields, and between the fields and the various refineries is chiefly effected by means of a great network of pipe-lines. The subsequent transport of most of the products of distillation and of a considerable amount of crude oil, is carried out by means of railway tank wagons. The crude oil produced in the Buzeu and Bacau districts is mostly transported to the refineries by railway tank wagons. The crude oil treated at Cernavoda refinery has also to be carried in railway tank wagons.

Practically the entire production of Rumania is refined in the country.

The principal refineries are situated at, or close to, Ploesti (85 kiloms., 53 miles from Predeal) and Campina. The following table gives the situation and estimated distilling capacity of the more important refineries in 1916:—

Name and Locality.		Annual Distilling Capacity.
Steaua-Romana,	Campina,	851,929 tons.
Astra-Romana,	Ploesti,	723,985 ,,
Vega.	,,	508,166 ,,
Romana-Americana	,, (near)	453,760 ,,
Aurora	Campina (near)	275,520 ,,
Aquila Franco-Romana,	Ploesti	244,439 ,,
Orion,	,,	237,888 ,,
Standard,	,,	164,107 ,,
Plopeni,	,, (near)	143,696 ,,
Anglo-Continental,	,,	96,768 ,,
Rumanian Consolidated,	,,	95,982 ,,
Fratia,	,,	51,472 ,,
Other Refineries at	,,	about 150,000 ,,
Colombia,	Cernavoda,	209,566 ,,
Aurora,	Tergoviste	102,842 ,,

The principal oil-fields of Rumania are given in the following table, with the production for 1915, in metric tons:—

Oil-field.		Production.
Moreni	Prahova District, 1,431,292 tons.	741,163 tons.
Bustenari		286,035 ,,
Campina,		120,657 ,,
Baicoi, etc., etc.		283,437 ,,
Gura Ocnitza, etc., Dambovitza District,		100,824 ,,
Arbanash, etc., Buzeu District,		112,098 ,,
Zemesh, Solonitz, etc., Moldavia		28,931 ,,
	Total,	1,673,145 tons.

The first four of these fields are connected with the refineries and the railway line leading to Predeal.

According to the United States Geological Survey, the production of petroleum for 1916 from the Prahova, Dambovitza, Buzeu, and Bacau districts is estimated at 1,432,296 metric tons.[1] No production is given for the month of December. In 1917 the whole of the production of Rumania was estimated at 373,000 metric tons.

The oil is found at no great distance from the surface, the depth of the producing wells, including the dug shafts, ranging from 100 to 400 metres. Drilling is, on the whole, easy, the strata perforated consisting of soft clay, shale, clay-shale, sand, and sandstone. The Canadian system of drilling was at first adopted, but the rotary system is now largely employed.

The difficulties which attend boring-operations resemble those encountered in Galicia, and arise partly from the high angle of inclination of the strata, which tends to deflect the boring tools, and partly from the alternation of porous and relatively impervious strata, but more especially from the occurrence of layers of water-bearing, or sometimes oil-bearing, quicksand, which are liable to cause "caving" of the well.

[1] 1 metric ton = 7·19 barrels of 42 gallons.

The colour of Rumanian crude oil is for the most part brown, of various shades, except that from Predeal, which is of a light reddish tinge, and that of Campina-Paijol, which is light yellow. The specific gravity varies considerably, not only in the same field but even in the same well, the lightest being 0·770 and the heaviest 0·935 (L. Edeleanu and I. Tanasescu, *Monit. Int. Pétrol. Roumains*, iv, 19 (Supplement), 1903).

Typical specimens of Rumanian petroleum collected by Mr. Blundstone and examined by the author had the following characters:—Colour very dark brown by transmitted light, with only a moderate amount of fluorescence. Odour not disagreeable. Specific gravity from 0·839 to 0·896. Flashing-point (Abel test) from below 20° to 123° F. With one exception the samples remained fluid when exposed to a temperature of zero F.

ITALY.

The petroleum-industry in Italy and Sicily dates from very remote times, the oil obtained from the neighbourhood of Agrigentum having been used for illuminating purposes about 2000 years ago.

In the year 1226, according to a report published by Signor Zoppetti in 1883, Frederick II constituted a municipal body at Salsomaggiore, which took for its emblem a salamander surrounded by flames, in allusion to the emanations of inflammable gas in the neighbourhood.

In 1400 the collection of the petroleum of Miano di Medesano formed the subject of a concession granted by the Ducal Chamber. M. de Montaigne, during his journeys in 1580 and 1581, visited Barigazzo and Pietramala, and described the indications of petroleum which he observed there. The celebrated petroleum of Modena, at one time largely used for lighting and medicinal purposes, and in the preparation of varnishes, paints, etc., was discovered in 1640 by Ariosto, a physician of Ferrara, at Monte Festino, about 12 miles from Modena. This product was subsequently examined by Boulduc (*Histoire de l'Académie Royale des Sciences*, Paris, 1715, 15). The wells were dug to a depth of from 40 to 60 feet, and the water that collected in them was found covered with a light reddish petroleum, which was skimmed off fortnightly. Three kinds of petroleum were collected at these pits, one being as clear as water. According to Psilanderhjelm (*Histoire de l'Académie Royale des Sciences*, Paris, 1736, 56), the naphtha of Monte Chiaro, near Piacenza in Italy, was superior to that of Modena. It was obtained by piercing the horizontal beds of gypsum and clay, drawing off the water and oil which collected, and separating the latter by skimming once a week.

The petroleum of Montechino was apparently not discovered until the beginning of the eighteenth century, while the deposits of Ozzano and Rico di Fornovo did not attract attention until early in the nineteenth, and those of Neviano de' Rossi, Salsomaggiore, and Lesignano de' Bagni were found still later.

Petroleum from the wells of Amiano, on the Taro, was used for lighting the cities of Genoa, Parma, and Borgo San Donnino as early as 1802, but the production at that time does not appear to have exceeded from 200 to 300 kilogrammes a day, and the wells seem to have been speedily exhausted.

The districts in Italy in which petroleum has been found in quantity are—(1) the Zone of **Emilia**; (2) the valley of the **Pescara,** in the province of Chieti; and (3) the valley of the **Liri,** near San Giovanni Incarico, about midway between Rome and Naples. The Zone of Emilia occupies the southern parts of the provinces of Piacenza, Parma, Modena, and Bologna, as shown on the map (fig. 1), which is reduced from that in the annual Government report *Relazione sul Servizio Minerario nel* 1890 (Florence, 1892).

In 1866 Professor Stoppani, the geologist, described the petroleum-wells of Montechino and the burning fountains or fires of Velleia, the latter of which occurred in two groups on the banks of the Chero, extending over an area of about 250 square yards. The gas issued from calcareous rocks associated with beds of bluish clay of the Subapennine formation. It burned with a flickering flame a few feet in height, and emitted a strong smell of petroleum. The wells of Montechino, on the right bank of the Riglio, were described by this authority as from 19 to 63 yards deep, lined with large bricks cemented together, and perfectly cylindrical. The wells were then yielding from 160 to 180 lbs. of petroleum daily. An artesian well drilled at Montechino in 1866 by a Genoese company was said to be yielding, at a depth of 50 metres, half a barrel daily of straw-coloured, very volatile petroleum. Stoppani notes that petroleum was plentiful on both banks of the Riglio, and had been collected by sinking in the bed of the stream a number of empty barrels, which became filled with the oil by infiltration.

The petroleum-deposits of this district have also been described by Mr. E. St. John Fairman (*A Treatise on the Petroleum Zones of Italy*, 1868).

The territory of Miano di Medesano is distant about 25 kilometres (about 15 miles) from Parma, and is bounded on the southwest by the River Taro, two streams, the Campanara and the Dordone, forming portions of the northern and southern boundaries respectively. The surface is hilly, and the ground slopes sharply in places to the watercourses. The whole area is also intersected by the beds of numerous rivulets, forming deep ravines. During rainy weather, and when the atmospheric pressure is low, the characteristic odour of bitumen is stated to be observed in the valleys, and at certain seasons of the year the oil itself is often found on the surface of stagnant water. In many places on the property, and especially on the banks of the Campanara and its tributaries, there are remains of dug wells. The usual depth of such wells is not more than 40 to 60 metres, though some are said to have been as much as 100 metres deep. The depth to which such wells can be sunk depends upon the quantity of gas met with, and in some localities—Ozzano, for instance—where gas is abundant, it is said that a depth of 25 metres cannot be exceeded. The wells are usually 1·3 metres in diameter, and are lined with bricks 2 inches in thickness. All those wells that came under the author's observation when he visited the district in 1894 had become filled with sand and water, but in and around several of them petroleum-gas was rising through the water in bubbles, and could be ignited. There appeared to be only one well (the Galetta well) in the field from which oil was then being obtained. In 1869 a company was established at Parma for the development of the petroleum resources of Miano, and two artesian wells were drilled on the American system to the respective depths of 124 metres and 203 metres. In these wells, gas, water, and petroleum of a greenish-yellow colour were met with. Unfortunately the wells were not properly cased, and they caved in after having yielded by pumping several barrels of petroleum, which was sold in Parma at 100 francs the 100 kilogrammes. The work commenced by this company was continued by Achille Donzelli & Co., who, as concessionaires, completed three dug wells lined with brickwork, and thus collected the surface-oil. Three petroliferous localities were proved to exist. The first, to the north of the Rio Campanara, yielding a straw-coloured oil; the second, known as the spring of the Rio della Fontana, 400 metres to the southwest of the first, producing a greenish-yellow oil; and the third, known as the spring of the Rio Lombasino, about 1000 metres

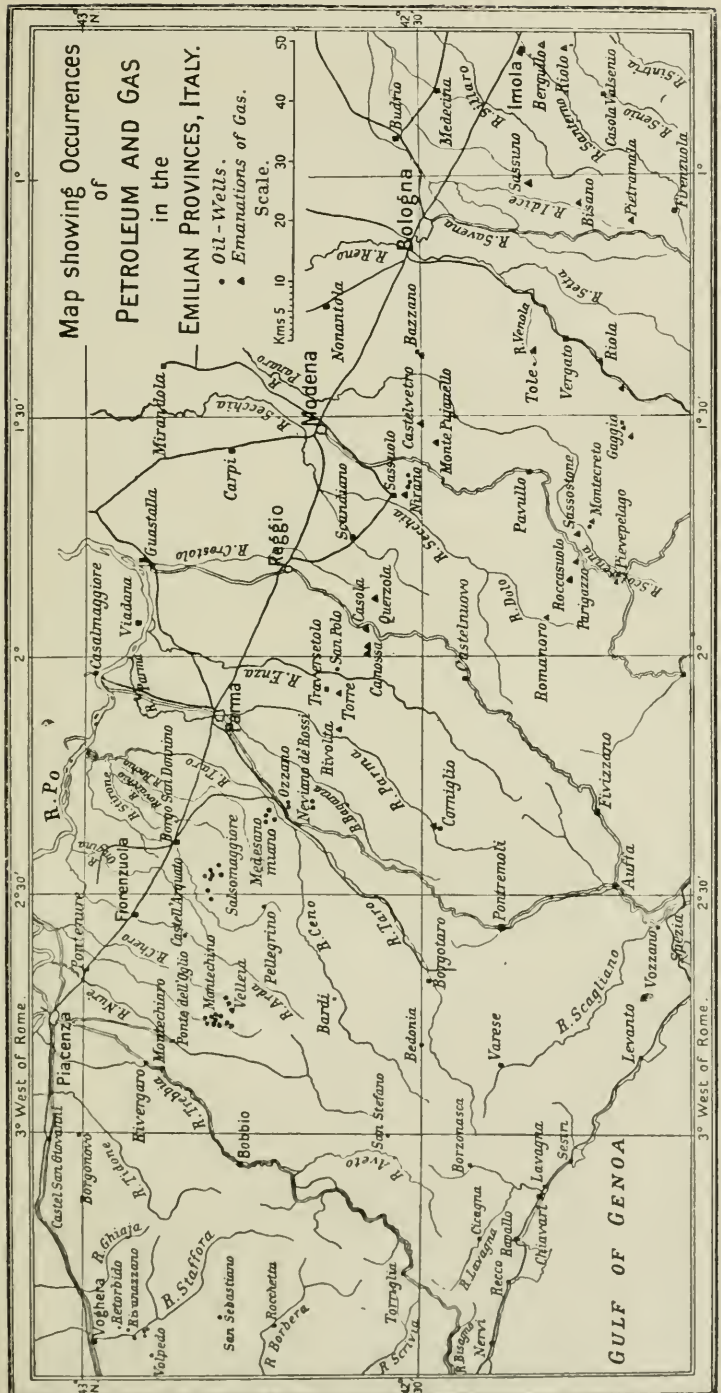

Map showing Occurrences
of
PETROLEUM AND GAS
in the
EMILIAN PROVINCES, ITALY.
• Oil-Wells.
▲ Emanations of Gas.
Scale.
Kms 5 10 20 30 40 50
R. Po
GULF OF GENOA
3° West of Rome.
2° 30'
2°
1° 30'
1°
Piacenza
Parma
Reggio
Modena
Bologna
Imola
Voghera
Bobbio
Fiorenzuola
Salsomaggiore
Guastalla
Mirandola
Carpi
Sassuolo
Castelnuovo
Pontremoli
Fivizzano
Spezia
Chiavari
Rapallo
Sestri
Levanto
Pavullo
Vergato
Riola
Tole
Nonantola
Bazzano
Budrio
Medecina
Firenzuola
Pietramala
Bisano
Sassuno
Montechiaro
Velleja
Montechino
Bardi
Bedonia
Borgotaro
Corniglio
Canossa
Casola
Querzola
Scandiano
Viadana
Casalmaggiore
Castel San Giovanni
Borgonovo
Rivergaro
Ozzano
Medesano
Bivolta
Torre
Traversetolo
San Polo
Castelvetro
Monte Pujanello
Roccasuolo
Romanoro
Sassostone
Montecreto
Gaggio
Pievepelago
Varese
Borzonasca
Lavagna
Recco
Nervi
Torriglia
San Sebastiano
Rocchetta
Volpedo
R. Trebbia
R. Taro
R. Ceno
R. Enza
R. Secchia
R. Panaro
R. Reno
R. Savena
R. Idice
R. Setta
R. Crostolo
R. Staffora
R. Scrivia
R. Aveto
R. Scagliano

FIG. 1.

to the south-southeast of the second, giving a reddish-brown petroleum. The yellow surface-oil was met with at a depth of about 50 metres, and the brown at less than 20 metres.

The petroleum property known as Neviano de' Rossi lies but a short distance to the southeast of Miano di Medesano, on the opposite side of the river Taro. In the general character of the surface, and of the geological formation, it closely resembles the Miano territory. The shallow wells which have been excavated in this locality are described as having perforated a bluish clay, interstratified with beds of sandy rock and thin bands of sandstone. The surface-deposits were charged with water. According to the official report previously referred to, wells having a diameter of a metre and a half, and a depth varying from 45 to 50 metres, have been dug in this district for many years past, and the majority of these wells have yielded oil. In 1877 a French company drilled a well in which the first oil-bearing formation was met with at a depth of 42 metres, and according to Zoppetti (*Ann. Agric.*, 1880, 227), a second and more productive oil-horizon was found at 52 metres. The oil obtained was described as being very pure, and of a straw-yellow colour. In a well at Neviano, which the author saw when it was being drilled, oil was said to have been found at a depth of from 54 to 60 metres. No sandstone or other compact rock was met with in drilling this well to a depth of 110 metres, but the clay was interstratified with bands of sand at a depth of 50 to 60 metres, and at a greater depth was sandy in character. In a well drilled on a neighbouring property at Ozzano Taro, nothing but clay was encountered down to a depth of 130 metres, below which bands of hard rock occurred. This well, which had at the time of the author's visit a depth of 200 metres, was stated to yield from 250–300 kilogrammes of oil a day. According to Zoppetti, natural outflows of petroleum have been observed at Ozzano, on the right bank of the Taro, for a very long time, and in 1880 two wells were dug here, both of which yielded oil. Subsequently three wells were drilled on the property by Deutsch & Co. The first gave at the commencement about one barrel of oil a day, the second was unproductive, and the third was abandoned unfinished.

Specimens of petroleum collected by the author in the districts referred to had the following characters:—

Miano—Sample from Galetta Well.—Colour, dark red by transmitted light. Considerable fluorescence. Odour very slight, and not disagreeable. Specific gravity 0·908. Flashing-point 190° F. (close test). Remains fluid at zero F.

Neviano—Sample from Drilled Well.—Colour, amber by transmitted light. Exhibiting very marked fluorescence, causing the oil to appear green by reflected light. Odour resembling that of benzol. Specific gravity 0·805. Flashing-point 44° F. (Abel test). Remains fluid at zero F.

Ozzano—Sample from Drilled Well.—Colour similar to that of the Neviano specimen. Odour characteristic of petroleum of good quality. Specific gravity 0·807. Flashing-point below zero F. Remains fluid at zero F.

In 1885, when it was expected that there would be a large production of petroleum at Salsomaggiore, a refinery was erected at Borgo San Donnino, and the petroleum produced at Salsomaggiore, Montechino, Velleia, and other places was refined there. In 1889 the amount so refined was 589 tons of crude petroleum. Subsequently another refinery was erected at Fiorenzuola d'Arda, and another near Velleia. There is also a refinery at Milan.

Many wells, from 14 to 22 metres deep, have been dug at Rivanazzano (Pavia), and artesian wells have been drilled to depths of 120 to 180 metres. In the latter, salt water was met with at a depth of 20 to 30 metres, while at a depth of 70 to 80 metres an outburst of gas occurred which ejected salt water, mixed with petroleum, from the borehole. The strata perforated are said to have consisted mainly of calcareous tufa and beds of sandy clay. The wells at first yielded several barrels of oil daily by pumping, but the output diminished to 20 or 30 litres daily. The property passed into the hands of an Italo-French company in 1880. Three wells were then drilled by the Canadian system to depths of from 200 to 300 metres, and these were asserted to yield regularly five or six barrels of oil a day. In 1883 Zoppetti (*Riv. Serv. Min.*) stated that there were in Rivanazzano four wells of over 200 metres in depth, and a fifth in course of boring. The rocks met with were, according to this authority, principally limestone, marl, and clay-sand. The oil appears to have been comparatively heavy, and to have been found in a soft, sandy bed, with salt water and much gas.

In the vicinity of Salsomaggiore, much gas has been met with in drilling, one well, of a depth of 120 metres, yielding such large quantities that the gaseous product was conveyed to the village by piping and used for lighting the roads. At Salsominore, on simply disturbing the surface of the ground, the gas issues in places in sufficient quantity to admit of being ignited. A similar phenomenon was observed by the author in the neighbourhood of Pietramala across the Tuscan frontier.

The *Rivista del Servizio Minerario* reported that the production of natural gas in Italy amounted in 1915 to 5,812,000 cubic metres, the Province of Parma contributing 1,112,000 cubic metres, and the Province of Piacenza 4,700,000 cubic metres.

The statistics of the production of petroleum in Italy, given in an appendix to this work, indicate that from 1860 to 1870 the principal production was in the Zone of Emilia and the valley of the Pescara, the oil from the latter district being entered under the heading of Chieti, while in the succeeding similar period the oil produced (602 tons) was mainly from wells at San Giovanni di Incarico, entered under the heading of Caserta, the industrial activity in the two former localities having almost ceased. After 1880 the yield of the wells at San Giovanni di Incarico diminished greatly, and at the same time fresh developments were commenced in the valley of Pescara, but the results were inconsiderable, the production in 1883 not exceeding 125 tons. In the Zone of Emilia, on the other hand, the production was maintained. In the latter part of 1889 the average yield was at the rate of about 120 tons per annum, but in 1890 it had increased to 360 tons, the efforts of producers being stimulated by the protection of the native industry afforded by an increase in the import duties on foreign petroleum. Towards the end of the last century considerable activity was shown by Zipperlen & Co., in drilling in the valley of the Chero, near Velleia. In this company's report for the year 1892, published in the Paris *L'Argus*, it is stated that the production of petroleum from the company's wells, which was 928,000 kilos. in 1891, had increased in 1892 to 2,391,666 kilos. There were seventeen productive wells, and six more in course of drilling. A Decauville railway had been laid to the wells, and telephonic communications had been established, by means of a line 8 kilometres in length, between Velleia and the furthest point on the concession, where the pipe-line delivered the petroleum from the wells on to the Chero. In 1893 the production of petroleum had increased to 2,648,803 kilos., the smallness of the increase, as compared with that of the previous year, being ascribed to the exploiting of a new zone. Four new wells were in course of drilling.

The production of petroleum has always been largest in Emilia, most of the oil coming from the province of Piacenza. From 1893 to 1903 the output remained practically stationary, but there was a great increase in 1905, the amount for that year being more than double that for 1904, or over 6000 tons. In 1908 the production was over 7000 tons, but in 1909 had fallen to 5895 tons, of which 5888 tons was derived from the provinces of Parma and Piacenza.

There was a slight increase in the year 1910, and in 1911 the production was nearly double that of 1909, though fewer wells were in operation. The output of petroleum, however, in Italy, which had never been of much importance, decreased slightly in 1914.

The development work which was carried out in 1914, near San Giovanni di Incarico, in the Province of Caserta, resulted in one well being brought in in February 1915, with an initial production reported at about 15 barrels a day, with the prospect of an increased flow. At this time other tests were being carried out at San Giovanni, and at Pilso, near Gaeta.

According to statistics taken from the *Rivista del Servizio Minerario*, the production in 1915 amounted to 6105 metric tons,[1] a slight increase on 1914. In 1916 the production amounted to 7035 metric tons, and in 1917 it was estimated at 7000 metric tons.

ZANTE.

The tar-wells of Zante, mentioned by Herodotus and other ancient writers, are situated near the south coast, in the Keri valley. The chief well is at the present time a shallow excavation of irregular oval form, about 8 feet by 5 feet in dimensions, filled with clear water to a depth of about 18 inches. The stones at the bottom are covered with a layer of viscid, black petroleum, and there is a constant formation of bubbles of gas, accompanying the upward flow of water. This action is said to be most energetic at the approach of earthquakes. The air in the neighbourhood is strongly impregnated with the odour of petroleum, and the surface of the sea is stated to be covered at times with a film of oil extending up to the coast of Greece. Near the wells, on both sides of the valley of Keri, are deposits of tar, which the country people amuse themselves by lighting. The material is collected by the fishermen, and used in pitching their boats.

Repeated attempts have been made to secure a commercially-valuable yield of this petroleum by boring, but all have proved futile, the frequency of earthquakes in this region having, apparently, so shattered the limestone in which the oil originally existed, as to have caused the loss of all but an insignificant and widely-dispersed residuum.

A specimen of the oil, collected by the author during a visit to the island in 1890, had a density of 1·02, while the oil since obtained by the boring operations, a specimen of which the author has also examined, has a specific gravity of 1·006. Both samples were of black colour, of tarry character, and had very little odour.

In 1901 a geological survey of part of the island of Zante, principally in the vicinity of Port Keri and the Pitch-Wells, was carried out by Mr. W. H. Dalton, F.G.S., late of the Geological Survey of England, on behalf of the author, and Mr. Dalton wrote as follows:—

"As to the probable upshot of drilling, prediction in a virgin field is impossible. All that can safely be asserted is the presence of petroleum, not only in the vicinity of the historic springs, but along a belt of rocks some hundreds of feet in thickness, and three or four hundred yards in width, along the Marathias shore to beyond Cape Daphnais, some two miles south of Port Keri, and along a similar belt for many miles inland northward. The evidence,

[1] 1 metric ton, crude = 7·1905 barrels.

as far as it goes, justifies full and proper trial by boring, but the somewha speculative character of the result must not be ignored."

As the outcome of this survey, drilling operations were carried out by the London Oil Development Company (1902), Ltd., in which Messrs. M. Samuel and Co. were interested. In the second of the two wells drilled oil was struck at 460 feet in small quantities. At 490 feet there were still traces of oil, which was reported to be of better quality than that first found. At 650 feet the report was " No traces of oil at present, but gas increasing." The well was carried considerably deeper, and traces of lighter oil were met with, but the work was discontinued in June 1905, the reason given being that the strata below 1250 feet was so broken up by the action of earthquakes as to preclude the probability of finding oil in commercial quantity.

A sample of the oil analysed by the author had a specific gravity of 1·019 at 60° F., and a flash-point of 276° F.

GERMANY. (Plate 4.)

The earliest mention of petroleum in Germany is in the year 1436, when petroleum from the Tegernsee district of Bavaria was employed under the name of " St. Quirinus's oil " as a medicinal preparation.

One result of the Great War has been the restoration to France of the oil-fields of Alsace. Accordingly, the description of those fields, which in the previous edition of this work appeared under the heading of Germany in the General Historical Account of the Petroleum Industry, will now be found under that of France. With the loss of Alsace there remain only two groups of oil-territories, viz.:—(1) Wietze, Steinförde, Oelheim, and elsewhere in Prussia, and (2) the Tegernsee district in Bavaria.

In **Prussia** (see Plate 4) the existence of petroleum has been known since the middle of the sixteenth century. In 1889 drilling was introduced in the Wietze-Steinförde district, and oil was found in sufficient quantity to be of commercial value. In 1894 the average production was about 40 barrels daily, and one well was reported to have yielded, for a short time, at the rate of 250 barrels a day. A sample of the oil, taken by the author from a well which was stated to be yielding about 20 barrels daily by pumping, was found to have a specific gravity of 0·951 at 60° F., a flashing-point of 200° F., by the Abel test, a cold test of 15° F., and a viscosity (taking that of rape oil at 60° F. as 100) of 986·6 at 70° F., and of 67·56 at 140° F., as determined by the Redwood viscometer.

A good deal of work has been done in the Oelheim field, and in 1881 there were here twelve wells, producing 1250 barrels of oil a week from an area of about 20 acres. Great difficulty was, however, experienced in excluding water from the wells, and in 1886 the production had declined to 60 or 70 barrels a day. Subsequently the wells yielded far more water than oil, and could not be profitably pumped.

In 1897 there were 80 wells in operation, each yielding on an average 20 barrels a day. In 1899 wells were sunk to depths of from 140 to 200 metres, and a more abundant supply reached, as much as 400 barrels a day being obtained from a single well. The oil was of a dark reddish-brown colour, with a specific gravity of 0·930, and was rich in lubricating oil. In 1901 the Celle-Wietze Petroleum Producing Company drilled yet deeper and found another oil-bearing stratum containing oil of a greenish colour, with a specific gravity of 0·890.

From that time the production in the Hanover district increased rapidly, and in 1904 was over 67,000 tons. In that year, out of sixty wells drilled in the Wietze field, twenty-eight were producing, the depth of these wells ranging from 450 to 1400 feet. A great increase in production took place in 1907, and continued in 1908, the total annual production in Prussia in 1908 and 1909 being over 113,000 tons.

According to the reports of the United States Geological Survey, the production of petroleum in Germany increased slightly between 1909 and 1912. In 1913 there was a very slight decrease. After this date it was impossible to obtain any trustworthy statistics.

GREAT BRITAIN.

In England, attention was directed to the petroleum and bituminous deposits of certain districts at an early date. In 1667 Thomas Shirley (*Phil. Trans.*, ii, 482) mentioned the escape of an inflammable gas from water in a spring near Wigan, and in 1739 Dr. Clayton (*Ibid.*, xli, 59) described the same or an adjacent spring. Mr. Shirley dammed off the water, and found that the gases escaping from the earth at that place could be ignited by a candle, and that the flame burned to a height of a foot and a half. The flame was found " not to be discoloured like that of sulphurous bodies, nor to have any manifest smell with it." Dr. Clayton referred to the locality as a " ditch two miles from Wigan in Lancashire, the water in which would seemingly burn like brandy, the flame being so fierce that several strangers boiled eggs over it." Noticing the proximity of coal, Dr. Clayton distilled some of the coal and, with the " spirit," he filled " a good many bladders . . . almost as fast as a man could have blown them with his mouth, and yet the quantity of coals distilled was inconsiderable." Camden, in his *Britannia* (ed. 1722, p. 971), also describes this place thus:—" Within a mile and a half of *Wiggin*, is a well: which does not appear to be a spring, but rather rain-water. At first sight, there is nothing about it which seems extraordinary; but upon emptying it there presently breaks out a sulphurous vapour, which makes the water bubble up as if it boyl'd. When a Candle is put to it, it presently takes fire, and burns like brandy. The flame, in a calm season, will continue sometimes a whole day, by the heat whereof they can boyl eggs, meat, &c., tho' the water itself be cold. By this bubbling the water does not increase; but is only kept in motion by the Halitus of the vapours breaking out. The same water *taken out* of the Well, will not burn; as neither the mud upon which the Halitus has beat [*Phil. Trans.*, N. 26]; and this shews, that it is not so much the *water* that takes fire, as some *bituminous* or *sulphureous* fumes that break out there."

Dr. Plot, in a " Discourse on the sepulchral lamps of the Ancients " (*Phil. Trans.*, xiv, 806, 1684), says, that at " Pitchford, in Shropshire, there is a naphtha or liquid bitumen that constantly issues forth with a spring there and floats on the water." The late Mr. Topley and the author, in the year 1894, inspected this spring, which is in the grounds of Pitchford Hall, and collected a small quantity of semi-solid bitumen from the surface of the water.

Martin Eele (*Phil. Trans.*, xix, 544, 1697) states that " in Brosely, Bently, Pitchford, and other places adjacent in Shropshire, there lies over most of the coal pits or mines a stratum or layer of a blackish rock or stone of some thickness, which is porous and contains in it great quantities of bituminous matters." Eele describes the separation of the tar by treatment with boiling water, and the distillation of the stone for obtaining " an oil which may be used for oil of Petre or turpentine, and has been used by divers persons in aches or pains." In conjunction with T. Hancock and W. Portlock, this observer obtained a patent (dated 1694, No. 330) for "A way to extract and make great quantities of pitch, tarr, and oyle out of a kind of stone."

The petroleum of Pitchford acquired considerable celebrity, for we read in Rees's *Cyclopædia* (1819, article "Bitumen") that the sandstone strata of this district are saturated with it, and that the oil obtained by distillation was sold at that time as "Betton's British Oil" for curing strains and rheumatism. The following reference to Pitchford occurs in Camden's *Britannia* (ed. 1722, 649):—"A little village call'd *Pitchford,* which formerly gave name to the ancient family of the Pitchfords, is now the possession of the Otelies. Our ancestors gave it the name of *Pitchford* from a spring of *pitchy* water; for in those days, they knew no distinction between *pitch* and *bitumen*. And here is a well in a poor man's yard, upon which there floats a sort of liquid *bitumen,* although it be every day scummed off: after the same manner as it doth on the lake *Asphaltites* in *Judaea,* and on a standing pool about *Samosata,* and on a spring by *Agrigentum* in Sicily; but the inhabitants make no other use of it than as pitch. Whether it be a preservative against the Falling-sickness, or be good for drawing and healing of wounds (as that in *Judaea* is), I know no one yet that has made the experiment. Here, and in the adjacent places, there lies over most of the Coal-pits or Mines, a *Stratum* or layer of blackish rock, of which, by grinding and boiling, they make pitch and tar, and from which also a kind of Oil is distill'd."

The same authority gives interesting descriptions of other deposits. Referring to Fife (p. 1232), he says:—"After this, upon the shore, is Dysert, situate on the side of a rising ground, with an open heath of the same name stretch'd out before it. Here is a good large place, which they call the *Coal-plot,* that hath great plenty of an earthy Bitumen, part whereof (ann. 1607) is on fire, not without damage to the neighbours." (Mr. Cunningham Craig is doubtful whether this connotes the occurrence of petroleum, as the Dysart Main Coal and other seams crop out on the foreshore and inland.)

In his description of Lancashire (p. 969), he speaks of—"Formby, where, in the mossy grounds, they cast up *Turves,* which serve the Inhabitants both for fire and candle. Under the turf there lies a blackish dead water, which has a kind of oily fat substance floating upon it."

Dr. Black (*Lectures on Chemistry,* 1803, ii, 377) records that a hard variety of bitumen was discovered in sandstone in cutting a level to a coal-mine on the bank of the Severn, and that St. Catherine's Well at Liberton yielded petroleum more than a century before his time.

A variety of bitumen, known as "mineral indiarubber," on account of its elastic properties, was found at an early date in the Odin Mine, near Castleton, Derbyshire, and was called *elaterite* by Hausmann (Aikin's *Dictionary of Chemistry and Mineralogy,* 1807, Article "Bitumen").

A considerable number of other districts where petroleum similarly occurs are known, and although it has been suggested that some, at least, of the deposits may have been produced, by a natural process of distillation, from coal or bituminous shales, there is no reason to doubt that most of them are true petroleum, and quite distinct from the oils which are obtained by known processes of distillation from either coal or shale.

An intermittent flow of petroleum, mixed with its own volume of water, occurs at the rate of from 70 to 100 gallons daily at the Southgate Colliery, Clowne, near Chesterfield. The rock from which it issues lies at a depth of about 320 yards above the Top Hard Seam of coal, the dip being about 1 in 12 east.

Petroleum also occurs at Worsley, and at Wigan, and West Leigh, in the

Lancashire coal-fields; at Longton, in North Staffordshire; and at Coalbrookdale and Wellington, in Shropshire. In 1874, a small refinery was erected at Cobridge, in North Staffordshire, for treating the oil found in the Mear Hay colliery, the yield being about 5 tons per week. The operations only continued for a few years. In 1811 Dr. Richard Bright (*Trans. Geol. Soc.* (1), iv, 199) described a Liassic limestone in the neighbourhood of Bristol, from which petroleum sometimes exuded. The rock contained large quantities of the remains of crustaceans, corallines, and encrinites. In the same year Mr. Arthur Aikin (*Ibid.* (1), i, 195) described the occurrence of petroleum in the coal-field of Shropshire. He states that the strata are two coarse-grained sandstones, having a total thickness of 15½ feet, but separated by a sandy slate-clay 4 feet in thickness. These sandstones supply the petroleum of Coalport, of which Dr. Prestwich (*Trans. Geol. Soc.* (2), v, 438, 1836) says:—"The well-known tar-spring at Coalport, which had its rise in one of the thick sandstones of the central series, formerly yielded nearly 1000 gallons a week, but it now produces only a few gallons in the same time. In sinking a shaft at Priorslee, the 20-yard rock was so charged with petroleum that the shaft was converted into a tar-well. It formerly yielded 2 or 3 gallons a day. In a pit at the top of the same dingle, petroleum exudes in so great abundance from every crevice in the 'little coal,' and from the shale forming the roof, that the colliers are obliged, in the latter case, to have large plates of iron suspended over them. More rarely, petroleum is found in cavities of the Pennystone nodules."

The occurrence of petroleum below the Broxburn shales has been described by Mr. D. R. Steuart in the *Journal of the Society of Chemical Industry*, vol. vi, pp. 128, 352 (1887).

The indications of petroleum at Down Holland were thus described in 1843 in a paper read by Messrs. Binney and Talbot before the Manchester Geological Society:—"The whole of the moss is in cultivation, either under the plough or in grass, and has been so for at least forty or fifty years, and all, or the greater portion of it, lies at a lower level than the high-water mark of the sea at Formby. On approaching the place where the peat containing petroleum occurs, from Down Holland, the authors soon became aware of its presence by an empyreumatic smell, resembling that yielded by Persian naphtha, and the water in the ditches was also coated with a thin film of an oily iridescent fluid that floated upon its surface. In walking over some oat-stubble fields, and thrusting their heels through the black decomposed peat forming the soil, they felt a hard pitchy mass of 3 or 4 inches in thickness, which yields no smell unless it is burned. On exposure to the atmosphere for a time, the pitchy mass lost the greater part of its inflammability, and was finally converted into black mould. This substance also occurred under the roots of the grass in old swardfields, but it then yielded an odour similar to the petroleum that floated on the surface of the water and pervaded the moist peat."

Attention was again drawn to the subject of the occurrence of petroleum in England, by the reported influx of a considerable quantity of petroleum into a water well at Ashwick Court, near Shepton Mallet in Somersetshire. The circumstances of the case were carefully investigated by the late Mr. Topley and the author, but the discovery, though perhaps of scientific interest, is of no commercial importance. The principal flow of oil into the well occurred immediately after the occurrence of an earthquake-shock in 1892, and it is stated that several barrels of oil were collected at the time. Ashwick Court stands on the higher beds of the Carboniferous Limestone on the northern slopes of the Mendip Hills, the elevation being about 670 feet above the sea. The central line of the Mendips is formed of Old Red Sandstone, reaching to elevations of over 900 feet. From this ridge the strata dip to the north on the northern side, the dip being 50° or more in many places in the neighbourhood of Ashwick. It is not easy to determine the dip of the limestone in the well itself. There are two lines of division traversing the rock; one dips to the north at an angle of from 70° to 80°, and contains red clay, from 1 to 2 inches in thickness, which yields distinct traces of petroleum. In appearance the clay resembles the new red marl of the district, and it has probably been introduced from the surface by the downward percolation of water. Other lines of division—probably joint-planes—dip to the southeast at an angle of from 35° to 40°. The bands of shale with their limestones (the "Upper Limestone Shales"), which occur occasionally between the Carboniferous Limestone and the overlying Millstone Grit, appear to be absent at Ashwick. At Giddy Lane, $1\frac{3}{4}$ miles east of Ashwick, and at Stoke Lane, rather over 2 miles E.S.E. of Ashwick, similar indications also occur.

The oil obtained at Ashwick Court was straw-coloured, transparent, and practically free from fluorescence. It had an odour resembling that of refined, rather than crude, petroleum. Its specific gravity at 60° F. was 0·816, and its flashing-point was about 175° F. (Abel test). When cooled to 28° F., separation of solid hydrocarbons commenced. The oil was found to be free from sulphur compounds.

Wells at Rose Hill, Ruabon, and at Erbistock Lodge, 1000 yards west of Rose Hill, are also contaminated by petroleum. The well at Rose Hill, 35 feet deep, which was examined by the late Mr. Topley and the author, appears to be sunk mainly through red marls, but in the lower 3 or 4 feet the strata are slightly sandy, and from there the water comes. That at Erbistock is said to be 90 feet deep, and the bottom would probably be about 900 feet above the top of the Coal Measures.

In the *Journal of the Society of Chemical Industry*, vii, 701 (1888), will be found a note stating that petroleum had also been discovered in a well at Anderton, Northwich.

In a paper read in November of the year 1911 before the Yorkshire Section of the Society of Chemical Industry, Professor Cohen and Mr. C. P. Finn described a spring of oil found in the Hemsworth Collieries, northeast of Barnsley, which has been flowing for about ten years, though only in small quantities.

Renewed attention has recently been directed to the occurrence of petroleum in England by discoveries at Kelham, near Newark, and in the neighbourhood of London, at Willesden. In the former locality, a flow of petroleum amounting to five or six gallons a day was obtained from a borehole which had been made in searching for coal. The oil, which was met with in porous sandstone at a depth of between 2400 and 2500 feet, was examined by the author, and was found to have a specific gravity of 0·914. It was a moderately viscous oil of dark reddish-brown colour, and had a flash-point of 146° F. It yielded no benzine, and only a little kerosene, but it contained 7 to 8 per cent. of solid hydrocarbons. At Willesden, traces of oil, accompanied by gas, are reported to have been met with at a depth of 1600 feet.

The Government have recently decided to undertake systematic exploration by drilling for petroleum in the United Kingdom, and have appropriated the sum of one million pounds sterling for that purpose. The work has been placed in the hands of Messrs. S. Pearson & Son, Ltd., who have devoted three years to the study of the geological conditions, with a view to the selection of the most suitable sites for wells, and drilling operations have been commenced at Hardstoft, near Chesterfield, and elsewhere.

In the Hardstoft boring oil was struck in May 1919, and the product is evidently a filtered crude, with a greenish fluorescence, calorific power of 20,300 B.Th.U.; specific gravity, 0·8280; sulphur, 0·35 per cent.; 5 per cent. of spirit (aviation); 32 per cent. of kerosene; 31 per cent. of gas-oil, and a residue consisting of a superfine lubricating base, together with paraffin. This residue has a viscosity of 730 seconds at 140° F. and 185 seconds at 200° F. The carbon content is 84·9 per cent. and the hydrogen 14·00 per cent. The author's last official work was the analysis of this crude.

It is reported (September 1920) that one of the two wells put down in Scotland, the D'Arcy bore-hole, has encountered a gas blow estimated to have a volume of 300,000 cubic feet daily at a depth of 724 feet.

The occurrence of **Natural Gas** near Wigan has already been described. It occurs also in Scotland and Wales, as mentioned in the following section. During the construction of the Thames Tunnel inflammable gas was met with in such quantities that it exploded on coming into contact with the lights used by the workmen. Natural gas is mentioned also in Mr. H. Willett's 13th Quarterly Report of the sub-Wealden Exploration, 1875, as occurring at Netherfield. But it is at Heathfield, in Sussex, that the chief source of it, as at present discovered in Great Britain, is found. Here it was first discovered in the year 1893, in a borehole sunk for water in the yard of the Heathfield Hotel, close to the Heathfield Railway Station, at a depth of 228 feet. As no water was found, and the gas was considered dangerous, the well was sealed. In 1896 the London, Brighton, and South Coast Railway Company made another boring for water near the mouth of the tunnel about 100 yards distant from the former one. At a depth of 312 feet gas was met with in considerable quantities, and, becoming ignited, a flame sprang up some 16 feet high. The bore was carried to 377 feet, and then abandoned, as no water was found. The well was capped, and the gas utilised for illuminating and heating purposes. The pressure is stated to be about 150 lbs., although about 1000 cubic feet have been used daily since 1896. It is said to be much richer in hydrocarbons than American natural gas, and to burn with a more brilliant flame. Other wells have been bored in the neighbourhood by the Natural Gas Fields of England, Ltd., in which gas is said to have been met with at a depth of 400 feet with a pressure of 200 lbs. to the square inch, and the aggregate output for the year 1904 is officially reported to have been 774,800 cubic feet. In 1909, 236,800 cubic feet were obtained, the gas being used by the East Sussex Gas and Water Company, and to light Heathfield Railway Station. The Home Office returns give the production of natural gas at Heathfield for 1915 as 87,000 cubic feet. In 1916 the production amounted to 85,000 cubic feet, and in 1917 and 1918 there was no alteration.

The manufacture of "tar, pitch, essential oils, volatile alkali," etc., by distilling pit coal, was made the subject of a patent by Archibald, Earl of Dundonald (No. 1291, A.D. 1781), and H. Haskins (Patent No. 619, A.D. 1746) obtained "a spirit of oyl" out of tar by distillation and repeated rectification. Reichenbach, in 1830, found paraffin in the products of the destructive distillation of wood (Schweigger's *Jahrbuch der Chemie und Physik*, xxix, 436–460); and in 1838 Selligue obtained a patent in France for the production of oil by distilling bituminous schist (No. 9467, A.D. 1838). Gesner used lamp-oil distilled from coal, at public lectures in Prince Edward Island, as early as 1846, and patented in 1854 (U.S. patents No. 11,203, 11,204, and 11,205) the production of "kerosene" by distilling "bitumen wherever found."

In 1847 James Young, the founder of the Scottish Shale Oil Industry, commenced working a petroleum deposit in the Riddings Colliery at Alfreton, in Derbyshire, and in 1850 secured a patent (No. 13,292) for obtaining "paraffine oil or an oil containing paraffine, and paraffine from bituminous coals."

In 1853 and 1854 Warren de la Rue obtained patents (No. 1897, A.D. 1853, and No. 2719, A.D. 1854) for preparing paraffin, etc., from petroleum. His process was formerly worked by Price's Patent Candle Company and Messrs. Chas. Price & Co., who operated on the "Rangoon oil" imported from the Yenangyaung district of Upper Burma.

A white or yellow waxy substance found from time to time in some of the Irish (and Scotch) bogs received the name of "bog-butter" or butyrellite, and was so described as a mineral in Dana's *System of Mineralogy*, 5th edition. Professor W. I. Macadam, however, submitted samples to chemical analysis, and obtained results demonstrating that the substance, if not ordinary butter, was of similar composition. In a paper giving the results of his experiments (*Mining Magazine*, vol. vi, p. 175, 1885), he thus sums up the evidence:—

"Taking all the above results into consideration, I am decidedly of opinion that Butyrellite has no claim to be called a 'mineral,' or to appear in text-books of mineralogy. The fact that a large number of the samples of this substance were found, and still exist in barrels, and can be seen by anyone who takes the trouble to visit the Museum of Antiquaries of Scotland, Edinburgh, or the Dublin Museum, or the Belfast Museum; that samples have been wrapped in cloth, or bearing the marks of woven cloth, with rushes or other plant fibre; that the substance is only found in peat bogs (noted for their powers of arresting decomposition): and, lastly, that tradition speaks of the butter-dyke or butter-safe being dug in bogs, all point to the material being of veritable animal origin, and having nothing in common with the mineral kingdom.

"But outside all this mass of evidence, chemical, circumstantial, and traditional, the butter—for butter it is—has its own story to tell. One and all of these samples, on being broken across, or, better still, when treated with ether, yield to the observer a number of hairs, which on being examined under the microscope can be readily identified as resembling in all respects cow's hair, and in one case at least the very same bog has furnished not only bog-butter, but heads of oxen—these heads having still attached to them hairs exactly corresponding to those embedded in the butter.

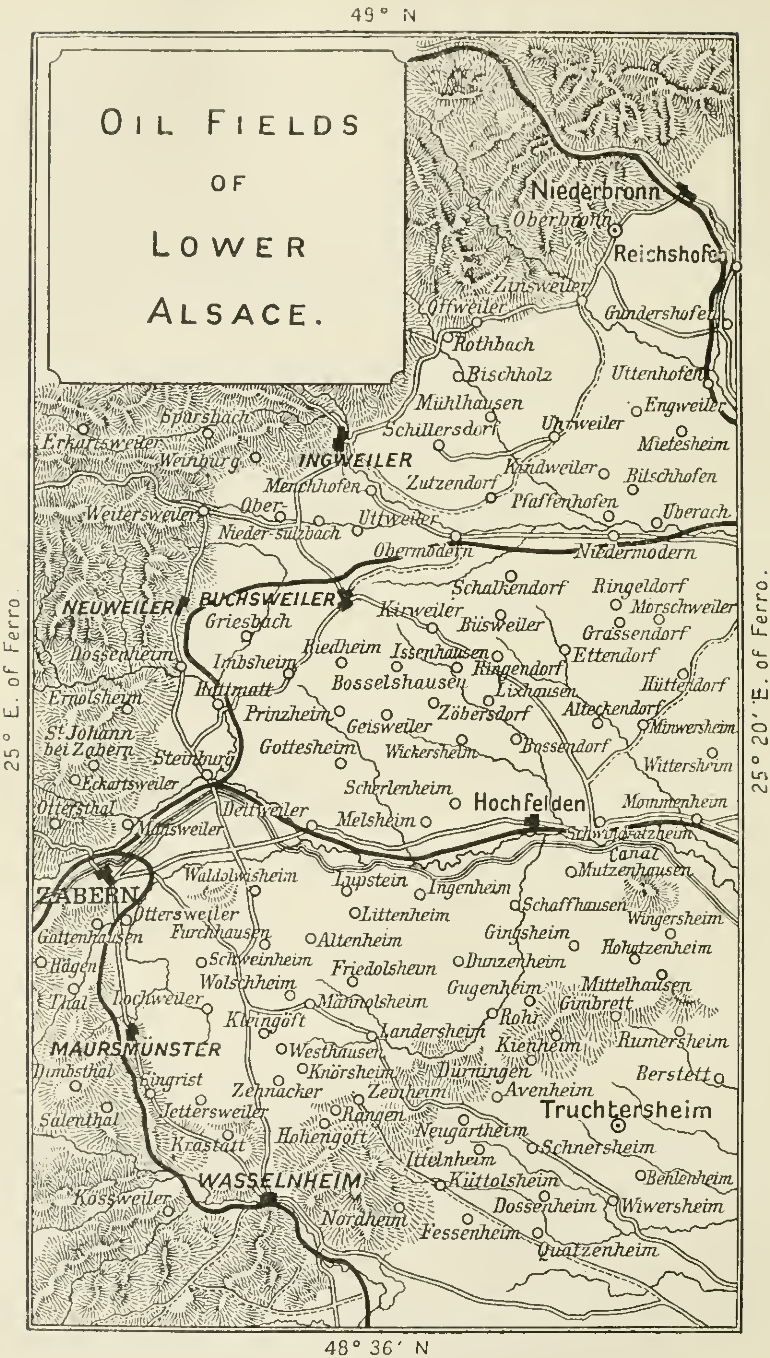
"As to how these kegs and masses of butter found their way into the positions from which they are now obtained we cannot here discuss; it is sufficient for our purpose to show that the material is not of mineral or even of resin origin, but of undoubted animal derivation. The material should therefore be erased from mineral lists."

FRANCE and SWITZERLAND.

In France and Switzerland, although petroleum and bitumen have been known to exist in many localities for at least two centuries, being mentioned in the *Mém. Acad. Paris* as early as 1715, no commercially profitable deposits of oil have yet been found, except in Alsace.

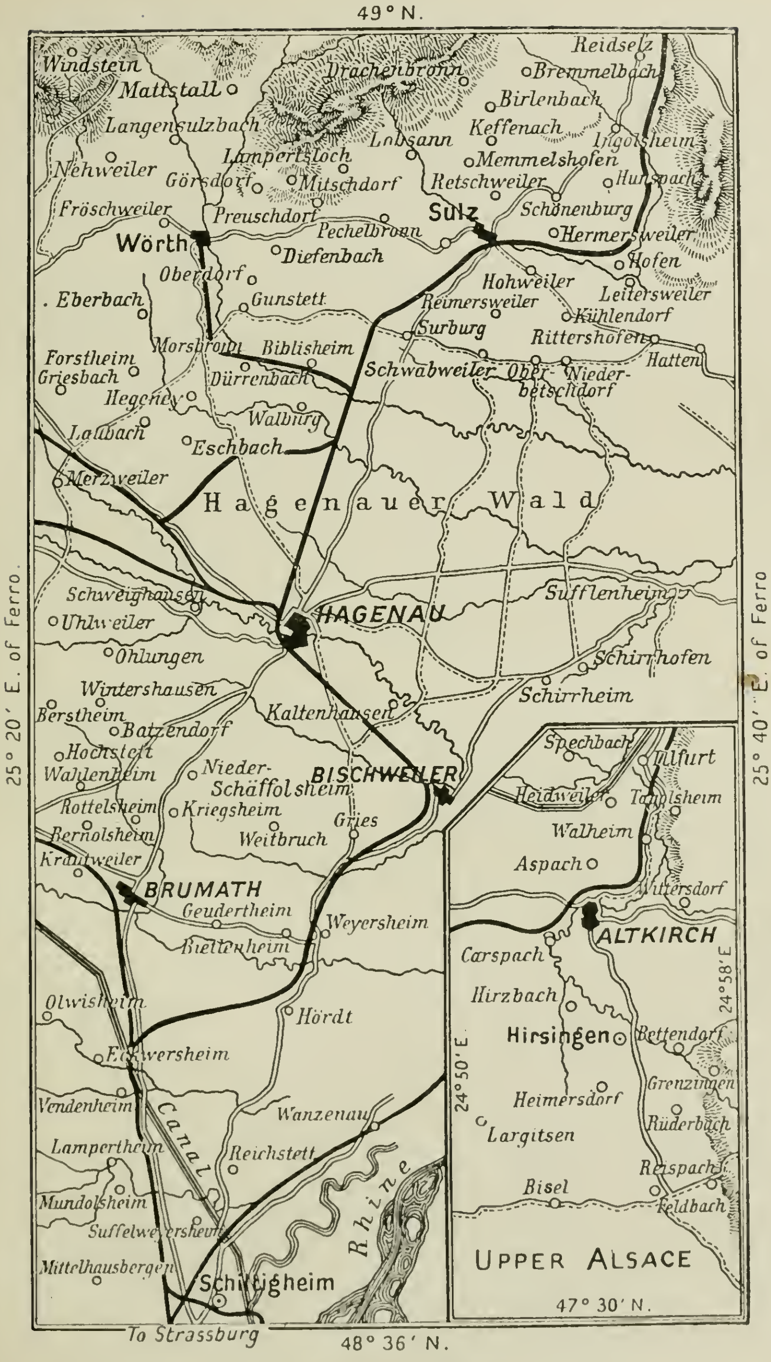
The oil-fields of Alsace include Lobsann, Pechelbronn (*pech*=pitch), Schwabweiler, and elsewhere in the neighbourhood of Hagenau (16 miles north of Strasbourg), in Lower Alsace, including Altkirch (20 miles westward of Basle in Upper Alsace)—see fig. 2.

These fields were by far the most important in Germany, apart from their possessing much historical interest. The petroleum of Pechelbronn (see fig. 2) was discovered in a spring in 1498, and was skimmed off the water and used by the peasantry as a lubricant and in lamps. In 1735 Dr. Eryn von Erynnis



Scale = 1 : 250,000

FIG. 2.



Scale = 1 : 250,000.

Fig. 2.

detected the outcrop of oil-sand 150 metres from the spring, and distilled the oil from it in a small cast-iron retort. In 1745 a formal concession was granted by Louis XV to M. de la Sablonnière, who had bought Dr. Erynnis's rights, and proved the ground by several borings, erecting also a small refinery. Operations on a large scale were delayed till 1785, and from that time to 1870 the bituminous sand was systematically mined by shaft and gallery, and the oil extracted by displacement with boiling water, but, losing its volatile elements by evaporation in the process, the product was a viscid, barely-fluid tarry substance. Gas-discharges had caused several accidents, and with the increasing depth of the mines, fluid petroleum appeared. For the next decade, work consisted in removing oil and sand from the galleries and shafts of the mines. In 1881 boring was introduced, the Fauvelle (water-flush) system being employed, as giving satisfactory results in the soft strata encountered. The wells in many cases overflowed, yielding large quantities of oil, generally with 30 to 50 per cent. of water. In some of the wells much gas, with a slight odour of sulphuretted hydrogen, accompanies the oil, but the latter is said to be free from sulphur-compounds. The yield generally continues for several years from each well, with but slight diminution, and the mining process was finally abandoned in 1888. On the property there is a refinery of considerable capacity, part of which is modern, and the usual commercial products are manufactured there.

On the adjoining concessions of the Alsace Petroleum Company, drilling was commenced in 1889, and subsequently the Canadian system was successfully introduced, the impervious clays making it easy to shut off the surface-water completely. The Company erected a refinery at Biblisheim for the product of the wells in that commune, in Oberstritten adjoining it on the east, and in Ohlungen and Uhlweiler, 12 kilometres southwestward. The Schwabweiler field, 7 kilometres east of Biblisheim, had a brief period of prosperity under the old system of mining the oil-charged sands, but with the thinning away of the lenticular beds this came to an end in 1883, and subsequent borings proved fruitless. Equally short-lived were operations in the Altkirch district of Upper Alsace, from 1782–1785 and 1817–1820.

Pari passu with the direct production of petroleum, operations, commenced in 1785, have been carried out in the asphaltic limestone and sandstone of Lobsann and Kleeburg, northwards of Pechelbronn, the rock being distilled for illuminating and lubricating oils.

The belt of asphaltic rock lies close to the foot of the Vosges Mountains, and in consequence of the steep slopes which are everywhere prevalent, the outcrop of the nearly horizontal asphalt series is comparatively narrow, and it is followed under the thick superjacent clay by adits, the original shafts serving for ventilation. The impervious cover practically prevents the access of water to the mines, which have not yet been carried back to the older rock which forms the mountain immediately to the northwest.

Dr. Engler states (*Dingler's polyt. Journ.*, cclxvii, 555 and 592: and cclxviii, 76) that the Pechelbronn oil has a specific gravity of 0·878 to 0·885, while that of the Tegernsee district, which otherwise resembles it, has a specific gravity of about 0·812. A specimen of petroleum from the wells at Ohlungen, on the Rudolph concessions near Hagenau, examined in the author's laboratory, had a specific gravity of 0·873, and a flashing-point of 37° F. (Abel test). It contained a very considerable proportion of solid hydrocarbons. The oil, which exhibited very little fluorescence, was of black colour by reflected light, but by transmitted light in a thin layer it was dark brown, and it had neither a strong nor a disagreeable odour.

From information supplied to the author by Mr. J. Berg, in 1902, it appears that there were at that time 248 producing wells in Alsace, with an aggregate output of 24,000 metric tons per annum. The production in 1908 was nearly 29,000 tons, and in 1909 somewhat in excess of that amount.

Production from the petroliferous areas in Alsace-Lorraine has doubtless increased since the beginning of the European war, but neither confirmation of this assumption nor any basis for estimating the magnitude of such increase is available.[1]

The shale deposits of France are of some importance, as is pointed out in the section describing the shale-oil industry, and the celebrated asphalt of the Val de Travers occurs in the Department of Ain.

The petroleum indications at Limagne, Puy de Dôme, have been described by M. Alfred Arbaux (*Notice sur le Pétrole d'Auvergne*, 1890). The plain of Limagne lies between the mountain ranges of Puy de Dôme and Forets, and is watered by the Allier and its tributaries. A trench cut in a field at Limagne is filled with water, on the surface of which oil occurs, especially in summer. Wells have been sunk to depths of 42, 50, 60, and 140 metres. At the greatest depth there was a violent disengagement of gas from a grey marl, so rich in bituminous matter that, when thrown on a fire, it burned briskly with a smoky flame characteristic of petroleum.

The following are the results of an analysis made at the École des Mines, Paris, in 1886, of a sample of very thick "liquid bitumen," said to have come from the neighbourhood of Clermont-Ferrand (Puy de Dôme):—Bitumen, 89·8 per cent.; water, 6·95 per cent.; ferruginous ash, 3·25 per cent.

The deposits of Clermont-Ferrand, Puy de la Poix, Malintrat, and Cœur were also examined by Mr. P. Juncker in 1890. The Tramway Company at Clermont-Ferrand sank a water-well to a depth of 165 metres, and found salt water, with which were associated drops of petroleum. At Puy de la Poix a well was sunk to a depth of 50 metres, at Malintrat to 42 metres, and at Cœur to 60 metres, but the work was abandoned for want of funds.

A sample of liquid bitumen, which was associated with salt water impregnated with sulphuretted hydrogen, was taken by Mr. Juncker at Puy de la Poix. The "bitumen" yielded 52 per cent. of "crude oil." Distillation commenced at 125° C., and was carried to 200° C.

A boring at Macholle, near Riom, was carried down in 1896 to a depth of about 1170 metres. Bitumen was met with in the clay at 638 metres, and a few litres of heavy sulphurous petroleum obtained. At 1115 metres brine and petroleum were found, and a few gallons of oil, of a specific gravity of 0·950, brought to the surface.

SPAIN.

In this country petroleum occurs in several localities. At Huidobro, about 30 miles north of Burgos, numerous surface-indications are observable, and a gallery driven for a distance of 56 metres into the side of a hill has shown the existence of heavy oil in the sandstone which was penetrated. A sample of this oil, examined by the author, was dark reddish-brown in colour by transmitted light, and had a slight and not unpleasant odour. Its specific gravity was 0·921, and its flashing-point 270° F. (Abel test). It contained solid hydrocarbons. Two wells have been drilled here, one of which was carried to a depth of about 500 metres, and traces of oil were met with.

At Conil, near Cadiz, an outburst of petroleum occurred in 1894 at a depth of 40 metres in a shaft sunk for mining sulphur. The oil was mingled with

[1] *United States Geological Survey, 1915.*

water, having a disagreeable, sulphuretted odour, and inflammable gas, also of sulphuretted odour, escaped. The outflow continued for three or four days, and from 15 to 20 litres of the oil was collected. A specimen of this oil, received by the author, was of pale reddish-brown colour, and not unpleasant odour. It had a specific gravity of 0·837, and a flashing-point of 110° F. (Abel test).

In 1907 renewed interest began to be manifested in the various possibly petroliferous districts of Cadiz. Three wells were drilled near Villamartin to a shallow depth, and in subsequent years trial borings were carried out in other parts of the province.

Certain known indications of petroleum in the neighbourhood of Cadiz were examined by the Spanish Government in 1914. In Northern Spain, near Santander, petroleum in small quantities was discovered in a boring which was being sunk for salt.

An account of the occurrence of oil-shale in Spain, and of the steps which have been taken for its utilisation, will be found in the section on the shale-oil industry.

ALGERIA.

The existence of petroleum in Algeria has been known at least since the time of Strabo, who mentions its occurrence at Aïn Zeft, in the Arrondissement of Mostaganem, in the department of Oran.

In 1877 operations were commenced here by driving headings into the outcrop and collecting the oil which flowed out. A considerable quantity of oil was thus obtained, but the difficulty pertaining to such a method of working, and other reasons, led to the abandonment of the attempt.

From an official report made in 1881 by M. Baille, ex-Chief Government Mining Engineer for the Province of Oran, it appears that a heading driven into the hillside at Vieux Jardin passed through grey, blue, and blackish marls and a vein of sulphur, into a stratum formed of blocks of gypsum cemented together by a blackish marl. M. Baille estimated that 56 cubic metres of petroleum had flowed out during the eighteen days preceding his visit, and states that there was then 238 cubic metres of crude petroleum stored in reservoirs at the springs, and 150 cubic metres at Djidiouia, where a refinery existed. In 1887 M. Jules Delecourt-Wincqz, Ingénieur Conseil de la Compagnie Internationale de Recherches des Mines et d'Enterprises de Sondages, et Secrétaire de la Commission des Mines, Bruxelles, reported on the property and recommended its development by modern methods. In 1891 the district was examined by the author, and subsequently reported upon by him in consultation with the late Mr. William Topley, F.R.S.

In 1892 some trial-borings were made. In one oil was struck at 420 feet, and gas occurred at 680 feet, but neither was considered of value, and at 975 feet the boring was abandoned, as were also others which were put down in the same locality. In 1895, however, a well drilled to the depth of 1348 feet was more successful, and oil is said to have been obtained to the amount of about 7000 litres a day for a time, but subsequently the yield was only about 1600 litres a day. The productive series along the Dahra range consists of alternations of marl, clay, etc., with bands of gypsum, alabaster, and limestone. A thin band of sulphur also occurs, and can be traced from Aïn Zeft to above Vieux Jardin. Above the marls in which the petroleum is found, there appears to be an impervious bed of hard blackish marl about 5 metres in average thickness. A sample of the oil obtained at a depth of 12 feet was examined by the author. It was of a very dark brown or brownish-black colour, had a sulphuretted odour, a specific gravity of 0·921 at 60° F., and a flashing-point of 60° F.

(Abel test). It ceased to flow at 32° F., and was found to contain about 5 per cent. of solid hydrocarbons. A company was formed to work these deposits in 1902, and drilled a well to the depth of 1550 feet. At 1400 feet oil was found which rose 1000 feet in the borehole.

At Port-aux-Poules, near Arzeu, are further evidences of petroleum. Off the fishing port of Port-aux-Poules, about 2½ or 3 miles out at sea, the author observed gas, which had the characteristic odour of petroleum, rising through the water. Drilling operations have been carried on in this neighbourhood, but oil has not yet been found.

According to a report published in 1894, a borehole 10 centimetres in diameter was drilled by M. Lâiné in the valley of Oued-Ouarizane, to a depth of 74 metres. During the progress of the work several springs of water were struck, and at the depth stated, the water, which had a temperature of about 40° C., spouted intermittently to a height of more than 15 metres above the top of the casing. The outflow resembled an intermittent geyser, and was accompanied by the emission of much gas, which, on being ignited, " burned with an immense flame."

In the province of Constantine, about 25 miles north of Aïn-Beida, oil has also been discovered, and in places bitumen oozes from the rocks.

The Algerian Oilfields, Ltd., was formed in 1910 to acquire a French Government concession to work a petroliferous area of 20,000 acres in the Relizane district, Department of Oran. The author examined samples of crude petroleum yielded by two wells which had been drilled in this field, and reported that in both cases he found the oil to be of unusually high quality. The oils were very mobile, had a dark reddish-brown colour by transmitted light, and had a pleasant benzine-like odour. Sample marked " 100 " had a specific gravity at 60° F. of 0·820, and a flash-point of 50° F. It contained 0·15 per cent. of sulphur. The percentage of commercial products by weight is given in the following table:—

	Per cent.
Benzine,	7·3
Kerosene (Sp. Gr. 797, F.P. 73° F.	60·3
Intermediate and heavy oils,	29·4
Solid hydrocarbons (paraffin),	2·0
Coke,	1·0
	100·0

The burning quality of the kerosene was excellent, and in practice a yield of 70 per cent. of this product of sufficiently good quality might be obtained.

Owing to the war, active operations were suspended during 1914 on the properties of the Algerian Oilfields, Ltd.

On 1st June 1916 the properties of the Algeria Consolidated Estates, Ltd., consisting of Government leases over oil-bearing properties in the Tliouanet district, were transferred to the Société Algerienne des Pétroles du Tliouanet, in order to comply with legal requirements. Three wells have been drilled at Nehma, two of which are producing. Two additional wells were also being drilled at the end of 1916. The wells drilled in the Beni-Zentis district resulted in the completion of a well which produced 8 to 9 tons of oil a day in May 1917.

EGYPT. (Plate 1.)

The oil-deposits of the Red Sea, known from time immemorial, as the Roman name, *Mons Petrolius*, connotes, have excited fresh interest of late years.

Some thirty years ago, the explorations of M. de Bay indicated the occurrence of workable deposits at Jebel-Zeit, on the western borders of the Red Sea, about 160 miles from Suez, and at Gemsah, 13 miles south of Jebel-Zeit, and Dr. Tweddle was engaged by the Egyptian Government to drill wells, which, however, gave no satisfactory result. The deposits have been reported upon by Mr. H. L. Mitchell (*Ras Gemsah and Gebel-Zeit: Report on their Geology and Petroleum*, 1887) and Colonel C. E. Stewart (*Report on the Petroleum Districts situated on the Red Sea Coast*, 1888) for the Geological Survey of Egypt.

An instructive geological report on the oil-fields region of Egypt, by Dr W. F. Hume, Director of the Geological Survey of Egypt, was issued by the Ministry of Finance, Egypt, Survey Department, in 1916.

Colonel Stewart quotes the following record of the strata perforated by a well (No. 2), drilled by the American system to a depth of 2120 feet, at Gemsah:—

1. Gypsum.
2. Indurated limestone.
3. Bluish-drab clay; sulphurous.
4. Gypsum.
5. Limestone, with sulphur.
6. Bluish-grey marl; sulphurous.
7. Dark brown indurated limestone, with a little petroleum.
8. Bluish-grey indurated limestone, with traces of petroleum.
9. Blue clay, with gypsum specks and nodules; some traces of oil.
10. Gypsum, with some asphalt.
11. Very dark fine grey sandstone at 740 to 760 feet; no petroleum.
12. Gypsum.
13. Blue clay, with petroleum.
14. Gypsum, with petroleum.
15. Light-coloured gypsum, sometimes highly indurated, approaching alabaster in character; more or less impregnated with petroleum and gas.

Petroleum oozed into the borehole at several points between 975 and 2012 feet, the flow being greatest at 1310 feet. There was no sign of oil at the depth at which boring ceased, but gas was found. No. 1 gave a somewhat similar section, but was only 370 feet in depth. Ozokerite was found in layers at 265 and 370 feet.

The petroleum from Gemsah and Jebel-Zeit has been examined by Weil (*Mon. Sci.*, xix, 295, 1877), Irvine (*Journ. Soc. Chem. Ind.*, vi, 130 and 276, 1887), and Kast and Künkler (*Dingler's polyt. Journ.*, cclxxviii, 34, 1890). The last-named report that it is a dark brown oil of specific gravity 0·935, yielding on distillation products of disagreeable odour, containing sulphur compounds. It furnishes a good lubricating oil, but practically no kerosene.

M. Pappel, of the Khedival Laboratory, Cairo, has reported on two samples of Egyptian crude oil, which had respectively a specific gravity of 0·908 and 0·933. The first was very fluid and possessed but little smell. A sample of crude Egyptian petroleum, examined in the author's laboratory, had a specific gravity at 60° F. of 0·945, a flashing-point (close test) of 146° F., and a viscosity of 173·0 at 70° F.

In 1905, the Egyptian Petroleum Company, Limited, was formed to acquire and work a licence from the Egyptian Government to prospect for petroleum in the neighbourhood of Gemsah, and in 1907 the Egyptian Oil Trust, Limited, was registered to take over the former Company's rights. Two productive wells having been successfully drilled on the shore of the Gulf of Suez, the Red Sea Oil Fields, Limited, was formed in 1910 to take over from the Egyptian Oil Trust, Limited, an area of 50 square miles on which the wells referred to are situated, and continue the drilling operations. The work of the two companies has been attended with continuous success, a number of highly productive wells having been drilled. The first met with a prolific oil-sand at the depth of 1290 feet early in 1909, while No. 2 also began to flow from a somewhat greater depth (1644 feet) in October of the same year. In July 1910 well No. 4 commenced to flow from a depth of 1720 feet, yielding 285 tons of oil and 30 tons of salt water in twenty-four hours, and well No. 6 was reported as "a gusher" at the depth of 746 feet.

In 1911 the Anglo-Egyptian Oil Fields, Limited, the management of which is vested in the Anglo-Saxon Petroleum Company, Limited, was formed to take over the properties and rights of the Egyptian Oil Trust, Limited, and the Red Sea Oil Fields, Limited. Since that time the development of the Gemsah field has been actively continued, and drilling operations outside that area have resulted in the important discovery of a more productive field at Hurghada, which lies to the south of Gemsah (see plate 1). In October 1914, oil was struck in well No. 1 at Hurghada, at a depth of 1670 feet, and well No. 7 in that field was completed in December 1915. The progress of oil-production in Egypt is shown by the following figures:—

Crude Oil Production.

Year.	Tons.
1911,	1,220
1912,	27,454
1913,	12,618
1914,	103,605
1915,	34,961
1916,	54,800
1917,	134,500

For some time past the reported production of the Gemsah field has only averaged about three tons a day, the output given above having chiefly been from the Hurghada field. At Gemsah, Hurghada, and Suez there are storage-tanks, with an aggregate capacity of about 100,000 tons. The crude oil is converted into commercial products in a refinery at Suez, with a capacity of 1200 tons a day, which was built in 1912. The refinery is connected with Port Tewfik, 2½ miles distant, by four pipe-lines.

Drilling operations have also been carried out on the adjacent islands (see plate 1), and on the Sinai Peninsula, but, so far, without results of industrial importance.

Five wells have been drilled on the island of Jubal, four of which are reported to have encountered granite after penetrating the gypsum and limestone beds. The deepest well is 1800 feet, and in two wells the limestone exhibited traces of oil.

Two wells have been sunk on Gaysum, one on Um el Heimet, and one on Ranim Island, the deepest being one on Gaysum, which was carried to a depth of 2668 feet. None of these borings penetrated the salt and gypsum beds. (A. Beeby Thompson.)

FARSAN ISLANDS.

There are reported to be extensive emanations in the Farsan Islands, off the Arabian coast of the Red Sea, about 17° N. latitude.

PERSIA. (Plate 7.)

In Persia the existence of petroleum springs has been recorded by various writers from the time of Herodotus. One of the most celebrated of these springs was at Kirab, as already mentioned on page 2.

The petroleum of Persia has been very fully described by Ritter in *Die Erdkunde von Asien*, vols. vii-ix, 1837–1840.

The petroleum-deposits of Persia extend in a general southeasterly direction from the Turko-Persian frontier, about 100 miles north of Bagdad, to the Persian Gulf.

Some experimental boring was carried out many years ago by the Persian Bank Mining Rights Corporation at **Daliki**, on the Persian Gulf, 35 miles from Bushire. In this locality petroleum, in various states of consistency, is found, both on the surface and at different depths. In a well sunk to a depth of 124 feet, the principal strata pierced were alternations of sandstones and "rock," with blue clay, and black semi-solid bitumen was encountered, together with small quantities of liquid petroleum. Two samples of the oil from Daliki, which is collected from the warm springs and sold by the natives, were examined by the author. One sample was viscid and dark brown in colour, and, like the water with which it was associated, possessed a strong odour of sulphuretted hydrogen. Its specific gravity was 1·016, its flashing-point (Abel test) was 170° F., showing that it contained none of the more volatile hydrocarbons, and its cold test was 45° F. The other sample consisted of a dark brown, semi-solid, bituminous mass, resembling some descriptions of crude petroleum which have had a lengthy exposure to the air. Its odour resembled that of the first sample, but was less marked.

Indications of petroleum are also found on the island of **Kishm**, in the Persian Gulf, where the same company bored without result. The oil-territory here is situated about 2 miles inland from the southern shore of the island, between Salakh and Namagdan, in an extensive basin. The island contains several gentle domes, with dips varying between 5° and 30°, mostly with axes parallel with the general trend of the island. The friable rocks at the top of the island have been so denuded as to form a crater-like basin, in the lower portion of which the oil indications occur. The lowest oil-bearing stratum is a greyish-green sandstone.

A sample of oil from Kishm, examined by the author, had a not unpleasant odour, and possessed a brownish-red colour by transmitted light. Its specific gravity was 0·837, and its flashing-point (close test) was 190° F.

In the course of recent surveys, specially favourable indications were found in two districts, one at Zohab, in lat. 34° 18′ N., long. 45° 55′ E., and the other near Shuster and Ahwaz, on the Karun River, at the head of the Persian Gulf, in lat. 31° 36′ N., long. 49° 22′ E. Near Kasr-i-Shirin, in the **Zohab** district, a number of shallow pit-wells were seen, which are said to have yielded oil for the past forty years in undiminished quantity. The crude oil collected from these wells is transported to Kasr-i-Shirin, where it is subjected to a primitive process of refining, the local demand in the surrounding villages and along the main caravan route as far as Kermanshah being thus met. According to report, the petroleum springs of this region have been commercially worked for the past three hundred years. In 1903–1904 two wells were drilled at Tchiah Sourkh, near Kasr-i-Shirin, by an English company, under a concession held by Mr. W. K. D'Arcy. One of these was completed as a productive flowing well at a depth of a little over 800 feet, and the other, at a greater distance from the crest of the anticlinal, reached oil at about 2100 feet. The crude petroleum has been subjected to examination in the author's laboratory. Its specific gravity is 0·815, and it evolves inflammable vapour at common temperatures. Its colour is brown, with strong fluorescence, and it has an agreeable odour, although it contains a small quantity (0·4 per cent.) of sulphur. On fractional distillation it yields, without cracking, 57·6 per cent. of kerosene of excellent quality, nearly water-white in colour, of a specific gravity of 0·792, and a flashing-point (Abel) of 75° F., besides 9·4 per cent. of benzine. It is a crude oil of paraffin base.

The **Loristan** deposits lie between the towns of Shuster and Romez, in lines parallel with the Bakhtiari mountains. The Musjid-i-Suleiman petroleum-springs are situated about 24 miles east-southeast from Shuster. The oil oozes from a bed of grey limestone of Miocene age, associated with gypsum, and containing native sulphur. The three principal springs are said to yield a total of not more than 30 gallons daily of a dark green oil, which is collected by the Seyds of Shuster, who appear to sell it mainly for external use upon camels, as a cure for the itch. The oil is said to have a specific gravity of 0·927, and to yield 27 per cent. of illuminating oil, and 45 per cent. of lubricating oil. The "white oil" springs occur at a distance of 40 miles to the southeast of Shuster. The oil-bearing strata dip at low angles, and the oil oozes from an impure limestone between two thick beds of blue clay. Some pits, dug to a depth of about a yard in the bed of a brook, receive the oil, which collects upon the surface of the water. As much as 34 gallons of oil is said to be obtained from a single pit daily. This so-called "white oil" is of a light straw colour by transmitted light, and is fluorescent. The oil is stated to contain sulphur compounds, but has no offensive smell. Its specific gravity is 0·773. Near the village of Shardin, 8 miles eastward from the town of Romez or Ram-Hormuz, there are said to be at least ten springs of a dark oil, the three principal springs yielding at the rate of 25 gallons daily. In this district there are also deposits of solid "bitumen," varying in thickness from 3 to 30 inches.

Several wells were drilled in this district under Mr. D'Arcy's concession, and in 1909 the Anglo-Persian Oil Company, Limited, was formed to take over the rights.

Active development of the petroleum resources of Persia is being carried out by the Anglo-Persian Oil Company, Limited, in which the British Government acquired a controlling interest in 1914.

The concession of this company covers an area of some 500,000 square miles in Southern and Western Persia. Of this area about 3000 square miles of Bakhtiari country, and a large area on the coast, have been geologically examined.

After preliminary drilling operations at Marmatain, the development of the Maidan-i-Napthun field was undertaken and its productivity proved in May 1908. Concurrently with the subsequent steady development of the Maidan-i-Napthun field the testing of the adjoining Maidan-i-Naftek field was undertaken, and a prolific yield of oil obtained from a depth of 1875 feet.

The total area on Maidan-i-Napthun and Maidan-i-Naftek proved by flowing wells is about 3½ square miles, and it is estimated that on this area between 400 and 500 wells can be drilled at a distance apart of 500 feet. In all cases the wells flow strongly, with high gas-pressure when the oil-bearing horizon is reached, the closed pressures on all producing wells averaging 275 lbs. per square inch, while there are several instances of much higher pressures being recorded on individual wells. In consequence of the difficulty in controlling the flow of the wells when the oil horizon is struck, no accurate estimates have so far been possible of their individual productions when fully opened out.

One of the principal wells in the centre of the Maidan-i-Napthun field, F. 7, the drilling of which was suspended in November 1911, when the source of the oil had been barely reached, and flowed, partly open, 3500 barrels daily until March 1914, when it "drilled itself in," has since produced an average of 10,000 barrels daily, through two 2–3-in. valves, with but slight diminution of the gas pressure. Equally good if not better wells (B. 20 and B. 21) have been obtained at both extremities of the area at present developed.

In 1919 the number of wells partly producing, in order to supply the present refinery requirements of $1\frac{1}{4}$ million tons per annum, is five, and the number of wells drilled, capped, and available for immediate production is fifty.

The depths at which the oil-bearing limestone is found throughout the field are uniform, and in wells where the gas pressure has admitted of deeper drilling, thicknesses of 200 and 270 feet of oil-bearing limestone have been proved.

Test-wells are at present being drilled on favourable structure at Tel Bazun, Sar-i-Naftek, and Gach Khalaj, in the vicinity of the Maidan-i-Napthun field.

All the wells have been drilled on the Canadian system, with steam engines and boilers, but, owing to the scarcity and bad quality of boiler-water, a complete plant is now being installed by means of which all future wells will be drilled by electricity. There are no pumping-wells.

From Maidan-i-Napthun the oil is conveyed by pipe-lines about 145 miles in length to a refinery on the island of Abadan, at the head of the Persian Gulf. One line is 6-inch diameter as far as Wais (53 miles), the remainder of this line being 8-inch from Wais to Abadan. A second line of 10-inch diameter throughout has been laid (1919), and is in operation. These pipe-lines, with one pumping-station, at present transport $1\frac{1}{4}$ million tons of crude oil annually to the Abadan refinery, but additional pumping-stations are now being constructed and pipe-lines are being added which will increase the pipe-line capacity to 4 million tons annually.

The Abadan refinery, which at present produces gasoline, kerosene, and fuel oil, has a crude oil capacity of $1\frac{1}{4}$ million tons annually, but extensions now in course of erection will increase the crude oil capacity to two million tons annually, and, in addition to the products produced as above detailed, these extensions will admit of the manufacture of gas oil, lubricating oil, paraffin wax, and pitch.

The crude oil at present produced and refined in Persia is of high grade. It has a specific gravity of 0·840, and gives the following results on fractional distillation:—

Initial boiling-point,	48° C.
Below 100° C.,	11·0 per cent.
Between 100° C. and 150° C.,	12·3 „ „
„ 150° C. and 280° C.,	29·6 „ „
Residue,	45·6

TURKEY.

Mesopotamia.—The Mesopotamian oil deposits extend for a distance from north to south, through the vilayets of Mosul and Bagdad, of at least 300 miles, with a minimum width of area of about 60 miles. Within this region, stretching from above Mosul, and following the southward course of the Tigris to the same degree of latitude as that of Bagdad, there are countless shallow petroleum pits, or so-called wells, the most important of these, according to a report made in 1907, being at Zakho, on the Khabur, which is a tributary of the Tigris, to the north of Mosul, Kalaat Schirkat, Tel-Kipara, Baba-Gurgar, Kerkuk Guel, Tuz-Khurmatli, Salahiah (Kifri), and Mendeli. On the Euphrates the best known of the oil-springs appears to be that which is situated half a day's journey below Hit. In some places along the course of the Tigris the out-flowing oil is described as forming lakes more than 650 feet in diameter. At Naft Khana, about 16 miles north of Mendeli, the seepages are very extensive, occurring along the crest for a distance of over a mile. At Baba-Gurgur there is stated to be a considerable emanation of inflammable gas. The Tigris oil is described as pale yellow in colour, and as having a somewhat offensive odour. Its specific gravity appears to be in many localities as low as 0·810. On the other hand, Euphrates oil is asphaltic in character, and has a comparatively high specific gravity.

Wherever the conditions are favourable for the local consumption of the product the wells are regularly worked and the crude oil refined on the spot. This applies to the wells at Mendeli, Tuz-Khurmatli, Baba-Gurgur, Kalaat Schirkat, and Zakho.

The petroleum is collected and refined in the following primitive fashion:—Where the surface indications are sufficiently definite to give promise of a supply, a pit is excavated through the overlying deposit of asphalt to a depth and with a diameter of 6 to 10 feet. In this pit the oil gradually collects on the surface of salt water, two to three days being usually sufficient for the formation of a stratum of oil 6 inches in thickness. This oil is drawn off and conveyed in sheep-skin vessels to the adjacent refinery. The refining plant consists of an iron still of a capacity of about 45 gallons, with a vapour pipe communicating with a coil-condenser. The distillation of a charge occupies five to six hours, and three products are obtained, viz. (1) a water-white oil of very low specific gravity, representing about 20 per cent. of the crude oil and containing all the more volatile hydrocarbons ; (2) a further distillate of yellowish colour, representing from 25 to 30 per cent. of the crude oil ; and (3) the residue in the still. The first of these products is sold as first-quality oil, and the second as second-quality oil, for lighting purposes, whilst the third is used as fuel.

There are many extensive deposits of solid asphalt in Mesopotamia, and, especially on the Euphrates, of fluid asphalt.

The occurrence of petroleum at so many points in this large area, and the facility with which the oil has long been collected, is small, but locally valuable quantities, in the manner described, have probably led to an exaggerated estimate of the favourable deductions to be drawn therefrom in forming an opinion as to the potential importance of Mesopotamia as an oil-producing country. Although some geological survey work has been carried out in parts of the petroliferous area at the instance of the German and Turkish Governments, and more recently by British geologists, but little is known of the underlying formation in which any large supplies, if existent, must be searched for, and in these circumstances it is satisfactory to learn that drilling operations have recently been commenced in Imperial interests. Owing to the masking effect of extensive deposits of alluvium, and other unfavourable conditions, the selection of sites for test-wells will be exceptionally difficult, and progress in the work of exploration with the drill should not be expected to be rapid. In the meantime any attempt to forecast the future oil-production of Mesopotamia as compared with that of Persia would be premature.

In addition to the Mesopotamian deposits referred to, indications of the occurrence of petroleum have been found in the western part of the Turkish Empire.

Boring for oil has been carried out at Alexandretta, and near Ganos, Myriofito, and Hora, on the Sea of Marmora, with results which were reported to be of an encouraging character.

INDIA.

Baluchistan.—In Baluchistan, a deposit which promised to be of considerable importance occurs at Khátan, in the Mari Hills, about 40 miles directly east of Sibi Station, on the Quetta branch railway. Borings made in the cold season of 1884–85, by Mr. R. A. Townsend, on behalf of the Indian Government (" Report on the Petroleum Explorations at Khátan," *Records Geol. Surv. India*, xix, 204, 1886), indicated that large quantities of petroleum were obtainable at moderate depths. From the disturbed character of the strata, drilling is extremely difficult ; the conglomerate is fractured in all directions, and through the fissures " the oil finds its way upwards, borne on the top of the warm waters which accompany it ; but while these fractures afford a ready means to the miner of ' striking oil,' they sadly interfere with his progress in boring, as the drilling tool in descending must inevitably enter many of these crevices at an acute angle to their planes, and it is almost impossible to prevent the tendency of the tool to follow the vagaries of such crevices, and thus produce a ' crooked hole,' which is fatal to further progress, unless straightened."

Mr. Oldham thus describes the operations :—" Mr. Townsend visited the place in January 1884, reported favourably on it, was deputed to obtain men and material from Canada, and began work in the cold weather of 1884. All through this cold weather, and well into the hot weather of 1885, work was carried on, and only abandoned on account of the sickness of the staff, sickness which, brought on by hardship, heat, and the want of pure drinking-water, resulted in the death of one of the staff, and very nearly in the death of Mr. R. A. Townsend himself. The result of this first season's work was the sinking of a borehole to the depth of 524 feet, which found oil at 28 feet from the surface, and again at 370 and 390 feet, whence 5000 gallons were raised in thirty-six hours. In the following year a second boring was put down, and between April and July 1886, 27,700 gallons of oil were sent to Sibi, and tried on locomotives of the North-Western Railway. The result of these trials showed that the evaporating power of the fuel was 9·82 lbs. of water against 6·91 lbs. evaporated by Welsh coal, for each pound of fuel. During 1887 the exploratory works were continued, and 1888 opened full of hope. It was believed that the Khátan oil-field was going to supply fuel for the whole North-Western Railway system up to Khanpur or Multan, and it was determined that the oil was to be used on the Khojak tunnel works instead of coal. During 1889 the sinking of wells was pushed on, but though 218,490 gallons of oil were despatched during the year, the beginning of the end was already apparent. The heavy rains of June and July flooded the wells, and reduced the output from 39,000 gallons to 2500. By dint of heavy pumping the water was gradually cleared out, and the yield of the wells slowly improved, till, in June 1890, it reached 20,000 gallons. The rains of 1890 again flooded the wells, and reduced the monthly output once more. Small quantities of oil were produced in the winter months of 1890, but by the beginning of 1891 the wells had ceased to be able to produce more than enough to supply fuel to the works at Khátan. In October 1889 I had been sent to Baluchistan to commence a geological survey of the oil-bearing tracts, and, after spending eighteen months in examining all the regions likely to produce oil sufficiently near the railway for it to be of any value, reported in June 1891 in favour of a final trial at a place called Siah Kach, about 5 miles from Khátan proper, recommending that if this proved a failure, as subsequently proved to be the case, all further expenditure should be stopped. This recommendation was adopted, and after the expenditure of over 5¼ lakhs of rupees, the attempt to work the Khátan petroleum was abandoned. But though the experiment has proved a failure, it must not be rashly assumed that it should never have been tried. The oil-springs of Khátan are separated from the nearest point on the railway by 45 miles of broken and hilly country, barren, except for a few small patches of scanty cultivation on the hill-tops, and supporting nothing but some scattered herds and a sparse population of cattle raiders and cut-throats. Under these circumstances it is evident that only a rich field would repay the cost of opening out, and we will see how far the local conditions were such as to hold out any prospect of a sufficient supply of petroleum to make the experiment worth trying. The Khátan oil-springs are situated at the end of a great bare hog-shaped hill, formed by limestone beds bent into an anticlinal. At its western extremity the crest of this anticlinal bends downwards, and where the valley turns round, the extremity of the hill is much broken up by faults and fissures, from which there flow numerous springs of hot sulphurous water accompanied by a thick, viscid, tarry maltha. Here there is not a porous stratum whose pores could become clogged by inspissated oil, but a compact rock traversed by open fissures, and, moreover, with a constant stream of heated water traversing it and assisting the escape of the oil. Under such circumstances one might have predicted, what afterwards was proved, that there was no large accumulation of oil, and that after what might have accumulated in the fissures near the surface had been pumped out, nothing more of importance would be got. In spite of this, however, the shows are so abundant at Khátan that we may feel sure that an experimental boring to test the value of the oil-beds would have been recommended in any case, and by anyone, though the ultimate cost of the experiment would have been materially reduced had the geological survey of the country preceded, and not followed, the purchase of machinery and sinking of trial boreholes" (*Records Geol. Surv. India*, xxiv, 83, 1891, and *Journ. Soc. Arts*, xlii, 151, 1894).

The Khátan wells were some years ago reported upon by Colonel Conway Gordon, who stated that, at the time of writing, any one of the four existing wells was capable of yielding "the entire supply of 50,000 barrels of oil, which is estimated to be the amount required for the Sind-Pishin section of the North-Western Railway" (*Administration Report on the Railways of India* for 1887–88).

The oil employed as fuel in the construction of the Khojak tunnel was carried a distance of 42 miles to Baber Kuch by camel, and was thence conveyed by wagon tanks to Shelabagh, at the eastern end of the tunnel. According to the *Times of India* (30th September 1893), a Mr. Eady received permission from the Local Government to resume the working, and to sink new wells within a four-mile radius.

The following record of one of the borings indicates the nature of the strata pierced by the drill (Table III):—

TABLE III.—Well Section at Khátan.

Nature of Rock.	Thickness.	Depth.
	Feet.	Feet.
1. Gravel, with boulders and bitumen,	12	12
2. Jointed blue limestone,	20	32
3. Hard, marine conglomerate, with abundance of flint,	195	227
4. Alternating bands of soft, bluish shales and hard flinty limestone with iron pyrites,	30	257
5. Rather hard shale with pyrites,	217	474
6. Dark grey limestone without fossils,	2	476
7. Soft grey shales,	48	524

The Khátan oil examined by the author has nearly the same density as water, and is only separated with difficulty from the water with which it issues from the wells. It is black or very dark brown in colour, and is almost odourless. Owing to the large amount of asphaltum which the oil contains, it is extremely viscous, and at the low temperature to which it would be sometimes exposed, could not be transported by pipe-lines of the usual diameter, with ordinary pumps.

Punjab.—The Punjab oil-springs have been reported upon by several observers. They were described by Mr. A. Fleming (*Journ. As. Soc. Bengal*, xvii, 1848, and xxii, 1853), by Mr. Maclagan in 1862, by Mr. A. Fenner in 1866 and 1869 (*Proc. Punjab Govt. Public Works Dept.*), and by Mr. B. S. Lyman more fully in 1870 (*Reports on the Punjab Oil Lands*, Lahore, 1870). Mr. Lyman reports that the Punjab oil-region lies between Kashmir and Kabul, and forms a nearly square area about 100 miles long east and west, and about 90 miles wide. He states that in the Rawal Pindi district there are some sixteen spots at which petroleum-indications occur. The oil-deposit always appears to cover only a small horizontal area, "sometimes only a few feet, seldom as much as a few hundred yards." Several natural springs occur in the neighbourhood of Gunda, some of them yielding from a gill to three quarts daily. In 1887 a concession was granted to the Punjab Oil-Prospecting Syndicate, and many wells were drilled, but without yielding sufficient oil to be worth working. A boring at Gunda, 75 feet deep, is said to have started with a yield of 50 gallons daily, and in five months yielded about 2000 gallons, but the output had then fallen to about 10 gallons daily. Mr. Lyman gives the density of the oil as 25° B. (0·907), but there appears to be some variation in the oil, for that of Gunda is said to be burned by the natives with a simple wick resting on the side of an open dish, while that of Panoba is described as more inflammable, and as requiring a tube for the wick.

In 1891 the yield of oil in the Punjab was 1812 gallons; in 1902, 1949 gallons; 1064 gallons in 1910; 1400 gallons in 1911; 950 gallons in 1912; 1200 gallons in 1913 and 1914 respectively. In 1915 there was an increase to 251,494 gallons; whilst in 1916 there was a slight decrease, the production amounting to 183,814 gallons. The production in 1917 increased to 619,517 gallons, and in 1918 to 750,807 gallons.

Flowing wells of moderate depth have recently been drilled at Khaur by the Attock Oil Company, Ltd.

The oil-deposits near **Mogalkot,** in the Sherani or Suleiman Hills, have been described in the *Records of the Geological Survey of India* by Messrs. R. D. Oldham, 1891 (xxiv, 83), T. H. Holland, 1891, 1892 (xxiv, 84; xxv, 175), and T. H. D. La Touche, 1892 (xxv, 171). The oil-springs occur near the village of Mogalkot, in a deep narrow gorge cut by the river Toi through a ridge of hard, fine-grained, quartzose sandstone, overlain by massive limestone. The flow is most copious near the base of the quartzose sandstone, the points of outflow being apparently determined by the existence of beds of shale interstratified with the sandstone. The oil is limpid, slightly yellowish and opalescent, and it has been calculated that one hole yields a gallon of oil in four and a half hours, while another yields a gallon in fourteen hours. The yield appears to be restricted to this gorge, although the ridge of rock which bears it extends for 30 miles north of the river. Mr. Oldham considers that the indications are not sufficient to justify the expense of trial-borings, as communication is so difficult that only an abundant yield could result in a profit. A sample of the oil collected by Sir Thomas Holland was deep yellow, mobile, and slightly turbid. Its specific gravity was 0·819 at 60° F., and its flashing-point (Abel test) was 75° F. The oil was said to contain 87½ per cent. of illuminating oil. Another sample was of a rich straw-colour, and clear. Its specific gravity was

0·811 at 60° F., and its flashing-point (Abel test) 64° F. It contained 84 per cent. of illuminating oil.

A trial-boring was sunk in 1894 in the neighbourhood of **Rohri,** on the Indus, a place to which attention was first drawn by Mr. H. B. Medlicott (*Records Geol. Surv. India*, vol. xix, 202, 1886). South-east of Rohri there rises a low, gently-sloping anticlinal of the Upper Nummulitic Limestone, and in 1891 Mr. Oldham recommended the sinking of a well on its crest. The site actually selected was at Sukkur, near the railway workshops, and not on the actual crest of the anticlinal.

Assam.—The points at which petroleum occurs in Assam are indicated on Plate 8. As long ago as 1825, Lieutenant Wilcox, in an expedition up the Dihing River, observed a place in the bed of the Buri Dihing at Supkong, in Upper Assam, where petroleum rises to the surface (*Edinb. Journ. Sci.*, vii, 63, 1828).

In 1828 Mr. C. A. Bruce observed petroleum-springs in more than one locality ; and in 1837 Major White discovered several springs of petroleum close to the camp on the Namrup River, which had hitherto been unknown to Europeans, and apparently almost unused by the neighbouring Singphos, as reported by Mr. H. Bigge (*Journ. As. Soc. Bengal*, vi, 243).

In 1837–38 Captain S. Hannay noticed petroleum rising from some of the coal outcrops, and in 1845 he described his search in the neighbourhood of Jaipur for petroleum. He also visited the Namchik River, and of this locality he writes :—" At Namtchuk Pathar, near the mouth of the river, the petroleum exudes from the banks, and a bed of very fine caking coal runs across the bed of the Namtchuk. The hills here are also intersected by ravines, and in one spot an extensive basin or hollow is formed at some height, which contains muddy pools in a constant state of activity, throwing out, with more or less force, white mud mixed with petroleum. This is, indeed, a strange-looking place, and I am told by the Singphos that at times there is an internal noise as of distant thunder, when it bursts forth suddenly with a loud report, and then for a time subsides " (*Journ. As. Soc. Bengal*, xiv, 817).

In 1865 a brief account of the petroleum-springs in connection with the coal-fields in Upper Assam was given by Mr. H. B. Medlicott (*Mem. Geol. Survey of India*, iv, 4, 14). The most abundant springs visited were those near Makum, where Mr Medlicott recommended that trial borings should be made, the copious discharge of gas being regarded as a favourable indication.

In November of the following year, Mr. Goodenough, a member of the firm of McKillop, Stewart & Co., having been granted certain rights over a large tract of land on both sides of the Buri Dihing, extending from Jaipur to the effluence of the Noa Dihing, commenced boring at Nahor Pung. In addition to several holes drilled by hand, one of which was 102 feet in depth, a well was carried down to a depth of 195 feet by the use of a Mather & Platt's steam boring machine ; but, according to the account published by Mr. T. H. Hughes in 1874, no good results were obtained in this locality, though a few signs of gas were noticed (*Rec. Geol. Surv. India*, vii, 55, 1874).

While these borings were in progress, others were begun at Makum, in lat. 27° 18′ N. and long. 95° 40′ E. Oil was struck in one hole on the 26th March 1867, at 118 feet, and it immediately rose 74 feet in the bore. After about 300 gallons had been drawn, the flow became intermittent, a condition which it was hoped would be remedied by sinking deeper. Eight holes were put down in the Makum district, and they were nearly all successful in tapping oil, though the yield varied in each. In January 1868, 100 to 125 gallons a day was collected from No. 4, while No. 5 yielded from 550 to 650 gallons. The action of

No. 5 bore was intermittent; water was spouted for three or four hours, then oil for fifteen to thirty minutes, after which all action ceased for an hour, or sometimes longer, and then activity set in again. The discharge from No. 5 bore was at times so copious that there was not storage-accommodation for the oil, and the flow was accordingly diminished by fixing a valve on the well-casing. The pressure exerted by the oil during the flow was 30 lbs. to the inch. In one period of thirty-five hours this well yielded about 3500 gallons of oil.

The development of the petroleum-industry of Assam has been mainly due to the initiative of the Assam Railways and Trading Company, Limited, though some drilling work was also carried out on adjacent lands by the Assam Oil Syndicate, Limited. The concessions held by these companies were taken over by the Assam Oil Company, Limited, which has actively continued the drilling operations at Digboi with uniformly successful results, and has erected a refinery equipped with modern appliances for the manufacture of the usual commercial products. At Makum the outcome of some test-drilling has been disappointing. Petroleum of the natural lubricating oil class was met with, but only in small quantities.

The actual concessions of the Assam Oil Company have an aggregate area of 12 square miles, of which 8 square miles are at Digboi, eight miles to the north of the Dehing River, and 4 square miles are on the south bank of the Dehing at Makum. The company also holds prospecting licences over neighbouring areas. Indications of oil have been examined as far to the west as Dekkiajuli and Jaipur, and eastwards to Namchik. Test wells have been, or are being, sunk on sites west and south of Digboi, at Namdang on the Makum concession, and at Namchik. The main development has been conducted on the Digboi field, where twenty-five to thirty wells supply the company's refinery with crude oil. The oil is found in loose sand formations, and it is supposed that it exists in lenticular deposits. Drilling is carried out both by percussion tools with wire rope, and by the rotary method, the latter being in process of superseding the former. Many of the wells flow. The whole of the oil produced is refined at the company's refinery at Digboi. The kerosene is marketed in the Assam Valley, whilst Calcutta provides a market for some of the heavier oils. Petroleum spirit of a good quality is also marketed locally, whilst the paraffin wax, which is of the high quality characteristic of the product of eastern oils, is exported all over the world.

The westerly extension of the Assam oil-field has not been traced, and Mr. F. R. Mallet ("On the Coal Fields of the Nágá Hills, bordering the Lakhimpur and Sibságar districts, Assam," *Memoirs Geol. Surv. India*, xii, part ii, 269–363, 1876) has enumerated the districts where oil has been noticed in the districts mentioned. Thick soft sandstone is the principal rock traversed by the drill, but blue clay also occurs. The oil always rises on or near the outcrop of the coal-bearing group, usually near the outcrop of a seam or seams of coal. Mr. Mallet records an instance in which the oil oozes from the coal itself, though, as he points out, this may have been merely due to the fact that the coal is the last rock through which the oil passed to the surface. Petroleum is found in rocks of the same age on the southern margin of the Khasi, Garo, Sylhet, Cachar, and Tipperah Hills. Mr. Oldham has observed in one of these localities an abundant discharge of gas, accompanied by a light mineral naphtha, along the outcrop of a highly inclined bed of sandstone.

Since 1894 the amount of petroleum obtained from Assam has largely increased. In that year it amounted to 167,000 gallons, in 1898 it was 598,000 gallons, in 1900, 753,000 gallons, and in 1903, 2,500,000 gallons; in 1910 it had increased to 3,320,680 gallons, in 1917 to 9,344,815 gallons, and in 1918 to 10,999,648 gallons.

Drilling operations carried out on the property of the Budderpore Oil Company, Ltd., at Budderpore, have given a commercial yield of oil of a quality which renders it available for use as fuel.

Some drilling has recently been undertaken near the ancient fire-temples in **Chittagong,** but no definite results have been reported.

Burma.—It is in Burma that the largest sources of petroleum in India are found. About one hundred and ninety years ago (1724) Boerhaave stated that the *Oleum Terrae* of India was in his time so scarce as to be " kept by the Princes of Asia for their own use," and was not imported, except as a rarity, into Europe (see Shaw's translation of Boerhaave's *Chemistry*, 1753, i, 117). But at the end of the eighteenth century, Major Symes was able to describe the petroleum wells 5 miles east of Yenangyaung, on the Irawadi, as those which " supply the whole Empire and many parts of India with that useful product " (*Embassy to the Court of Ava in 1795*, London, 1800, 261 and 442), a statement supported by Captain Cox, who declares that the Burman Empire gave the greatest supply of petroleum in the world. He states that the district of Rainanghong (a name said to signify a " town through which flows a river of earth oil ") had then (1797) 520 active wells producing petroleum free from water, and amounting to 400,000 hogsheads annually (*Asiatic Researches*, vi, 127, 1799). Rainanghong is one of many variants of the name Yenangyaung. A further description by Captain Cox is contained in *An Account of the Petroleum Wells in the Burmese Dominions*, Calcutta, 1826.

Major Symes (*loc. cit.*) thus describes the scenes he witnessed :—" The mouth of the creek was crowded with large boats waiting to receive a lading of oil, and pyramids of Eastern jars were raised in and around the village disposed in the same manner as shot and shell in an arsenal. We saw several thousand jars filled with oil ranged along the bank." He also thus describes the operations at the wells he visited :—" Walking to the nearest, we found the aperture about 4 feet square, and the sides lined, as far as we could see down, with timber. The oil is drawn up in an iron pot fastened to a rope passed over a wooden cylinder, which revolves on an axis supported by two upright posts. When the pot is filled, two men take hold of the rope by the end and run down a declivity which is cut in the ground, to a distance equivalent to the depth of the well. Thus, when they reach the end of the track, the pot is raised to its proper elevation ; the contents, water and oil together, are then discharged into a cistern, and the water is afterwards drawn through a hole in the bottom."

A fairly productive well was said to contain oil up to the waist of a man. The wells were dug in beds of sandy clay resting on sandstones or shales, beneath which coal was said to occur. Crawfurd (*Account of the Embassy to the Court of Ava in 1826*, London, 1834, i, 93, and ii, 23, 206) similarly describes the working of these wells, and states that the oil is of a dirty green colour, and of a thin watery consistency when raised, but that it thickens on keeping, and even " coagulates " in cold weather. Writing in 1858, Captain Yule (*Mission to the Court of Ava in 1855*, 19 and 316) gives the number of productive wells in this district as about 80, and states that all are contained in an area of half a square mile. Those wells which were measured varied in depth from 180 to 306 feet.

Most of the petroleum at present produced in Burma is obtained from three oil-fields, all near the Irawadi River, and situated at (1) **Yenangyaung** (Magwe district), (2) **Singu** (Myingyan district), and (3) **Yenangyat** (Pakokku district). These fields are respectively about 275, 300, and 325 miles from Rangoon.

Over 600 wells have been drilled by the Burmah Oil Company alone at Yenangyaung since 1891, but the productive area does not exceed two miles by three-quarters of a mile. In the Singu field, the Company has since 1901 completed about fifty wells. The oil in this field is met with under strong gas-

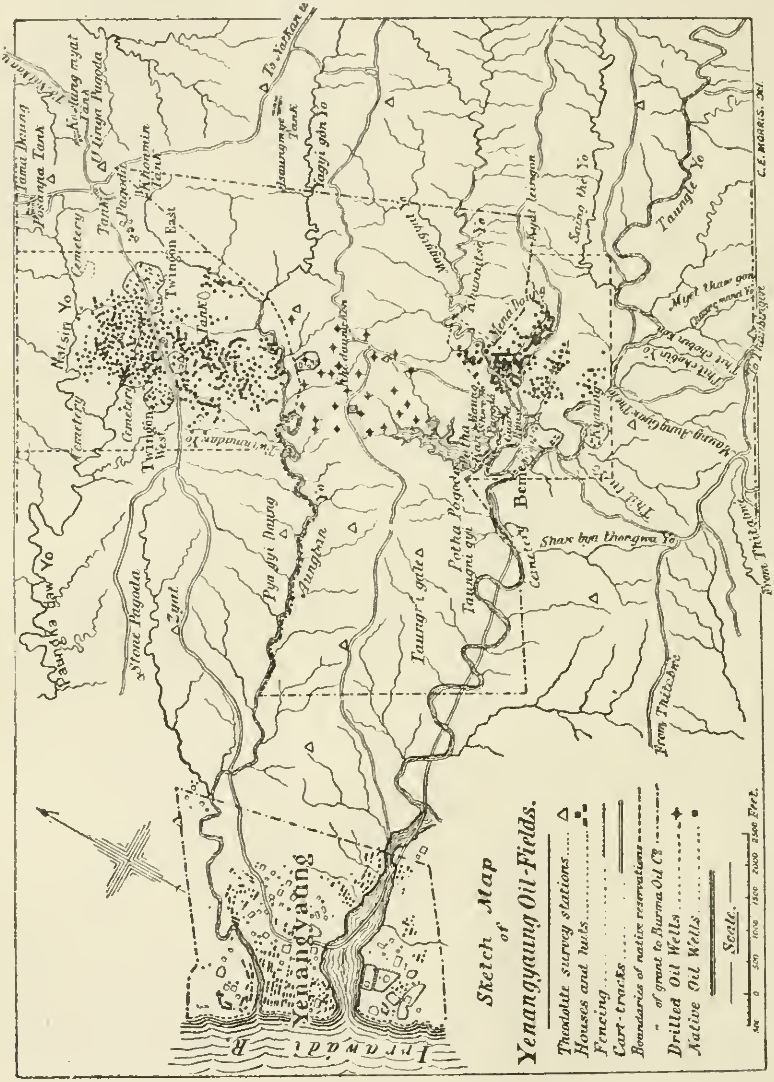


FIG. 3.

pressure, and flowing wells are obtained. A number of wells have been drilled in the Yenangyat field, some of which gave a large initial yield, but the production has steadily declined.

In the **Minbu** field, both flowing and pumping wells have been obtained near the town of that name, some 18 miles southward of Yenangyaung, on the west bank of the Irawadi, but on the whole the results have, so far, been disappointing, the initial yield of the wells having rapidly fallen off.

In other parts of this field, in more recent years, oil has been struck, but here too with discouraging results.

Test-drilling has been carried out in many other parts of Burma, but, with the exception of a small production in the Chindwin, without any success.

Fig. 3 shows the general configuration of the Yenangyaung district, the ground being much broken and intersected with ravines, some of which are from 200 to 250 feet in width and from 100 to 150 feet in depth. These ravines have been produced by the action of water upon strata of unequal durability, mainly consisting of ferruginous conglomerate and soft sandstone.

Contrary to the general experience in other countries, the drilled wells in the Yenangyaung district do not at first invariably yield oil having a lower specific gravity than that of the produce of the dug wells, but with increasing depth the oil is much lighter.

The Yenangyaung oils are opaque in bulk and of a dark greenish colour by reflected light. They are almost odourless, and in many samples are solid at the ordinary temperature. The great variation in the character of the oils from native wells, even when contiguous and of the same depth, is shown in Table IV relating to the wells of Beme.

These results indicate that there are at least two descriptions of oil, one having a high specific gravity and viscosity, but containing practically no solid hydrocarbons, while the other has a comparatively low specific gravity, but contains a large proportion of paraffin. Thus, wells 26, 27, 28, 31, and 33, whose depths range from 100 to 140 cubits, yield oils ranging in specific gravity from 0·915 to 0·925, and containing little or no paraffin; whilst wells 54 to 61 inclusive, the depth of which is from 10 to 140 cubits, yield oils of specific gravity 0·870 to 0·875, which are very rich in paraffin. Wells 62, 64, and 76 yield oils of 0·950 to 0·956 containing no paraffin, but these wells are so shallow that they probably yield only surface oil, though it may be pointed out that well 49, which is of about the same depth, gives an oil of specific gravity 0·905 which is very rich in paraffin. To a large extent, no doubt, the lower density of the oils containing paraffin in large quantity is due to the fact that the specific gravity of the solid hydrocarbons is not as great as that of the oils in which they are dissolved; for it has been shown by Beilby, that paraffin in solution in a mineral oil has practically the same specific gravity as when in the molten condition.

The occurrence in this field of oils containing practically no paraffin is an important fact, in view of the usual statement that the Yenangyaung oil is extremely rich in paraffin. Specimens of the heavy crude oil from this district have, however, been subjected in the author's laboratory to a temperature of 0° F. without the slightest separation of solid hydrocarbons.

Most of the wells are drilled by the American (cable) system, though Canadian pole tools have been employed to a small extent.

The specific gravity of the Yenangyaung crude oil ranges from 0·737 to 0·899, that of the Singu oil from 0·731 to 0·904, and that of the Yenangyat oil from 0·770 to 0·890.

A pipe-line, for the transport of the crude oil, has been laid from Yenangyat and Singu to Yenangyaung, a distance of 48 miles, and another, 10 inches in diameter and 275 miles in length, from Yenangyaung to Syriam, on the left bank of the Pegu River, about five miles from Rangoon. This main line has two pumping-stations.

The Company has four refineries: one at Dunneedaw, on the bank of the Rangoon River, about a mile from the town of Rangoon, one each at Syriam and Bogyok, on the left bank of the Pegu River, about five miles from Rangoon,

TABLE IV.—CRUDE OILS OF BEME.

No. of Well.	Depth.	Daily Yield.	Specific Gravity of Oil at 60° F.	Remarks.	No. of Well.	Depth.	Daily Yield.	Specific Gravity of Oil at 60° F.	Remarks.
	Cubits	Viss				Cubits	Viss		
1	122	10	·900	Colour very dark.	45	50	140	·880	Very rich in paraffin.
2	102	10	·869		46	45	150	·890	,,
6	112	15	·890	Rich in paraffin.	48	60	150	·872	,,
8	155	30	·882	,,	49	5	110	·905	,,
9	156	80	·877	,,	50	10	110	·926	Little or no paraffin.
10	148	15	·860		51	20	145	·868	Rich in paraffin.
11	117	4	·867		53	5	57	·900	
12	140	5	·862		54	140	155	·875	Very rich in paraffin.
13	150	60	·875	Little paraffin.	55	25	140	·872	,,
14	150	70	·890	Rich in paraffin.	56	25	140	·874	,,
15	150	20	·885	,,	57	25	120	·871	,,
17	145	50	·872	Moderate quantity of	58	25	120	·872	,,
				paraffin.	59	90	140	·874	,,
18	155	50	·877	Very rich in paraffin.	60	10	130	·870	,,
19	157	20	·880	,,	61	45	110	·873	,,
20	155	45	·880	,,	62	4	30	·956	No paraffin. Oil of
23	150	15	·890	,,					high viscosity.
25	50	50	·890	,,	63	5	30	·919	Little or no paraffin.
26	140	10	·915	Little or no paraffin.	64	4	30	·950	,,
27	120	8	·915	,,	65	5	83	·919	,,
28	110	2	·920	,,	66	210	120	·886	Very rich in paraffin.
31	100	8	·925	,,	72	80	140	·881	,,
32	160	110	·882	Rich in paraffin.	73	80	140	·881	,,
33	130	2	·925	Little or no paraffin.	74	40	140	·890	,,
34	110	10	·892	Rich in paraffin.	75	5	80	·940	No paraffin. Oil of
35	100	25	·902	Small quantity of					high viscosity.
				paraffin.	76	3	50	·956	,,
36	80	20	·890	Very rich in paraffin.	77	40	140	·894	Very rich in paraffin.
37	65	10	·890	,,	79	70	137	·904	,,
38	30	160	·883	Rich in paraffin.	80	60	145	·890	,,
39	40	150	·881	,,	81	60	140	·880	,,
40	10	100	·900	,,	84	30	110	·884	Rich in paraffin.
41	67	160	·880	Very rich in paraffin.	86	40	80	·890	Very rich in paraffin.
42	120	145	·890	,,	88	40	100	·876	Rich in paraffin.
43	15	90	·882	,,	89	7	120	·880	,,
44	40	120	·875	Small quantity of paraffin.					

1 cubit (attaung) = 19 inches. 1 viss = 3·65 lbs.

and one at Yenangyat. These refineries cover over 400 acres of ground, and have an aggregate capacity of fifteen to sixteen million gallons of crude oil per month.

There are five pipe-lines each five miles long for the delivery of the refined oil from the Syriam refinery to the tank-steamer loading-berths on the Rangoon River.

The Company owns seven tank-steamers of an aggregate cargo capacity of 21,000 tons.

The production of crude petroleum in Burma increased from about 4,000,000 gallons in 1890 to 13,000,000 gallons in 1895. The output for 1899 showed an increase of 76 per cent. over that for the previous year, and in 1901 it had grown to half as much again, being not far short of 50,000,000 gallons. In 1904 it was over 100,000,000 gallons, and in 1909 over 230,000,000 gallons.

According to a report issued by the Government of Burma, the output of petroleum in Burma increased steadily during the three years 1914–1916, and in 1916 reached the highest figures yet recorded. In 1917, however, there was an appreciable falling off, and the production, though over 18 million gallons more than in 1914, differed little from the production in 1913.

The yield from the Yenangyaung oil-field (Magwe district) declined from 199 million gallons in 1916 to 177 million gallons in 1917. After Yenganyaung, the Singu field was the largest producer. The output from this field rose slightly during 1917, and was about 11 per cent. higher than in 1915. The yield from the Yenangyat oil-field (Pakokku district) has continued to increase, and whilst in 1915 it was only 4 million gallons, it had risen in 1916 to 5½ million. The increase is attributed to the tapping of lower horizons by the deepening of several wells. The production from the Minbu field in 1917 was the highest since 1912. Exploitation work has been carried on in the Minhla field and in the Thayetmyo district, but this has proved disappointing.

Fig. 4 shows the relative position of oil-fields on the Irawadi River. The following table gives the production of petroleum in Burma from 1912–1918 in imperial gallons :—

1912,	245,335,209	gallons.
1913,	272,865,397	,,
1914,	254,652,963	,,
1915,	282,291,932	,,
1916,	291,769,083	,,
1917,	272,795,191	,,
1918,	274,834,556	,,

In the **Arakan Islands** (fig. 5), petroleum occurs in the Barangas, in Ramri, and in Cheduba. Much information regarding these deposits and the oil industry of these islands has been given by Mr. F. R. Mallet (*Records Geol. Surv. India*, xi, 1878, 188–207). He describes two types of wells, one appearing to communicate with a reservoir from which the oil, usually accompanied by large quantities of gas, rises rapidly, and the other type receiving thin oil by slow percolation from a rock more or less saturated with petroleum. The wells of Létaung, on the southwestern coast of Ramri, are stated to belong to the former class. One of them, 25 feet deep and 4 feet square, contained water covered with oil, which was drawn twice daily. A similar well 40 feet in depth existed about 200 yards to the northwest. The oil was of a pale yellow colour. These wells are said to have existed without diminution of their output, which, however, amounted only to a few gallons daily, since the Burmese domination. Considerable quantities of gas issued through the water and oil in both the wells. In the islands of Ramri and Cheduba, where the industry is of long standing, it is the practice of the villagers to occupy their spare time after the rich harvest in digging shallow wells in which the oil accumulates. Captain Halsted states that petroleum is obtained in Cheduba by turning up the soil to a depth of 2 feet, and raising a bank of earth so as to form a shallow pond about 20 yards square. The oil rises to the surface of the water which collects during the rainy season, and is skimmed off at intervals, just as the Indians formerly collected it in Pennsylvania.

In the eastern of the Baranga Islands, which lie just south of Akyab, there are many producing wells. In sinking one of these wells, when a depth of 66 feet had been attained, " the workmen were surprised and terrified by a sudden outburst of gas and oil, accompanied by loud subterranean sounds as of distant thunder." The oil and gas poured in considerable quantity into the well, the yield averaging 1000 gallons daily for seven days, and then falling to 120 gallons. In another well oil was struck, and a violent escape of gas occurred at 68 feet, the yield amounting to 150 gallons daily.

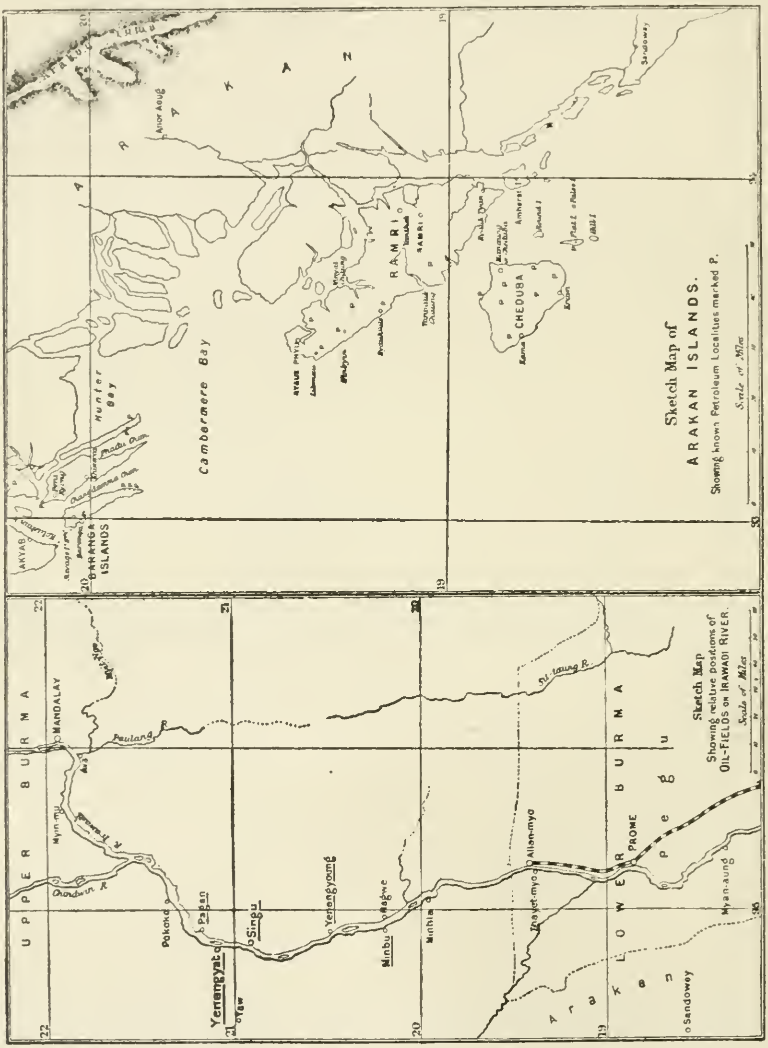


Fig. 5.

Fig. 4.

Much of the Arakan oil has the appearance of brandy or sherry, and may be burned in ordinary lamps in its crude state. Specimens of petroleum from the Eastern and Western Barangas, examined by the author, were dark brown in colour, of pleasant odour, and of a specific gravity of 0·835 and 0·888 respectively. Mr. Mallet has compared the Arakan oil with that from Upper Burma (" Rangoon oil ") as follows:—" In this connection the difference between the petroleum of the Irawádi valley and of Rámri may be noticed. The mud volcanoes of the former region have been described by Dr. Oldham as very sluggish, and as never exhibiting the fiery paroxysms to which those in Rámri are subject. At the same time the oil is dark coloured, is as thick as treacle, or even solid at 60° F., being indeed often spoken of as 'Rangoon tar,' and contains paraffin to the extent of sometimes more than 10 per cent. The Rámri oils are associated with much gas, and are themselves sometimes as transparent and light coloured as brandy. They have a lower specific gravity than the above, and at 60° are perfectly mobile. Without venturing to assert that the above differences are due to a difference in the temperature at which the oils have been produced, it may be noticed that at Baku, on the Caspian, where there are mud volcanoes subject to fiery eruptions, similar to those of Rámri, the oil is in part of the same pale transparent kind, and is accompanied by immense quantities of gas" ("The Mud Volcanoes of Rámri and Cheduba," *Records Geol. Surv. India*, xi).

A sample of light-coloured oil from the mud-volcanoes at Kyauk Phyu was found by the author to have a specific gravity of 0·818, and to consist almost wholly of kerosene.

Test boring was carried out many years ago on the Arakan Islands by the Baranga Oil Refining Company. In 1880 a well sunk on the Outer Baranga Island to a depth of 800 feet was reported to yield at first 30 barrels daily, but the production soon declined to 4 or 5 barrels. Another well near to this yielded at an estimated rate of 6 barrels daily at 600 feet, and was subsequently deepened to 1200 feet. At this depth the well was flooded by water, and large quantities of inflammable gas escaped. A considerable number of unproductive wells were also sunk.

At Minbain, on Ramri Island, fourteen wells were drilled, eight of which were productive, and at the close of 1884 were said to be giving a total yield of from 100 to 140 barrels weekly.

THE EASTERN ARCHIPELAGO.[1] (Plate 10.)

Petroleum is largely produced in the islands of Java, Sumatra, and Borneo, as well as, to a comparatively small extent, in Ceram (Molucca Islands). It also occurs in Timor, and in the Philippine Islands.

In the previous edition the statement was made, on the authority of the Asiatic Petroleum Company, that the Bataafsche Petroleum Maatschappij, of the Hague, owned or controlled all the petroleum production in the Dutch East Indies, and that the aggregate production since the constitution of the latter company had been as follows:—

In 1906, 1,331,499 tons; in 1907, 1,330,649 tons; in 1908, 1,254,838 tons; in 1909, 1,413,741 tons; and in 1910, 1,435,240 tons.

The author is indebted to Sir Marcus Samuel for the following statement giving the production of crude petroleum in the Dutch East Indies for the year 1917:—

South Sumatra,	266,050 tons.
North Sumatra,	317,334 ,,
Borneo,	869,123 ,,
Java,	232,636 ,,
Ceram,	2,248 ,,
Total,	1,687,391 tons.

Later figures taken from the U.S. Government Report, 1917, gives the production for the Dutch East Indies as 1,778,495 metric tons, including British Borneo.

[1] The Dutch use of *oe* for *u* in place-names is here abandoned, except where it occurs in the names of operating companies.

The Dutch company has refineries at the following places:—In *Java*, at Tjepu, Samarang, and Surabaya (Wonokromo); in *Sumatra*, at Pankalan, Berandan, Rantau Pandjang, Pladju, and Bagus Kuning; and in *Borneo*, at Balik Papan.

New fields have been developed from time to time both in Borneo (notably in the island of Tarakan) and Sumatra, and details of earlier developments will be found below.

According to statistics furnished by the Hoofdbureau van het Mijwezen, Batavia, the production of natural gas in the Dutch East Indies for 1916 amounted to 91,121·2 metric tons, Java contributing 24,371·3 metric tons; Sumatra, 66,122·8 metric tons; and Borneo, 627·1 metric tons.

Java.—In 1904, Mr. Adrian Stoop, director of the Dordtsche Petroleum Maatschappij, furnished the author with the following particulars of that Company's properties in Java:—

The petroleum industry of Java after 1886 gradually acquired considerable importance. The fields at present worked by the Company are situated at a distance of 10 kilometres due south and southwest of the town of Surabaya, and bear the names of Kutei pool and Lidah pool. The latter of these has proved highly productive for the past fourteen years. In addition to these the Company owns two prolific deposits in the residency of Rembang, known as the Tinawun pool and the Panolan pool.

The depth of the wells ranges from 500 to 800 feet, and the drilling is chiefly done by the water-flush system. The average production of the wells is not large, but the yield is satisfactorily sustained.

The crude oil has a density ranging from 23° to 40° Baumé (0·916 to 0·825 specific gravity), and although it contains a considerable percentage of asphalt, it yields a large proportion of paraffin of unusually high melting-point (60° to 62° C., American test).

The Company has three refineries for the manufacture of kerosene, situated in Surabaya, Rembang, and Samarang, a refinery for lubricating oils, and a paraffin refinery with a daily output of 6 to 7 metric tons of paraffin of high melting-point, in connection with which is a candle-factory where paraffin candles suited for use in a tropical climate are made.

For the past ten years (1894–1904) the annual output of kerosene in Java, which is entirely consumed on the island, has been between 1,450,000 and 1,900,000 cases, and almost the whole of this has been delivered from the Company's refineries.

Sumatra.—In 1883 a concession of oil-bearing territory in Langkat, North Sumatra, was granted, and in 1885 a boring was completed on these lands which produced a small quantity of oil as a spouter. In 1900 the concession was transferred to the Royal Dutch Company, which continued the drilling operations and erected two refineries.

In 1890 the Royal Dutch Company was formed. The Company first acquired a concession of 891 acres situated along the course of the River Lepan, in the district of Langkat, in the Deli section of the East Coast Residency, North Sumatra. Nearly two years were occupied in the construction of a refinery on the Bay of Aru, the laying of a pipe-line from the field to the refinery, and other work. Meanwhile a well was drilled at Telaga Baru, and a second was put down near the first in 1892, the collective yield of the two being nearly 50 tons of oil a day. A third well drilled subsequently yielded at the rate of half that quantity. In 1893 and 1894 additional wells were drilled, and in 1895 one at a depth of 471 feet proved to be a spouter yielding over 60 tons a day. In 1896 eight more wells were drilled, of which only one was unproductive, one yielded at the rate of about 60 tons a day, one nearly 20 tons, and the remaining five over 6 tons in the aggregate.

In 1895 the Company acquired three more concessions, not far distant from the first one, viz.:—Besitang, with an area of 21,600 acres; Aru Bay, of 108,000 acres; and Bukit Mass, of 97,200 acres.

In the first instance it was thought that four wells would suffice to furnish sufficient crude oil for the refinery, which required 80,000 to 100,000 tons per annum, and sufficient attention was not paid in the earlier years of the Company's existence to keeping up the supply. In 1898 a great decrease in the Company's production occurred, and this was accentuated in the following year, when the production decreased by two-thirds. In 1890 the Royal Dutch Company commenced drilling (1) at Perlak, in the Atchin Residency, where three wells were sunk to the respective depths of 420 feet, 770 feet, and 350 feet, all of which were spouters; (2) in the Palembang Residency, at eleven different places in the basin of the rivers Musi and Lalang, where wells to the aggregate depth of 24,850 feet were put down, which were either unproductive or gave but the small daily yield of 2 to 10 tons each; (3) in the Langsar district, in the Atchin Residency, where 882 feet were drilled without obtaining oil; (4) on the old fields at Perlak, where wells were drilled to a greater depth than had previously been reached in those fields. At Telaga Said six wells were drilled to an average depth of 1260 feet, only two of which yielded oil, at the rate of about 5 tons a day, but this production soon declined to about $1\frac{3}{4}$ tons a day. At Babalan one well, 2240 feet in depth, yielded 10 tons daily for several days, but in a short time ceased production altogether. Seven other wells were sunk here to depths ranging from 2240 feet to 2380 feet, but without result. In 1901 boring was continued with great energy. In Perlak 4200 feet were drilled, and all the wells proved productive. This property yielded, in 1901, 150,000 tons of oil. At Langsar one new well proved successful. On the Telaga Said field, 8190 feet were drilled, but the results were very discouraging. At Palembang, though 29,820 feet were drilled, the operations were not attended with success. The construction of a pipe-line from the Perlak field to the refineries contributed materially to improve the position of the Company's business.

The first refinery of the Royal Dutch Company was erected in 1891, at the village of Pangkalan Brandan, on the Babalan River, not far from the sea, and a tank-steamer loading station was built on the island of Sembilan, in Aru Bay. The distillation was conducted on the intermittent system. In 1897 a second refinery was constructed not far from the first, at the village of Besitang. The crude oil contains from 30 per cent. to 40 per cent. of benzine, and yields from 40 per cent. to 50 per cent. of kerosene of specific gravity 0·809.

In 1897 the Sumatra Palembang Petroleum Company was formed to work an area of 54,000 acres, situated in the residency of Palembang, south of the river Lalang. Drilling was commenced in the northwest part of the concession, in the district of Meliamun, and in 1898 and 1899 more than thirty wells were drilled to an average depth of 595 feet, but of these only five yielded oil. In 1900 an additional twenty-three wells were drilled to an average depth of 700 feet, but of these only eleven were productive. In 1901 seventeen more wells were drilled to an average depth of 945 feet, most of which were at Liaman Lului. In 1900 fourteen of the wells drilled at Meliamun, which had ceased yielding after an earthquake in January of that year, were deepened by about 455 feet, and of these twelve began to spout again. The crude oil has a specific gravity of 0·765 to 0·775. In 1898 a pipe-line 20 miles long was completed from a station near the Meliamun plot to Bajung Lentjir, on the left bank of the river Lalang, where a refinery was built.

In 1897 the Moeara Enim Company was formed to work a concession of about 180,000 acres in the residency of Palembang in South Sumatra, at the mouth of the river Enim, which falls into the Lematang, a tributary of the Musi. Another concession, embracing what is known as the Kampong Minjak field lying between the rivers Enim and Niru, was subsequently transferred to the Company. On the latter concession a spouting well of great productivity was completed at a depth of 651 feet. During the two succeeding years fifteen more wells were drilled on the Kampong Minjak field, with depths ranging from 490 to 700 feet. In 1900 fourteen additional wells were drilled, of a depth of 630 to 910 feet, and the aggregate daily production of crude oil was then about 400 tons. In 1901 seventeen new wells of an average depth of 1120 feet were completed, two of which were in a distant part of the concession, the production being thus augmented to 130 tons a day. The wells were drilled by the Canadian system with round iron rods, the later ones having a commencing diameter of 10 to 12 inches and being finished with 7-inch or 8-inch casing. The drilling of each well occupied from $2\frac{1}{2}$ to $3\frac{1}{2}$ months. Up to 1904 about fifty wells had been drilled on the Kampong Minjak field, and ten on the other part of the concession, but about one-third were abandoned as no longer sufficiently productive. Nearly all were flowing wells, and some spouters yielding from 400 to 800 tons daily have been obtained, but the average production has been from 18 to 20 tons a day. The average specific gravity of the crude oil is 0·792. In addition the Company owns the Babat concession, situated on the left bank of the river Misu, and the Bandjar Sari concession, lying between the rivers Enim and Lematang. The Babat field was at first very promising, but has proved disappointing. On the Bandjar Sari concession an abundant flow of a very light crude oil was obtained in two or three bore-holes, and in 1902 the laying of a pipe-line 14 miles in length from this field to Kampong Minjak was commenced. The Kampong Minjak field is connected with the Company's refinery on the right bank of the Musi, 3 miles below the town of Palembang, by a 4-inch pipe-line. The capacity of the refinery is about 1600 tons of crude oil a day (twenty-four hours). The distillation is conducted on the continuous principle.

In 1901 the Moesi Ilir Petroleum Company was formed to work an area of 135,000 acres situated on the right bank of the Musi, in the residency of Palembang, not far from the Babat field. Eight wells were drilled to a depth ranging from 245 to 350 feet, all of which proved to be spouters. The specific gravity of the crude oil ranges from 0·812 to 0·889. A 4-inch pipe-line, of a length of 164 kilometres, has been laid from the field to Palembang, where a refinery similar to that of the Moeara Enim Company, and of a capacity of 250,000 tons of crude oil per annum, has been constructed.

The Mines and Forests Exploitation Company of Lower Langkat, otherwise known as the Langkat Shanghai Company, which has been in existence for several years, has its own oil-field and a small kerosene-refinery in the village of Gebong, near the Town of Tandjong Pura, in Langkat.

The Sumatra Petroleum Company possesses oil-fields and a refinery near Gebong.

A new field of great promise was opened up by the Batavia Petroleum Company in 1917, and a well at Pangalan Soesoe is reported to have given an initial flow at the rate of 1200 tons of light gravity oil a day.

Borneo.—In 1904, Messrs. M. Samuel & Co., managers of the Shell Transport and Trading Company, Limited, furnished the author with the particulars on which the following account of the Company's properties in Kutei is based.

The area over which the Nederlandsch-Indische Industrie en Handel Maatschappij has exploitation rights is roughly between 500 and 600 square miles. This territory is situated on the southern half of the east coast of Borneo, and may be described as a strip of the mainland 6 to 8 miles in width, running almost north and south. It is bounded on the northeast by the Kutei or Mahakkam River, and it extends towards the south to Balik Papan Bay, but it embraces also a strip of land on the south of the bay. The northernmost point is approximately 0° 30″ south, and the southernmost about 1° 20″ south. Preliminary inspection of the territory was carried out in 1895, and the first trial-boring was commenced on 31st December 1896, but boring on a working scale was not undertaken until a year or two later.

The earlier wells, which tapped the upper strata, gave heavy oil of an asphalt base. Deeper wells yielded a light oil of the same asphalt base, but still deeper ones have given a large supply of paraffin-base oil of high commercial value.

The Company's refinery is situated on the northern shore of Balik Papan Bay, where there is ample depth of water for the largest steamers which can navigate the Suez Canal to lie alongside the Company's wharves.

The exploration of the petroliferous territory of **Sarawak** was commenced by the Anglo-Saxon Petroleum Company in 1911, and the production has steadily increased year by year until 1917, when there was a slight decline, as is shown by the following tabular statement:—

Production of Crude Petroleum in Sarawak.

1911,	170 tons.	1915,	66,846 tons
1912,	5,635 ,,	1916,	88,548 ,,
1913,	26,067 ,,	1917,	75,787 ,,
1914,	64,490 ,,		

Petroleum has long been known to exist in the island of **Labuan,** on the northwest coast of Borneo. Some prospecting was undertaken in 1866, and a well bored to a depth of 19 feet 6 inches, at a distance of about 100 yards from the shore, and 3 miles along the northern coast from a place known as Reffles Anchorage, gave a small flow of oil. This well was found to be still flowing in 1879, at an estimated rate of 12 gallons daily. A sample of the oil examined by the author had a dark brown colour, very little odour, a specific gravity of 0·965 at 60° F., and a flashing-point of 216° F. (Abel test). It remained fluid at the temperature of zero F. The belt of petroliferous rocks extends westward to Sarawak.

According to the statistics furnished by the Dutch Secretary-General to the Department of the Colonies, the production in Borneo has increased since 1900 as follows:—1900, 59,352 metric tons; 1901, 85,554 metric tons; 1903, 105,102 metric tons; 1904, 215,109 metric tons; 1905, 439,487 metric tons; 1908, 511,049 metric tons; 1909, 411,506 metric tons; in 1910, 633,472 metric tons. The following years showed a steady increase, the production in 1916 reaching 1,047,462 [1] metric tons.

Timor.—In 1891 a geological survey of Timor was made by Dr. G. Seelhorst, from whom the author has received much interesting information respecting the occurrence of petroleum on the island. Oil was found oozing out in the bed of a river named the Mota Mutika at the estimated rate of about 15 gallons a day, at a place called Pualaka, in the kingdom of Laculubar, whilst in the jungle, at a spot about 2000 yards distant and at about 1000 feet higher

[1] Includes 90,067 metric tons produced in British Borneo.

level, natural gas issuing from a calcareous rock was found burning. Both the oil and the gas appear to have been known to the natives from the earliest times of which there are any records. The fire, which is said to burn more brightly during the rains, is regarded by the natives as sacred, and the oil is collected by them for use in lamps. Access to the oil-field is difficult from the north, as the Casa Baucu mountains, which are from 3000 to 4000 feet in height, have to be crossed by narrow and precipitous paths, but it is easy from the south, one point at which oil occurs not being more than 1000 feet above sea-level, and being easily approached up the River Mota Sahe, of which the oil-creek Mota Mutika is a tributary. There is, however, no port or landing-place on the south coast at present. Subsequently to Dr. Seelhorst's visit, a hole was drilled by a hand-machine to a depth of about 30 feet from the bottom of a pit 5 or 6 feet deep, dug in the spot where the principal surface outflow had been found, and between 2000 and 3000 gallons of oil was collected. A sample of this oil examined by the author was of dark brown colour, and exhibited considerable fluorescence. The odour of the oil was not strong, and was free from any disagreeable characteristic. The oil was very mobile, its viscosity at 70° F. being only 5·86 (rape oil at 60° F.=100). It had a specific gravity of 0·825, a flashing-point of 105° F. (Abel test), and a solidifying point of 10° F. It yielded about 68 per cent. of kerosene, and was rich in paraffin.

The eastern half of the island where development work has been carried out belongs to Portugal, and the western half to the Netherlands. In 1914 it was reported that there were four principal organisations concerned in the work, one of which was formed in Hong Kong, one in England, and two in Sydney, Australia. The climate is good, but the operations have been greatly retarded owing to the cost of transport.

The Philippine Islands.—For about thirty years petroleum has been collected to a small extent in these islands. The most promising areas are said to be in Luzon, Panay, Negros, and Cebu, but many of the other islands contain oil. The oil of Panay is of a dark greenish colour, and is obtained at a depth of 100 to 150 metres. In the island of Cebu there are considerable surface indications, and two wells have been drilled by hand to a moderate depth. Oil was obtained in both, but from the second it flowed continuously, and much gas was also emitted. The oil was found by Mr. Warren to have a specific gravity of 0·809, and it contained so much paraffin that at a temperature of 73° F., or a little below, it ceased to flow. A specimen of this petroleum, which the author received from Mr. Warren, is of brown colour, with some fluorescence, and disagreeable odour, and at common temperatures is filled with crystals of solid hydrocarbons. The strata in which the oil occurs have been much disturbed.

CHINA.

Reference has already been made to the antiquity of the use of petroleum and natural gas in China and Japan.

From the description of the Szechuen " fire-wells " by Père Imbert (*Ann. Assoc. Propag. Foi*, iii, 369, 1828), it appears that the borings for natural gas usually extend to a depth of 1500 or 2000 feet, and the gas is conducted to the desired places through pipes. The largest, and one of the oldest, of the springs of natural gas is that at Tse-liu-tsin, close to the mountain of the same name ; while that of Chu-pai-Ching had been in operation day and night for forty years. As much as 40 0or 500 lbs. of fetid oil, which burns on water, may be obtained from a well in a single day. When a well produces petroleum alone, the oil is conveyed to special reservoirs, but where it is found mingled with the brine, it floats on the top of the liquid in the brine reservoirs, and is skimmed off. The colour of the oil varies from skim-milk white to greenish-white, yellow, and black, the latter oil being viscous, and burning with little light but much smoke. The Chinese do not refine the oil, but burn it as it comes from the well, in tightly closed lamps, permitting only the passage of the wick. The oil is also used in medicine for certain skin diseases and rheumatic affections. About thirty or forty oil-wells are worked in the salt district, fifty or so being the total number in the whole province. Where gas is the chief product of a brine-well, all the other products are neglected. The gas appears to come from two separate horizons, one comparatively near the surface, and the other at a depth of about 200 tchang (about 720 yards). The gas from the former is not very abundant, and burns with a white flame, while that from the deeper source comes up in strong jets, burning with a blue and yellow flame.

When a gas-vein is tapped in drilling, the tools are frequently blown out of the well, wrecking the derrick and apparatus, and if any light or fire is near, the escaping gas ignites. Moreover, the gas percolates through the adjacent soil, so that a conflagration sets in round the well. To prevent this, the Chinese, before sinking a well, arrange reservoirs of water all around, so as to flood the region of the well when occasion arises, and thus extinguish the flame. The gas is utilised for heating the brine pans, and is conveyed from a reservoir erected round the mouth of the well, through prepared bamboo pipes into other reservoirs underground, and thence to the evaporating-sheds. Variations of weather affect the flow of gas from the wells. When it is fine and calm the jets are strong, but they become weak, and almost cease, in windy or foggy weather. The deeper wells are less affected by these changes. It was reported in 1913 that the production of petroleum in the province of Szechuan amounted to about 30,000 barrels a year.

In 1914, under the terms of an agreement entered into by the Chinese Government and the Standard Oil Company of New York, a joint investigation of the petroleum resources in the provinces of Shensi and Chihli was carried out. Active drilling operations were commenced during the year in the Yenchang field, Shensi, in a locality where a number of wells drilled six or seven years ago resulted in two small producers, supplying oil to a small refinery with a purely local trade. Unofficial reports are to the effect that three wells were drilled in 1915, one of which yielded a fair show of oil, though the other two were dry.[1]

In "Notes on a Journey through Shensi," by Mr Eric Teichman, H.B.M. Consular Service, published in the *Journal of the Royal Geographical Society*, Dec. 1918, the following reference to the petroleum of this region occurs:—

"The oil used to flow out of the ground into the Yen Shui, but about 1906 someone conceived the idea of exploiting it. Two wells were sunk and fitted with Japanese machinery, and they have produced a steady flow of oil ever since. Some eight years later the Standard Oil Company took the matter up, negotiated a co-operative agreement with the Chinese Government, and started in to exploit the supposed oil-field of North Shensi on modern lines. Geologists, drillers, and machinery were imported from the States, several wells were sunk, and visions of busy oil-fields, pipe-lines, railways, and general wealth and prosperity arose in the minds of the local Chinese. But, unfortunately, no oil was discovered, save in the immediate neighbourhood of the original Yenchang wells, and after two years or so of great activity the enterprise was abandoned and the Americans departed, to the great regret of the

[1] *Report of the United States Geological Survey, 1913.*

local Chinese. The original wells still produce a steady flow of oil, working with the original machinery. The concern flourishes in a small way, and sells as much oil, principally across the Yellow River in North Shensi, as it can refine and as the deficient transport facilities at its disposal enables it to distribute. Only one well therefore is usually at work."

It has been recently reported that the Nippon and Hoden Oil Companies of Japan conjointly are to undertake the exploration of the petroliferous area of Shensi Province.

JAPAN. (Plate 9.)

In Japan, as already mentioned, petroleum and natural gas have been known for many centuries. The oil-fields extend from the western shore of Sakhalin or Karafuto in the north, through the western part of the highlands of Yezo or Hokkaido, and along the coast of the Sea of Japan, and thence, traversing the provinces of Mutsu, Ugo, Utzen, Echigo, and Shinano, reach the coast of the Pacific Ocean in the province of Totomi in the south. There is also an oil-field in the northern part of the west coast of Taiwan or Formosa. The chief centre of the industry is in the province of Echigo, which produces about 99 per cent. of the total output of petroleum in Japan. The usual depth of the wells is from 600 to 1200 feet, and the American system of drilling is employed. Mr. Lyman, in his *First Report of the Geological Survey of the Oil Lands of Japan* (Tokio, 1877), p. 17, speaking of a visit to Kusôdzu, says: " It is said that the oldest oil wells of Echigo were here, and they are supposed by the inhabitants to have been dug several hundred years ago. It is said in the Japanese history, called *Kokushiriyaku* (I am told), that rock oil (or ' burning water ') was found in Echigo in the reign of Tenjitenno, which was 1260 years ago, or about A.D. 615 ; and that was probably at Kusôdzu, where there are still very old natural exposures as well as dug wells. The name of the place, *Kusôdzu*, is the name given in the country to rock oil, and means stinking water ; and the very fact that the word is by contraction so much changed from its original form Kusai midzu, shows of itself considerable antiquity. Natural gas even is called *Kazakusôdzu*, the first two syllables meaning ' wind ' or ' air,' and evidently identical, etymologically, with our very modern western word gas." Prof. S. Takano, however, gives the date as A.D. 674, and the Emperor's name as Tenchi, and says that the " burning water " and " burning earth " (asphalt) were presented to him for use in his palace.

In 1613 a man named Magara obtained oil in the vicinity of Niitzu, in the Echigo Province, and attempted refining it on a small scale for the purpose of illumination ; but not till about 250 years later did the modern development of the industry commence, when Ishizaka Shuzo put down some wells at Zenkoji, in Shinano Province. He was unsuccessful, but made another attempt in Echigo Province. This also proved a failure, but his efforts led to other persons engaging in the search for oil, and by 1866 there were numerous wells and refineries existing in at least fifteen districts. In 1876 Dr. B. S. Lyman, of Philadelphia, was appointed to make a geological survey of the oil-lands, and his reports in 1877, 1878, and 1879 show the progress then made. The following particulars are condensed from these reports:—In the Miyôhôji and Kusôdzu (Echigo) oil-region, there are (besides a larger number of old abandoned wells) about 178 productive wells, which altogether yield about $4\frac{2}{3}$ barrels a day, making an average of about 1 gallon a day for each well. The best well is at Machikata, and yields about half a barrel a day. The best of the former wells was at Kitakata, and for fourteen days (in 1871) it yielded a daily average of 19 barrels, but after that it gradually ceased to yield. Reviewing all the Echigo oil-fields, we find that there are in all 522 productive wells, of which the deepest is 122 fathoms (732 feet) deep, the greatest yield is about 1·2 barrel a day, and the total yield about 22 barrels a day, giving an average of about 2 gallons a day for each well. Such a yield, if kept up through the whole year, summer and winter, would amount, for all the wells together, to 9500 barrels a year, worth, at 12 gallons to the dollar, $31,650. At Shinano, on the other hand, the total is far smaller. There are in that province, in spite of the numerous traces of oil and gas, only twenty-two productive wells, of which the deepest is 57 fathoms (342 feet) deep, and the best has a yield of 2½ barrels a day; and the total yield is a little over 5 barrels a day, or an average of 9⅓ gallons a day to each well; or in a year, less than 1900 barrels altogether, worth about $6250. The whole yield of the two provinces, then, is about equal to that of two average Pennsylvania oil-wells. Yet two or three cases have occurred in Echigo of a yield of 15 to 19 barrels a day for a few days when the wells were new. At Miyôhôji they talk of having had a profit of $70,000 to $80,000 from a single well, and the general estimate of the yield of that field has been high.

In 1888 Professor Fesca observed a water which had a strong odour of petroleum, in Mabana, in the Province of Kadzusa, but although he was able to ignite the film of oil on the surface, he states that he could not collect enough for testing in the laboratory.

In 1886 the Japan Oil Company was formed, and introduced the American system of drilling with considerable success, though it has not yet superseded the primitive method of collecting the oil by means of timbered shafts. In the Amaze district flowing wells were struck, some of which furnished large quantities of oil. Early in 1899 this Company discovered a rich field at Nagamine, 15 miles southwest of Amaze; and a few months later another very rich field was found at Kamada, not far distant. In that year these two fields alone yielded about 28,000,000 gallons of crude oil.

Echigo, the centre of the industry, contains the following fields:—Niitzu, the oldest and richest, the production having increased from 634,000 koku (1 koku=39·7 imperial gallons) in 1905 to over 970,000 in 1907, followed by a decline in 1908 to about 800,000 koku; Nishiyama, which embraces Nagamine and Kamada, and has steadily increased its production from 271,495 koku in 1905 to 492,393 koku in 1908; Higashiyama, which, like Niitzu, showed an increase from 1905 to 1907, but declined to 263,667 koku in 1908; Kubiki, which has decreased from over 97,000 koku in 1905 to less than 63,000 in 1908; Amaze, at one time the most important field, but which produced only 12,447 koku in 1907, a considerable increase over the two preceding years; and Ojiya, the production of which has fallen from 14,000 koku in 1905 to 7000 in 1908.

Totomi Province, in which the industry has been carried on since 1888, has also several oil-districts, of which Sagara, an important and promising field, is the chief.

In October 1903 a notable strike of heavy oil was reported to have been made by the International Oil Company at Hachemancho in **Hokkaido,** at a depth of 1780 feet, the oil being stated to have spouted above the surface of the ground; and a second well is said to have given a similar result. About 2000 koku was produced in 1909.

According to a report of the United States Geological Survey, about fifty rotary drilling rigs were introduced into Japan during 1913, and have been sufficiently successful in their operations to result in an increased production.

The rotary system is credited with drilling-in the first Japanese gusher on 22nd May 1914, near Akita. It gave several thousand barrels a day from a sand 54 feet thick at a depth of about 1400 feet.

In 1914 great interest was centred in the neighbourhood of **Akita,** where the Nippon Oil Company brought in a large well on its Kurokawa property on 25th May. The estimated production of this well was 12,000 barrels a day. In this field the same company completed a second gusher with an initial daily output of 5500 barrels on September 1st. Another event of importance in 1914 was the establishment of a plant for the manufacture of gasoline from natural gas. This was also undertaken by the Nippon Oil Company.

The oil from the Japanese fields is about 25° Baumé in gravity, and resembles the oil of California, though containing traces of paraffin. Five small refineries, or rather "topping" plants, are reported to be in operation, two located on the Pacific coast and the remaining three on the coast of the Sea of Japan.

An appreciable gain in production of petroleum is credited to Japan in 1915, the output exceeding 3,000,000 barrels for the first time in the history of the country. The increase came chiefly from the Kurokawa field in Akita. However, despite the great interest in the development in Akita, the bulk of Japan's production of oil is derived from the fields in Echigo, the output from which was in 1916 slightly greater than in 1915.

The installation and successful operation of a wax plant in the Naoyetsu refinery, the first of its kind in Japan, is a source of great gratification to the Nippon Oil Company who own it. The plant has a capacity of 300 barrels of wax distillate a day. The residuum used as the source of the wax is from the crude oil produced in the Nishiyama and Kubiki fields.

FORMOSA.

In this island a field of some importance has been developed at Byoritsu, on the northwest coast, and trial borings have recently been carried out at several places in the southern part of the island.

It has recently (1918) been reported that the Japanese Department of the Navy has entrusted the exploration of the Formosa fields to the Nippon and Hoden Oil Companies; that the investigation of both the Kosempo and Nairyo fields in Ako district has been completed, and that it has been decided to drill a test-well on Tenshiko, in the Kosempo field.

Oil indications extend over 400 miles in length, and three fields were in operation in 1910, viz. Shuikkoko, in Shinchikucho, Senshiurgo in Tarnancho, and Rokujuker in Kagicho.

CANADA. (Plate 11.)

The oil- and gas-deposits of British America have been somewhat fully described in the various reports of the Geological Survey of Canada, more especially in the *Summary Reports of the Geological Survey of Canada for the years 1888 and 1889* (Montreal, 1890), in the reports of E. D. Ingall (*Report for 1889 to the Division of Mineral Statistics and Mines of the Geological Survey of Canada*, Montreal, 1890, and *Report for 1898*, Montreal, 1899), of H. P. Brumell (*Report on Natural Gas and Petroleum in Ontario prior to 1891*, Ottawa, 1892), of R. W. Ells (*Report on the Mineral Resources of the Province of Quebec*, 1890); also in a Bulletin of the Imperial Institute in Part I of the article on *The Principal Petroleum Resources of the British Empire*, pp. 183 and 399. Much of the following account has been derived from these sources.

Most of the petroleum produced commercially in the Dominion is yielded by wells in the province of Ontario, though a small amount has been obtained in New Brunswick.

The presence of oil in the swamps of the township of Enniskillen, in the county of Lambton, at the extreme west of Ontario, was noticed at an early date, the occurrence of a thick dark-coloured oil in the water of the district, and the presence of a gummy substance intermingled with the soil in parts of the swamps, forming the so-called " gum beds," seriously detracting from the value of the land for agricultural purposes.

A liquid, known as " gum oil," was formerly extracted from these deposits, but it was not until the sinking of a well by Mr. James Shaw, in 1861, that practical attention was attracted to the district as an oil-country.

The two distinct oil-pools of Lambton county are known as the Oil Springs and the Petrolea fields. The latter, and larger, field has an area of about 26 square miles, and extends W.N.W. about 8 miles and E.S.E. about 4 miles from the village of Petrolea, while the Oil Springs field covers about 2 square miles, and includes the southeastern part of the village of Oil Springs. The output from these two pools amounted to over 600,000 barrels annually for some years. In 1894 the production in Canada reached a total of 829,104 barrels, the highest figure attained. In 1900 the yield was 692,650 barrels, and in 1913, 481,504 barrels. In 1909 it was 420,755 barrels ; 1910, 315,895 barrels ; 1911, 291,096 barrels ; 1912, 243,336 barrels ; 1913, 228,080 barrels ; 1914, 214,805 barrels. In 1915 there was a very slight gain, the production amounting to 215,464 barrels. The 1916 production dropped to 198,123 barrels ; in 1917 there was an increase to 213,832 barrels ; and in 1918 to 304,741 barrels.

In the Oil Springs field the depth of the wells is from 370 to 400 feet, in the Petrolea field from 460 to 480 feet. The oil is chiefly refined at Sarnia.

The first flowing well of **Oil Springs** was struck in 1862 by Mr. Shaw in what is now known as the *Upper Lime*, at a depth of 160 feet. Mr. Henry describes this flowing well as " a huge fountain of what seemed to be black mud, bursting with great violence from the hole where he [Shaw] had been digging. The ' mud ' emitted a very offensive odour. The ' jet,' when he first cast eyes upon it, was, as nearly as he could judge, about a foot in diameter, and it every moment increased in volume, frequently shooting high up into the air. . . . Upon examination the substance proved to be crude petroleum. The well continued to flow, with occasional brief cessations, for upwards of sixty-seven hours, and this in a large and swift stream which poured into the adjoining creek. . . . Though Western Pennsylvania has produced numerous flowing wells of wonderful capacity, there is no quarter of the world where the production attained such prodigious dimensions, as in 1862, on Black Creek, in the township of Enniskillen. The first flowing well was struck there on 11th January 1862, and before October not less than thirty-five wells had commenced to drain a storehouse. . . . Some of these wells produced 300 and 600 barrels per day. Others yielded 1000, 2000, and 3000 barrels per day. Three produced, severally, 6000 barrels per day, and the Black & Matthewson well flowed 7500 barrels per day."

Owing to the low price of petroleum at the time, there was no sale for the oil, but production was still pushed to the utmost. Prof. A. Winchell estimates that during the spring and summer of 1862, not less than 5,000,000 barrels of oil floated off on the waters of Black Creek (*Sketches of Creation*, New York, 1870).

The same authority gives the following as the daily output of some of the principal wells of Black Creek, in the vicinity of Oil Springs:—The Jewry &

Evoy, the Sanborn & Shannon, the Wilkes and the Allen, 2000 barrels each; the McLane, the Bradley, and the Petit, 3000 barrels ; the Webster & Shepley, the Swan, and the Fiero, 6000 barrels each.

Shortly after the excitement at Oil Springs, another large oil-deposit was struck at Bothwell, in Kent county, about 30 miles to the southeast, and soon after, in 1865, a third at Petrolea, about 7 miles north of Oil Springs.

In 1867, the celebrated King wells were struck at **Petrolea,** and the latter district quickly became so productive as to lead to the desertion of Oil Springs, although the wells at that place were shortly afterwards drilled to a greater depth, and produced from 10,000 to 12,000 barrels monthly in 1886. Petroleum was also subsequently worked at Euphemia, 17 miles from Bothwell. It is estimated that 15,000 wells were sunk in Canada prior to 1886, and that 2500 were then producing at an average rate of three-fourths of a barrel daily.

The following is extracted from the evidence given by Mr. J. H. Fairbank, of Petrolea, before the Royal Commission on the mineral resources of Ontario (Toronto, 1890):—" In 1859 or 1860 the first attempt was made at utilising Canadian petroleum. This consisted in extracting a liquid from the ' gum oil ' that found its way to the surface at what then was known as the ' gum beds ' at Oil Springs. Then surface wells were dug to a depth of 40 to 60 feet ; they were not flowing wells. Near the surface rock was a bed of gravel, and on reaching that the oil would press into the well, and rise in it quite a number of feet. The well was usually a shaft of 4 or 5 feet in diameter. This was done both at Oil Springs and here (Petrolea), and was the first development. The first drilling in the rock was at Oil Springs, about 1861, and soon after rock wells were sunk here. After a few had been put down at Oil Springs, they struck the great flowing region. At that time they cribbed a 4-foot shaft down to the rock, and most of the drilling was done by hand power. In the winter of 1861–62 flowing wells were struck which produced very largely, some of them reaching into the thousands of barrels in twenty-four hours. The great bulk of that oil went into the creek and was lost. Quite a number of such wells were put down, and I think at one time there must have been twenty flowing wells ; there was hardly a pump operated. . . . Between the striking and the controlling of the flowing wells there was a period of great waste. I think these wells did not continue more than two years after they were struck ; they changed to pumping wells, the supply seeming gradually to become exhausted, and water took the place of the oil. Between that time and the end there were two periods of excitement, and some years after that Oil Springs became practically deserted. About 1865 developments were made at Petrolea within the present Corporation, but no flowing wells were struck till a later period. The flowing-well period in Petrolea was about 1866 ; that was in what is known as the King district, a little west of the present town. We have had wells there which yielded as much as 400 barrels a day. At Oil Springs the flow was very much stronger ; I think the Black & Matthewson well at Oil Springs gave as much as 6000 barrels in twenty-four hours. . . . That great flow was only of short duration, lasting a few days until it was controlled. Here the greatest flow was from 400 to 800 barrels, and not much was wasted. These wells continued to flow a good while, and then it became necessary to pump them ; some of them are pumping wells to-day. Some small flowing wells were found beyond the King district, but that was the great centre. Flowing wells were generally found where there were crevices. . . . I would estimate the number of new wells last year here and at Oil Springs at 400."

The **Bothwell** field in Kent county again attracted attention at the beginning of the century, and in 1902 produced about 50,000 barrels. In that year the flowing well, known as the "Gurd gusher," was struck at Chatham in this field, and yielded at first 1750 gallons per hour, but this declined in the early part of 1903 to 3500 gallons a day. Another well at Thamesville is stated to produce 1225 gallons of oil a day. The depth of wells in this field is about 400 feet. The production in 1909 was 38,707 barrels.

In the **Dutton** oil-field, in the township of Dunwich, in Elgin county, near the shore of Lake Erie, there were in 1901 thirty-two wells, mostly about 435 feet deep, producing upwards of 35,000 gallons a month. This field produced over 10,000 barrels in 1909.

In 1901 the development of the **Tilsonburg** field in Oxford county, in the valley of Big Otter Creek, was commenced, the first well yielding 840 gallons a day.

Oil is also found in many other parts of Ontario, particularly where the territory is occupied by the Hamilton and Corniferous formations. In the township of Collingwood, the Utica Shale which there outcrops was distilled in 1859 as a source of oil, and similar oil-shales occur in the Devonian formation in Bosanquet, Lambton county. In December 1891 oil was found in the Medina Sand at a depth of 750 feet, near Sherkston, Welland county. Other localities are mentioned in the following section.

A review of the Canadian petroleum industry was given in the 20th annual report of the Canadian Bureau of Mines, issued in 1911, by order of the Legislative Assembly of Ontario. According to this report, a gradual decrease in production had reduced the annual output to less than one-third of the quantity obtained twenty years previously. The output of the producing districts was given as follows:—

	Barrels.
Lambton,	205,456
Tilbury,	63,057
Bothwell,	36,998
Dutton,	7,753
Onondaga (Brant County),	1,005
Leamington,	141
	314,410

The falling-off was general, though more marked in the newer Tilbury and Leamington districts than in the older Lambton field.

Since the date of that report the decline has continued, and the output only amounted to 198,123 barrels in 1916. According to the United States Geological Survey, the decline in production in 1916 was almost entirely in the Lambton district in Ontario, the principal area of production, which includes the Petrolea and Oil Springs fields, but in 1917 and 1918 there was a steady increase, due to the development of the Mosa field in Ontario.

The largest area over which indications of petroleum occur in Canada lies in the Province of **Alberta** and the **Mackenzie** Territory in the northwestern part of the Dominion. Of the valley of the Athabasca, then known as the Elk or Elbe, Capt. Sir G. Back writes in 1833, on the authority of Mr. John Richardson, under Sir John Franklin (*Second Expedition*, 1828, vol. i), as follows:—"There is a peaty bog whose crevices are filled with petroleum, a mineral that exists in abundance in this district. We never observed it flowing from the limestone, but always above it, and generally agglutinating the beds of sand into a kind of pitchy sandstone. Sometimes fragments of this stone contain so much petroleum as to float down the stream" (*Journ. R. Geogr. Soc.*, iii, 65).

The bitumen of the Athabasca region was also noticed by Sir Alexander Mackenzie (*Voyages through North America to the Frozen and Pacific Oceans*, 1789, 1793), and by Sir John Richardson (*Arctic Searching Expedition*, 1851).

Later exploration in the region caused the Select Committee of the Senate of Canada to report as follows:—" The evidence submitted to your Committee points to the existence in the Athabasca and Mackenzie Valleys of the most extensive petroleum field in America, if not in the world. The uses of petroleum and consequently the demand for it by all nations, are increasing at such a rapid ratio that it is probable that this great petroleum field will assume an enormous value in the near future, and will rank among the chief assets comprised in the Crown Domain of the Dominion. For this reason your Committee would suggest that a tract of about 40,000 square miles be for the present reserved from sale, and that as soon as possible its value may be more accurately tested by exploration and practical tests, the said reserve to be bounded as follows:—Easterly, by a line drawn due north from the foot of the Cascade Rapids on Clearwater River to the south shore of Athabasca Lake ; northerly, by the said lake shore and the Quatre Fourche and Peace Rivers ; westerly, by Peace River and a straight line from Peace River Landing to the western extremity of Lesser Slave Lake ; and southerly, by said lake and the river discharging it to Athabasca River and Clearwater River as far up as the place of beginning " (*Report of the Select Committee of the Senate appointed to inquire into the resources of the Great Mackenzie Basin.* Ottawa, 1888).

The Dominion Government subsequently decided to have a trial-boring made near Athabasca Landing, and selected a site 70 miles north of Edmonton. Operations were commenced in August 1894. Strong flows of gas were met with at 245 feet and 334 feet, but no oil, and at 1770 feet the boring had to be abandoned owing to the caving-in of the bore. The Tar Sand was not reached, but it was believed that it would have been if the drilling had been continued a short distance further. In 1897 another trial-boring was commenced 90 miles lower down the Athabasca River, at the mouth of the Pelican River. The Tar Sand was reached at a depth of 750 feet, and a strong flow of gas ensued, but no oil was obtained. A boring was also commenced in 1897, at Victoria, on the Saskatchewan River, but though gas was met with at 1030 feet, a depth of 1840 feet was reached without any indications of oil or of the Tar Sand, and the undertaking was abandoned in 1899.

In 1902 a boring was made on the Belly River, in Alberta, but unfortunately just as the oil-bearing beds were reached at a depth of 1200 feet, the drilling tools stuck, and the experiment failed.

Within recent years much attention has been directed to the results of drilling operations in the **Calgary** field of southeastern Alberta, and in 1915 Mr. W. E. Park, of the Oil City Derrick, reported as follows :—In the Calgary field a great many tests have been abandoned. The Southern Alberta Oil Co. has secured a producing well at 3527 feet, and is refining the light oil into gasoline, most of which is sold locally. The Alberta Petroleum Consolidated people claim to have a well good for 100 to 150 barrels, but have not attempted to produce. The Dingman No. 1 of the Calgary Petroleum Products, Ltd., which was last year a small producer, yielding 387 barrels, is now being deepened. A number of other companies have claimed important shows, but these are the only definite results of two and a half years' drilling. In the Sweetgrass field of Southern Alberta no oil in commercial quantities has yet been discovered, but a large gas production has been developed, and arrangements are now being made to market this gas. In 1917 there were four producing properties.[1]

Near the boundary between **British Columbia** and Alberta, petroleum occurs in the South Kootenay Pass, near Waterton Lake, on the eastern side of the Rocky Mountains, and in small tributaries of the Flathead River, between the

[1] Canadian field: *Oil and Gas Journal*, vol. 16, No. 37, 1918.

South and North Kootenay Pass. The best indications are in the valley of the Kettle River and around Grand Forks. On the eastern side of the mountains oil was said to issue from the surface to such an extent that a farmer made money by skimming it off the ponds on his farm and selling it for lighting purposes and as a cure for cattle-diseases. A well drilled on the South Kootenay in 1904 is said to have produced 12 barrels a day. On Graham Island a test-well being drilled by the British Columbia Oilfields, Limited, had reached a depth of 800 feet at the end of 1916.

In **Nova Scotia** several shallow borings have been made on the shores of Lake Ainslie, Cape Breton Island, within the last forty years, but the results obtained were not followed up. Recently renewed interest has been manifested in the region as a possible source of petroleum.

New Brunswick.—The author is indebted to Dr. J. A. L. Henderson for the following particulars, dated March 1919, relative to New Brunswick :—

In New Brunswick the existence of petroleum, in its solid, plastic, liquid, and gaseous forms, was known to the early settlers long before the work of exploration for these minerals was undertaken. In the southern portion of the Province, where the Lower Carboniferous Albert Shale Series is exposed in many localities, numerous veins of albertite, extensive beds of rich bituminous shales, oil-bearing sandstones and deposits of plastic maltha are found at surface, together with widely distributed gas and oil springs, accompanied often by brine.

Following upon the discovery by Abraham Gesner in 1849 of the remarkable vein of albertite at Frederick Brook, near Hillsboro, and of the successful exploitation from 1850 to 1882 of that deposit in the Albert Mine, from which it is estimated that more than 230,000 tons was won, interest was aroused in the petroleum possibilities of the Province, and a number of unsuccessful attempts were made until 1906 to exploit the albertite, oil-shale, liquid oil, and natural gas deposits of the country. In 1864 a bench of retorts was erected at Baltimore, about eight miles west of Albert Mines, and a considerable quantity of oil-shale mined at this locality was treated, whilst at Taylorville on the Memramcook River, in 1865, about 2000 tons of oil-shale was mined and exported to the United States. The advent of cheap natural oil from the new oil-fields of Pennsylvania rendered the working of both albertite and oil-shale unprofitable, and the industry was abandoned.

Liquid oil and natural gas were encountered in intersected sandstone beds during the working of the Albert Mines, but not in commercial quantity. In 1859 the first boring was undertaken by Dr. H. W. C. Tweddle, of Pittsburgh ; five shallow wells being sunk by him at St. Joseph College and Dover, Westmorland county, yielding small, unprofitable quantities of oil and gas. In 1879, Mr. R. S. Merrill, of Boston, and Mr. Lewis Emery, of Bradford, Pennsylvania, and from 1899 to 1906 the New Brunswick Petroleum Company, Limited, a local organisation, undertook further exploratory drilling, chiefly in the same localities, with similarly disappointing results ; although in all 87 wells were sunk, one being 3000 feet deep. The area thus tested was unfavourable, being disturbed, with the strata highly tilted and the oil-sands outcropping in the immediate neighbourhood. Success first attended the efforts of Maritime Oilfields, Limited, an English company, formed in 1908, which acquired an option over the extensive Crown lease of 10,000 square miles, embracing the eastern third of the province, held under exceptionally favourable terms by the New Brunswick Petroleum Company. In 1909 a prolific gas-field, yielding also liquid oil in some quantity, was discovered at Stony Creek, nine miles south of Moncton. It is 2½ miles long, with a maximum breadth of 3000 feet, on a structural terrace in the Albert Shale Series, on the south flank of a partly denuded anticline. Its axis runs about N. 70° W. The largest wells yield initial gas-flows of from 11,000,000 to 13,000,000 cubic feet per day, and 40 to 60 barrels of oil, from five groups of lenticular gas- and oil-bearing sandstones, individual sandstones attaining a thickness of 100 feet, distributed within a vertical depth of about 1700 feet in the Albert Shale Series. The maximum observed gas pressure is 1060 lb. per square inch, whilst the highest pressure-gradient, 48 lb. per 100 feet of depth, is considerably higher than hydrostatic pressure. A sixth group is known, but has not yet been tested as regards its productivity. From 1909 to the end of 1918, 4,000,000,000 cubic feet of gas, valued at $1,203,000, and about 18,400 barrels of oil, valued at $40,600, have been produced. The production of oil is retarded or precluded by the presence of gas under high pressure in some of the wells.

The gas is dry, free from sulphur, and consists, on the average, of 76·5 per cent. methane, 20·5 per cent. ethane and higher paraffin hydrocarbons, and about 3·0 per cent. nitrogen, with a calorific value of 1130 B.T.U. per cubic foot, the yield of condensable hydrocarbons—natural-gas-gasoline,—by the absorption process, being very small, about one-eighth of a gallon per 1000 cubic feet.[1] A distributing company supplies the gas to domestic consumers in three neighbouring towns, and to a few industries. The crude petroleum (Sp. Gr. 0·836 to 0·839) is of excellent quality, with a paraffin base, and is practically free from sulphur. It yields from 14 to 15·3 per cent. of motor spirit, 38 per cent. of kerosene, and lubricating oils or fuel oil of high quality, containing 0·14 per cent. of sulphur. Of the 51 wells drilled, 25 are productive of gas and 2 of oil only, the remainder being dry exploratory wells near Stony Creek Field and within an area of 800 square miles in southern New Brunswick. The large northern area of the lease has not yet been tested by drilling.

The present owning company, New Brunswick Gas and Oilfields, Limited, was formed in Scotland in 1915, to amalgamate the interests of Maritime Oilfields, Limited, and New Brunswick Oilfields, Limited, and arrangements have been made for the further examination and testing of the large area so far unexplored. It is possible that the underlying Devonian beds, which yield a high-class oil at Gaspé, near the northern margin of this geological basin, may prove productive within this area. The production of petroleum in New Brunswick in 1917 reached 2341 barrels.

Natural Gas has long been known in Ontario, the "Gas Spring" at Caledonia Springs, in Prescott county, and the "Burning Spring" on the Niagara River, below the cataract, having been described at the beginning of the last century, but it received practically no commercial application until within the last thirty years. It then, however, rapidly came into use, and Mr. Brumell has given the following estimate of the available output of all the wells which were yielding at the close of the year 1889:—

	Cubic feet per diem.
Ruthven, Essex County,	10,000,000
Welland County,	15,050,000
Collingwood and Delphi,	9,000
Small wells in Ontario,	11,000
Total for Ontario,	25,070,000
Quebec,	55,000
North-Western Territories,	75,000
Total,	25,200,000

[1] Series of experiments carried out by U.S. Bureau of Mines, Pittsburgh.

As regards the natural-gas industry of Ontario, Mr. Brumell reports that in August 1888 seven wells had been bored on the Niagara peninsula, three of which were at Port Colborne, two at Niagara Falls (South), and one each at Thorold and St. Catherine's in the township of Bertie. The first well drilled for gas in Ontario was sunk in July 1885 at Port Colborne, in Welland county. It had a roughly-estimated flow of 50,000 cubic feet daily, and was followed by two others which struck gas at 762 and 764 feet. Small producing wells were sunk at Collingwood and Delphi in 1887 and 1888 ; while in the Essex field, the "Coste No. 1" well, in the township of Gosfield, near Ruthven, had in 1889 a measured daily flow of 10,000,000 cubic feet. This well is believed by Mr. Brumell to be supplied from a vesicular dolomite, probably of the Clinton division. The well was sunk to a depth of 1017 feet, when the first strong flow of gas was obtained. It was continued to a depth of 1031 feet, when the pressure of gas became so great as to necessitate a stoppage of the boring. The important gas-field situated in the townships of Bertie and Humberstone, in Welland county, lies near the northern shore of Lake Erie. Out of seven principal wells, four had a daily output exceeding 2,000,000 cubic feet, and one reached 6,900,000 cubic feet.

Mr. Eugene Coste furnished the following record of well No. 1 of the Provincial Natural Gas and Fuel Company of Ontario. The well yielded 2,000,000 cubic feet daily in 1889 from the lower white sandstone at a depth of 836 feet:—

TABLE V.—Gas-Well Section, Welland County.

Character of Beds.	Thickness.	Formation.
Surface deposits, ...	2 feet.	Drift.
Dark-grey limestone, ...	25 ,,	Corniferous.
Drab and grey dolomites, black shales and gypsum,	390 ,,	Onondaga.
Grey dolomite passing into brown, . . .	240 ,,	Guelph and Niagara.
Black shales, ...	50 ,,	Niagara.
White crystalline dolomite, grey towards bottom,	30 ,,	Clinton.
Red sandstone, ...	55 ,,	Medina.
Red shales, ...	10 ,,	
Blue shales, ...	5 ,,	
White sandstone, ...	5 ,,	
Blue shales, ...	20 ,,	
White sandstone, ...	15 ,,	

At Forest a small and short-lived supply of gas was obtained from the gravel and shales which lie beneath the Erie Clay.

The various productive wells of Ontario struck gas at greatly varying depths, from 95 feet at Delphi (Field's Crossing) and other shallow depths in Simcoe county, to 2394 feet in the Thorold well in Welland county. It is said that in 1894 gas was piped from Canada to Buffalo, in New York, to the value of $91,637.

Extensive boring for gas has been carried out in Quebec since 1885, and wells have yielded small supplies at Beausejour, in Nicolet county, apparently from the Medina formation, at Maisonneuve and other localities near Montreal, and at Louisville (Rivière du Loup en haut). Mr. Obalski observes that, as the heavy flow of gas at the base of the Medina in the Beausejour well corresponds with that from the same deposit in the Ohio wells, it would be advisable to bore down to the Trenton Limestone, a total depth of 2800 feet, in the hope of a yield from that formation, as in Ohio (*Rep. of the Commissioner of Crown Lands*, Quebec, 1885, 116). He remarks that "An all-important consideration in connection with the probable occurrence of these reservoirs is that of the geological structure of the district; and while, for reasons in connection with this, I have never had any faith in their occurrence on the north side of the St. Lawrence, I consider that the probability of such reservoir existing on the south side, in the country between Lake St. Peter and St. Hyacinthe, is very great, especially along, or in proximity to, the central part of the line indicated by Sir W. E. Logan as the course of the Deschambault anticlinal."

The value of natural gas produced in Ontario in 1899 was $110,901, and in 1903, $196,535; in 1909 it had increased to $1,188,179.

In 1909 a small fraction of the total production (valued at $1,207,029) of natural gas in Canada came from wells near Medicine Hat in the Province of Alberta; at the beginning of the year there were twelve producing wells in that field.

In 1915 a large production of natural gas was obtained in the Sweetwater field of Southern Alberta.

The preliminary report on the mineral production of Canada in 1916, issued by the Canada Department of Mines, Mines Branch, contains the following particulars of natural-gas production in Canada:—

The total production of natural-gas, according to returns received, was 25,238,568, thousand cubic feet, valued at $3,924,632, as compared with a production in 1915 of 20,124,162 thousand cubic feet, valued at $3,706,035. The production in 1916 by Provinces was as follows:—Ontario, 17,953,109 thousand cubic feet, valued at $2,765,105; New Brunswick, 610,118 thousand cubic feet, valued at $79,628; and Alberta, 6,904,231 thousand cubic feet, valued at $1,113,296. In 1918, Ontario, 13,029,524 thousand cubic feet, valued at $2,884,460; New Brunswick, 792,396 thousand cubic feet, valued at $107,842; and Alberta, 6,318,389 thousand cubic feet, valued at $1,358,638.

NEWFOUNDLAND.

The existence of petroleum on the west coast of Newfoundland has been known for a century, for it was in 1812 that Mr. Parsons, after whom Parsons Pond is named, used the crude oil of this district as a cure for rheumatism.

In 1867 Mr. Silver of Halifax, Nova Scotia, sunk a well, which is said to have been about 700 feet deep, on this property, and obtained slight shows of oil, but owing to lack of capital, further exploitation was abandoned. In June 1890 Mr. Pippy obtained concessions from the Government, and his operations led to the formation in 1894 of the Newfoundland Oil Company, Limited. The first well was begun in 1895, and struck oil at 700 feet and again at 900 feet, and a still larger source at 1230 feet, but the total production was inconsiderable. A second well struck oil at 900 feet, and a better supply at 1160 feet, but at 1176 feet the tools were lost, and the well had to be abandoned. A third well was started, but when it had reached a depth of 120 feet a fire took place, and operations ceased. In 1901 another attempt was made at a spot about 500 yards to the west of these wells, and drilling was carried to a depth of 1500 feet, slight shows of oil being met with at 810, 1130, and 1410 feet. A boring was also undertaken near the original well put down in 1867, and was carried to a depth of 1210 feet, when the tools were lost, shows of oil being met with at 65, 505, and 1210 feet. During 1903 a well was drilled near Parsons Pond in which what is described as a good flow of oil was met with at 1204 feet.

In 1898 some trial-borings were put down on the shore of Port-au-Port Bay, about 100 miles southwest of Parsons Pond, in some of which there were evidences of petroleum in small quantities, with a paraffin base. More recently oil is said to have been obtained at St. Paul's Bay at a depth of 1700 feet.

THE UNITED STATES. (Plate 12.)

Although the petroleum industry of America is of recent origin, the crude oil has undoubtedly been long used by the Indians. Ancient oil-pit heaps, sometimes supporting trees of the growth of centuries, have been found in the vicinity of Oil Creek, Pennsylvania. The earliest mention occurs in a letter dated 1629, and published in Sagard's *Histoire du Canada*, 1632, which describes a visit of a Franciscan, Joseph de la Roche d'Allion, to the oil-springs of what is now the State of New York, and states that the Indian name of the place signifies "there is plenty there" (Peckham, *The Production, Technology, and Uses of Petroleum and its Products*. Washington, 1884). In 1748 North America was visited by Peter Kalm, a Russian naturalist, who on his return published his travels, together with a map on which the oil-springs of Oil Creek were indicated. The existence of asphaltum and semi-solid bitumen in Santa Barbara, California, is said to have been known since 1792 (Gesner, *A Practical Treatise on Coal, Petroleum, etc.*, 1865, 17).

In the first edition of this work a paragraph appeared in which it was stated that in 1750 the Commander of Fort Du Quesne (Pittsburgh) wrote a letter describing the religious ceremonies of the Indians as witnessed by him. It is now known that this was a fictitious production, and owed its origin to the eminent jurist, Judge J. Thompson, and the noted divine, Dr. Cyrus Dickson, who conjointly published in 1830 an imaginary history of N.W. Pennsylvania in a Franklin weekly paper (J. J. McLaurin, *Sketches in Crude Oil*, Harrisburg, Pa., 1896, p. 17). The extract was as follows:—"I would desire to assure you that this is a most delightful land. Some of the most astonishing natural wonders have been discovered by our people. While descending the Allegheny, 15 leagues below the mouth of the Conewango and three above the Venango, we were invited by the Chief of the Senecas to attend a religious ceremony of his tribe. We landed, and drew up our canoes on a point where a small stream entered the river. The tribe appeared unusually solemn. We marched up the stream about half a league, where the company, a large band it appeared, had arrived some days before us. Gigantic hills begirt us on every side. The scene was really sublime. The great Chief then recited the conquests and heroism of their ancestors. The surface of the stream was covered with a thick scum, which, upon applying a torch at a given signal, burst into a complete conflagration. At the sight of the flames the Indians gave forth the triumphant shout that made the hills and valleys re-echo again. Here, then, is revived the ancient fire-worship of the East; here, then, are the children of the Sun." The site is Oil Creek, Venango county, Pennsylvania.

Petroleum was formerly used in America as a cure for rheumatism, burns, coughs, sprains, etc., under the name of "Seneca oil," found near Lake Seneca, Allegheny county, New York, the vicinity of which provided the earlier supplies. This oil-spring was thus described in 1833 in the *American Journal of Science* (1), xxiii, 97, by Prof. B. Silliman, sen.:—"The oil spring, or fountain, rises in the midst of a marshy ground; it is a muddy and dirty pool of about 18 feet in diameter. The water is covered with a thin layer of petroleum, giving it a foul appearance as if coated with dirty molasses, having a yellowish-brown colour. They collect the petroleum by skimming it like cream from a milk-pan. For this purpose they use a broad flat board, made thin at one edge like a knife. It is moved flat upon and just under the surface of the water, and is soon covered by a thin coating of the petroleum, which is so thick and adhesive that it does not fall off, but is removed by scraping the instrument on the lip of a cup. It has then a very foul appearance, like very dirty tar or molasses ; but it is purified by heating and straining it while hot through flannel or other woollen stuff. It is used by the people of the vicinity for sprains and rheumatism and for sores on their horses, it being in both cases rubbed upon the part. It is not monopolised by anyone, but it is carried away freely by all who care to collect it, and for this purpose the spring is frequently visited. I could not ascertain how much is annually obtained ; but the quantity is considerable. It is said to rise more abundantly in hot weather than in cold. Gas is constantly escaping through the water, and appears in bubbles upon its surface."

Although the existence of petroleum over a large area in the States was known at a very early period, there are no records of the systematic collection of the oil prior to its being obtained in comparatively large quantities from the brine-wells or springs which were worked for the extraction of salt. Such wells were extensively bored on the banks of the Kanawha River in West Virginia. Many of these wells were drilled to a great depth, and nearly all yielded oil and natural gas to a greater or less extent. So noticeable, in fact, was the association of oil and brine, that surface-indications of the occurrence of petroleum often led to the selection of the locality for boring a brine-well. The presence of the oil was, however, invariably regarded as objectionable, and often resulted in the closing of the works. The petroleum was collected and sold by a few as a curiosity, and for medicinal use.

Writing in 1833, Dr. S. P. Hildreth thus refers to the early use of petroleum : "From its being found in limited quantities, and its great and extensive demand, a small vial of it would sell for 40 or 50 cents. . . . In neighbourhoods where it is abundant it is burned in lamps in place of spermaceti oil, affording a brilliant light, but filling the room with its own peculiar odour. By filtering it through charcoal, much of this empyreumatic smell is destroyed, and the oil greatly improved in quality and appearance. It is also well adapted to prevent friction in machinery, for, being free of gluten, so common to animal and vegetable oils, it preserves the parts to which it is applied for a long time in free motion ; when a heavy vertical shaft runs in a socket, it is preferred to all or any other article. This oil rises in greater or less abundance in most of the salt-wells of the Kanawha, and collecting as it rises in the head of the water, is removed from time to time with a ladle" (*American Journal of Science* (1). xxiv, 63).

Prof. S. F. Peckham, in his monograph on petroleum, quotes a paper written by Dr. J. P. Hale of Charleston, West Virginia, for the volume prepared by Prof. M. F. Maury and issued in 1876 by the State Centennial Board, on the resources and industries of the State. It contains an account of the drilling of "the first rock-bored brine-well, west of the Alleghanies, if not in the United States," by the brothers Ruffner, about 1806. This, "the legitimate precursor of all the petroleum wells of the country," was bored on the bank of the "Salt Lick," or "Great Buffalo Lick," to a depth of about 58 feet, and was followed by the drilling of large numbers of wells, the Muskingum and Duck Creek Valleys soon becoming noted. "Nearly all the Kanawha salt wells have contained more or less petroleum, and some of the deepest wells a considerable flow. Many persons now think, trusting to their recollections, that some of the wells afforded as much as twenty-five to fifty barrels per day. This was allowed to flow over from the top of the salt cisterns to the river, where, from its specific gravity, it spread over a large surface, and by its beautiful iridescent hues, and not very savoury odour, could be traced for many miles down the stream. It was from this that the river received the nickname of 'Old Greasy,' by which it was for a long time familiarly known by Kanawha boatmen and others. At that time this oil not only had no value, but was considered a great nuisance, and every effort was made to tube it out and get rid of it."

A well bored in 1814 to a depth of 475 feet at Duck Creek, periodically discharged from 30 to 60 gallons of oil, together with large quantities of natural gas, at intervals of from two to four days. The following account of the "American" well bored in 1829 for brine at Little Pennox Creek, is from Niles's *Register* (3), xiii, 4:—"Some months since, in the act of boring for salt water on the land of Mr. Lemuel Stockton, situated in the county of Cumberland, Kentucky, a vein of pure oil was struck, from which it is almost incredible what quantities of the substance issued. The discharges were by floods at intervals of from two to five minutes, at each flow vomiting forth many barrels of pure oil. . . . These floods continued for three or four weeks, when they subsided to a constant stream, affording many thousand gallons per day."

This well yielded plentifully until 1860, and the oil was largely sold as "The American Medicinal Oil, Burkesville, Kentucky" (*Burkesville Courier*, 11th October 1876).

About the year 1849, S. M. Kier, a druggist of Pittsburgh, noticed the close similarity between the "American Oil" prescribed for the sickness of his wife, and the petroleum obtained by his father from a brine-well at Tarentum, and commenced to bottle and retail the latter oil for medicinal use, soon bringing up the sale to about three barrels daily. Finding that the production far exceeded the sale, Mr. Kier began about 1855 to refine the oil in a roughly-constructed still. The "light, wine-coloured" distillate, which first came over, was found useful for illuminating purposes, while the heavier product was employed at a factory in Cooperstown for cleansing wools.

Oil from Coal and Shale.—Shortly after the introduction of Young's process for obtaining paraffin and paraffin oils by the distillation of coal and shale, a considerable number of refineries were erected in the United States, and were worked under licenses from Young's Company. At some of these imported coal was distilled, but most of them received their supplies of raw material from the extensive shale and coal deposits of Virginia, Kentucky, and Missouri. Near Boston, Mass., the large works of Downer were erected at a cost of half a million dollars, and at Portland, Mr. Downer erected a smaller works for distilling imported coal.

The manufacture of oil from coal and shale continued to increase until there were not less than fifty or sixty establishments devoted to this industry in the United States, one of which was in Portland, one in New Bedford, four in Boston, one in Hartford, five in the environs of New York, eight or ten in western Pennsylvania, twenty-five in Ohio, eight in Virginia, six in Kentucky, and one in St. Louis. Many, if not most, of these were of small capacity, however, and the greater part of them were not more than fairly started when the discovery of petroleum prostrated the whole business, and threatened its projectors with overwhelming loss, from which they were happily rescued by converting their oil factories into refineries, which was done with very little trouble (Henry).

Development of the Petroleum-Industry.—Having been shown some petroleum obtained from the Cherrytree Township of Venango, Mr. George H. Bissell, a lawyer of New York, joined Mr. J. G. Eveleth of the same city in organising a company, which was incorporated at the end of 1854 as the Pennsylvania Rock Oil Company. Some of the oil from the Cherrytree deposits was sent to Prof. B. Silliman, jun., whose report, dated 16th April 1855, is referred to in the section of this work dealing with the Chemistry of Petroleum.

The operations of the Pennsylvania Rock Oil Company were not very successful, and in March 1858 Bissell and certain other members of the Company formed themselves into the Seneca Oil Company, which leased a plot of land on Oil Creek from the parent company, and started operations at Titusville under the control of Mr. E. L. Drake, for obtaining the oil by means of artesian wells. After many vexatious delays Drake engaged two drillers who had been employed in boring salt-wells at Tarentum, and at the beginning of 1859 work was commenced. Finding all attempts at digging through the surface-deposits to the rock, which was to be penetrated by the drill, to be futile on account of the caving-in of the shaft, Drake successfully adopted the expedient of driving an iron tube through the quicksands and clay to the rock, a system which has since been largely employed. After drilling to a depth of 69 feet, the drill suddenly dropped, on 28th August 1859, into a crevice, and on the following day oil was found to have been struck. At first the well yielded about 25 barrels daily to the pump, but its production rapidly diminished, until, at the close of the year, it did not amount to more than about 15 barrels daily. The total yield during 1859 is said to have been under 2000 barrels.

The success of the Drake well led to the rapid development of the petroleum industry. Bissell immediately secured all the available leases down the creek and along the Allegheny, and largely bought up the stock of the Pennsylvania Rock Oil Company. Others also secured many valuable leases, usually no rent being charged, but a royalty of one-eighth to a quarter of the oil obtained being paid by the lessee. Cone and Johns (*Petrolia*, N.Y., 1870) and Henry (*Early and Later History of Petroleum*, 1873) have collected a large amount of interesting information on the development of the industry along Oil Creek and its vicinity. "Commencing at Titusville in 1859, the tide of development swept over the valley of Oil Creek and along the Allegheny River, above and below Oil City, for a considerable distance. Cherry Run in 1864 furnished the first subsequent excitement. Then came Pithole Creek, Benninghoff, and Pioneer Run. The Woods and Stevenson farms on Oil Creek, near Petroleum Centre, came in like succession in 1865 and 1866. Tidioute, or rather Dennis Run and Triumph Hill, was a promising candidate for public favour in 1867, and in the latter part of the same year Shamburgh, on Upper Cherry Run, made its brilliant *début*. For 1868 the Pleasantville oil-field furnished the chief excitement" (Cone and Johns).

The next well after Drake's was that of Barnsdall, Meade, Abbott, and Rouse, who struck oil almost within a stone's-throw of Drake's well, at a depth of 80 feet. At that depth, however, a yield of only about five barrels was obtained; but in February 1860, at a depth of 160 feet, a second supply was struck, which yielded 40 to 50 barrels daily. Most of the early wells on Oil Creek were sunk by means of the "spring pole," which was used even to a depth of 400 or 500 feet.

During the early days of the petroleum-industry in America, drilling was carried on in an unsystematic manner, without regard to any geological or other features of the country, save such delusive indications as were furnished by superficial outflows of oil, the rising of gas and oil in wells drilled for water or brine, or the appearance of exudations of oil and semi-solid bitumen.

The appearance of gas and oil in the brine-wells at Tarentum and elsewhere, and the subsequent drilling of wells for the express purpose of obtaining the oil, were the most potent factors in the early development of the industry in America, and the successive boring of neighbouring wells, together with the energy displayed by the "wild-cat" prospectors, who drilled wells in unknown territory, and in many cases regardless of any indications whatever, soon led to the mapping out of a large area of producing country in Pennsylvania and

New York. The drillers in Venango county quickly discovered that the oil was contained in a series of sandstones imbedded in shale ; three of these deposits, respectively termed the first, second, and third sands, and all included under the general name of oil-sands, being known.

In June 1861 the first flowing well was struck. This was the Fountain well, and was sunk on the Upper McElhenny or Funk farm, to a depth of 460 feet, being the first well drilled to the Third Sand-rock. It yielded 300 barrels daily for six months, and then suddenly ceased to produce, having, it was said, been choked by the solidification of paraffin. The Empire well, drilled to the same depth on the same farm, was completed in September 1861, and commenced to flow at the rate of 2500 barrels daily. The yield even after six months was maintained at 2200 barrels, but in about eight months the flow suddenly ceased. The well was ultimately cleaned out, and yielded 300 barrels daily to the pump for some time.

The Lower McElhenny farm gave, amongst others, the Davis & Wheelock well, flowing at the rate of 1500 barrels daily, and the Densmore wells, Nos. 1, 2, and 3, which daily yielded 600, 400, and 500 barrels respectively.

The Maple Shade well, struck in August 1863, on the Hyde & Egbert farm at Petroleum Centre, produced 800 barrels daily, and is said to have given a million and a half dollars profit to its owners. The J. W. McClintock farm, afterwards covered by the city of Petroleum Centre, consisted of 207 acres, and was the site of not less than 150 wells, nearly 80 per cent. of which were remunerative.

At a depth of 491 feet, the Phillips well, on the Tarr farm, was struck in November 1861, and gave a stream of 3000 barrels daily, the yield being maintained at nearly that amount for months. The well, which is estimated to have yielded 750,000 to 1,000,000 barrels, flowed for a year, and was then pumped. It produced largely for twelve years, but was finally shut down in 1873. The Woodford well, a few rods from the Phillips, yielded 2000 barrels daily, and was found to be connected with that well, for, when either ceased working, only water could be obtained from the other.

On the Farrel farm was the Noble & Delamater well, which flowed at the rate of 3000 barrels daily. It was sunk in 1863, and continued to yield until 1865, having, it is estimated, produced $3,000,000 worth of oil. The Sherman well, on the opposite side of the creek, commenced flowing at the rate of 2000 barrels in 1862, and it is said to have yielded 900 barrels daily for two years.

The excitement at Pithole commenced in January 1865, when the celebrated United States or Fraser well was struck on the Thomas Holmden farm in a ravine on Pit Creek. This well, the property of the United States Oil Company, commenced to flow at the rate of 650 barrels daily ; but the yield gradually diminished, and in November of the same year came to an end. On the same farm were the Twin wells (800 barrels daily), the No. 54 well (800 barrels), the Grant well (450 barrels), and the Eureka well (800 barrels). Other flowing wells were struck on the adjoining Rooker farm, and on the adjacent Hyner and Copeland farms ; but, although all gave excellent results at the commencement (the Holmden farm producing from three to four thousand barrels when at its best) none of the wells yielded for more than a few months.

Pithole was a typical oil city. Built up in an incredibly short time, it had a population estimated at twelve to sixteen thousand before the end of September 1865 ; its post-office ranking next in importance in the State to those of Philadelphia and Pittsburgh. As, however, its production fell off, its prosperity rapidly declined, and within two years of its foundation it was practically deserted.

Borings in the valley of the Muskingum, in Ohio, and on the little Kanawha, were also attended with success.

The development of the Mecca field in Trumbull county, Ohio, dates from 1860, when boring operations were started on a large scale. Several thousands of barrels were taken out yearly for some time, but the greater number of the wells, which were very shallow, rarely exceeding 100 feet in depth, were soon abandoned, and subsequent operations did not result in any large increase.

In 1860 an old brine-well at Burning Springs, West Virginia, was reopened, and yielded about 50 barrels of oil daily ; and the following year the Llewellyn well, with a depth of only 100 feet, flowed over 1000 barrels daily, and subsequently at the rate of 1400 to 2000 barrels daily for some months. Oil was also obtained in 1860 and 1861 at Oil Springs, on the Hughes River.

The occurrence of petroleum in brine-wells in Washington county is referred to by Hildreth (*American Journal of Science*, 1833, xxiv, 63 ; and 1836, xxix, 87), and several wells were drilled from 1860 to 1865 at Cow Run and elsewhere in this district.

Although wells had been drilled near the junction of the Clarion and Allegheny rivers as early as 1863, the development of the " lower country " lying in Butler, Armstrong, and Clarion counties did not commence until 1868.

The following statement roughly indicates the early growth of the American petroleum industry:—In 1859 the total produce, which was wholly obtained from Oil Creek, was 2000 barrels. In June 1860 the wells along Oil Creek yielded about 200 barrels daily, and in September about 700. The yield then rapidly increased, owing to the discovery of flowing wells, until during the winter and spring of 1861 to 1862 it amounted to about 15,000 barrels daily. The price obtained for the crude oil then fell so low that production was largely arrested, until " the production of 1863 was scarcely half that of the beginning of 1862, and that of 1864 still less. In May 1865 the production had declined to less than 4000 barrels a day, the valley of Oil Creek being the only producing locality at that time " (Cone and Johns). It is estimated that some ten million barrels ran to waste in Pennsylvania in and prior to 1862 owing to the absence of a market.

The *Oil City Register* for May 1862 gives the following estimates for the Oil Creek valley at that date:—Daily production, 5717 barrels ; flowing wells, 76 ; wells sunk and in process of being drilled, 358 ; amount of oil in hand, 92,450 barrels ; total production prior to May 1862, 1,000,000 barrels ; cost of sinking wells, $498,000 ; and cost of machinery, buildings, tanks, etc., $509,000.

After the middle of the year 1864 the industry began to expand, and the production has since steadily increased. For some years the Pennsylvanian fields remained the principal source of supply, but a small quantity soon began to be raised in the States of Ohio, West Virginia, Kentucky, Tennessee, and California. After 1881 the production of Ohio rapidly increased, and that of West Virginia after 1890 ; from the same date that of California also increased steadily to nearly 30,000,000 barrels in 1904, and Colorado and Indiana began to contribute appreciable quantities to the total supply. Very small productions were also recorded from Illinois, Kansas, Texas, Missouri, and Indian Territory at the beginning of the last decade of the nineteenth century, but towards its close, Kansas and Texas began to develop their petroleum resources to a fuller extent, and Wyoming also appeared on the list of producing States.

From 1901 to 1904, while the eastern fields showed a decline, California, Texas, and Louisiana, with the Indian and Oklahoma Territories, Kansas, and

Indiana, increased their production to a remarkable extent. Down to the end of 1904 the entire output of petroleum in the United States since its discovery in quantity in 1859 was estimated at 1,382,815,006 barrels, which sold for $1,363,069,897, an average price of 98·6 cents per barrel (Oliphant, *Mineral Resources of the United States for* 1904).

According to the annual reports of the United States Geological Survey, the most important features in connection with the production of petroleum in that country during the years 1904–1918 have been as follows:—

In 1904 there was a continuance of the remarkable increase in the production of an inferior grade of petroleum in California, Texas, and Louisiana, and of the increase in Kansas and Indian Territory of the production of a fair grade of petroleum ; for the first time in the history of the petroleum industry the quantity produced west of the Mississippi River was greater than that produced east ; there were new fields developed in Texas, California, and Kansas ; the regularity of the sum of production of the older fields continued to be remarkable ; there was an increase in the demand for refined petroleum throughout the United States, especially for the lighter grades used in internal-combustion engines, and there was an increased quantity of the heavier crude petroleum produced in Louisiana, Texas, and California consumed in fuel.

In 1905 the development of the Mid-Continent field, and the extension into Illinois of the Lima-Indiana field indicated a great increase in the future production of the lighter grades of oil, whilst the production of the Eastern fields showed signs of permanent decrease. The completion of the pipe-line from Humboldt, Kansas, to Whiting, Indiana, marked another step in the transportation of oil. In 1906 there was an extension of the area of the Mid-Continent field, and an increase in the daily production of oil in that region ; an expansion of the area in Illinois from which oil was being produced ; considerable growth in the consumption of fuel oil in California ; decline in the production from the Coastal Plain district of the Gulf States ; and further decrease in the average daily production from the Appalachian field. Additional transport facilities were provided by the laying of a second pipe-line from the Mid-Continent field to Whiting, Indiana, and the building of a pipe-line across the Isthmus of Panama for the delivery of the oil from the California field to the Atlantic Ocean. In 1907 there was a total output of crude oil far in excess of that of any previous year, with an unparalleled accumulation of stocks ; and great increase in production in the new Illinois field, in the Glenn pool in Oklahoma, and in California. In 1908 there was a steady growth in the production in Illinois and California, and a decline in the production in the Glenn pool and in various Texas and Louisiana pools. In 1909 California was the chief centre of attraction, the production increasing to the extent of 21·35 per cent., but Oklahoma and West Virginia also showed some gain. In 1910 a further increase of 31·62 per cent. was recorded in California, and Louisiana more than doubled its output ; the production of oil in Wyoming also began to assume importance.

In 1911 the extension of the Oklahoma fields with Osage and Pawnee counties, and the discovery of oil still further west in Kay county, substantially increased the Mid-Continent yield. There was a concurrent decline in production in Illinois and in States further east.

In 1912 the greatest increase in output was in California, but there was also a remarkable gain in Wyoming.

In 1913 there was increased production in the Mid-Continent field and in California.

In 1914 the output constituted a new record. The increase resulted from deeper drilling in the Mid-Continent and Gulf Coastal Plain regions, and further developments in Oklahoma, northern Texas, northwestern Louisiana, Wyoming, and California.

The year 1915 may be characterised as a period of readjustment in which activity in production was purposely curtailed. Nevertheless, the output showed a considerable increase over that of the previous year.

In 1916 there was a further gain in production, the output amounting to 300,767,158 barrels, as compared with 281,104,104 barrels in 1915; the production for 1917 was 335,315,601 barrels, and for 1918, 355,927,000 barrels.

Having regard to the dominant position occupied by the United States in the petroleum industry, the following paper, presented at the annual meeting, February 4-6, 1919, of the Society of Automotive Engineers, by the Chief Geologist of the United States Geological Survey, for a copy of which the author is indebted to Mr. George Otis Smith, Director of the Survey, is reproduced :—

"The Unmined Supply of Petroleum in the United States.[1]

"The justification of an estimate so highly speculative as must be that of the petroleum resources in the ground in the United States lies in the widening angle between the flattening curve of production and the rising curve of consumption. The standards of living, the industrial power and the prosperity of the country are dependent to so great a degree upon our oil supply, and the question of the adequacy and duration of this supply so directly concerns, at the present moment, the individual citizen as well as the public in general, that an estimate, even if it is but a scientific guess, based, with careful study, experience, and judgment on the best information available, is imperatively necessary.

"In response to the growing interest of the public four estimates of the oil resources of the United States have been made. In 1908 Dr. David T. Day,[2] then in charge of petroleum statistics in the U.S. Geological Survey, calculated the total amount of oil originally available in the ground as ranging somewhere between a minimum of 10,000,000,000 and a maximum of 24,500,000,000 barrels. In 1915 Dr. Ralph Arnold[3] placed the original supply of oil at 9,098,557,000 barrels, of which he believed 5,763,100,000 barrels remained in the ground at the end of 1914. The third estimate was made by the geologists of the oil and gas section of the Geological Survey for the use of the Secretary of the Interior in responding to a Senate resolution of 5th January 1916, and was published in Senate Document 310, Sixty-fourth Congress, first session, 2nd February 1916. According to this estimate the reserve of oil available at the end of 1915 was 7,629,000,000 barrels. In the spring of 1917 the production records and the possible oil regions were closely reconsidered with marked conservatism by the same geologists, each studying the regions with which he had field acquaintance, with the result that the total oil available in the ground at that time was estimated at 6,182,000,000 barrels.

"In the preparation of estimates by the U.S. Geological Survey consideration has been given to the general character of the geologic formations—stratigraphy, geologic history, structure—the number, thickness, continuity, and pore space of sands, the curves of production, the gas pressure, the water

[1] By David White, chief geologist, U.S. Geological Survey. Published by permission of the Director of the U.S. Geological Survey.

[2] *U.S. Geological Survey Bulletin*, No. 394, page 30, 1909.

[3] *Economic Geology*, vol. 10, No. 8, page 695, December 1915.

relations, and the results of drilling in near-by or geologically similar regions. A large part of the producing or possibly productive area in the Western States has been examined and mapped by the oil and gas geologists of the Survey or is now under examination. Typical areas in the Central, Gulf, and Eastern States have also been studied. Nevertheless, the criteria upon which estimates can be based vary in every degree of inadequacy in the different regions, and the quality of the results, therefore, varies with the extent and character of the data available and with the personal equation of the estimators. Necessarily the estimates for areas not yet tested, especially those remote from the producing fields, are based upon theoretical conditions, carefully considered. For most of the areas estimates were first formulated by the geologists who had studied the areas. Later, these estimates were discussed in conferences.

"*Recent Geologic Investigations.*—Further recent geologic investigations in the field and the study of the results of testing and exploration, especially in the Rocky Mountain and Gulf States, have furnished the basis for a more reliable recalculation of the estimates for a number of the regions. The conclusion reached is that the available oil in the ground at the end of 1918 approximates 6,740,000,000 barrels.

"The new estimates, combined according to the commercial fields, are given in the accompanying table, in which for comparison and information are shown the marketed production for 1917 and the estimated output for 1918, as compiled by John D. Northrop, of the Geological Survey, in charge of statistics of petroleum and natural gas, and the approximate total production of petroleum in the United States to the end of 1918, also based on Geological Survey records. For the immediate convenience of the reader there is also included the percentages of average gasoline recovery from the oils of the different fields at the present time. For the latter data the writer is indebted to Chester Naramore of the Bureau of Mines, in which bureau the returns of gasoline recovery from the oil runs are compiled. The general characteristics of the various crude oils in the different fields are too well known to require discussion in this paper, and their especial qualities will be fully considered in those to follow. It will, however, be noted that the reserves of the heavy oils of California and the Gulf coast are estimated at about 3,000,000,000 barrels. Probably such low-gasoline oils comprise more than one-half of the total reserves.

"Those who have followed the history of petroleum in America and understand how much of our present-day oil-field development has taken place since Day made his estimates in 1908, and even since Arnold calculated the reserves in 1915, will appreciate the great advantages, mainly in the form of results of exploration and records of production, enjoyed by those who make computations now. However, with these circumstances in mind, we may, nevertheless, for comparison, compensate and bring to date the earlier estimates by deducting subsequent production to the end of 1918. The available oil in the ground at present would be according to these estimates, as follows :—

"Day (estimate in 1908), 5,402,000,000 to 19,902,000,000 barrels.

"Arnold (estimate in 1915), 4,500,000,000 barrels.

"Geological Survey (estimate in 1916), 6,647,000,000 barrels.

"Geological Survey (estimate in January 1919), 6,740,000,000 barrels.

"The recent estimate by the Geological Survey, as given above, and as differentiated by fields in the accompanying table, differs from that of 1916 mainly in a more conservative view as to prospects in Montana and recoveries along the Gulf coast and in a more optimistic attitude toward Kansas and the

States of little or no present production. As compared with the very conservative estimate formulated in the Geological Survey in 1917 they represent greater confidence in Wyoming, North Texas, and Alaska, and several of the minor States. In general, they are to be regarded as conservative, and there is little probability that the actual yield will fall short of the calculated amounts. They are, however, likely to be again revised in the near future, as the modes of occurrence of oil and gas in different regions become more fully understood, as exploration proceeds, and as the areas offering possibilities of oil discoveries are examined more in detail.

"Available Oil remaining in Ground, as estimated by the U.S. Geological Survey. (Bbl. of 42 gal.)

Oil Fields.	Marketed Production in 1917.	Marketed Production in 1918 (preliminary estimate).	Total Marketed Production to end of 1918.	Available Oil left in Ground, January 1919.	Present Average Gasoline Extraction, per cent.
Appalachian,	24,932,205	25,300,000	1,221,737,000	550,000,000	28·0
Lima, Indiana,	3,670,293	3,100,000	448,404,000	40,000,000	20·0
Illinois,	15,776,860	13,300,000	298,159,000	175,000,000	22·0
Mid-Continent,	144,043,596	139,600,000	990,573,000	1,725,000,000	24·0
North Texas,	10,900,646	15,600,000	78,971,000	400,000,000	33·0
North Louisiana,	8,561,963	13,000,000	90,902,000	100,000,000	28·0
Gulf,	24,342,879	21,700,000	303,954,000	750,000,000	1·5
Wyoming,	8,978,680	12,370,000	39,793,000	400,000,000	40–50
California,	93,877,549	101,300,000	1,114,000,000	2,250,000,000	12·0
Alaska, Colorado, Michigan, Montana, etc.,	230,930	230,000	10,651,000	350,000,000	..
Total,	335,315,601	345,500,000	4,598,144,000	6,740,000,000	..

"The reports of production of petroleum in the United States, as compiled by the Division of Mineral Resources of the Geological Survey show that since 1858 approximately 4,598,000,000 barrels of petroleum have been taken from the ground. This is more than two-thirds as much as the amount which according to the latest estimate by the Geological Survey remains available, and exceeds what would now be left according to Arnold. Further, the oil companies are now taking out over one-third of a billion barrels a year.

"*Relation of Production and Consumption.*—The situation as to petroleum production and the importance of the remaining oil resources of the United States are both graphically indicated by the curves in fig. 6. The most significant features here shown are the steep ascent of the consumption curve and the flattening, in 1918, of the curve of actual production in spite of the vigorous efforts of the oil companies to increase their war-time output even at the expense of their proved reserves. To fill the gap between our actual domestic production and the requirements of domestic consumption it has been necessary to reduce the oil in storage to the extent of 27,000,000 barrels and to supplement this with a net importation of 31,000,000 barrels, chiefly from Mexico. The deficiency of our current production during 1918 has, therefore, amounted to 58,000,000 barrels, nearly half of which has been withdrawn from storage. That is to say, this country has to the extent of 27,000,000 barrels of storage oil been 'living on its hump,' which is now reduced to about 123,000,000 barrels.

"According to general expectations, barring disaster or shortage of supply, or much higher prices which might result from such shortage, the consumption curve is destined during the next year, and probably longer, to continue its present general trend beyond the 400,000,000-barrel mark, which it nearly reached (397,000,000 barrels) in 1918. On the other hand, whether the domestic production can be increased in volume to correspond to the consumption remains to be seen. Glenn pools and Cushings may await discovery, but the strike of a Glenn pool such as produced the bulge in the storage curve for 1907 and 1908, or of new Healdtons and Cushings, such as were largely responsible for the production swell of 1914-15, will make a less conspicuous wave in the greatly expanded and diffused production of to-day. Texas, the Osage country, and Wyoming will furnish notable contributions, but so many fields are now running down that it will require numerous successive strikes of large magnitude to send the production curve so high that oil will go into storage without considerably increased importations. On the whole, even with prices stimulating the driller to greater efforts, it seems unlikely that the domestic production of petroleum can at best gain appreciably on the reasonably expected increase in consumption. It seems more probable that, unless consumption is restrained by high costs, the gap between consumption and production will continue to widen. In any event, this gap must be filled with oil from other sources. Further exhaustion of stocks in 1919 is a certainty that can be successfully minimised only by still larger importations.

"The situation demands not only the prevention of waste, but the most economical and efficient use of our oil. Also, it warns operators to consider more thoughtfully and promptly the acquisition of foreign oil reserves. Mexico, to which the American public looks with optimistically hopeful eyes, probably contains less oil—perhaps very much less—than remains in the ground in the United States.

"How long the commercial production of natural petroleum will continue in this country is a question whose answer is no less speculative than the quantitative estimates. After the production peak is passed, be it one year or seven, the annual output of natural oil will decline gradually for a long time. Oil-wells will be producing at least 75 years hence. The pools cannot all be so soon discovered; the oil cannot immediately be got out of the ground. The discovery of deep sands is likely to give new life to many old or even abandoned fields. Pools will be found after prolonged search and repeated wildcatting in old as well as new regions, and this is probably especially true of the Gulf coast, where, unless geologic discovery and consequent new methods of search come to the aid of the driller, it may be 75 years before some of the productive salt domes are revealed.

"The most significant feature of the prospect, however, is the probability that, although an estimated two-thirds of our reserve is still in the ground, with an annual drain of one-third of a billion barrels, the peak of production will soon be passed—possibly within three years. The date when the peak will be reached is a matter of individual opinion, in which predictions have wide range. There are many well-informed geologists and engineers who believe the peak in the production of natural petroleum in this country will be reached by 1921 and who present impressive evidence that it may come even before 1920.

"*Development of Oil-Shale.*—In her deposits of oil-shale the United States has an anchor to windward. Oil-shale is a richly bituminous shale, some of it approaching cannel in character, interbedded, like coal, in series of shales, sandstones, and limestones. The most extensive and valuable deposits known in America if not in the whole world are in northwestern Colorado, northeastern Utah, and southwestern Wyoming, mainly in what is known as the Uinta Basin. Rich beds of oil-shale also occur in very limited areas in northeastern Nevada. Minor deposits, more conveniently located but for the most part leaner and less promising, are found in the Mississippi Valley and the Appalachian States. D. E. Winchester[1] and A. R. Schultz, of the Geological Survey, have estimated that there are in Colorado, Utah, Wyoming, and Nevada deposits of oil-shale in thicknesses of 3 feet or more, and capable of yielding 25 gallons or more of oil per ton, sufficient to produce at least 75,000,000,000 barrels of oil.

"The oil is generated through the destructive distillation of the shale, and its character and composition depend largely on the processes employed. Rough dry or steam distillation tests produce distillates—essentially heavy petroleums—carrying both paraffin and asphalt with considerable nitrogen and yielding gasoline in an average of about 12 per cent. These rough tests indicate that the gasoline obtainable by distillation of these shales, even by simple methods, far exceeds in amount all the petroleum yet produced in the United States and may equal the remaining natural oil.

"The production of oil from these shales is still in the experimental stage, in which various methods are being tested. Much doubtless depends on the processes devised and adopted. It is possible that initial commercial success may be determined as much by a study of methods and of the possible by-products and their values as by a further advance in oil prices. The technologic problems connected with the utilisation of the oil-shales are worthy of research by the best hydrocarbon engineers and chemists.

"Shale-oil is the most natural, satisfactory, and ample substitute for petroleum, and it is likely to come into the market as the production curve of the natural oil glides downward beyond the peak, if not sooner. It must be borne in mind, however, that in spite of the probable very rapid growth of the shale-oil industry beginning with the day that shale-oil is produced profitably on a commercial scale, it will require several years to construct and put into operation the enormous plants necessary to treat the millions of tons of shale which must be distilled in order to offset the waning production of natural oil, or fill a part of the gap between the production and consumption of petroleum in the United States" (see fig. 6).

According to the United States Geological Survey, the average yield per well per day was 3·3 barrels in 1909; 3·7 barrels in 1910, 1911, and 1912; 3·9 barrels in 1913; 4·1 barrels in 1914; and 4·2 barrels in 1915.

Describing the **gas-fields** of the United States in 1890, Mr. Weeks remarks:—"In a general way it may be said that natural gas has been found in varying quantities all through the territory from the Hudson River on the east to California on the west. In Alabama, California, Colorado, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Missouri, New York, Ohio, Pennsylvania, South Dakota, Tennessee, Utah, West Virginia, Wisconsin, and Wyoming, its existence is reported. In some of these States, however, it has not been found in commercial quantities. . . . In 1889 gas in commercial quantities was reported as having been produced in Arkansas, California, Illinois, Indiana, Kansas, Kentucky, Michigan, Missouri, New York, Ohio, Pennsylvania, South Dakota, Texas, and Utah. At the present time the important gas-fields are those of western Pennsylvania, eastern-central Indiana, western New York, and northwestern Ohio. . . . The most important gas-fields in these territories are those in the gas district in Pennsylvania, in the neighbourhood of Pittsburgh,

[1] *U.S. Geological Survey Bulletin*, No. 641-F, 1917; *Bulletin*, No. 691-B, 1918.

including the Murraysville and Grapeville fields of Westmoreland county and the several Washington county fields. In McKean and Venango counties there was also a large production of gas, and considerable from Elk county. In Ohio, the most important field is what has been called the Findlay, situated in Hancock county, while in Indiana the chief fields are in the neighbourhood of Anderson, Kokomo, Murion, and Muncie" (*Eleventh Census Report of the U.S.*, 1890).

The production of natural gas has reached enormous proportions, and although the older fields are evidently becoming exhausted, new pools are being continually opened up.

In December 1889 there were 2247 wells reported as producing gas in the

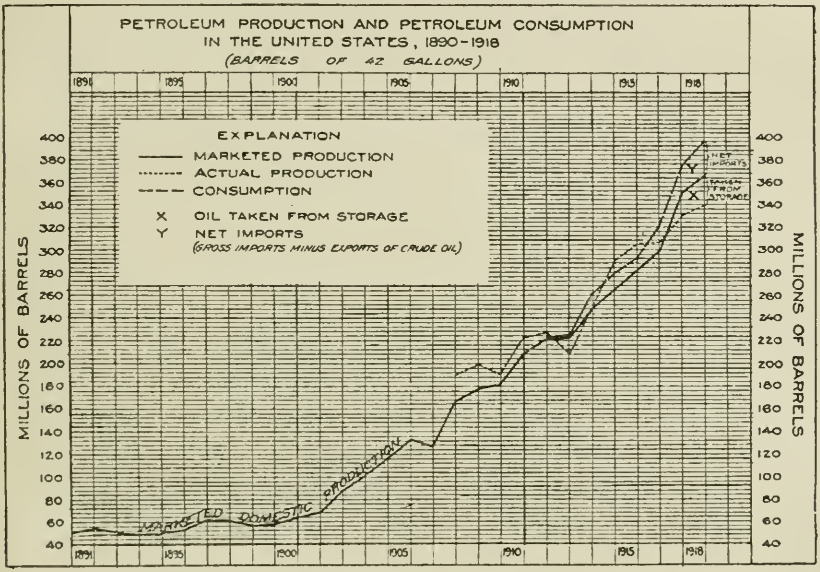


FIG. 6.—CHART GIVING THE RELATIONS BETWEEN THE PRODUCTION AND CONSUMPTION OF PETROLEUM IN THE UNITED STATES FOR YEARS 1890 TO 1918.

United States. This number was made up as follows :—Pennsylvania, 999 ; Indiana, 576 ; Ohio, 448 ; New York, 119 ; Missouri, 13 ; Kansas, 25 ; California, 6 ; Illinois, 10 ; Kentucky, 37 ; West Virginia, 4 ; Texas, 1 ; Arkansas, 2 ; Utah, 2 ; South Dakota, 1 ; New Mexico, 1 ; Tennessee, 1 ; Wisconsin, 2. In 1902 it was estimated that no less than 205,784,453,333 cubic feet of natural gas was utilised in the United States.

At the end of 1903 there were 15,689 wells producing gas, distributed among the States thus :—Pennsylvania, 5915 ; Indiana, 5514 ; Ohio, 1523 ; West Virginia, 1099 ; New York, 707 ; Kansas, 666 ; Kentucky, 123 ; Illinois, 43 ; California, 38 ; Missouri, 22 ; Texas, 18 ; Indian and Oklahoma Territories, 7 ; South Dakota, 5 ; Colorado, 3 ; Tennessee, Arkansas, and Wyoming, 2 each.

The volume of natural gas produced in 1903 amounted to 238,769,067,000 cubic feet at atmospheric pressure, and represented approximately 5,968,725 tons. If the density remained the same, this quantity would fill a reservoir with a base of one square mile to a height of 1·65 miles ; it would fill a pipe that encircled the earth at the Equator, and that had an internal diameter of 49 feet. Its heating value would equal 11,938,453 tons of bituminous coal (*Oliphant*).[1]

At the end of 1908 there were 22,709 wells producing gas, distributed among the States thus :—Pennsylvania, 8831 ; Ohio, 3691 ; Indiana, 3223 ; West Virginia, 2511 ; Kansas, 1966 ; New York, 1211 ; Illinois, 400 ; Oklahoma, 350 ; Kentucky, 218 ; California, 62 ; Arkansas, 55 ; Missouri, 45 ; South Dakota, 33 ; North Dakota, 15 ; Alabama, 11 ; Wyoming, 9 ; Iowa, 6 ; Tennessee, 5 ; Michigan and Colorado, 3 each ; Oregon, 1.

The production of natural gas in the United States in 1909 was estimated at 480,706,174,000 cubic feet, valued at $63,206,941.

In his report to the United States Geological Survey on Natural Gas for the year 1916, Mr. John D. Northrop remarks that although natural gas was first utilised commercially in the United States in 1821, the development of the natural gas industry with which we are familiar to-day has taken place for the most part in the past eighteen years.

The volume of natural gas commercially utilised in 1916 was greater than that utilised in any other year in the history of the natural-gas industry. The volume used, which amounted to 753,170,253,000 cubic feet, constituted a new record of production, exceeding by nearly 125,000,000,000 cubic feet, or 20 per cent., the former record, established in 1915.

The market value of this gas likewise attained record proportions. It amounted to $120,227,468. Credit for the increased production in 1916 belongs, in the order given, to West Virginia, Oklahoma, Pennsylvania, California, Louisiana, Kansas, Texas, and Arkansas, which together produced 132,000,000,000 cubic feet more gas in 1916 than in 1915. A significant increase, important locally, but unimportant as affecting the production of the entire country, was credited to Illinois, New York, and Montana. In only two States was there a significant decrease in the production of natural gas in 1916. The rapid exhaustion of the prolific Cleveland field, in Cuyahoga county, Ohio, resulted in a net loss of 9,600,000,000 cubic feet in the total volume of gas produced in Ohio, and the steady decline of the oil-fields in Indiana caused a falling off of 600,000,000 cubic feet in the output of that State.

The general increase in the production of natural gas in the United States in 1916 is attributed principally to an enormous expansion of the natural-gas gasoline industry in all natural-gas producing States, and to a greatly augmented demand for natural gas as fuel by industries engaged in the manufacture of munitions of war. In 1917 a new record was established, the volume produced and utilised being estimated at not less than 795,110,376,000 cubic feet.

Within recent years plant has been erected in various States for the extraction of gasoline from natural gas.

The description given in the following pages of the various oil- and gas-producing districts is largely founded on Geological Survey Reports and other official publications, the exhaustive reports of Mr. J. F. Carll, Mr. J. D. Weeks, Dr. E. Orton, Profs. J. P. Lesley and S. F. Peckham, Mr. F. H. Oliphant, Dr. David T. Day, and Mr. John D. Northrop having been particularly consulted.

The matter is arranged according to States, but this classification corre-

[1] Report to the Department of the Interior, United States Geological Survey, by Mr. F. H. Oliphant, on the Production of Natural Gas in 1903.

sponds generally with the division into oil-fields, as may be seen from the following table :—

TABLE VI.—PRINCIPAL OIL-FIELDS OF THE UNITED STATES.

Field.	States.
Appalachian.	Pennsylvania, New York, West Virginia, Kentucky, Tennessee, and Southeastern Ohio.
Lima-Indiana.	Western Ohio and Indiana.
Illinois.	Illinois.
Mid-Continent.	Kansas, Oklahoma, and Northern Texas.
Gulf.	Texas and Louisiana.
Colorado.	Colorado.
California.	California.

PENNSYLVANIA and NEW YORK. (Plate 12.)

This oil-field was conveniently divided, in the *Eleventh Census Report of the United States*, into the Bradford, Middle, Lower, and Washington or Southwestern districts. The last-named, though insignificant in 1885, subsequently became so productive as to be one of the most important of the Pennsylvanian fields, and contained the richest pools ever known in the State. One of these pools, that of Washington, yielded in 1889 nearly one-fifth of the production of Pennsylvania and New York, and was only surpassed by the Clarion and Butler and the Bradford districts.

The **Bradford district** (see fig. 7) lies chiefly in McKean county, but extends into New York State, and includes a pool lying in Carrolton township, in Cattaraugus, the outlying district of Kinzua, in the southwest, and the Windfall-run field, near Eldred. The oil from this district is amber, green, or black, and is usually heavier than that of the Lower field.

The development of this highly productive field was at first attended with results of a very discouraging character. In 1866 the Barnsdall well, which had been drilled to a depth of 200 feet and then abandoned in 1862, was deepened to 875 feet without success ; and in 1865 a well was drilled in the Valley of Tuna Creek to a depth of 900 feet, but again without finding oil. A well, however, sunk by the Foster Oil Company on the Gilbert farm, reached " slush oil " at a depth of 751 feet, and the owners, thus encouraged, continued boring until, in November 1871, the oil-sand was reached at a depth of 1100 feet. This well only yielded about 10 barrels daily. At the close of 1874 the same firm bored a well (the Butts well No. 1) on the Archy Buchanan farm, and obtained a daily production of 70 barrels. From this time boring was rapidly carried on in the district until, in 1879, no less than 2536 wells, only 3 per cent. of which were " dry," were sunk. In December 1878 the Bradford field yielded an average of 23,700 barrels daily, which was about four-sevenths of the total production for the State of Pennsylvania ; and in December 1880 the yield was 63,000 barrels daily, out of a total for Pennsylvania of 72,214 barrels.

Dr. Ashburner estimated the area of the field at 135 square miles, and its total production up to January 1885 at 109,000,000 barrels, an average of 820,000 barrels per square mile (*Trans. Am. Inst. Min. Eng.*, xiv. 419, 1886). Between 1876 and 1889 it yielded, in the aggregate, over 5,000,000 barrels more than all the fields combined (*Carll*). It is usually grouped with the Allegany district of New York, which has an estimated area of 31 square miles, and includes the Richburg and several smaller fields. Dr. Ashburner estimated that the Allegany field had yielded 419,000 barrels per square mile up to January 1885.

The Middle Field.—The oil-fields between Oil Creek and the Allegheny River soon extended to Warren county, and formed the well-known Warren district, which includes the oil-pools in the east of Warren county and the northeast of Forest county, with a total productive area of 35 square miles. Up to January 1885, this district produced no less than twelve million barrels of oil.

It was in the Warren district that the celebrated Cherry Grove flowing well was completed in 1882, the result being to lower the cost of crude oil from 85 cents per barrel to 49 cents in a few days, thus, it is estimated, reducing the value of oil in stock, and of oil-territory, to the extent of $30,000,000.

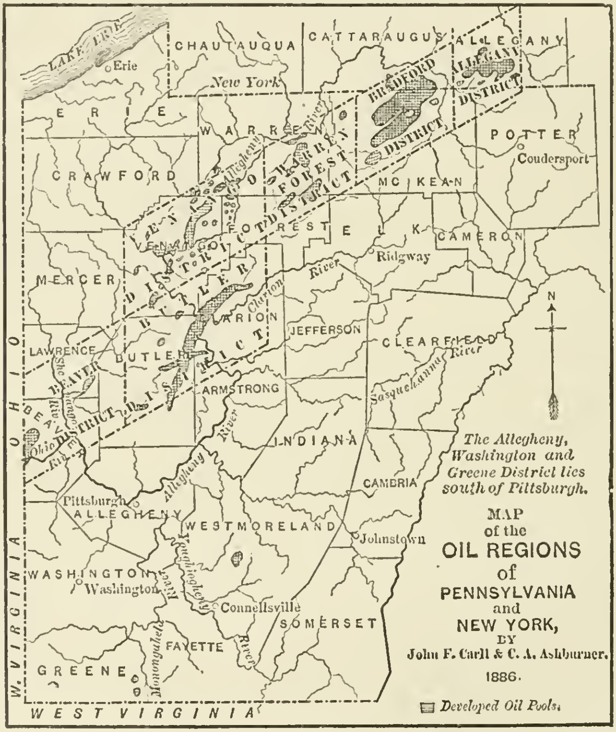


Fig. 7.

This well (No. 646) was commenced in the spring of 1882 by a band of four prospectors in the hitherto untried district of Cherry Grove, and was boarded up and guarded to prevent any knowledge of its character being gained by the public. Notwithstanding these precautions, however, it was soon ascertained that the well was a flower, and that a new oil-field had been discovered. Before the end of June (the well having been completed on the 17th May) two towns had been partially built, and by the end of September 320 producing wells had been sunk in a clearing two miles long by half a mile wide. The great "646" well yielded 4000 barrels the first day, and others were bored with almost equal success. In August 1882 the field yielded 40,000 barrels daily, but the supply soon diminished, and by October had fallen off to less than one-tenth of that amount.

The pools of Cherry Grove, Balltown and Cooper, Stoneham, Clarendon, Tiona, Kane, Grand Valley, and others in Warren and Forest counties constitute the Middle field. The oil from the different pools varies considerably, but is generally described as "amber" oil.

The **Lower field** includes a few fields in the southwest of Warren and the west of Forest county, and all the pools to the south, comprising those of Venango, Clarion, and Butler, the field on the Ohio River in Beaver county, and the fields of Lawrence county. The oil of the Venango division is obtained from the First, Second, and Third Sands, and is generally green or black, but is occasionally amber in colour; it varies in density from 30° to 51° B. The Butler division includes Butler, Clarion, southeastern Venango, and Armstrong counties, while the Beaver division comprises the Slippery Rock and Smith's Ferry fields, which yield heavy oil from the Pottsville Conglomerate, and amber oil from the Pithole Grit. A well drilled at Thorn Creek, Butler, in 1884, is said to have produced for some hours at the rate of 9000 to 10,000 barrels a day. Dr. Ashburner estimated the area of the Venango district at 65 square miles, and that of Butler at 76 square miles.

The important Smith's Ferry field of Beaver county extends over an area of about 2500 acres into Columbiana county, Ohio. In 1889 it produced 29,000 barrels of heavy, amber-coloured oil, yielding much lubricating oil. The celebrated "Heavy-Oil" district of Franklin, Venango, comprises a few square miles of French Creek, 7 miles from Oil City. All the wells require to be pumped, but are long-lived, although not of great productiveness. In 1889 the output was 65,276 barrels. The oil is obtained from the First Sand, which in Franklin reaches a thickness of 35 feet. It is a dark, brownish-green oil, of density 31° to 33° B., and is totally different in appearance and properties from the oil yielded by the same stratum in other parts of Venango, and in Warren and Washington counties.

The **Washington** or **Southwestern district** yields oil similar to that of the Lower district, and comprises the pools of Allegheny, Washington, and Greene counties.

The Allegheny pool includes the Shannopin and Brush Creek districts, the former of which derives its oil from the lower part of the Venango oil group, and is characterised by the large proportion of dry wells which have been drilled into that group.

In December 1884 the Citizen's Fuel Company drilled a well for natural gas on the Gantz farm, near Washington, and at a depth of 2200 feet obtained a small yield of oil, but no gas. In August of the following year the famous Gordon well commenced flowing; while in March 1886 the Pew & Emerson Manifold well, and in April the Thayer well, flowing at the rate of 2000 barrels daily, were completed. In August 1886 the Washington field gave an output of 16,000 barrels daily, but the production subsequently diminished, and in 1887 was but 4800 barrels daily.

The Greene county field is practically an extension of the Washington field, and yields oil of a similar character.

Further developments in the Washington county field comprised the McDonald pool in 1890, and, if the field be considered to extend into West Virginia and eastern Ohio, the Sistersville pool, lying 137 miles south of Pittsburgh in 1891. The McDonald pool lies on the borders of Washington and Allegheny counties, about 18 miles south of Pittsburgh, and has yielded as much as 40,000 barrels in twenty-four hours, an output only exceeded by that of the Bradford pool. In September 1891 it had been proved over an area of about 3 miles by 1 mile, though the area actually under the drill was not above 2000 acres. Much of the oil is obtained from the Gordon Sand, but many wells have been drilled to the Fifth Sand.

In August 1892 the Sistersville field had thirty-six completed wells (only one of which was "dry"), and gave a yield of 4510 barrels daily. In the last week of that month the Sistersville and McDonald fields gave over one-third of the total production of Pennsylvania—*i.e.* about 30,000 barrels daily. In April 1894 it was stated that, in the McDonald field, 1266 wells had been drilled, over an area of 10,000 acres, and had produced over 22,000,000 barrels in less than three years. The total cost of drilling, royalties, etc., was estimated at over $12,000,000. The oil-sand group largely changes to shale in passing from western Allegheny eastward into Westmoreland, so that the promise of new oil-pools in that direction is not great (Carll, *Seventh Report on the Oil and Gas Fields of Western Pennsylvania*, 1890, p. 8).

The Pennsylvania fields have been popularly divided into the Southern and Northern oil-fields, and the "White Sand" and "Black Sand" districts. The White sands embrace all the oil-horizons south of McKean county, including the Warren and Forest sands. The Black sands include the Bradford and Allegany districts.

Prior to 1876 all the production may be accredited to the white sands, although a few of the Bradford wells had then been drilled. In 1886 the white sands gave their highest yield, 13,066,740 barrels, or 35,000 barrels daily. Though the output of the black sands never reached two figures in the thousands until 1875, their value soon became manifest, the yield rapidly increasing to 382,768 barrels in 1876, 6,206,746 in 1878, and 13,914,509 in 1879.

In 1869 Pennsylvania produced 4,215,000 barrels, and in 1879, 19,685,176 barrels; the States of Ohio, West Virginia, and California bringing up the total for the United States to 19,914,146 barrels. In 1889 the Pennsylvania fields yielded 21,486,403 barrels; while Ohio, which ten years previous had only yielded 29,112 barrels, produced 12,471,965 barrels. In 1891 the production of the Pennsylvania fields had risen to 33,009,236 barrels, and that of Ohio to 17,740,301 barrels.

From that date the Pennsylvania fields have declined, and in 1902 produced only 12,518,134 barrels, while in 1909 the output had fallen to 9,299,403 barrels, and in 1910 to 8,794,662 barrels. The decline has since continued at an average rate of about 3 per cent. a year, and in 1916 the output was 7,592,394 barrels. In the same year New York State produced 874,087 barrels compared with 1,053,838 barrels in 1909. In 1917, contrary to the trend in recent years, there was a considerable gain in the output of Pennsylvania petroleum, the output in 1917 amounting to 7,733,200 barrels.

According to Dr. Ashburner, **natural gas** was probably first obtained commercially in America at Fredonia, Chautauqua Co., N.Y., where in 1821 a well was sunk, which supplied gas for thirty burners; the inn was illuminated by it when Lafayette passed through the village about 1824.

In 1903 the value of the output of natural gas in New York State was $493,686. The counties producing this gas were Allegany, Cattaraugus, Erie, Livingston, Niagara, Onondago, Ontario, Oswego, Seneca, and Steuben.

In 1909 the value of the gas consumed in the State was $3,286,523, most of this being utilised for domestic purposes. This was derived from 1279 wells, situated in the following counties:—Allegany, Cattaraugus, Chautauqua, Erie, Genesee, Livingstone, Monroe, Niagara, Onondago, Ontario, Oswego, Seneca, Schuyler, Steuben, Yates, Wyoming.

In 1910 Pennsylvania was forced to yield first place, based on the market value of gas produced, to West Virginia, and since that year it has retained second place without serious competition.

The natural-gas fields of Pennsylvania are essentially coincident with the oil-fields of the State, though they extend a few miles in advance of the oil belt along its eastern boundary. They are distributed over twenty-three counties in the western and northwestern parts of the State and occupy the broad belt of gently-folded strata that make up the Allegheny Plateau.

Natural gas in Pennsylvania is obtained commercially from a great number of productive sandstone layers included in the stratigraphic range between the Kane sand in the lower division of the Devonian system and the Hurry-up sand at the base of the Conemaugh formation of the Pennsylvanian (Upper Carboniferous) series.

The estimated volume of natural gas produced in Pennsylvania in 1916 was 129,925,150,000 cubic feet, a gain of 14 per cent. over the output in 1915. This gain, which was in direct response to greatly increased demands for natural gas in the iron and steel districts about Pittsburgh, was brought about by greater activity in drilling in fields already proved. In 1917 there was a gain to 133,397,206,000 cubic feet.

At the end of 1916 there were 13,917 gas-wells in service in Pennsylvania, in addition to a great number of wells producing both gas and oil. At the end of 1917 there were 14,534 gas-wells in service, a net gain of 613 wells.

WEST VIRGINIA.

This district, in part, forms a continuation of the Pennsylvanian field, and of the Macksburg or Eastern field of Ohio. It may be divided into four districts —the Turkey Foot district, in Hancock county; the Mount Morris district, including Monongalia and Marion counties; the Volcano and Eureka districts, in Wood, Ritchie, and Pleasant counties; and the Burning Springs district, in Wirt county. The Sistersville field has already been mentioned in connection with the Washington county oil-territory of Pennsylvania. Certain districts, such as the Sistersville and Eureka fields, lie on both sides of the Ohio river, and the oil which they produce is run indiscriminately into pipe-lines and storage-tanks, in a manner which renders it impossible to accurately allot the production between West Virginia, western Pennsylvania, and eastern Ohio. The Mannington region also developed into an oil-producing pool of some value. Although for three years it had yielded oil from the Big Injun Sandstone, it was not until the Gordon Sand was reached, in the summer of 1892, that the output became of any importance.

Most of the oil of the Volcano and Burning Springs districts is found near the top of the Carboniferous rocks. The oil-strata and the product of the Mount Morris and Turkey Foot fields resemble those of the Pennsylvanian Lower field, while the Eureka field resembles the Macksburg region described under Ohio. The density of the West Virginian oil varies from 27° to 45° B., but is usually below 33°. The heavier oil, which is chiefly obtained from the shallower wells, is suitable for lubricating purposes.

Up to 1876 West Virginia is estimated to have produced 3,000,000 barrels. In 1889 the output from its 623 producing wells amounted to 544,113 barrels, of which the Turkey Foot and Mount Morris fields gave about two-thirds. In 1892 the production was 3,810,086 barrels, while in 1893 it amounted to 8,445,412 barrels, and in 1903 to 12,899,395 barrels, after having reached upwards of 16,000,000 barrels in 1900. From 1903 to 1907 the production steadily declined, and was somewhat in excess of 9,000,000 barrels in the last of these years. During the following two years there was a slight increase to 10,745,092 barrels for 1909. In 1916 the output had declined to 8,731,184 barrels, and in 1917 to 8,379,285 barrels.

West Virginia has for many years ranked first among the gas-producing States.

Natural gas has been utilised in West Virginia since 1841, when it was adopted as a fuel for evaporating brine in the salt industry that was centred in the Great Kanawha Valley, near Charleston. As early as 1884 natural gas was supplied to domestic and industrial consumers in Wellsburg, Brooke county, but it was not until the nineties that the natural-gas industry in this State became important. Since 1896 the value of the annual production of natural gas in West Virginia has shown a steady increase, doubling once in 1898, again in 1900, again in 1903, and again in 1916.

The natural-gas fields of West Virginia are distributed over 32 counties of the State and lie west of the Appalachian Mountains, in the Allegheny Plateau province. They are broadly coincident with the oil-fields, but, as in Pennsylvania, the eastern boundary of the gas belt lies a few miles in advance of the eastern limits of oil production.

The output of natural gas in West Virginia in 1916 amounted to 299,318,-907,000 cubic feet, a gain of 18 per cent. over that of 1915. The volume of natural gas produced and marketed in West Virginia in 1917 amounted to 308,617,101,000 cubic feet, more than double the production credited to any other State in that year.

Exclusive of the great number of wells that produced both gas and oil, there were in this State, at the end of 1916, 8508 wells yielding only gas. At the end of 1917 there were 9329 wells producing gas exclusively.

KENTUCKY and TENNESSEE.

In Kentucky much prospecting was carried on prior to 1890 in Barren, Clinton, Cumberland, Pulaski, Russell, and Wayne counties, but the only production reported in 1889 was from Boyd's Creek, in Barren county, and this amounted to 5400 barrels. In 1891, 9000 barrels was produced, but the output then declined, until in 1897 only 322 barrels was obtained ; the production then began to increase very rapidly until 1905, when the output from the two States was 1,217,337 barrels, of which Tennessee only produced about 10,000 barrels.

The operations in Tennessee date from 1893, but for ten years the only important results were those obtained in the Bobs Bar well, drilled in 1896, which at first yielded 5000 to 6000 barrels annually ; practically all the oil produced in Tennessee came from this well down to 1904. In that year some development took place at Poplar Cove, Fentress county, a few miles north of Bobs Bar, and several good wells were obtained, leading to the extension of the Cumberland pipe-line into the new district in 1905. In spite of this the production declined rapidly, and after 1908 no production was recorded from Tennessee until in 1916 oil was discovered in Scott county and 677 barrels was marketed in that year. In 1917 Tennessee contributed 12,196 barrels, or eighteen times its contribution for 1916, due to the success of the Glenmary field, Scott county. The profitable production of natural gas in Tennessee in 1916 was limited to the output of 4 wells of small capacity. The actual production reaching 2,000,000 cubic feet. In 1917, as a result mainly of activity in the search for petroleum in Scott county, the production of natural gas in Tennessee was 10,900,000 cubic feet.

A well drilled in 1829, in Cumberland county, Kentucky, yielded oil which, as already mentioned (on p. 87), was sold as "American Medicinal Oil." At one time the largest oil-field in western Kentucky was in Barren county, the Glasgow pool proving very persistent since work was commenced there in 1866.

The oil of Cumberland county is green, and closely resembles that of Oil Creek in Pennsylvania, in appearance, odour, and density, while that of Barren county is more like the Lima oil in character. Professor W. Dicore reports that a greenish-brown oil, obtained from a sand at a depth of 85 feet, near Somerset, Pulaski county, had a specific gravity of 0·870.

A well which flowed 300 barrels a day for a month was struck in May 1901 in Wayne county, near the Tennessee line, at a depth of 878 feet. The oil was dark green in colour, inclined to amber. This led to a good deal of drilling in the vicinity, and though the results were at first insignificant, Wayne county in 1908 produced about 460,000 barrels out of a total for the State of 727,767 barrels. In that year the next largest production came from Wolfe and Bath counties. The production of the whole State in 1909 was only 639,016 barrels, and further declined in 1910 to 468,774 barrels.

In 1916 a new epoch of expansion began, based on increased production from new territory, and the output for that year amounted to 1,203,246 barrels. The results of drilling in Kentucky in 1917 were distributed over forty-six counties, and included 1162 oil-wells, the marketed production amounting to 3,088,160 barrels.

The production of natural gas in Kentucky, though important locally, amounts to less than 1 per cent. of the total volume produced annually in the United States. The first well drilled in Kentucky that produced natural gas in considerable volume was the Moreman well, drilled in 1863, near Brandenburg, Meade county. Since 1889 Kentucky has been a regular though small contributor to the gas supply of the United States. The natural-gas fields of Kentucky, as now developed, are widely distributed, but lie mainly in the eastern third of the State.

The output of natural gas in Kentucky in 1916 was 2,106,542,000 cubic feet. In 1917 the output amounted to 2,802,079,000 cubic feet.

OHIO and INDIANA.

Although the output from the **Ohio** oil-fields had steadily increased for ten years previously, the important position of the State as an oil-producer only dates from 1885. Drilling was then pursued with great activity, and the yield was enormously increased until, in 1889, no less than 12,471,965 barrels of crude petroleum, valued at $2,174,219, was obtained. The total production in 1896 was 23,941,169 barrels, the highest recorded. In 1900, 22,362,730 barrels was obtained, but since that time the output has steadily declined to 10,632,793 barrels in 1909, valued at $13,255,377. In 1916 the production only amounted to 7,744,511 barrels, but the quantity of petroleum marketed from all sources in Ohio in 1917 was 7,750,540 barrels.

The oil-fields of Ohio are divided in Mr. Weeks' *Eleventh Census Report*, 1890, into the Macksburg or eastern district, including Washington, Noble, Belmont, and Harrison counties; the Mecca-Belden field; and the Lima or northwestern field, including Allan, Auglaize, Hancock, Sandusky, and Wood counties.

Of these three districts, the first two now constitute, with the States previously described, the great Appalachian field, the northwestern region of Ohio forming part of the Lima-Indiana field.

The **Southeastern** district, corresponding to the first division of Mr. Weeks, now includes the counties of Belmont, Harrison, Guernsey, Jefferson, Monroe, Morgan, Noble, Perry, and Washington, as well as others of minor importance. The chief pools are in Washington and Noble counties. The region was exploited as early as 1860, but acquired no importance until 1884. In 1886 the production was over 700,000 barrels, and, after some variable years, the output began to increase steadily, being 5,585,858 barrels in 1903. It decreased to 4,717,069 barrels in 1909; in 1916 to 4,608,544 barrels; in 1917 there was an increase to 4,839,679 barrels.

The **Mecca-Belden** pool in Lorain and Trumbull counties produces a small quantity of very high-grade lubricating oil. At the close of 1892 there were only thirteen productive wells in the whole of the Mecca-Belden district, which yielded for that year about 3000 barrels; in 1903 the total production was 575 barrels; in 1909 it was 367 barrels, valued at $2325, and in 1910 only 41 barrels was produced.

The **Lima** district obtains its oil from the Trenton Limestone, and first came into prominence in 1885, the first large yield being from the Hume well in the spring of 1886.

The discovery of oil in the Trenton Limestone was made early in 1885 in the Paper Mill well at Lima, although gas had been obtained from this formation some months earlier at Findlay (November 1884) and Bowling Green (February 1885). This well struck oil at 1247 feet, but although it was tubed and pumped, only 200 barrels was obtained during the first six days. In the summer of 1885 the Citizens well was bored, and by 20th April 1886 had yielded 5000 barrels. All the earlier wells required to be pumped, but the Shade well No. 1, sunk in February 1886, and others on the same farm, were flowing wells.

Writing in 1887, Dr. Edward Orton, State geologist of Ohio, thus describes the production and promise of the Lima field:—"Drilling in the Lima field was begun in the spring of 1885. It was a year, however, before the oil-producers entered vigorously upon its development. The wells on the Shade farm, south of the town, made the first significant departure from the day of small things with which the work was begun. All these were flowing wells. The early summer of 1886 marked the beginning of rapid development. The production of single wells increased from 60 and 70 barrels to 100 barrels a day, and presently, in the Hume well, to 250 barrels a day, and a little later to 700 barrels in the Tunget well. To the southward, great wells were presently found. The Ridenour farm, the Hueston, Moore, Ditzler, Ballard, Lehman, Goodenow, and Spear farms all became centres of large and certain production. By October 1st the character of the field had come into clear view as second to none yet found in the United States in volume of production. During September 1886, 33 wells were added to the 128 previously drilled. Of these one was dry. The total production of the new wells was 2455 barrels daily, showing an average of 75 barrels to the well. Six of these wells were credited with an aggregate production of 1300 barrels daily. In November a number of other great wells was brought in, and the Douglas, Crumrine, Boop, Mechling, McLain, and other farms were added to the prolific areas. A well drilled during this month on the Alonzo McLain farm, section 13, Shawnee township, reached a production for its first day of nearly, or quite, 1000 barrels. This well is still flowing (1887) at the rate of 150 barrels a day. The largest production in the Lima field for a single day is that of a well on the J. W. Ridenour farm, section 18, Perry township. It put into tanks in the first twenty-four hours 2760 barrels of oil. . . . On the 1st of May 1887 there were 4444 wells in the Lima field" (*Eighth Ann. Rep. U.S. Geol. Surv.*, 1890).

In 1889 and 1896 the field yielded over one-third of the total production of oil in the United States. It includes the counties named above, and is usually divided into the Lima, Findlay, North Baltimore, Saint Mary's, Gibsonburg, Upper Sandusky, and Spencerville fields. The oil was obtained at a depth of about 1300 feet, and the wells commonly yielded from 50 to 75 barrels a day, although the output of several has amounted to hundreds of barrels daily, and a total of even 1500 barrels has been reached. The proved oil-territory of Lima comprises a tract 8 or 10 miles long and 2 or 3 miles broad. The oils are dark and heavy, resembling those of Canada and Tennessee, and on account of the sulphur compounds in them, which were only removed with difficulty, they were formerly principally employed as fuel. In fact, of the total production of Ohio in 1889, no less than 12,153,188 barrels was used as fuel, only 317,037 barrels being utilised for illuminating purposes, and 1740 barrels as a lubricant. But in recent years a process of refining has been adopted, by means of which a good illuminant is produced, and the crude oil is now largely used in this way.

Dr. Orton gave, in the *First Annual Report of the Geological Survey of Ohio*, 1890, a very complete account of the production of oil and gas in the most important districts of Ohio. In 1890 more than half the total oil output of northwestern Ohio was produced in Wood county, the oil-territory covering the eastern parts of Henry and Liberty, and parts of Portage, Montgomery, and Bloom townships. Another important pool occurs to the eastward, and extends for a width of about 1 mile, and a length of about 6 miles, through Bloom and Portage. Dry gas, followed in a few days by a strong flow of oil, characterises these wells.

In the Findlay district (Hancock county), gas-wells have given place to oil-wells. In 1890 a well drilled in Allen township for gas yielded 1965 barrels of oil in two days at 450 feet below tide level, and led to a considerable development of the district as oil-producing. In later years there were numerous wells from which a good supply has been obtained, particularly in Marion township.

The Gibsonburg field, and the adjoining Helena field in Sandusky county, were opened in 1887, and much activity afterwards prevailed, nearly a thousand wells being drilled in 1895.

Since 1896, when 20,575,138 barrels was obtained, the production of the Lima field has steadily declined, and in 1910 the output was only 5,094,136 barrels; in 1916 it had further fallen to 3,135,967 barrels; in 1917 to 2,910,861 barrels.

Gas is obtained in Ohio from the Berea Grit, the Ohio Shale, the Trenton Limestone, and the Clinton Limestone.

It has been in use in that State since 1838, when it was employed as fuel in the residence of Daniel Foster, in Findlay, Hancock county, the supply being derived from a well drilled for water. In 1860 gas was used in the manufacture of salt at East Liverpool, Columbiana county, but it was not until the early seventies that the drilling of wells specifically for gas was undertaken in Ohio.

The Ohio Shale yields low-pressure gas with great persistency, and is an important and trustworthy gas-horizon. The closed pressure of the wells appears never to exceed 100 lbs., and seldom rises even to 30 or 40 lbs., whilst the daily output is always below 100,000, and rarely exceeds 20,000 cubic feet. The wells are usually not more than 400 feet in depth, and the supply is very regular. The gas is largely used by small consumers, but is not obtained in sufficient quantity for manufacturing purposes. Dr. Orton has suggested that the gas of the Berea Grit is derived from the Ohio Shale, which everywhere underlies it to a minimum thickness of 600 feet.

In the Trenton Limestone, high-pressure gas was first tapped at Findlay in November 1884, and this discovery was followed by the drilling, in 1885, of twelve wells, the best of which yielded 3,500,000 cubic feet daily. It was not, however, until the opening of the Karg well on the 20th January 1886, with a daily yield of 14,000,000 feet, that the new gas-horizon attracted great attention. From that time the great Findlay field rapidly increased in productiveness, the gas being obtained in such abundance that, according to the estimate of Dr. Orton, about 1,500,000,000 feet was lost by " wilful waste " during part of 1886. The daily consumption of gas in Findlay in the year 1890 was not less than 30,000,000 feet, of which only from 4,000,000 to 5,000,000 feet was employed for domestic purposes. Though even then on the decline, the Findlay field gained some of its larger producers in 1888 and 1889. In the former year the Tippecanoe well was drilled at Findlay, and yielded, after torpedoing, the largest volume of gas obtained at that time in the State. The open pressure on the first day was 38 lbs., falling on the third day to 11 lbs., and the yield was 32,000,000 and 19,000,000 cubic feet for the first and third days respectively. The well, however, proved short-lived. In 1889 the Mellott well, near Stuartsville, 6 miles north of Findlay, started with a yield of 28,000,000 cubic feet daily, at an open pressure of 28 lbs. ; and one drilled near Bairdstown, Wood county, yielded about 33,000,000 cubic feet daily, at an open pressure of 45 lbs. In August of the same year the Kagy well started in Allen township, Hancock county, at a closed pressure of 460 lbs., falling by May 1890 to 285 lbs.

The chief fields of Ohio supplied in 1889 from the Trenton Limestone were in Hancock, Wood, Auglaize, and Mercer counties, the two first-named giving by far the highest yield. Nearly all the eighteen townships of Hancock county have supplied gas. By 1890 the township of Allen gave the highest yield, Cass, Washington, and Marion ranking next. The most productive well ever drilled was sunk about the middle of May 1894, on the James Wallace farm, in Fostoria, Hancock county. It is said to have yielded at the rate of 50,000,000 cubic feet daily, but the whole was lost by fire. The flow only lasted for three days, and it is stated that at the end of that time there was not enough gas issuing to ignite on application of a flame.

In Wood county the principal centres of production are Bloom, Perry, Henry, Portage, Plain, and Centre townships. The wells have shown a good average yield, most giving over 3,000,000 cubic feet daily, and one (the Simons well) over 12,000,000 cubic feet.

The Clinton Limestone has acquired considerable importance as a gas-producer. It first yielded to the shallow wells of Fremont, and then gave large supplies of high-pressure gas at Lancaster, Newark, and Thurston. So far as is known, it has not supplied either oil or gas on a commercial scale except in Ohio. Its value as a source of gas was first ascertained by drilling at Lancaster and Newark in search of gas in the Trenton Limestone. It has thus far been defined as a gas-rock in a line extending from Lancaster to Newark in a north-easterly direction, its length being about 25 miles, and its breadth 2 or 3 miles. Owing to the irregular character of the stratum, its yield and the pressure at which the gas issues vary considerably. The maximum closed pressure observed has been 800 lbs., and the maximum yield (in the vicinity of Lancaster) 7,000,000 to 8,000,000 cubic feet daily. No supply amounting to less than 100,000 cubic feet daily has yet been struck. The gas contains less sulphur than that from the Trenton Limestone, and is said to burn with a more luminous flame.

In the Lancaster district, which was opened in 1887, the Sugar Grove field was tapped in 1899 with an original pressure of 750 lbs. to the square inch, but this soon dropped to less than 100 lbs. Of 72 wells drilled, only 4 were dry holes, and the average flow was about 4,000,000 cubic feet in twenty-four hours. One well started at 14,000,000 cubic feet, but fell off to about 9,000,000 cubic feet (*Oliphant*).

At the end of 1903 there were 1523 producing gas-wells in the State of Ohio, and the approximate value of the gas yielded in that year was $4,479,040. In 1909 the number of wells had increased to 4042, their output being valued at $9,966,938.

Inclusive of shale gas-wells, but exclusive of the oil-wells that contribute to the gas supply in Ohio, it is estimated that 6054 gas-wells were in service in Ohio at the end of 1916. The production of natural gas in Ohio in 1916 was 69,888,070,000 cubic feet, and the State maintained its position of fourth among the gas-producing States. In 1917 the production was 68,917,231,000 cubic feet, and there were 5979 gas-wells in service.

The oil industry of **Indiana** developed with remarkable rapidity between 1891 and 1904, but since that date the production has declined with even greater speed. In 1871 Dr. T. Sterry Hunt (*Amer. Nat.*, v, 576) states that a well sunk at Terre Haute for water was carried to a depth of 1900 feet, and yielded about two gallons of oil daily. A second well, a quarter of a mile east-by-north from the first, yielded 25 barrels daily, at a depth of 1625 feet. For many years only very small results attended the efforts of prospectors. The output during 1889 from the districts of Terre Haute in Vigo county, and Montpelier in Blackford county, the only fields included in the *Eleventh Census Report*, was 33,375 barrels. In 1890 the output from the whole of Indiana was 63,496 barrels ; in 1891, 136,634 ; in 1892, 698,068 ; in 1893, 2,335,293 barrels. and from that time it steadily increased to 5,757,086 barrels in 1901, and 11,339,124 barrels in 1904. The production in 1909 was only 2,296,086 barrels, and in 1916 it had further declined to 769,036 barrels, and in 1917 to 759,432 barrels. In 1891 the number of wells completed was at the rate of 11 per month; in 1904 the number completed was 3766, or an average of 314 per month ; in 1909 the total number completed was 305, or a little over 25 per month. The rapid development of the oil territory which raised Indiana to the position of fifth among the oil-producing States, and the equally rapid decline to ninth, are here clearly shown.

Of the wells completed in 1902, more than one-third (1050) were in Grant county, which proved a very rich district, though in 1893 the four wells drilled in it were all dry holes. The principal developments in 1904 were in this county and in Delaware. Active drilling was carried out in eastern Indiana in 1917.

In respect of its contribution to the natural gas supply in the United States, Indiana occupies a relatively unimportant position. Natural gas had been found in small quantity in a well drilled for oil in Delaware county in 1876, but it was not until after the successful completion, in 1886, of a well at Kokomo, Howard county, credited with an initial open-flow capacity of 2,000,000 cubic feet of gas a day, that the natural-gas resources of Indiana began to be developed.

At the end of 1889 there were 576 gas-producing wells, whose output was valued at $1,362,472, Madison county being credited with nearly half of the total. At the end of 1893 there were 498 producing wells, the yield during that year being valued at $5,718,090, as against $6,488,000 from 841 wells in Pennsylvania, and $1,510,000 from 207 wells in Ohio. At the end of 1903 there were 5514 producing wells, with a yield of the value of $6,098,364, but the price being only about half that obtaining in Pennsylvania, the actual output of the two States was probably nearly equal. In 1909 the number of producing wells was only 2938, the value of the gas from them being estimated at $1,616,903.

The volume of natural gas produced in Indiana in 1916 amounted to 1,715,499,000 cubic feet, which was 24 per cent. lower than the total for 1915. The value of this gas was $503,373. Apart from those wells, which also yielded oil, there were 1967 gas-wells in service in Indiana at the end of 1916. In 1917 the volume of natural gas produced was 1,711,434,000 cubic feet, and the value of this gas was $453,310.

ILLINOIS.

Down to 1902 the only production of petroleum in Illinois was near Litchfield, Montgomery county, where some 1460 barrels was obtained in 1889, and several hundred barrels each year till 1902, when 200 barrels was obtained. The whole of this oil was used as a lubricant, but no production was recorded in 1903 or 1904.

During the early "oil-rush" in Pennsylvania, some wells were drilled in Clark county, Illinois, a few miles north of the town of Casey, at a place called Oil Field, and these were reported to have met with small showings of oil. In 1904 a Pittsburgh group drilled a well very close to these old tests, obtaining a slight showing of oil and gas. A second boring resulted in a 35-barrel well, and in 1905 some 300 wells were drilled, extending the field through Clark to Cumberland and Crawford counties. There were three principal areas, one between Casey and Westfield in Clark, another southeast of Casey, and the third near Robinson in Crawford. The first of these was in 1905 connected by pipe-line to the Cincinnati, Hamilton and Dayton Railroad at Oil Field Station. The production in 1905 was 181,084 barrels.

In 1906 the producing area was extended to Bridgeport in Lawrence, and the production of the whole field was collected by the pipe-lines of the Ohio Oil Company, the total amount obtained in 1906 being 4,397,050 barrels.

Additional pipe-lines were laid down in 1907, and active exploration with the drill was undertaken. According to Dr. David T. Day (*Mineral Resources of the United States,* 1909) 4988 new wells were sunk in 1907, of which 4260 were productive: these were situated in the following counties:—Crawford, Clark, Lawrence, Cumberland, Coles, and Edgar. The total production for the year was more than five times that of 1906, or 24,281,973 barrels. A new "deep-sand" producing area was found in Crawford county in 1917.

The output increased to over 33,500,000 barrels in 1908, but, owing to the decrease in Clark, Coles, Cumberland, and Edgar counties, without the finding of very prolific wells in other counties, the total for 1909 showed a decline to 30,898,339 barrels. In spite of this, Illinois maintained its position in the list of producing States, having advanced from non-inclusion in 1904 to third place in quantity and second in value amongst the States of the Union in 1908. An increased output was recorded in 1910, when over 33,000,000 barrels was raised. In 1916 the production was only 17,714,235 barrels, and in 1917 fell to 15,776,860 barrels.

Though of minor importance, the **natural gas** industry of Illinois has also developed rapidly during the years 1906-1911. In 1894 the value of the output was $15,000, and in 1903 only $3310. In 1906 there were 200 wells, and the value of the gas was estimated at $87,211. In 1909 the total quantity produced was 8,472,860,000 cubic feet, valued at $644,401, which was obtained from 414 wells in the counties of Bureau, Clark, Crawford, Cumberland, Lawrence, and Pike.

In 1911 the value of the gas produced reached its maximum of nearly $688,000. In the four-year period 1912-1915, it decreased to nearly one-half the record value, but in 1916 there was a substantial gain. In that year the production amounted to 3,533,701,000 cubic feet. In 1917 there was a further gain, the production reaching 4,439,016,000 cubic feet. Much of this gain is credited to the Staunton district in Macoupin county.

KANSAS and OKLAHOMA.

These two States, with areas of oil production in northern and central Texas, and northern Louisiana, constitute the **Mid-Continent field,** which has acquired its present importance since 1904.

Operations have been carried on in **Kansas** since 1865, when two wells were sunk about 10 miles east of Paola. In 1873 a boring, 7 miles from Paola, near a large tar-spring, met with a strong flow of gas at 320 feet, and was abandoned. In 1888 a very heavy black oil was found, and in May 1889 a good oil-sand was struck at 330 feet. In 1890 thirteen producing wells were in operation in the Russell tract, and in 1894 the output amounted to about 40,000 barrels. More active development then commenced, and in 1896 the production was 113,571 barrels, though it declined in 1899 to 69,700 barrels. After 1900 the industry began to develop with the discovery of new sources of oil at Chanute in Neosho county, and at Humboldt in Allen, the previous production being almost entirely derived from Neodesha in Wilson county. In 1903 the output had risen to 932,214 barrels, and the fields had extended over a stretch of territory reaching from Miami county to the Arkansas River in Indian Territory, an area of nearly 12,000 square miles of productive but undeveloped territory.

In 1904 the first notable advance took place, the production being more than four times that of the preceding year, or 4,250,779 barrels ; but, owing to the lack of transport facilities, this great increase of output at first tended to depress the industry. With the completion of the pipe-line from Humboldt, Kansas, to Whiting, Indiana, in 1905, the outlook changed, and the Mid-Continent field began to engage the attention of petroleum producers to the exclusion of nearly all other fields. The developments extended into Indian Territory and Oklahoma, and the total production for the united fields was 12,013,495 barrels in 1905 and 21,718,648 barrels in 1906. From that time the production of Kansas decreased to 1,128,668 barrels in 1910, while that of the new State of Oklahoma has increased with great rapidity.

In the closing months of 1915 a large production was obtained from the prolific Augusta and El Dorado fields of Kansas, and the output for 1916 was raised to 8,738,077 barrels, an increase of 209 per cent. over that for the previous year.

The continued development of the petroleum resources of Kansas met with such success during 1917 that there was a fourfold increase in the output for that year, making Kansas third instead of sixth among the producing States of the country. The output for 1917 reached 36,536,125 barrels. The remarkable increase is credited almost entirely to Butler county, and to Towanda township in that county.

The development of the **natural gas-fields** in Kansas has made great progress. Mr. F. H. Oliphant thus describes it in *Mineral Resources of the United States* for 1902 (Washington, 1904) :—" The present development begins at

Paola and extends in a series of pools southwest across the southeast portion of the State to Indian Territory, embracing the counties of Miami, Allen, Neosho, Crawford, Wilson, Montgomery, and Labette. The principal pools of high-pressure gas with large volume have been developed at Iola, Gas City, and La Harpe, in Allen county ; at Chanute in Neosho county ; and near Cherryvale, Independence, and Coffeyville, in Montgomery county. . . . The volume of many of these wells is as high as 5,000,000 cubic feet in twenty-four hours, and a few have gone as high as 10,000,000 cubic feet. The original rock pressure, which was 325 pounds to a square inch in a number of the pools, has decreased somewhat.

"The early history of this district dates back thirty years, when the Acres Mineral well was completed at Iola, which gave a small flow of natural gas. After several wells had been drilled near this location a vigorous well was found in 1893 which flowed about 3,000,000 cubic feet in twenty-four hours. In 1892 gas began to be introduced successfully in a small way. In the year 1899 it was successfully applied to the reduction of zinc ore, and began to be used by many of the large towns in southeastern Kansas, and it began to be used also in the manufacture of brick and hydraulic cement, and in numerous other manufactories. Development in the last year has been active, and numerous natural-gas wells have been found."

The value of natural gas produced in this State in 1903 was $1,123,849, an increase of $299,418 over the previous year ; in 1909 the State was third in the Union as a gas-producer, the quantity being estimated at 75,074,416,000 cubic feet, valued at $8,293,846, an increase in value, but a decrease in quantity, from 1908.

After 1909 the value of the gas produced in Kansas declined steadily to $3,288,000 in 1913, since which year it has gradually increased with the development of prolific gas-fields in Butler county, though it is still far below the maximum. The volume of natural gas produced in Kansas in 1916 amounted to 31,710,438,000 cubic feet. There was a big falling off in the volume of gas produced in the El Dorado and Augusta fields in 1917, which decreased the actual production from Kansas to 24,438,848,000 cubic feet.

Prior to 1907, **Oklahoma** was known as the Indian and Oklahoma Territories, and until 1904 the oil resources of the region remained practically untouched, partly as a result of the conditions imposed by the Government in respect of leases.

Down to 1903 the only field in the Indian and Oklahoma Territories which had been developed to any extent was one belonging to the Osage Nation, which yielded 37,000 barrels from 13 wells in 1902. In 1897 a well 4 miles southwest of Red Fork, in the territory of the Creek Nation, struck petroleum of a green colour at 600 feet, and some of a black colour at 1223 feet. In 1901 an oil of light olive colour, capable of being used in a lamp without refining, was stated to have been obtained at Red Fork at a depth of 537 feet. In 1902 a light oil of amber colour and good illuminating quality was reported to have been met with in this territory ; black oil, with a specific gravity of 0·915 to 0·875, had also been found in the district of the Cherokee Nation. A heavy lubricating oil was found at Granite at a depth of 165 feet ; and near Lawton, Comanche county, in a well sunk in 1901, oil was met with at 137 feet, which gave the following analysis in the hands of Dr. William B. Phillips, of the University of Texas :—Naphtha, 9·32 per cent. ; burning petroleum, 46·6 per cent. ; heavy petroleum, 36·8 per cent. ; black asphaltum and loss, 7·28 per cent.

The field as a whole began to develop with very great rapidity after 1904, though for 1905 and 1906 the production was included with that of Kansas.

In 1906 the Glenn pool was discovered in the Creek Nation, and at the end of that year there were 110 wells in a proved area of about 7000 acres. In 1907 Oklahoma State produced 43,524,128 barrels, and the output increased to 47,859,218 barrels in 1909, when the Preston pool was developed to the north of Okmulgee in Creek county. In that year 3279 wells were drilled in the State, of which 2742 were producers; these were situated principally in Cherokee, Cleveland, Creek, and Osage counties. In 1910, 52,028,718 barrels was produced in Oklahoma.

Thereafter there was a steady annual progression, except during the year 1912, until in 1917, for the third time in its history, Oklahoma attained to first rank among the petroleum-producing States, the output amounting to 97,915,243 barrels, or 35 per cent. of the total production of oil in the United States. The premier position occupied by Oklahoma on the previous occasion, viz. in 1908, was due to the output of the newly-developed Glenn pool in eastern Creek county, and the return to first place was again the result of the wonderfully prolific character of the oil-bearing formation of this county, demonstrated this time in the Cushing field, near its western boundary. The predominance which Oklahoma thus gained in the industry was largely augmented by the circumstance that the oil obtained was of high grade. This predominance was maintained in 1916, when the output of the State was further augmented by 9 per cent., to 107,071,715 barrels; in 1917 the production increased to 107,507,471 barrels, the increase being generally contributed to by the productive fields other than Cushing, the output of which exhibited decline. Although the Glenn, the Osage, and other less important districts shared in the increase, the most notable gain was in the Healdton district, Carter county.

The **natural-gas** industry of Oklahoma has developed with great rapidity of late years.

A well with a capacity of 500,000 cubic feet a day was reported in 1901 near Bartlesville in the Osage Territory, and at Blackville, in the Creek Nation, two more of similar capacity were announced in 1902.

In February 1906 a well was drilled four miles south of Caney, Kan., one mile from the State line in Cherokee Nation, which at 1500 feet was completed as a very prolific gas-well, described as one of the most spectacular known. This gave a great impulse to the development, and the value of the output rose from $247,282 in that year to $1,743,963 in 1909.

Since 1911 Oklahoma has ranked third among the gas-producing States, and in 1916 the output, which was obtained from 31 counties lying in the eastern half of the State, amounted to 123,517,385,000 cubic feet, a gain of 41 per cent. on that for 1915, which was itself a record yield; in 1917 the volume of natural gas produced reached 137,384,154,000 cubic feet, a gain of 11 per cent. over the former record output in 1916. The only new important field discovered in 1917 was the Walters field in the eastern part of Cotton county. At the end of 1917 there were 1433 gas-wells in service in Oklahoma.

TEXAS and LOUISIANA.

As already stated, the comparatively small area producing petroleum in northern and central Texas is considered to form part of the Mid-Continent field, but with this exception the oil-bearing districts of Texas and Louisiana constitute what is known as the **Gulf Field**. The northern Texas fields include those of Corsicana, Henrietta, and Powell.

According to Mr. H. S. Kneedler (*Through Storyland to Sunset Seas*, 1898) the settlers knew of the existence of petroleum in **Louisiana** as far back as 1820, "and they resorted to the places where it oozed from the ground as a black and pasty mass to gather it, though their only use for it was to grease the axles of their waggons, and to protect their implements from rust."

The first development of the petroleum industry in **Texas** was in the sixties, when oil was found near Nacogdoches at a depth of about 100 feet, and a few wells flowed to a very limited extent. A pipe-line was constructed, and storage-tanks built; but the industry remained in a stagnant condition for many years. In 1895 the amount of oil obtained was only 50 barrels. In 1893, however, petroleum had been found at Sour Lake, at a depth of 230 feet, and in 1894 it was discovered near Corsicana, from which neighbourhood about 1000 barrels was obtained in 1896. In 1897 the output had increased to nearly 66,000 barrels and the next year to 546,000 barrels.

On the 10th January 1901 the noted gusher known as the Lucas well was brought in at Spindle Top, near Beaumont, at a depth of 1050 feet, and during the nine days that elapsed before it could be shut-in it was estimated to have yielded about 700,000 barrels of oil. When first tapped the pressure was so great that it shot 1000 feet of 4-inch iron tubing from the borehole, completely wrecking the derrick, and then poured forth a solid column of oil, 6 inches in diameter, to a height of 160 feet with unabated force till it was closed down. A sample of the oil submitted to the author had a specific gravity of 0·922, and contained 1·33 per cent. of sulphur. Great activity immediately prevailed in the neighbourhood, and a large number of wells were drilled, but the production quickly declined, and the field proved most disappointing. Productive areas have also been opened up at Sour Lake, about 20 miles to the northwest of Beaumont, and at Saratoga, Batson Prairie, and Humble. The output from Texas rose to 4,393,658 barrels in 1901, and to 18,083,658 barrels in 1902. In 1903 it declined to 17,955,572 barrels, but increased in 1905 to 28,136,189 barrels; in the following year the quantity obtained was only 12,567,897 barrels, and the output further decreased to 8,899,266 barrels in 1910.

For the year 1916 the production had increased to 27,644,605 barrels, which was only 2 per cent. less than that for 1905. As in 1905, the gain in production was chiefly to be credited to the prolific Humble pool in Harris county. In 1917 the production increased to 32,413,287 barrels; the greater part of the credit for this increase belongs to the Electra and Burkburnett districts in the Stratum Division.

Natural gas is obtained in Clay and Navarre counties, and in small quantities in many of the coast fields. A considerable amount is derived from oil-wells, some of those in the Beaumont field showing a pressure of 250 pounds to the square inch.

The principal area of the commercial production of gas in Texas is the Petrolia oil and gas district in Clay county. Second in importance is the Mexia-Groesbeck field, in Limestone county. The output of natural gas in Texas in 1916 amounted to 15,809,579,000 cubic feet, a gain of 19 per cent. over that for 1915, and 18 per cent. larger than the record yield in 1914. In 1917 the production of natural gas exceeded that of any preceding year and amounted to 17,047,292,000 cubic feet.

Louisiana first came into prominence as an oil-producer in 1902, yielding in the last eight months of that year 548,617 barrels, all derived from the Jennings field, where a flowing well was brought in at a depth of 1822 feet in August 1901. The Welsh field, 12 miles to the west, began to produce in 1903, and Anse-la-Butte, 40 miles east of Jennings, in 1905. A "big gusher" was brought in here on 14th November 1907, which led to considerable increase in output in the following year. The Caddo field near Shreveport showed great developments in 1908, and in 1909 the production was 1,028,818 barrels, increasing to over 5,000,000 barrels in 1910.

The production of the State increased from 548,617 barrels in 1902 to 9,077,528 barrels in 1906, but with the decline of the Jennings field, the total output fell to 3,059,531 barrels in 1909. The greatly increased output of the Caddo field and the rise of that of Vinton brought the production in 1910 to 6,841,395 barrels.

The output of petroleum in Louisiana in 1915 exceeded that of 1914 by 3,882,104 barrels, and established a new record for production of oil in that State. This was chiefly due to the contribution of the Crichton field, only half of which was required to offset the decline in the Caddo and De Soto districts. In the following year it declined by 16 per cent., the total being 15,248,138 barrels, 78 per cent. of which came from the oil districts of northern Louisiana, and 22 per cent. from the Saline-dome pools of the southern part of the State. In 1917 the production declined to 11,392,201 barrels.

Enormous quantities of **natural gas** are obtained in the Caddo field, though much is wasted ; and it is considered that the great capacity and high pressure of the wells in this district make it one of the greatest gas-producing fields known in the United States (Hill, *Mineral Resources*, 1909).

In 1916 a prolific gas-field was discovered in the neighbourhood of Elmgrove, about 20 miles southeast of Shreveport, and another field of considerable potential importance was discovered in the same year in Morehouse parish, in the northeastern part of Louisiana.

The production in 1916 amounted to 32,080,975,000 cubic feet, a gain of 26 per cent. on that for 1915. The greater part came as previously from the oil districts in Caddo, De Sotto, and Red River parishes. In 1917 the production decreased to 31,286,476,000 cubic feet. Late in 1917 two gas-wells of unusually large volume and rock pressure were completed near Montegut in Terrebone parish, 50 miles southwest of New Orleans.

COLORADO.

The development of the oil-industry in Colorado dates from 1886, and this State was at one time the sixth in the order of production, but its output is declining, for whereas in 1892, 824,000 barrels were produced, in 1903 the output was but 483,925 barrels, notwithstanding that great activity in prospecting prevailed in 1901 and 1902. In 1909 the production was only 310,771 barrels, and in 1910, 239,794 barrels. The greater part of the output was obtained from the Florence field, in the valley of the Arkansas River, west of Pueblo, the remainder, about 27 per cent. of the whole, being obtained from the Boulder field. In 1913 the output had further declined, but in that year oil and gas had been found near De Beque in Mesa county. After several unsuccessful attempts in drilling for oil at and near De Beque since 1900, the Grand River Valley Oil and Gas Company drilled a well in 1913 a short distance west of the town and found a good sand at 1135 feet. The casing collapsed, but the gas pressure was sufficient to throw water intermittently to a height of 100 feet. A second test in 1914 gave a well with a reported yield of 100 barrels a day at 1900 feet, but water trouble was met with. The results, however, stimulated much leasing in the neighbourhood, and a thorough test of the district was decided upon. In 1914, as in former years, the marketed production of petroleum in Colorado, came almost entirely from the old Boulder and Florence fields, the former showing a decline of nearly 45 per cent. below the output in 1913, and the latter registering an increase of 22 per cent., which, together with a small production from the De Beque and Rangley fields, was sufficient to increase the total output of oil of the State 18 per cent. over that of 1913. The fact that no wells were drilled during the year in the Boulder field, together with the fact that eleven new producers were completed in the Florence field, readily explains the fluctuations in production noted above. In the De Beque district the year's activity resulted in the completion of one small producer of oil and one barren hole. In the Rangley district, Rio Blanco county, there were no wells completed, the 23 productive wells in the field being capped and shut-in, awaiting transport facilities. Wild-cat tests during 1914 resulted in barren wells near Fowler, Crowley county, and near Falcon, El Paso county. The marketed production for 1914 was 222,773 barrels. As previously, the contribution to the United States petroleum industry from the Colorado field came chiefly from the Boulder district, in Boulder county, and the Florence field, in Fremont county, but there was a slight production from the rejuvenated district in Garfield county, a few miles southeast of Vernal, Utah. No new wells were drilled in the De Beque district in 1915, and the only well capable at the beginning of 1915 of producing small quantities of oil was abandoned. At Rangley one well was completed and capped, and one well was abandoned. Late in the year a test was started 6 miles north of Hotchkiss, Delta county. In 1915 the production of Colorado fell to 208,475 barrels ; in 1916 was less by 11,240 barrels than the output in 1915. No petroleum was marketed from the Rangley or De Beque districts. For 1916 the production had fallen to 197,235 barrels, of which 97 per cent. came from the Florence and the remaining 3 per cent. from the Boulder field, in Boulder county. In 1917 the production, which came almost entirely from wells in the Florence district, Fremont county, Boulder district, Boulder county, and from a seep of oil developed by the Urado Oil Company in Garfield county, decreased to 121,231 barrels. The oil from the Florence field is of a dark green colour, and has a density of about 31° B., yielding from 35 to 44 per cent. of illuminating oil of about 120° fire-test. The oil from the Boulder pool, which is obtained from a depth of about 2000 feet, has a gravity of 43° B. Although not largely productive, the wells of the Florence field yield very regularly, and in many cases the output increases for some days or weeks after the wells are completed. The *Oil and Gas Journal* instanced the case of a well which had been pumped for twenty-three years, and had yielded over 600,000 barrels.

A small production of natural-gas gasoline is credited to Colorado in 1917 from one plant operated by the Boulder-Greeley Oil Company, on casing head-gas from the wells in the old Boulder oil-field, Boulder county.

CALIFORNIA. (Plate 13.)

Until 1881 the production of petroleum in California was not large, the output in 1880 being but 40,552 barrels, mainly derived from Ventura, Los Angeles, and Santa Barbara districts. Since that time it has rapidly increased, and California became first in the rank of petroleum-producing States, the yield in 1903 being nearly 24,382,472 barrels. In 1907 and 1908 Oklahoma produced more petroleum than California, but in 1909 the latter again held first place with 54,433,010 barrels, and in 1910 the production was over 73,000,000 barrels. In the year 1915 the output exhibited decline, and as this coincided with a remarkable increase in Oklahoma, California again took second place in the rank of petroleum-producing States. In 1916 the relative positions of the two States remained substantially unaltered, although there was an increased production in California of over 4,000,000 barrels, bringing up the total for that year to 90,951,936 barrels. In 1917 the production of California reached 93,877,549 barrels. The increase recorded is due to the development of relatively shallow territory in the districts in San Joaquin Valley, by the completion of a few prolific deep-sand wells in the Whittier-Fullerton district, and from new and important discoveries at Casmalia, Santa Barbara county.

In a memorandum on the subject of the duration of the supplies of Californian petroleum, addressed to the Secretary of the Interior, and published in 1910,[1] Mr. George Otis Smith, the Director of the U.S. Geological Survey, estimates the quantity of petroleum remaining underground at about 7,000,000,000 barrels. After discussing the probable demand for fuel oil, he expresses himself as follows :—

" With the market possibilities as now seen, I am inclined to agree with the belief of Mr. Requa, that 100,000,000 barrels may be the ultimate maximum annual consumption, and that a market for this amount of Californian oil will be found within five years. This brings us to the question of duration of supply. At this rate of consumption, which, it will be noticed, is over 50 per cent. in excess of the present rate, the life of the California field may be estimated as follows : At about thirty-seven years, according to Mr. Orcutt's minimum estimate for California's petroleum resources—his own estimate of life being fifty years at an annual rate of 75,000,000 barrels ; at from forty-five to eighty years on the basis of the Survey estimates of quantity ; and at over a century on Mr. Requa's own maximum estimate. Of course the production will not keep up to the maximum the whole life of the field, but during the later decades will be in amounts unequal to the industrial demands.

" Mr. Requa's latest word is that he believes the assertion warranted 'that Californian oil will dominate the fuel market of the Pacific, at least through the present century.' Although this statement may represent the extreme of optimism, I would hesitate to discount his estimate more than a third."

Mr. George Otis Smith has obligingly informed the author that the estimate above referred to, and a later one published in 1916, have been reconsidered and revised twice on the basis of subsequent discoveries and the results of exploration with the drill and geological investigation, and that the more recent estimate places the available petroleum still in the ground in California, 16th January 1919, at 2,250,000,000 barrels.

The oldest wells are in the Pico Cañon, about 6 miles west of Newhall, Los Angeles, where the Pico well was drilled in 1869. In the autumn of 1886 the defined area of this field was about two miles by a quarter of a mile, and about 16 wells, producing a total of 500 barrels daily, were then in operation.

The oil is usually described as jet black, though occasionally greenish or brownish. It varies in density from 22° to 45° B., that of Santa Barbara having the highest density. Although the oil yields comparatively little kerosene, it finds a ready sale for fuel. The Santa Clara oil was formerly employed as a source of paraffin wax by the Pacific Coast Oil Company.

In the recorded statistics of marketed production published by the

[1] *Mineral Resources of the United States*, Pt. II, 1910, pp. 416–417.

United States Geological Survey, the oil-fields of California are classified as follows:—

COASTAL AND SOUTHERN DIVISION.

Los Angeles County.
- Los Angeles City.
- Newhall.
- Salt Lake.
- Puente.
- Whittier.

Orange County.
- Fullerton.

Ventura County.
- Santa Paula.

Santa Barbara County.
- Lompoc.
- Santa Maria.
- Summerland.

San Luis Obispo County.

Santa Clara County.

SAN JOAQUIN VALLEY DIVISION.

Fresno County.
- Coalinga.

Kern County.
- Kern River.
- Lost Hills.
- McKittrick.
- Midway.
- Sunset.

Los Angeles and Orange Counties.—During 1914 no field developments of any importance took place either in **Los Angeles City** or in the **Salt Lake** field, west of the city, and no developments of consequence took place in 1915. During this year near the town of Chatsworth, at the west end of San Fernando Valley, after drilling to a depth of 2430 feet in an effort to discover oil, the Placerita Oil Company completed its well as a gas-well. In 1916 a few wells, averaging about 20 barrels each, were completed in territory already proved in the Salt Lake field. In the City field operations were restricted to the pumping of old wells. The production from Los Angeles City for the year 1914 was 296,862 barrels; for 1915, 164,873 barrels; in 1916, it increased to 299,781 barrels; and in 1917 decreased to 261,348 barrels.

During 1914 operations in the **Whittier-Fullerton** field were fairly active, the chief interest centring in the Coyote Hills locality, where a number of gusher wells were completed. At the east end of La Habra Valley, in the vicinity of Placentia and Carlton, developments were equally successful, and important additions to the productive area were made. As a result of the increased production of the southern California fields in 1914, an abundance of oil was assured to the refinery of the Standard Oil Company at El Segundo for some time. The regularity with which oil-wells of relatively large initial capacity were completed on proved leases, particularly in the East Coyote Hills field, was perhaps the most significant feature of development work in the Whittier-Fullerton field in 1916. The production for 1915, including that of the Coyote Hills field, was 11,885,150 barrels; in 1916 there was an increase, the amount being 14,069,701 barrels; in 1917 the production reached 16,671,715 barrels.

Ventura County.—Little activity was apparent in Ventura county during 1914 outside the operations of the Montebello Company, along Oakridge, on the south side of Santa Clara Valley, and the operations of three or four companies in a small field in the Simi Valley, called the Santa Susana field. In 1915 the drilling activity was fairly well maintained in the oil-producing areas where shallow wells of small capacity are to be found. In the Bardsdale field, on the south side of Santa Clara River, a number of excellent wells were completed by the Montebello Company. A deep sand reached on the Shiells lease at 2600 to 2900 feet furnished wells of 250 to 300 barrels capacity.

In the **Santa Paula** district the best well of the year was drilled by the Santa

Clara Oil Company, which was completed at a reported depth of 3300 feet, and yielded an initial production of 70 barrels a day. The oil was reported to contain about 30 per cent. of gasoline at 60° B., and about 18 per cent. of kerosene. In the **Simi Valley**, through the efforts of the Santa Susana Syndicate and Petrol Co., operating on the north side of the Simi Valley, three productive wells were added to the small field at the mouth of Tapo Canyon.

Normal activity prevailed in 1916 in the scattered fields in Ventura county, the net effect on production being 3 per cent. gain, compared with 1915. Development work was especially active in the Bardsdale field, where the deepening of wells to the lower sand found in 1915 was the chief feature of importance. The production for 1916 was 932,028 barrels, against 908,359 barrels in 1915; and in 1917 it reached 936,422 barrels.

Santa Barbara County.—In 1913 the **Santa Maria** field benefited very largely by the advances made in connection with the topping and dehydration of oils, and the economies effected by many minor improvements in the great refineries at Point Richmond, Oleum, and El Segundo contributed equally to the problem of efficient refining. In 1914 developments in the various subdivisions of the Santa Maria field were without any special interest, and owing to the high cost of drilling activities in this area were less than usual. In 1915 the principal interest was centred in the operations of the Western Union Oil Company on the Carreaga estate, 10 miles southeast of Santa Maria, where well No. 36, completed at a depth of 3894 feet as a 500-barrel producer, a few days after completion increased its natural flow to nearly 6000 barrels a day.

Drilling was revived late in 1915 in the old **Casmalia** field, 7 miles southwest of Santa Maria. Near **Lompoc** a deep test-well drilled by the Union Oil Company on the Buell Ranch was abandoned.

In the various fields which make up the Santa Maria field there was but little activity in 1916.

Two additional tests of potential importance were started in this district by the Standard Oil Company of California. They were located on a tract of 3700 acres known as the Pezzoni and Tognazzini ranches, a few miles back from the ocean between Casmalia and Guadalupe, in the northwest corner of Santa Barbara county. In August 1917 these were abandoned as failures. The marketed production for Lompoc and Santa Maria (Santa Barbara county) for the year 1914 was 4,310,236 barrels, in 1915 this dropped to 4,272,630 barrels, but in 1916 it again increased to 4,439,619 barrels. In 1917, owing to the success of the newer Casmalia fields near Los Alamos, the production reached 4,801,065 barrels.

The production of petroleum from the Summerland field for the years 1911 and 1912 averaged between 63,000 barrels and 65,000 barrels; in 1913 it reached 66,000 barrels, and in 1914 it dropped slightly, the marketed production amounting to 53,561 barrels. In 1915 there was a great falling-off, the production only amounting to 18,314 barrels. The influence of higher prices for crude oil in 1916 brought about a cleaning of the old wells in the old ocean-beach field at Summerland, with the result that the output for that year amounted to 42,223 barrels. No new wells were drilled in 1917 in the old Summerland field, but the production increased to 47,036 barrels.

San Luis Obispo County.—In the Edna or Arroyo Grande district, 8 miles south of San Luis Obispo, where a heavy asphaltic oil is found, which is used chiefly for the manufacture of asphalt at Edna, the completion of a productive well in 1915 caused some speculation as to the future possibilities of the field. In 1916 the production of oil remained practically stationary in this district, but late in the year preparations were made for active drilling with a view to the thorough testing of the territory. The output of oil from the Arroya Grande district increased moderately in 1917 owing to the completion of six new wells.

Santa Clara County.—An increase in the marketed production amounting to 81 per cent. of the 1914 output, the completion of one well, and the abandonment of one exhausted producer constitute the record of activity in the Sargent or Watsonville district in Santa Clara county in 1915. In 1916 there was renewed activity in this district, which consisted in the cleaning out and deepening of the old wells and the drilling of one new producer, this resulting in a substantial gain in the output of the field. The production from the Santa Clara county, together with that from San Luis Obispo county, was 20,751 barrels for 1914; for 1915, 37,617 barrels; for 1916, 45,603 barrels; for 1917, 98,715 barrels.

San Joaquin Valley Division.—The development of the **Coalinga** field, in Fresno county, was commenced in 1890. In 1909 it produced more oil than any other Californian field, the output being 14,795,459 barrels, and in 1910 this increased to 18,387,750 barrels. One of the most important events of that year was the bringing in of the Silver Tip well on Section 6, said to have been the largest producer ever drilled in the State up to that time, with the exception of the Hartnell well of the Santa Maria field. Both these wells were subsequently eclipsed by the famous Lake View gusher of 1910. At that date the gravity of the oil ranged from 11° to over 40° B. (specific gravity, 0·9930 to below 0·8251), and the depth of the wells varied from 800 feet to over 2000 feet, though in a few instances wells of over 2500 feet had been drilled.

In 1912 the Coalinga territory was extended by the development of good wells to the south, and its value was enhanced by the increased utilisation of natural gas, including the enterprise of piping natural gas from the valley fields to Los Angeles, and by the increased amount of gasoline obtained by compressing natural gas. In this district the year 1913 produced many eventful features, including extensions of territory to the east, and the discovery of additional deep sands that yielded petroleum containing paraffin and a larger proportion of light oils. The value of this field is indicated by the sale late in the year of the California Oilfields Limited to the Shell Transport and Trading Company. In 1914 activity was chiefly centred in the East Side field, where the Shell Company made preparations to develop the properties they had acquired from the California Oilfields. In the West Side area great trouble was encountered with water, which retarded the successful operation of a number of properties. The quantity of petroleum marketed from the Coalinga district in 1915 was 18 per cent. less than the corresponding output for 1914. The completion of only 20 wells in 1915, as compared with 35 in 1914 and 91 in 1913, indicates the lethargy that existed throughout the district. The deepening, however, of an old well in the white-oil district adjacent to Oil City, northwest of the East Side field, in December, was attended with such favourable results that a revival of drilling activity in this pioneer district was planned for 1916. Increased activity in drilling in 1917 resulted in the completion of 104 oil-wells, compared with 54 in 1916.

Although a few wells were completed in 1916 in the East Side field, the greater part of the activity in the Coalinga district was in the shallower West Side field, where the deepening of the old wells to the second sand was the principal feature of the operations in the northern part of this area. The acquisition by the Standard Oil Company of California of the producing property of the Home Oil Company in the old Oil City was followed by a cleaning out and redrilling of the six productive wells that resulted in a material gain in the output of a light-gravity oil. The marketed production from the Coalinga field for 1915 was 12,851,034 barrels; in 1916 it increased to 14,231,251 barrels; and in 1917 to 15,984,766 barrels.

Kern County.—The development of the **Kern River** field was commenced in the year 1899, and for some time this field was the most productive one in the State of California. At the beginning of 1904 there were 860 wells yielding oil the gravity of which ranged from 11° to 16° B. (specific gravity, 0·9930 to 0·9594). The average depth of the wells sunk on the eastern border of the field was, at that time, about 600 feet, and that of those on the western side about 1200 feet.

In 1914 the marketed production of the old Kern River district showed a decrease of 32 per cent. below that of 1913. This was partly due to the normal decline of the field, but to a much greater extent to the closing of a great number of wells for whose product no market was available. Great interest was taken at this time in the successful efforts of the Standard Oil Company of California to extend the field to the northwest along the low foothills bordering the San Joaquin Valley on the east. In September of that year a wild-cat well put down in the Mount Diablo meridian, 2½ miles northwest of the developed portion of the field, was completed with an average production of 125 barrels of oil a day. Other test-wells were being drilled in sections 5, 15, and 35 of the same township. The discovery of oil in this district was of great interest, because it tended to substantiate the theory held by many geologists, that the productive sands of the Kern River field extend northward and westward from the developed part of the field, but that they lie at a considerably greater depth than in the old field.

In 1915 an increased demand for fuel in California and the adjacent States, and the enlargement of the capacity of the Bakersfield refinery resulted in an output of oil from the old Kern River district 13 per cent. greater than that of 1914. Active work was carried on by the Standard Oil Company of California in order to demonstrate a westward extension of the Kern River field into section 27 T, 28 S, R 27 E. At the end of that year No. 2 well was completed at a depth of 2467 feet, with a capacity of 100 barrels of oil a day.

In 1916 a decided increase of drilling in the old Kern River field met with excellent results. The greater part of the work was carried out in proved territory. In 1917 activity in drilling was decidedly less, only 39 new wells being completed against 102 in 1916.

The marketed production of the Kern River field for 1915 was 7,585,400 barrels; for 1916, 8,226,788 barrels; and for 1917, 8,144,348 barrels.

Great credit is due to the California State Mining Bureau in connection with the methods employed, under their supervision, in 1917, to combat the ruin of this field by salt water.

The **McKittrick** field is situated on the edge of the desert at the eastern base of the coast range of mountains, about 35 miles west of Bakersfield. It was opened up in a small way towards the close of the last century, and at the beginning of the year 1904 there were rather more than 100 wells, varying in depth from 200 feet to 1500 feet, which yielded oil of a gravity varying from 11° to 17° B. (specific gravity 0·9930 to 0·9530).

Early in 1914, owing to the demand for oil as fuel, there was considerable activity in drilling in the McKittrick, Lost Hills, and Belridge districts, but the market restrictions in the later months of the year brought about a cessation of the new development work.

Drilling activity in these three districts attained only moderate proportions during 1915, and the output of petroleum declined about 15 per cent. The only development of consequence in this area was the completion, at a reported depth of 4125 feet, of well No. 4 by the Belridge Oil Company. The initial output of this well was estimated at 300 barrels a day, and the importance of the discovery lay in its location 20 miles northwest of McKittrick and 6 miles northwest of the Belridge development, where one or two wells drilled previously had furnished only a small quantity of oil from shallow depths. As a consequence of this discovery additional work was started in order to ascertain the value of the prospective field. The marketed production for the McKittrick district, including Belridge, for 1916 was 4,467,668 barrels, and for Lost Hills, 3,433,034 barrels ; in 1917 the McKittrick production, including Belridge, amounted to 5,024,320 barrels, and for Lost Hills, 4,249,039 barrels.

The moderate depth at which petroleum is obtainable in the Lost Hills district, and the relatively high grade of the oil found, furnished an incentive that made development work especially active during 1916. The trend of the development work in this district was toward the northwest, along the crest of the Lost Hills anticline. Principal interest in the Belridge district was centred in the new territory 6 miles to the northwest.

Additional drilling in this locality, which occupies the southeastern part of T 27 S, R 20 E, resulted in the extension of proved territory from section 35 to the west and northwest into sections 34 and 27 and to the east into section 36. In the McKittrick district development work was most active in 1916 along what is known as the McKittrick Front, 3 to 5 miles north of McKittrick and between the old McKittrick field and the Belridge district.

The **Midway** field may be regarded as an extension of the Sunset field in a northwesterly direction. At the beginning of 1904 it had a proved oil-bearing area of about 4000 acres, upon which there were 61 wells yielding oil of a gravity of 17° to 18° B. (specific gravity, 0·9530 to 0·9466). Great development commenced in this district in 1909, the production for that year being 2,019,952 barrels, as compared with 1,609,559 barrels for 1908, whilst for 1910 it had increased to 10,436,137 barrels.

In 1912 some good producers in the Midway and other valley fields were injured by an influx of water.

The increase in the marketed output of petroleum in California in 1914, which was slightly more than 2 per cent. above the record established in 1913, was chiefly due to the Midway-Sunset division of the San Joaquin Valley fields, but in part to the Whittier-Coyote division of the southern California fields. The most successful development work carried out in the Valley fields in 1914 was centred in the Midway-Sunset district, interest being chiefly localised in the North-Midway and Maricopa Flat subdivisions. The North-Midway development took place north and west of Shale and consisted of active drilling for heavy gravity oil found in unusually thick oil-sands at depths of less than 1000 feet. More activity in drilling was apparent in the Midway district in 1915 than in any other part of the San Joaquin Valley division, though the results both as to number of wells completed and as to new production were below those of recent years, with the result that no developments of consequence were recorded. During the year 1916 the development work in the Midway district was pretty general, and the gain of 6 per cent. in output compared with 1915 can be credited to no particular quarter of the field. In 1917 the production amounted to 28,829,674 barrels, a decrease of 9 per cent. compared with 1916.

The **Sunset** field is the oldest field in Kern county, and for many years asphaltum has been manufactured locally from the oil obtained there, and shipped to all parts of the world. After 1899 the field was gradually extended, and at the end of 1903 the proved petroliferous area was about 3000 acres, with 113 completed wells, varying in depth from 500 to 1500 feet. The oil then obtained was heavy, the average gravity probably being about 13° B. (specific gravity, 0·9791). The field is situated in the southwest corner of the San Joaquin Valley, and is distant about 30 miles southwest from the town of Bakersfield, or about 25 miles from the McKittrick field.

Early in 1913 the Sunset field was extended southeast by the drilling of large wells on the Maricopa flats, with the result that, as had previously occurred, production exceeded consumption. The fact that this great increase involved no discovery of new oil pools, but was merely the extension of the Sunset pools southeast is significant as to the conditions of the occurrence of oil in California. In 1915 the marketed output in the Sunset district declined less than 6 per cent. from that of 1914 when gushers of large capacity supplied a large proportion of the yield. The record well of the year 1915 was No. 3 of the Union Oil Company, on the Coronation lease. This well was completed in September at a reported depth of 3275 feet, and was credited with an initial flow of 3500 barrels.

Development work in 1916 failed to lead to any discoveries of especial note. The world-famous well of the Lakeview Oil Company, that came in as a 70,000-barrel gusher in 1910, was cleaned out by the Union Oil Company, and was rejuvenated as a producer capable of yielding 30 barrels of oil a day when pumped. On the Maricopa flats additional wells of relatively large initial capacity were brought in on the holdings of the Union Oil Company. In 1917, 2 new wells with good yields were completed in this district.

The production from the Sunset field in 1911 was 6,350,298 barrels, showing a slight decrease, but in 1912 it was somewhat higher, being 6,509,093 barrels. This was increased to over 8,000,000 barrels in 1913; in 1914 it reached 9,241,814 barrels, dropping in 1916 to 7,357,818 barrels; and in 1917 to 6,680,581 barrels.

The author is indebted to Dr. William Hope Henderson for the following particulars, dated February 1919, with the map reproduced as Plate 13, relative to the petroleum fields of California:—

Bulletin 82 (Second Annual Report of the State Oil and Gas Supervisor of California) shows in its text the subdivision of the many fields as follows:—

OIL-FIELDS.

FRESNO COUNTY.
- Coalinga, etc.

KERN COUNTY.
- Lost Hills.
- North Belridge.
- Belridge.
- (Wild-Cat Territory.)
- McKittrick Front.
- McKittrick.
- Midway.
- Sunset.
- Kern River.

MONTEREY COUNTY.
- Watsonville (Arroyo Grande Field).

SANTA BARBARA COUNTY.
- Santa Maria.
- Casmalia.
- Cat Canyon.
- Lompoc.
- (Los Alamos.)
- Summerland.

VENTURA COUNTY.
- Simi.
- Piru.
- Bardsdale.
- Sespe.
- South Mountain.
- Santa Paula.
- Ojai.
- Ventura.

OIL-FIELDS—*continued.*

LOS ANGELES AND ORANGE COUNTIES.

Newhall.
Los Angeles City (eastern-central-western) and Salt Lake (including Beverly Hills).
Whittier-Fullerton—
Olinda.
Brea Canyon.
Whittier.
Coyote Hills.
Montebello.
Puente.
Yorba-Linda, this last is a new field, and is now included.

On the accompanying map these fields are shown. Green lines have been drawn to point to the centres of such fields in Los Angeles and Orange counties, while in Ventura and Santa Barbara counties and in the Newhall of Los Angeles county these lines run to approximately the centres of the districts comprised under the names, and a blue line indicates such an area. This is necessary in Ventura county, especially where the districts may cover several small and scattered fields. The Ventura field in the county of that name, and the Los Alamos field of Santa Barbara county are not as yet of importance, neither is the Yorba-Linda field of Orange county.

In **Los Angeles County** the Montebello field has become very important, and in Orange county the Yorba-Linda field appears to be opening up very well, while further south in this county, the discovery of heavy oil at Newport has attracted a good deal of activity, and this field may become of some significance as development proceeds.

The following notes may be of interest :—

Los Angeles County.—The Montebello field is situated half-way between Los Angeles and Whittier, one mile north of the town of that name, and it occupies the crest and flanks of an anticlinal dome known as La Merced Hills, which is a low range of hills forming a spur extending in an east-west direction. Erosion has effaced evidence of the original dome contours, the longer axis unning east-west and the centre of the dome being somewhat east of the centre of the hill.

Surface exposures show formations of the Pleistocene and Fernando ages only, the former being from zero to several hundred feet in thickness, while the thickness of the Fernando has not been determined, but it is suggested that the base of the Fernando is reached at from 1500 to 2000 feet, and that production being obtained comes from the underlying sands and sandy-shales of the Puente.

This field has lain in the centre of an oil-producing belt for years undiscovered, and its discovery was due to scientific geological study.

The **Standard Oil Company** started drilling on 16th December 1916, and completed the well on 24th February 1917, thereby opening up a field which has promise of being one of the most important in the State. This well had an initial production of 650 barrels of oil at a depth of 2395 feet. Thereafter wells were drilled by many companies and large production obtained ; one well drilled to 3755 feet at the end of 1917 had an estimated production of about 15,000 barrels a day, but was shut down to 6000–7000 barrels, of 26° B. The manner in which this field has increased may be judged from the general figures here noted, which are as nearly correct as possible :—

February 24, 1917.	Oil discovered.			
June 1917, . .	Daily oil production about	850 bbl. from		2 wells.
December 1, 1917, .	,, ,, ,,	8,500 ,, ,,		5 ,,
June 1918, . .	,, ,, ,,	15,000 ,, ,,	about	20 ,,
February 1, 1919, .	,, ,, ,,	25,000 ,, ,,	,,	35 ,,

The deepest wells sunk were more than 4000 feet; the general average depth of the producing wells is about 3000 feet; the oil about 25° B. The cost of drilling is about $50,000 to $60,000 per well on the pump, and leases were paid for, after the discovery, up to as high as $3000 an acre as bonus, with royalty on production of from one-fourth to one-eighth of the oil recovered.

In **Orange County** towards the end of 1918 a well drilled near Yorba to a depth of 2760 feet came in with some 3000 barrels of 18° B. oil a day; this discovery led to wide leasing and heavy bonuses were paid. Within the last few months about six wells have been started, and some have already reached 3000 feet. The discovery well may be deepened. The possibilities of this new field are unknown, but during the next few months the field may be indicating its future. It is known as the Yorba-Linda field.

On the coast in this county, near Balboa and Newport, there are now some five exploration wells. The Liberty Well, drilled in 1918, obtained very heavy oil of about 10° B. at from 1800 to 2000 feet, and is said to yield from 50 to 150 barrels a day; thus this old field is again receiving consideration.

In **Ventura County** the Bardsdale field is of chief importance, and the South Mountain bids well to bring that field into prominence. In the first-named the discovery in 1911 in Shields Canyon of shallow oil, and later in Guiberson and Shields Canyons of deep oil, brought this field into prominence. At present in the two canyons named there are some 80 wells with a total production of about 1000 barrels a day of oil of 33° to 37° B. In the South Mountain field, discovered in June 1916 after many previous failures, there are now six wells flowing. The depths are about 3000 feet, the oil 35°–37° B., and the total production about 500 barrels a day. There are many new rigs ready for starting work.

In the Ventura field, north of the city, developments are of scientific interest, owing to the very light oil discovered. In May 1916, Well No. 2 Lloyd was started; a strong showing of oil was encountered at 2185 feet, but at 2250 feet a strong flow of water with gas came in; this could not be controlled and formed a crater at the top of the hole, from which the oil was saved at the rate of 100 barrels a day of 56° B. Later the yield decreased to 50 barrels, 25 barrels, and 12 barrels, and then, the crater being 50 feet in diameter and 35 feet deep, remedial work was ordered by the Oil and Gas Supervisor. Other wells drilled did not secure such quantities of oil, with the exception of the Barnard No. 1 about nine months ago, which, from a depth of 2255 feet, was producing more than 100 barrels of 54° B. oil a day; this production has since decreased.

In **Santa Barbara County** the Casmalia field has been very actively developed during the last three years, and while the oil is chiefly some of the heaviest in the State, the production has been substantial.

The developments at Lost Hills and Belridge in Kern county have been of importance during recent years.

Transport in California.—One of the most important events in 1903 was the opening of a pipe-line, constructed by the Pacific Coast Oil Company, from Bakersfield to Point Richmond, a distance of 278 miles. This transport of heavy oil by pipe-line was a new departure, and as the petroleum produced in Kern county has an average gravity of 15½° Baumé, some difficulty was at first experienced in pumping it, but this was overcome by heating the oil with exhaust steam, and insulating the line by coating it with a non-conducting material. The pumping of the oil was also facilitated by mixing with it some of the lighter petroleum produced at Coalinga, and in some instances by the admixture of water.

Asphalt and **maltha** occur in many parts; according to Mr. Hanks, formerly State mineralogist, the following are the principal localities in California where they are found:—Santa Ynez and Kayamos [Santa Maria] Valleys; near Mission, San Buenaventura; at the Goleta Landing, 7 miles west of the town of Santa Barbara; near Dos Pueblos and Carpinteria, in Santa Barbara county; at the oil-wells near Sulphur Mountain, Ventura county; Rancho La Bréa, Los Angeles county; on the Corral de Piedra, San Luis Obispo county; about Buena Vista Lake, Kern county; and on Sargent's Ranch, Santa Clara county. The deposits are found at varying altitudes. They show no uniformity of structure, and are of various periods. The asphalt of San Luis Obispo and Santa Cruz is a sandstone saturated with bitumen. That of Ventura county, which was largely mined in 1888, contains about 24 per cent. of bitumen, and has nearly four times the market value of that of Santa Cruz and San Luis Obispo. In 1888 California produced 50,000 tons of bituminous rock.

Natural gas occurs in many parts of California, and at the end of 1889 there were in California six producing wells. In that year the gas obtained was valued at $12,680; in 1903 the amount obtained was valued at $101,521, and in 1909 at $146,933.

The steady expansion that has characterised the trend of the natural-gas industry in recent years was continued in 1916. The output for that year was 31,643,266,000 cubic feet, valued at $5,440,277; and in 1917 it reached 49,427,331,000 cubic feet, valued at $6,816,524.

The greater part of this production came, as in previous years, from Midway district, in Kern county. In this field the wells range in depth from 2100 to 3000 feet, and closed pressures average about 300 pounds to the square inch. Second in rank as a contributor to the natural-gas supply in California is the Whittier-Fullerton district, in Orange and Los Angeles counties.

A small volume of natural gas is obtained for local use.

WYOMING.

Development operations have been carried out in the Salt Creek district, Natrona county, since 1899, and in 1903 the production amounted to 8960 barrels. At Spring Valley, Uinta county, the Union Pacific Railroad, in boring for water in 1901, discovered petroleum which was described as olive-green in colour, as having a specific gravity of 0·8329, and as yielding 27 per cent. of naphtha, 25·5 per cent. of water-white kerosene, and 40·5 per cent. of lubricating oil.

The trend and extent of recent developments are indicated by the following tabular statements of the sources from which the production of 6,234,137 barrels was obtained in 1916, and 8,978,680 in 1917:—

	1916.	1917.
Big Horn County,	139,854 barrels.	62,040 barrels.
Fremont County,	62,564 ,,	49,797 ,,
Natrona County,	3,933,403 ,,	3,910,511 ,,
Hot Springs County,	1,369,807 ,,	2,756,402 ,,
Converse County, Park County, Unita County,	728,509 ,,	2,199,930 ,,

In his Geological Survey Report for 1916, Mr. John D. Northrop remarks that the steady increase in production of petroleum in Wyoming since 1912 has been attended with the development of such conclusive evidence of the inherent richness of its oil-sands that this State has come to be recognised as the dominant factor in the situation in respect to high-grade petroleum in western North America. The fact that the greater part of the yield consisted of high-grade oil capable of furnishing 15 to 25 per cent. of gasoline by modern refining methods, indicates for the local industry a position of economic importance not suggested by the statistics alone. The marketed output of petroleum for 1916, viz. 6,234,137 barrels, constitutes a record which is greater by 1,988,612 barrels or 47 per cent. than the former record in 1915. In 1917 Wyoming advanced from tenth to seventh in the ranks of oil-producing States. The total production in 1917 reached 8,978,680 barrels.

FIELDS OF MINOR IMPORTANCE IN THE UNITED STATES.

Alabama.—The existence of petroleum in Alabama has been known for a century. In the Tennessee valley in the northern part of the State, there are tar-springs, oozings, and other indications of the presence of petroleum. Near Decatur is a spring which was used by the Indians for rheumatism and other complaints. According to the U.S. Geological Survey Report for 1916, oil had so far not been obtained in commercial quantities in the State, but natural gas is produced in Madison and Fayette counties; and in 1917 a gas-field of promise was opened in northern Alabama.

Arizona.—A test-well was begun in 1914, in Tonto Basin, near Lake Roosevelt, in Gila county; in 1915 this had reached a depth of 2000 feet without having encountered any significant signs of oil or gas. Renewed activity in the Virgin River district in southwestern Utah aroused interest in the possibilities of oil being found in adjoining parts of Mohave county, Arizona. No drilling was carried out in this State during 1916. In 1917 it was decided to test the Big Chino Valley.

New Mexico.—Near Bernalillo large deposits resembling the "gum-beds" of Enniskillen are found in the valley separating the Sandia and Tuerto mountains, and in many localities in the vicinity oil oozes from the outcropping sandstones. An oil-well was sunk many years ago near Gallup, in the same county, but was abandoned at a depth of 400 feet. The oil-stratum is said to be a loose grey sandstone overlying bituminous shale.

A considerable amount of prospecting has been carried on in the State, and a flowing well is said to have been obtained in 1910 near Dayton, in Eddy county, yielding about 15 barrels per day.

In 1912 the old Brown well, 2½ miles northeast of Dayton, in Eddy county, which had been yielding three barrels a day, was greatly improved by setting a packer between the oil-sand and the artesian water stratum which lies some 100 feet above, the well then yielding 50 barrels of oil a day. In 1913 the Pecos Valley Oil and Gas Company began drilling a test-well on the Martin farm, 1 mile southwest of the Brown well. A deep test-well was also made in the same region by the Dayton Petroleum Company. In 1914 one exhausted well was abandoned, and one barren well drilled, both in the Eddy county. In San Juan county one well was being drilled at the end of the year. In 1915 a test-well was drilled in McKinley county, in the San Juan Basin, 50 miles northwest of Albuquerque. It is reported that the well yielded a copious flow of salt water from a depth of 1100 feet, but it was afterwards abandoned. In 1916 interest was renewed and elaborate plans were made for active drilling in 1917.

In 1915 and 1916 a great deal of test-drilling was carried out in some of the smaller States, including Florida, Maryland, Idaho, Nebraska, and Virginia, but without any very hopeful results.

Gas has also been struck in Bernalillo and Eddy counties.

Arkansas.—Since 1902 natural gas has been obtained in Sebastian county, and is utilised in the towns of Mansfield, Van Buren, Fort Smith, and Huntington. The wells vary from 970 feet to 2380 feet in depth, and the pressure from 160 to 225 pounds. The output of natural gas in Arkansas in 1916 amounted to 2,387,935,000 cubic feet, a gain of about 248 per cent. over that of 1915; and in 1917 to 5,609,484,000 cubic feet. Credit for the large increase in production belongs to the Kibler field, discovered late in 1915, in Crawford county. In four different counties five wells were drilled for oil in 1913, but with no result except dry holes. In 1914 tests were begun in the State in or near Meg, Franklin county; Paris, Logan county; Hope, Hempstead county; and De Queen, Sevier county. During 1915 the successful development of the natural-gas industry in the vicinity of Fort Smith led to the drilling of many test wells for oil in different parts of Arkansas, but the efforts proved unsuccessful. A great deal of wild-cat drilling for oil was carried out in 1916 and 1917, but without any hopeful results. Asphalt sands are mined near Pike City.

In **Missouri** only 20 barrels of oil were reported as produced in 1889. The product resembled that of Paola, in Kansas, and was all obtained from one well in Boone township, Bates county. Much prospecting for gas has been carried on in the State, but the only commercially available supplies have been obtained in Bates, Cass, Clay, and Jackson counties. The wells are about 480 feet deep, and are supplied by a reddish sandstone from 10 to 40 feet thick, which sometimes also contains a thick black oil. Gas to the value of $35,687 was produced in 1889, but only to the value of $2154 in 1902, which was, however, more than in any year since 1895. In 1902 oil of good lubricating quality was found at Belton, Cass county, together with natural gas which is utilised for heating and illuminating purposes. The gas was obtained at a depth of 366 feet, and the oil from 340 to 490 feet. The quantity of gas produced in the State in 1916 was valued at $17,594. The discovery of oil at shallow depth at Swartz, in Vernon county, Mo., in 1913, led to some excitement and to the drilling of two shallow wells without any results up to the close of the year. A shallow well was drilled in Adair county which yielded a showing of oil, but no production. In 1914 the commercial production of Missouri was limited to Jackson county. The drilling at Swartz failed to result in the discovery of more than a small quantity of thick asphaltic oil, and further efforts in this locality were discouraged, but at the end of 1914 additional tests were in progress north of Takio, Atchison county, and near Excelsior Springs, Clay county. In 1915 the successful development of the new areas of production in Kansas had a decided influence on Missouri, and a number of tests were proposed along the Kansas boundary. Oil in commercial quantity was produced only in one locality during 1916, viz. in Jackson county, and the output was less than in 1915. It seems doubtful whether there was any commercial production in 1917.

Mississippi.—During 1914, 1915, and 1916 a number of test wells were drilled, without any satisfactory result. In 1917 a deep test well was begun by the Altas Oil Company.

New Jersey.—The reported discovery of oil in November 1916, at a depth of 800 feet, in a well drilled on Steelman farm, 4 miles east of Millville, Cumberland county, brought this locality into prominence, especially as the State Geologist had reported that the conditions were unfavourable to the occurrence of oil in commercial quantities.

Michigan.—In 1909 some gas was produced in the State from artesian wells in Macomb county, the whole being used locally. In 1912 oil was struck in the city of Saginaw, Saginaw county, and the usual drilling excitement ensued; the wells, however, were a failure, and the enterprise was abandoned in 1913. There was the ordinary small production from the wells in St. Clair county in 1913. In 1914 two wells were completed in this field, and two were abandoned, leaving 26 productive wells in the State at the end of December. The small production of petroleum credited to Michigan in 1914 consisted, as in previous years, of natural lubricating oil, from a few wells near Port Huron, St. Clair county. In 1915 the production from this source was greatly increased as a consequence of more active field operations. Wells in this locality derive their oil from a sand encountered at an average depth of 650 feet, and although the initial production rarely exceeds 5 barrels a day, the value of the oil, and the low cost of obtaining it, render it a profitable development. In 1916 the production from this State decreased 35 per cent. as compared with 1915; the output consisting, as before, of a natural lubricating oil from a few shallow wells near Port Huron, St. Clair county. In 1917 the production, though small, was 160 per cent. greater than in 1916.

Minnesota.—Considerable prospecting for gas has been carried on at public expense in the State of Minnesota, and the result has been published in a report by Professor N. H. Winchell (*Geological and Natural History Survey of Minnesota*, Bulletin No. 5, St. Paul, 1889). The work was undertaken on account of the discovery of gas in a sandy layer in the drift about 75 feet below the surface at Freeborn, but no permanent supply has been obtained.

South Dakota.—Gas is produced from artesian wells in Hughes, Lyman, Sully, Stanley, and Walworth counties, and the towns of Pierre and Fort Pierre are partly supplied from these sources. The value of the gas consumed in 1909 was $16,164.

North Dakota.—In 1909 gas was piped from wells in Bottineau county to the town of Westhope, and some is also obtained in Lamoure county. The value of the product consumed in 1909 was $3025. A small production of natural gas was obtained from South Dakota, Alabama, and North Dakota in 1916 and 1917.

Montana.—Although in 1915 the Montana field failed to take its place among the oil-producing States, the failure was solely due to the fact that arrangements for shipping the oil discovered in the State were not completed until after the close of the year. The discovery referred to was in Carbon county and took place in 1915 on the Silver Tip anticline, at the north end of the Elk Basin field opened in Wyoming in November. The credit for completing the first successful well in Montana is ascribed to the Ohio Oil Company.

The appearance of Montana among the oil-producing States in 1916 was due to the marketing of 44,917 barrels of petroleum from the north end of the Elk Basin district, in Carbon county, during that year. Outside this district, which had 10 producing wells at the end of 1916, there was no commercial production. At the end of 1916 test-wells were being drilled on the Dry Creek anticline, north of Red Lodge, at Golden, and at Silesia, in Carbon county; and near Dillon, in Beaverhead county. Owing to increased drilling the production of petroleum in 1917 reached 99,399 barrels.

Decided progress was made in 1916 in the development of the natural-gas resources of the State, the marketed production for that year amounting to 213,315,000 cubic feet; and in 1917 to 334,421,000 cubic feet.

Washington.—In 1902 a number of test-wells were drilled in various parts of this State, but no petroleum in paying quantities was found. In Chehalis county, north of Gray's Harbour, a considerable amount of gas was met with, but only slight indications of oil; at Lapush, above the Hole River, some oil is said to have been found.

A good deal of wild-catting for oil had been carried out during 1912, and in 1913 this resulted in the finding of small quantities of oil. Near Taholah, at the mouth of the Queniult River, the Jefferson Oil Company began the exploration of the gas indications of that region, and obtained a small quantity of oil. In 1913 a field examination of the oil and gas indications of this region was made by Mr. C. T. Lupton of the United States Geological Survey. Analyses of the oil collected by Mr. Lupton show a paraffin oil of very high grade, containing no asphaltum. During 1914 two barren holes were completed at the mouth of the Hoh River in Jefferson county, and one near Willapa Harbour, Pacific county. Late in the year the discovery of oil in a well near Tenino, Thurston county, was reported, but efforts to obtain oil in commercial quantities in this or other wells failed, and the enthusiastic drilling campaign started in 1914 and carried on during 1915, proved to be only temporary.

In **Utah** both ozokerite and asphalt occur. A variety of the former product, somewhat resembling the ozokerite of Galicia, occurs near Thistle Town, while a mineral containing 90 per cent. of bitumen, and known as gilsonite, uintahite, or uintaite, occurs in the northeastern part of Utah, near Fort Duchesne, east of the Uintah Indian reservation, and in the Umcompahgre-Ute reservation, near the Colorado State line. Another substance, known as wurzilite, occurs in Wasatch county, about 113 miles east of Salt Lake City. Seal (*Journ. Franklin Inst.*, cxxx, 402, 1890) describes the Utah ozokerite as a dark brown, waxy deposit, containing crystals of gypsum.

During 1902 much prospecting was carried on, and a small quantity of lubricating oil of excellent quality was obtained in Emery county, on Green River; oil was also obtained at Sinbad, 25 miles southwest from Green River station; and near Bluff in San Juan county.

Petroleum has been discovered in three other counties, namely, near Dragon in Uinta, in Sanpete, and in Washington, where there are several wells from 500 to 700 feet in depth, in what is known as the Virgin field.

Although no production was recorded in 1913, more or less prospecting work was carried on, especially in Uintà county, and an interesting well was being drilled north of Ogden. One dry hole in the San Juan field constitutes the record of wells completed in 1914. Late in the year considerable interest was aroused by the discovery of a small quantity of oil in a well near Fillmore, in Millard county. The locality is one in which encouraging oil "showings" have previously been encountered in water wells, and is one which it was decided to test thoroughly. In 1915 one oil-well, the capacity of which was not reported, was completed in the San Juan field. This was the sixth well in the field in which oil was found. No commercial production was reported, however, as the area is remote from transportation facilities and difficult of access. Though interest in this district was still very keen in 1916, it led to very little actual drilling. In the San Juan district one dry hole was completed, and one well formerly classed as a producer was abandoned. Five other wells capable of producing, remained capped during the year owing to the absence of marketing facilities. Late in the year interest in the possibility of a production of oil from the old Virgin River district in Washington county was revived, and plans were made for drilling test-wells in 1917. In Northern Utah considerable interest was aroused in Tooele county by the drilling of a deep well near Grants, on the Western Pacific Railroad, 30 miles west of Salt Lake City. In Cache county an unsuccessful test-well was drilled about half a mile east of Mendon. One of the most significant developments of 1916 bearing on the petroleum industry was the formation of a number of companies for the purpose of developing the vast deposits of oil shale existing in Uinta, Grand, Duchesne, Carbon, Emery, Wasatch, Sanpete, and Juab counties. Plans were also made for the erection of an experimental plant for the distillation of shale, at Manti, in Sanpete county, and by another county for a similar plant near Colton, Utah county. Active drilling work was being carried out in 1917.

Utah for a few years produced some natural gas from wells 12 miles north of Salt Lake City, the yield in each of the years 1895 and 1896 being of the value of $20,000; but the wells became choked and have yielded no gas since 1898.

Nevada has not yet yielded any oil in commercial quantities, but opposite to Elko, on the Humboldt river, there is a bed of shale, said to be rich in hydrocarbons and paraffin, from which oil has been obtained for fuel for domestic purposes. It is stated that it contains 16 per cent. or more of the more volatile hydrocarbons and 15 per cent. of paraffin.

Alaska.—Petroleum occurs (1) at Cape Yaktag, (2) near the mouth of Copper River, in the Controller Bay district, (3) on the west shore of Cook Inlet, and (4) in the region of Cold Bay. A distance of 75 miles separates (1) and (2), a distance of about 320 miles (2) and (3), and a distance of about 160 miles (3) and (4).

Oil rights at Katalla, in the Controller Bay district, were secured by a group of American operators many years ago and were transferred to the Alaska Development Company, by whom the property was leased to the Pacific Coal and Oil Company, a Canadian Corporation. In turn the Canadian company granted a lease to the Pacific Mines Company, Limited, and the author, who had been consulted, deputed his colleague, Mr. H. T. Burls, to make a geological survey of the property, and locate sites for wells. Four wells were drilled, one of which was named the Redwood well, and oil was found in quantity. In 1910 the Amalgamated Development Company was formed for the active exploitation of the property, a pipe-line was laid, and tankage erected. According to a statement made in the *Canadian Mail* for 3rd June 1911, on the authority of Mr. William Whyte, Vice-President of the Canadian Pacific Railway, the Redwood well spouted to a height of 110 feet for three days before being capped, and the aggregate production of the four wells, the deepest of which was 1500 feet, was 2100 barrels a day. The oil is said to have a specific gravity of about 0·828, and to give a large yield of gasoline and kerosene.

The Katalla field during 1914 yielded a small output of petroleum, which was absorbed by the local refinery. One productive well was completed during the year, additional activity consisting only in the carrying out of the annual assessment work required on a few unpatented oil claims entered prior to the withdrawal from entry of Alaskan oil lands in 1906. In 1915 Brooks[1] describes the petroleum developments in Alaska as follows:—"There were no important developments in the Alaska oil-fields in 1915. The company which had been producing oil and making gasoline at Katalla was abandoned, and reorganised. Operations were, however, not interrupted, and the production of crude petroleum and gasoline was continued. According to reports an oil seepage was discovered in northern Alaska near Wainwright Inlet, about 100 miles southwest of Point Barrow; if this is confirmed, it is probably a western extension of the field occurring southwest of Smith Bay. . . ." In

[1] A. H. Brooks, "Mineral Resources of Alaska in 1915," *U.S. Geological Survey Bulletin*, 642, 1916.

1916 the production of petroleum in Alaska was restricted to 6 wells in the Katalla district, the output of which was about 40 per cent. less than in 1915. In the early part of 1916 the producing properties in this district and the small refinery at Katalla were taken over by the St. Elias Oil Company, with the idea of additional work being carried out.

In 1918, according to the annual report of Mr. Lane, U.S. Secretary of the Interior, petroleum was being produced in paying quantities from wells near Katalla, with further drilling in progress. The petroleum found is a high grade, with a paraffin base. There is a small plant at Katalla producing gasoline and distillate, the residue being sold for fuel oil.

Some drilling has been carried out in the Cook Inlet region, and both oil and gas were found.

In the Cold Bay region three wells were commenced in 1903, and in one of them a heavy oil was met with.

MEXICO. (Plate 14.)

The following statement indicates the progressive development of the Mexican petroleum industry up to December 1919 :—

Surface indications of petroleum have long been known to exist in the Gulf States of Mexico, but exploratory drilling was not carried out before the early eighties. The fields may be considered in three main groups, namely, the northern fields, the Isthmus of Tehuantepec, and those of Chiapas and Tabasco ; some prospecting has also been carried out on the Pacific coast of Mexico.

Northern Fields.—Report says that the Totonacs, one of the tribes of the Aztec family, found, on wandering along the shore of the Gulf coast of Mexico, a thick asphaltic oil, which at the time of the Spanish Conquest was a common article of commerce as far inland as Mexico City, and was dealt in under the name of "Chapopote," said to be derived from the words "Tzuac," meaning paste, and "Popochile," meaning perfume ; it is mentioned by Brother Bernardino de Sagahun, who wrote of it soon after the Spanish invasion.

Report also says that a mention of a spring of oil near Soto de la Marina (in the Hacienda of San José de las Rusias, State of Tamaulipas) was made in a grant of land by the King of Spain, and in 1864 Ildefonso Lopez was given a concession to exploit this spring ; a similar concession was granted to Carrales in 1865 to work the deposits at Vejarano, also in the State of Tamaulipas. It is not known whether these concessions included the subsoil, but as they were subsequent to the "Drake" discovery in Pennsylvania, it is quite possible that these enterprising Mexicans had the subsoil included.

In 1868 Dr. Autrey discovered the Cugas (now called Furbero) deposit, and a well was drilled to 125 feet without result, but an adit driven into the side of the hill gave a production of 45 barrels a day, from which source a total quantity of some 200 cans was refined ; this was done under the auspices of Cia Exploradora de Golfo Mexicana, which had but a short career. In 1879 or 1880 Dr. Autrey "denounced" the property he had previously discovered for himself, and refined some 4000 gallons of kerosene.

In 1878-79 the Secretary of Hacienda published a report on seepages by J. W. Foster.

Between 1880 and 1883 wells were drilled to the north of the Tuxpam River in the Haciendas of Chapopote and Cierro Viejo, and one flowing well was brought in by the owners of the *Boston Post* in the latter place.

In 1884 petroleum became the property of the owner of the surface.

In 1898-99 Mr. Arthur W. Eastlake was asked to proceed to Mexico to make an examination of the Cugas (Furbero) field.

In 1898 Colonel Temple of the Commercial Development Department of the Mexican Central Railway received an inquiry from interests associated with those of the Santa Fé Railway Company, for information regarding oil indications in proximity to the Mexican Central Railway, when he furnished them with that regarding the seepages in the flat stretch traversed by the railway between the Sierra Madre Oriental from Las Palmas to Tampico, and a party of capitalists came down in 1899, headed by Messrs. Doheny, Canfield, McIntosh, and others, and invested some $600,000 U.S. in the purchase of oil land in this district. In 1900 the Mexican Petroleum Company (of California) was registered, drilling commenced near Ebano station in 1901, and a small well was brought in at 425 feet in May of that year. In 1904 they removed the scene of their operations to Cerro de la Pez, a few miles to the south, where in that year they brought in their No. 1 well, which flowed for at least nine years, during which time it yielded approximately 3½ million barrels.

In January 1910 the Huasteca Petroleum Company (a subsidiary of the Mexican Petroleum Company) brought in their Juan Casiano No. 2; in March their No. 1; in July their No. 6; and in September their famous No. 7, which up to the end of November 1919 had yielded 80,000,000 barrels, when it turned to salt water. In February 1916 they brought in their Cerro Azul No. 4 well, which was certified by Dr. I. C. White as producing 300,000 barrels a day when it was opened, but has been practically shut-in ever since.

In 1904 the Furbero (Cugas) field, 55 miles (88 kilometres) south-southwest of Tuxpam, was discovered by the Oilfields of Mexico Company (now very closely related to the Pearson interests) by a well 1269 feet deep. The oil obtained was of a much superior quality to that then being produced in the Tampico district, as it had a considerably higher gasoline and kerosene content, and was at first better than the oils later discovered in the region between Tampico and Tuxpam.

The Pearson interests in 1906 began to acquire properties in the Tuxpam-Tampico region by the acquisition of the Pennsylvania Oil Company, and in April 1908 the San Diego field, 52 miles (83 kilometres) south of Tampico, was discovered, but in July of the same year this field was destroyed by a well, known as "Dos Bocos," "drilling itself in" when at a depth of 1834 feet, the casing being hurled out of the hole and huge cracks opening in the earth wide enough for people to walk about in. The oil immediately caught fire from a crack which opened under the burning fuel which had been withdrawn from the boilers and quenched with water on the upper surface of the pile, but remained incandescent on the under side. This fire raged for some forty days with a flame 1800 feet high, emitting such a light that a newspaper could be read at midnight at a distance of seven miles. The flame was visible from ships at sea at a great distance, as also from the edge of the Sierra Madre Oriental Mountain range at Tezuitlan, a distance of 125 miles. Large pumps were installed to discharge sand, etc., on to the burning well, and it was extinguished almost immediately these began to operate, but it is questionable whether this was due to their action or to water which began to come with the oil. The enormous volume of liquid which had flowed from the well and the cracks in the ground round it carried away the earth and formed a crater several acres in extent, so that it was impossible to control the well after the fire was out. The water rapidly increased until the field became drained of oil and ruined. A stream of salt water of some 15,000,000 barrels a day began to issue from this crater. On 1st February 1910 the Tanhuijo field, 75 miles

(120 kilometres) south of Tampico, was discovered, which from a shallow depth produced a high-grade oil of specific gravity 0·8974 (26° B.). Within a few hours of this discovery the Potrero del Llano field, some 20 miles to the southwest of Tanhuijo, was discovered by a well 1933 feet deep, and in December of 1910 the famous 100,000-barrel well (No. 4) of that field was brought in. Over 100 million barrels of oil has been obtained from this well to December 1918, in spite of its having been entirely shut-in for some months and only allowed to flow an amount varying from 20–50 per cent. of its capacity for the rest of the time, and it is estimated that almost 18 million barrels was lost in the first rush before it could be brought under control. This famous well began to show emulsion during December 1918, when it was shut-in. This oil has a specific gravity of 0·928 (21° B.) and was very satisfactory for refining purposes, yielding over 10 per cent. gasoline and 12 per cent. kerosene, with a residue of high calorific value eminently suited for liquid fuel. In September 1913 the Los Naranjos field, 62 miles (100 kilometres) south of Tampico, was discovered by the Mexican Eagle Oil Company's No. 1 well at a depth of 1885 feet. The well flowed 50,000 barrels daily of a similar oil to that of Potrero.

Since that date the following important producers have been completed in this neighbourhood :—

12. 3. 14. *Mexican Eagle Oil Company's* Los Naranjos No. 4, estimated at 40,000 barrels at a depth of 1920 feet.
26. 3. 18. *International Oil Company's* well on Amatlan Lot 252, estimated at over 20,000 barrels of oil and 10,000,000 cubic feet of gas at 2065 feet (the well was finally completed in April 1918).
1. 7. 18. *Tepetate Petroleum Company's* No. 1 well on Amatlan Lot 251, estimated at 50,000 barrels at a depth of 1880 feet.
2. 11. 18. *International Oil Company's* well No. 1 on Amatlan Lot 251, estimated at 3000 barrels at 1898 feet, and 25,000 barrels at 1905 feet.
16. 5. 19. *Tepetate Petroleum Company's* No. 2 on Amatlan Lot 251, estimated at 80,000 barrels at a depth of 1880 feet.
2. 11. 19. *Mexican Eagle Oil Company's* Los Naranjos No. 10, estimated at 60,000 barrels at a depth of 2260 feet.
8. 11. 19. *The Texas Company's* No. 2 well on Chinampa Lot 133, which flowed 10,000 barrels per day from a depth of 1923 feet.
10. 11. 19. *Mexican Eagle Oil Company's* Los Naranjos No. 5, estimated at 50,000 barrels at a depth of 1915 feet.
14. 11. 19. *Mexican Eagle Oil Company's* Los Naranjos No. 9, estimated at 90,000 barrels at a depth of 1830 feet.

The East Coast Oil Company commenced the development of the Panuco field in 1910, with a small 20-barrel producer at 1760 feet, while on 28th March 1912 the Veracruz Mexican Oil Syndicate's Peralta No. 1 came in at the rate of 1000 barrels a day.

During the early part of 1914 a number of gushers were discovered. In January 1914 the Panuco Excelsior Company (Spellacy Interests) brought in their Barbarena No. 1 at 900 barrels, and on 11th January the Corona Petroleum Company brought in their Pazzi No. 5, with the potential production of 100,000 barrels a day. This is the largest well of the Panuco field.

This well was followed in rapid succession by the Freeport Mexican Fuel Company's Zurita No. 3, with a production of 20,000 to 30,000 barrels a day; the Veracruz Mexican Syndicate's Petralta No. 5 with 4000 to 5000 barrels a day; the National Oil Company's Chijoles No. 2 with 25,000 barrels a day; and the Tal Vez Company's No. 1 with a production of 1000 barrels a day.

In July 1914 the Mexican Gulf Oil Company brought in their Zuniga No. 2, with a production of 2000 barrels a day, and during late September or early October the Panuco Valley Oilfields, Limited, brought in their Ugarte No. 1

at 2000 barrels a day. On 28th November 1914 the Tal Vez Company completed their Maza No. 2, with a production of 4000 to 5000 barrels; and on 8th December 1914 the Mexican Gulf Oil Company completed their Zuniga No. 3, with an estimated initial production of 10,000 barrels.

During September 1915 the Chotes No. 1 well of José de Soria et al was completed at 60,000 barrels, the well being an offset to the big Corona gusher Pazzi No. 5. In October the Cia. Pet. Hispano-Mexicana completed their Alamo No. 1, with a production of 1500 barrels a day; and on 30th November 1915 the Pan-American Oil Company completed their Don Juan No. 1, with a 1000 to 2000 barrels daily production.

In June 1913 the second offset to the Corona gusher (Pazzi No. 5), Chotes No. 1 of R. E. Brooks' interests, was completed at 8000 barrels.

Since this date, the principal completions have been the following :—

Penn Mex Fuel Company	40,000 barrels.
Mexican Gulf Oil Company, . . .	20,000 „
Cia. Zonas Pet. de Panuco, ...	20,000 „
New England Fuel Oil Company, . .	15,000 „
East Coast Oil Company, ...	10,000 „
E. F. Simms, ...	10,000 „

These wells were all completed in the year 1917.

During 1918 the following were the principal completions :—

Eureka Petroleum Company,. . . .	7,000 barrels.
Transcontinental Company (Standard), . .	25,000 „
Mexican Sinclair Petroleum Company, . .	7,500 „

During 1919 the following :—

Tampascas Oil Company, ...	30,000 barrels.
Orvananos Company, ...	12,000 „
East Coast Oil Company, ...	12,000 „

The East Coast Oil Company brought in the first gusher in the Topila field on 24th March 1911, with a production of 2500 barrels a day.

Further operations in this field were of little account, resulting generally in 25- and 50-barrel wells, until March 1915, when the Mexican Fuel Company brought in their No. 5 well. This well appeared to be a great gusher, but at the end of a few days its entire production, amounting to 100,000 to 150,000 barrels of fluid a day, was to the extent of 95 per cent. salt-water.

On 27th May 1915 there was an event of interest in the completion of the American Fuel Company's Loma del Pozo No. 1, which gave some 10 to 15 million cubic feet of gas per day. By 30th May oil had begun to appear, and by 1st June the well was making 1000 barrels of oil a day.

Since that date, the principal completions have been as follows :—

Cia. Pet. de Poblana, ...	14,000 barrels.
Corona Petroleum Company, . . .	13,000 „

Both these wells were completed in 1917.

Up to the end of 1919 the following wells of note were completed :—

Cia. Regiones Petroliferous Mexicana . .	20,000 barrels.
The Texas Company, ...	10,000 „
Mexican Fuel Oil Company (Pierce Oil Corp.) .	30,000 „

The Penn Mex Fuel Company (subsidiary of the South Penn Oil Company) brought in their Alamo field, just south of the Tuxpam River, in May 1913 with their Alamo No. 1 at 2186 feet, which was estimated at 1000 barrels a day.

In October of the same year they brought in their well No. 2, at a depth of 2150 feet, which is believed to be now producing 20,000 barrels daily of 23° B. oil. In December 1915 their Alamo No. 3 was brought in at 2280 feet, with a production of 100 barrels a day. Since that date they have drilled up to Alamo No. 9, this latter well producing 25,000 barrels a day at a depth of 2195 feet. Of the other wells, Nos. 4 and 5 were non-producers and yielded only salt-water at depths of 2490 and 2677 feet respectively; Nos. 6 and 7 were producers of 1000 and 5000 barrels at depths of 2243 and 2136 feet respectively, and No. 8 was abandoned in salt-water at a depth of 2307 feet.

In addition to this Alamo group of wells, they drilled two wells on their Molino property, almost the next adjacent property to the north on the other side of the Tuxpam River. Of these wells, the first was abandoned in salt-water at 2850 feet in May 1917; while the other was brought in as a producer reckoned to-day at 15,000 barrels of rather heavy gravity oil, *i.e.* 12° B., in December 1917, at a depth of 2713 feet.

The Tepetate field was brought in by the Cortez Company in August 1915 with their No. 1 at 2074 feet, with 1000 barrels production, and in September 1915 with their No. 4, at 5000 barrels a day.

This was followed in August 1916 by the Tepetate Petroleum Company's well No. 1 on Tepetate Lot 8, which was afterwards sold to the Mexican Gulf Oil Company, and is to-day reckoned at 40,000 barrels daily at a depth of 2025 feet.

In March 1917 the Huasteca Petroleum Company brought in their Chinampa No. 1 on Chinampa Lot 163, which is reckoned to have an output of between 8000–10,000 barrels a day. This well turned to salt-water on 30th November 1919.

On 21st May 1917 the Island Oil and Transportation Company brought in a well which so far has been the largest in the field, with an estimated production of 70,000 barrels at a depth of 2171 feet. This well went to emulsion on 26th March 1919.

On 17th January 1918 the Texas Company brought in their No. 2 well on Tepetate Lot 11, with an estimated production of 50,000 barrels at a depth of 2007 feet. This well went to emulsion on 8th November 1919. From this time up to the present the number of producing wells brought in has been considerable, most of which have turned to salt-water, as will be seen from the following table:—

—. 2. 18. *The Mexican Gulf Company* brought in their Lacorte No. 2 on Tepetate Lot 8, at 2112 feet, with an estimated production of 50,000 barrels. Turned to salt-water on 29th May 1919.

3. 6. 18. *The Mexican Eagle Oil Company* brought in their Chapopote No. 1, within a few metres of the Huasteca Petroleum Company's No. 1, Chinampa, at 1947 feet, with an estimated production of 45,000 barrels, latterly only producing 15,000 barrels per day.

24. 6. 18. *The Cortez Oil Corporation* brought in their No. 5 well on Tepetate Lot 5 at 2087 feet, with an estimated production of 25,000 to 40,000 barrels. Turned to salt-water on 15th July 1919.

26. 9. 18. *The Texas Company* brought in their Policarpo Rosas No. 3 at 1965 feet, at an estimate of 1500 barrels a day. At 1978 feet the flow was reported constant at 8000 barrels a day, but on deepening to 2048 feet the production decreased to 2000 to 3000 barrels a day. Turned to salt-water on 18th November 1919.

5. 12. 18. *The Texas Company* brought in their Obano No. 2, Chinampa Lot 153, at an estimate of 25,000 barrels at 2030 feet.

16. 12. 18. *The Island Oil and Transport Corporation* brought in their No. 1 well on Chinampa Lot 162 at an estimate of 50,000 barrels.

Tepetate Petroleum Company brought in their No. 1, Chiconcillo Lot No. 2, estimated at 35,000 barrels per day at a depth of 2142 feet, but this well has never been exploited.

31. 12. 18. *The Transcontinental Petroleum Company* (Standard interests) brought in their Chinampa No. 1 on Chinampa Lot 163, with an estimated production of 50,000.

5. 1. 19. *The Mexican Gulf Company* brought in their Chinampa No. 1 on Chinampa Lot 163, with an estimated production of 60,000 barrels per day at a depth of 2122 feet, but this turned to emulsion on 6th November 1919.

1. 2. 19. *The Mexican Gulf Company* brought in their Lacorte No. 3 on Tepetate Lot 8 with an estimated production of 60,000 barrels per day at a depth of 2000 feet, but turned to salt-water on 6th November 1919.

10. 3. 19. *The Transcontinental Company* (Standard) brought in their No. 2 on Lot 135 Chinampa with an estimated production of 25,000 barrels per day at a depth of 2258 feet.

19. 8. 19. *The Mexican Gulf Company* brought in their No. 1 on Chinampa Lot 95, with an estimated production of 40,000 barrels per day at a depth of 2128 feet.

In Chihuahua in 1907, some considerable distance north of the Conchas River, oil was reported to have been discovered in 1907 in a well or wells drilled by interests connected with Mr. Hurst.

Shale, smelling of oil, is found near Monclova, in the State of Coahuila, and wells were drilled there by Mr. McIntosh's Company (American International Fuel and Petroleum Company) to 1700 feet and 2170 feet in 1905, which met with an oil show, but not promising.

In Tamaulipas, a gas-field has been discovered near Laredo, but so far has only been developed on the United States side of the boundary.

More or less desultory drilling had been done on the Hacienda of San José de las Rusias previously to the Corona Company taking over operations there, and since then the Company have drilled six wells to a depth of nearly 4000 feet without, so far, any result, except that some heavy oil has seeped into one or two of the wells.

In Lower California there have been frequent reports of oil indications, but, so far, although the State has been examined by the geologists of several important companies, little or no drilling has been done. Seepages have been reported on or near the island of Angel dela Guarda in the Gulf of California.

In Jalisco, seepages have also been reported and samples brought from near one of the streams which flows into Lake Chapala.

SOUTHERN FIELDS.

Viscount Cowdray (Sir Weetman Pearson) in 1901-2, while reconstructing the railway across the Isthmus of Tehuantepec, became impressed with the possibilities of obtaining liquid fuel from the immediate neighbourhood, where oil indications had been known for a long time, and described by J. C. Spear in his supplementary report to that of Captain Shufeldt of the U.S. Commission for a Tehuantepec Isthmus Canal in July 1871. In 1901-2 Viscount Cowdray visited the Texas field, which had just recently been opened up, when he obtained expert advice and drilling was started, with the result that in November 1904 the San Cristobal oil-field, 30 miles (46 kilometres) from Puerto Mexico on the Atlantic side of the Isthmus, was discovered.

Other small fields were later discovered in this region, *i.e.* Soledad, in October 1909; Tecuanapa, in August 1910; and Ixhuatlan, in March 1911, but they have all been fields of comparatively shallow wells (400 to 1000 feet) and of small production.

In the neighbourhood of Port Angel, Oxaca, a certain amount of drilling was done by a company known as the Pacific Petroleum Company, to a depth of 1700 feet, without result. The late Mr. G. Stockfleth obtained samples of light oil of good quality from this district.

In the Macuspana District of Tabasco, indications of oil led to trial wells being drilled to depths of over 2000 feet, with the result that large quantities of gas and moderate quantities of high-grade oil were met with, but at present the exploitation is only being carried out for local use. Drilling was also undertaken near the boundary of this State and that of Chiapas, between the villages of San Francisco and Reforma, without so far having led to any result, although drilling will probably be resumed there.

In Chiapas, the Anglo-Mexican Oilfields, Limited, encountered a medium quality oil in their first well near Pichucalco, but, although they have drilled several other wells, they do not seem to have repeated the comparative success of their first well, and operations are at present suspended.

Pipe-lines.

A 6-inch pipe-line was laid in 1908, 14·5 miles (23·3 kilometres) in length, by the Pearson interests from their San Cristobal field to their refinery at Minatitlan, with a capacity of 12,000 barrels a day, and an 8-inch line for refined oil was laid from their Minatitlan refinery to Puerto Mexico in 1909, 14 miles (22·5 kilometres) in length, with a capacity of 24,000 barrels.

A 6-inch pipe-line was laid in 1909 under the auspices of the Pearsons from Furbero (Cugas) to Tuxpam, 55 miles (88 kilometres) in length, with two berths and one sea-line to each berth from the shore to the steamer, half a mile (800 metres) long, with a capacity of 12,000 barrels.

A 6-inch line was laid in 1910 from Potrero to Tancochin, 40 miles (61 kilometres) in length, with a capacity of 9000 barrels. In 1912 part of this line was combined with an 8-inch line leading direct to Tampico, and by doubling portions of the 6-inch line and short sections of the 8-inch line the capacity was brought up to 15,000 barrels. In 1914 an 8-inch branch was laid from one of the pump stations (San Diego) on the Tampico 8-inch line to Los Naranjos, a distance of 15 miles (22 kilometres), with a capacity of 30,000 barrels, and the rest of the line into Tampico was brought up to the same capacity, except for the Potrero-San Diego section, which remained at about 22,000 barrels capacity.

In 1911 an 8-inch line was constructed from Potrero del Llano to Tuxpam, a distance of 32·62 miles (52·2 kilometres), with a capacity of 35,000 barrels. At the coastal end of this line a third berth with two 8-inch loading lines was completed, and at the same time the loading capacity of berths 1 and 2 was increased by the addition of an 8-inch line to each of these berths. These lines, about 1·5 kilometres (·93 mile) long, were constructed in a very novel fashion, *i.e.* by screwing the entire length of line together on shore, and launching it out to sea by a steamer, which was an original idea and so successful that it has now been copied by four or five other oil companies. The 8-inch line from Potrero to Tuxpam was duplicated in 1917, and the combined capacity of these two lines is now 55,000 barrels.

In 1912 a 4-inch line was constructed from Ixhuatlan field to Nanchital River landing, a distance of 7 miles (11 kilometres), with a capacity of 6000 barrels.

In 1914 a 2-inch line was constructed from Tecuanapa field to Ribera del

Carmen on the river, 13·75 miles (22 kilometres) in length, with a capacity of 800 barrels.

In 1919 an 8-inch line was completed from Naranjos to Potrero, a distance of 22 miles (33·5 kilometres), with a total daily capacity of 60,000 barrels. Four sea loading lines are now in existence at Tuxpam, with a combined loading capacity of 100,000 barrels a day.

The Company to-day is completing a double 8-inch pipe-line from Naranjos to Tampico and from Naranjos to Tuxpam, *via* Potrero, and expect soon to be able to handle 110,000 barrels daily.

The chief pipe-lines of other companies in Mexico are the three lines of the Huasteca Petroleum Company (each 8-inch) from their Casiano field into Tampico (101 kilometres long), with an extension of one of these lines running still further south to their Cerro Azul field.

The Gulf Company have an 8-inch line about 100 kilometres long, running into Tampico, which was completed in March 1918.

There are three companies with lines out of the Tepetate field to a new port on the coast at Port Lobos, about 30 kilometres distant, *i.e.* the Cortez, with a composite 10-inch and 6-inch line; the Island Oil Company, with a composite 10-inch and 8-inch line; and the Texas Company, with an 8-inch line. Several other companies have lines to Port Lobos under consideration.

The East Coast Oil Company (subsidiary of the Southern Pacific) have an 8-inch line from the Panuco field into Tampico; the Corona Company (Shell interests) have a 10-inch line, and the Freeport Mexican have a 10-inch line in construction between the same places.

Refineries.

The Pierce Oil Company started refining imported crude oil from the United States in Mexico in the middle eighties, and had three refineries—one in Mexico City, one in Veracruz, and one in Tampico. The Mexico City one has for many years been closed, and so was the Veracruz one for several years, and it has only recently been reopened, but their Tampico Refinery has been constantly enlarged, until probably to-day it has a capacity of about 10,000 barrels daily.

The Pearson's refinery at Minatitlan commenced operations in 1908, and it now has a capacity of at least 12,000 barrels a day, with a complete wax, asphalt, and lubricating plant. In 1913 their Tampico refinery was built, and it now has a capacity of 20,000 barrels a day, with asphalt and wax plants, and it is continually being enlarged.

The Huasteca Petroleum Company have a topping plant at Tampico (Mata Redonda), with 10,000 barrels capacity.

The Texas Company have a 10,000-barrel refinery at Tampico practically completed, while another one of similar capacity at Port Lobos is also almost ready for operation.

The Atlantic Refining Company are considering a projected topping plant at Port Lobos, which may later be converted into a refinery; while the Freeport and Mexican Transport Company are also considering the installation of a topping plant at Tampico, both of 10,000 barrels capacity.

The Standard Oil Company have a topping plant also at Tampico with an estimated capacity of 4000 barrels daily.

The Corona Company are constructing a 6000-barrel refinery at Tampico, and the Continental Mexican Petroleum Company have under construction a 10,000-barrel refinery also at Tampico.

Tankage.

In northern Veracruz, at the close of 1919, the tankage capacity was approximately as follows :—

Steel tankage	23½ million barrels.
Earthen storage, ...	24 ,, ,,
Concrete storage, ...	1¼ ,, ,,

The Mexican Eagle interests now have about 8 million barrels of steel tankage and the greater portion of the above-mentioned earthen storage.

Railways.

At the end of 1919 there were 90 miles of 4 ft. 8½ in. gauge, 58 miles of 3 ft. gauge, and 112 miles of 2 ft. gauge railways belonging to the oil companies; since which time there have been some slight additions. The Pearson interests now have over 80 miles of 2 ft. gauge and 7 miles of 4 ft. 8½ in. gauge.

Fleet.

There is now a large fleet of steamers in the Mexican oil trade, many of which were built exclusively for this industry, such as those of the Mexican Eagle Transport, who have some 17 tankers ranging from 9000 to 18,000 tons, and averaging about 13,000 tons each, as well as having numerous tankers on order. The Pan-American Transport (subsidiary of the Mexican Petroleum Company) have about an equal number of tankers. The Atlantic Refining Company have a certain number of tankers which were built for the purpose, and the Standard Oil Company have also put a good number of their tankers on to this trade.

Statistics.

The production of Mexico from 1901 to 1919 inclusive has been 378,267,256 barrels (55,627,538 metric tons), of which the Mexican Eagle Oil Company have produced 115,956,207 barrels.

The Government report that to the end of 1919, 1013 wells had been drilled in Mexico, of which the Pearson and Furber interests have put down 430. The producing wells at that date numbered 305.

WEST INDIES.

In some of the West Indian Islands petroleum occurs abundantly, especially in the forms of " asphalt " or " pitch," and " tar."

Havana, in **Cuba,** was in early days known to sailors as Carine, for there they careened their ships, and pitched them with the tar of the locality.

Petroleum has not yet been found in sufficient quantities in Cuba to be produced commercially, although it occurs in many places. The asphalt of Cuba, however, is a well-known article of commerce, of which 7252 tons was exported to the United States in 1902 ; in 1909, 10,796 tons was exported.

A very complete account of the petroleum-deposits of Cuba is given in H. C. Brown's *Mineral Resources of Cuba in 1901*, in the Civil Report of Brig.-Gen. Leonard Wood, Military Governor of Cuba, 1902, vol. v, pt. 2, from which the following information is gathered. In the province of Matanzas, about 10 miles west of Cardenas, is a well from which 100,000 gallons of oil is said to have been taken. To the southeast, about 8 miles south of Cardenas, are a number of wells, formerly small producers, but now abandoned.

In the adjoining province of Santa Clara there is the San Juan well, sunk in 1881, in which petroleum was found at a depth of 300 feet. Salterain thus describes the product: "It is colourless, transparent as the clearest water, easily inflammable, and leaves no sensible residuum after its complete combustion; its density is 0·754; it boils at a temperature of 85°, dissolves asphaltum and resinous matter, and possesses the characteristics of naphtha." The boring was continued to a depth of 900 feet, and then abandoned, although the supply continued. Before the Americo-Spanish War this deposit yielded more than 20,000 gallons. The oil has been used successfully in the engine of a steam-launch, and for automobiles; and the gas from the well is used for domestic purposes. A considerable quantity of gas issues from the ground in the neighbourhood. A similar well was bored at Lagunillas, in the province of Matanzas, from which at a depth of 82 feet a supply of 18½ gallons a day was obtained, but this also was not worked.

Near Santa Clara is Sandalwood Spring, in which oil appears on the surface. Dr. H. N. Stokes, of the United States Geological Survey, who examined it in 1890, says: "The oil, which is about as viscous as strong sulphuric acid, is somewhat turbid from suspended water, but when dried over calcium chloride, it is perfectly transparent, amber-coloured, and shows the merest trace of bluish-green fluorescence. Its odour is agreeable, and in no way suggestive of even refined American petroleum, but rather of cedar wood. The specific gravity at 33° is 0·901." Oil of a specific gravity 0·754 has also been obtained from a well at a depth of 285 feet.

In the province of Santiago de Cuba there are several undeveloped deposits of oil, samples of which are said to have given the following analytical results:—Water-white oil, 50 per cent.; very small percentage of benzine, no gasoline, an extremely small residuum, with a loss of 2½ per cent. The crude oil is said to be amber-coloured, with specific gravity 0·74.

The chief deposits of asphalt or chapapote are the following:—Extensive beds near the harbour of Cardenas, 70 feet thick; in Pinar del Rio, near Havana, 18 feet thick; at Canas Tomasita, 105 feet thick; and a specially pure deposit near Vuelta. The average analysis, as given in R. C. Taylor's *Statistics of Coal* (1848), p. 244, is—carbon, 34·97 per cent.; volatile matter, 63 per cent,; ashes or cinders, 2·03 per cent.

According to the United States Geological Survey Reports, drilling operations near Habana, Cardenas, and Motembo, during 1914 and 1915, were not attended with any very promising results. Near Cardenas, several shallow wells and one to a depth of 2400 feet were drilled without oil being found. At the end of 1915 the Union Oil Company of Habana was reported to have obtained "a fair showing" of amber-coloured oil at a depth of 320 feet in a test-well 12 miles east of Habana. The search for oil appears to have been continued during 1916 in the neighbourhood of Habana; in 1917 the Cuban Petroleum Company met with success in their No. 1 well near Bacuranao, about 15 miles northeast of Habana.

In the Santo Domingo (or Dominica) portion of the Island of **Hayti**, boring for oil was undertaken in 1865, but negative results were obtained. In a communication to the author, Mr. Nelson Boyd states that when on the island in 1886 he was told that large quantities of oil were found on the surface over a considerable area, at a point on the coast beyond a place called Santo

Cristobal, about 10 to 15 miles west of the town of Santo Domingo. A sample of this oil, analysed at the École des Mines in Paris, was described as very liquid and free from water.

The West India Petroleum Mining and Export Company acquired oil rights over an area of about 314 square miles at Azua, within a few miles of the harbour in Ocoa Bay, on the southern shore of the island. According to a contemporary report, the Company began drilling on the 21st September 1904, on a site about 7 miles northwest of the harbour, and on the following 15th November, at a depth of 940 feet, obtained a "gusher," with an estimated production of 2500 barrels a day. The well was finished with 6-inch casing, and is stated to have spouted to a height of 180 feet. The oil is reported by Professor A. H. Gill, of the Massachusetts Institute of Technology, to have a specific gravity of 0·917, a flash-point of 133° F., and to contain 2·5 per cent. of sulphur. The yield of burning oil (distilling between 150° and 300° C.) is given as 45·5 per cent. No commercial production is as yet recorded from the Dominican Republic. According to the United States Geological Survey it is reported that under a Government concession granted in 1916, the Haiti-American Corporation secured for its subsidiary, the Haiti Oil and Refining Company, absolute control of the oil industry in **Hayti**, including the sole right to operate refineries on the island and to import crude oil free of duty for use in its plants.

Barbados.—Under the name of "Barbados tar," the dark green or black petroleum of Barbados early held an important place in the Materia Medica of this and other countries (see Neumann's *Chemistry*, translated by Lewis, 1759, p. 231 ; James, *Medicinal Dictionary*, 1745 ; Chambers' *Universal Dictionary*, 1738). Griffith Hughes, in his *Natural History of the Island of Barbadoes*, 1750, says : "The most remarkable fossil of bituminous kind is green tar. It is obtained by digging holes or a trench, and it rises on the water. It issues from hills, and is gathered in the months of January, February, and March, and serves to burn in lamps."

The deposits which yield this tar occur in the Scotland district, which includes the parishes of St. Joseph and St. Andrew. The rocks in the district consist of thick-bedded sandstones, coarse grits, bituminous sandstones and shales, and dark grey and mottled clays. The strata are much disturbed, and are broken by many faults, being in some places vertical, while close by they may be seen at an angle of 13° to 15°.

In many places the oil is found in pools on the fields, and in a little valley about 1000 yards east of the Lloyd wells, at St. Andrews, the oil trickles out along the foot of a hill. In this district there is also what is known as the "boiling" spring, which consists of a pool of water through which inflammable gas bubbles. The Lloyd wells formerly numbered twenty-one, but in 1895 only five. These were dug wells 5 feet in diameter, and from 80 to 140 feet in depth, lined with pinewood. They all yielded oil, and it was estimated that one or two barrels could be obtained daily from each well. Specimens of the oil from three of these wells, examined by the author, were of black colour, tarry character, and free from disagreeable odour. Their densities ranged from 0·946 to 0·971, and their flashing-points from 218° to 300° F. (close test). One of the destroyed wells is said to have yielded a light-green oil.

Drilling operations have been carried on for some years by the West Indian Oil Syndicate and subsequently by the West Indian Petroleum Company, and oil has been obtained in some quantity at a moderate depth.

Trinidad. (Plate 15.)—The "Pitch Lake" of Trinidad, the most important, if not the largest, deposit of solid or semi-solid bitumen known, has been described by many writers. Sir Walter Raleigh visited it in March 1595, and records that he saw there "that abundance of stone pitch, that all the ships in the world might be laden from thence; and we made trial of it in trimming our ships, and found it to be excellent good, and melteth not with the sun as the pitch of Norway."

In 1789 Anderson (*Phil. Trans.*, lxxix, 65) thus describes it:—"It is of circular form, about 3 miles in circumference. At my first approach it appeared a plain as smooth as glass, excepting some small clumps of shrubs and dwarf trees that had taken possession of some spots of it; but when I had proceeded some yards on it, I found it divided into areolæ of different sizes and shapes: the chasms or divisions anastomosed through every part of it; the surface of the areolæ perfectly horizontal and smooth; the margins undulated, each undulation enlarged to the bottom till they join the opposite. On the surface, the margin or first undulation is distant from the opposite from 4 to 6 feet, and the same depth before they coalesce; but where the angles of the areolæ oppose, the chasms or ramifications are wider and deeper. When I was at it all these chasms were full of water. . . . The truest idea that can be formed of its surface will be from the areolæ and their ramifications on the back of a turtle. Its more common consistence and appearance is that of pit coal, the colour rather greyer. It breaks up into small fragments of a cellular appearance and glossy, with a number of minute and shiny particles interspersed through its substance; it is very friable, and, when liquid, is of a jet-black colour. Some parts of the surface are covered with a thin and brittle scoria a little elevated. I . . . could make no impression on its surface without an axe; at the depth of a foot I found it a little softer, with an oily appearance, in small cells. . . . Besides this place, where it is found in this solid state, it is found liquid in many parts of the woods; and at the distance of 20 miles from this about 2 inches thick in round holes of 3 or 4 inches diameter, and often at cracks or rents. This is constantly liquid. . . ."

Dr. Nicholas Nugent (*Trans. Geol. Soc.*, i, 63), in 1811, in an account of a visit paid by him in 1807, gives a very similar description. In 1832 Capt. J. E. Alexander (*Edinb. Phil. Journ.*, xiv, 94) gives the size as about a mile and one-half in circumference; and in 1855 Mr. N. S. Manross (*Amer. Journ. Sci.* 2, xx, 153) describes it as "a black circular plain of pitch, one-half mile in diameter," but gives the entire surface covered by the pitch as 3000 acres. Other writers who have written accounts of this remarkable deposit are Wall and Sawkins (*Report on the Geology of Trinidad*, 1860), Rojas (*Lago de Asfalto en la Isla de Trinidad*, Caracas, 1869), Hon. W. P. Pierce, U.S. Consul at the Port of Spain, who has given a very complete report in *Rep. Cons. U.S.*, xl, 169 (1892), Mr. S. F. Peckham (*Amer. Journ. Sci.* 3, l, 33, 1895), and Peckham and Linton (*ibid.* 4, i, 193, 1896).

These authors differ widely as to the area of the "lake," but the most trustworthy estimates place it at 99 to 100 acres. A constant outflow is going on towards the sea, the stream of pitch averaging 15 to 18 feet in depth. The pitch, which is sufficiently firm for the most part to support a team of horses, is worked with picks to the depth of a few feet, the excavations soon becoming filled up again by the fresh plastic material rising from below and hardening.

The working of the deposit is in the hands of the New Trinidad Asphalt Company, who pay the Government a royalty of $1·60 per ton, as compared with $1·20 paid by the owners of "village" lots at La Brea and elsewhere outside the lake. The concessionaires have secured mining rights subject to a minimum payment of royalty of £10,000 a year till the year 1930. A circular line of tramway has been constructed on the lake, supported upon palm-leaves, to facilitate the removal of the asphalt, the cars being run in groups of four, with a gross weight when loaded of 6000 pounds. Very large quantities are exported annually for paving and other purposes, amounting to about 130,000 tons from the lake and 30,000 from other properties ; in 1901 a total of 171,000 tons was shipped, and under 142,000 tons in 1909. Messrs. Wall and Sawkins estimate the amount of pitch in the lake at 158,400 tons for each foot of depth, which, with an average of 20 feet, would give a total of 3,168,000 tons ; but though about two-thirds of that quantity has been removed in the last forty years, but little impression has apparently been made on the amount.

According to Mr. W. H. Delano (*Natural Asphalt*, London, 1893), the raw bitumen from the Trinidad lake contains 33 per cent. of fireclay, sand, and vegetable matter, and 33 per cent. of water. This writer considers that the term asphalt should be applied solely to the bituminous rock, such as that of the Val de Travers.

Mr. Peckham describes what the workmen call a "blowhole," such as is of frequent occurrence in the lake. This was a circular hole about 6 inches in diameter, from which bitumen more fluid than any he saw elsewhere in the island was ejected to the amount of perhaps a barrel. It was so soft as to flow readily, of a brilliant black colour, and apparently contained little, if any, mineral matter. Fluid bitumen also oozes from the bottom of the sea on both sides of the island. At Guapo, a few miles southwest of the lake, there are said to be large springs of maltha or liquid asphaltum. Springs of liquid petroleum are also abundant in Trinidad. Messrs. Wall and Sawkins (*op. cit.*, p. 145) state that "nothing is more common in the La Brea district than to observe it [the oil] exuding from the soil or issuing from the fissures in the cliffs." The oil contains sulphur, and a sample examined by the author yielded solid paraffin among the products of distillation. It is of interest to note that solid paraffin does not, apparently, exist in Trinidad asphalt. The same authors also mention (p. 94) that in 1858 an American company established a refinery at La Brea for the manufacture of burning and lubricating oils, and it is said that the former oil was extensively used in the colony. The company was not commercially successful, but it appears probable that the material distilled was not the fluid petroleum, but the solid or semi-solid bitumen of the district. It may be noted that it was from Trinidad asphalt that Mr. Gesner first prepared *kerosene* by distillation (Gesner, *Treatise on Coal, Petroleum, etc.*, New York, 1861).

Petroleum apparently occurs over a great part of the southern half of the island.[1] The first important concession of oil-bearing territory was granted some years ago, on the initiative of Mr. Randolph Rust. It embraced an area of more than 50 square miles at Guayaguayare in the southeastern corner of the island. Although the early drilling operations were attended with success, very little progress was made in the work of development until the concession passed into the hands of the General Petroleum Properties of Trinidad, Limited. Among a large number of other companies formed to participate in the exploration and exploitation of the oil-lands of Trinidad was the Trinidad Oil Fields, Limited, which acquired the rights over areas in the Guapo and La Brea districts on which successful results had already been obtained by the Trinidad Petroleum Company, Limited. It was, however, in the neighbourhood of the Pitch Lake that the earliest important progress was made. There, through the enterprise of the American concessionaires of the lake and their associates, the Trinidad Lake Petroleum Company,

[1] See Map (Plate 15).

Limited, a number of wells were drilled, a refinery was built, and the first shipment of oil was made in May 1911.

In November 1911 the Trinidad Oil Fields, Limited, obtained a very prolific spouter in their well No. 13, which was estimated to have produced 25,000 barrels in three and a half hours, before it became choked.

Within the last few years steady progress has been made in the development of the oil-industry of Trinidad. The three companies controlling the largest areas in 1918 were the Trinidad Central Oilfields, Limited, Trinidad Leaseholds, Limited, and the United British West Indies Petroleum Syndicate, Limited.

In prospecting for oil in Trinidad there are many obstacles to be overcome. Most of the Crown Lands leased to the various companies are covered with dense tropical forests, and this fact, together with the great depth to which disintegration of the strata at the surface has taken place, makes it difficult to obtain trustworthy information upon which to base the location of a well. It has also been found that within short distances the oil-sands thin out and disappear, and that, consequently, the experience gained in one field may be quite valueless as a guide in exploiting an adjacent field. In the drilling of wells in Trinidad difficulties arise from the varying nature of the strata, the occurrence of shifting sands, and the high pressure at which gas is met with. In one field a well had to be abandoned at a depth of only 500 feet, owing to the mass of soft clay which forced its way up the borehole as fast as it was removed. Another well, during cleaning operations, ejected shale and sand to such an extent that the sills of the derrick were blown out and the whole structure moved, boulders weighing over 10 lbs. each being also thrown up outside the well-casing from a depth of at least 1100 feet. Gushers are of frequent occurrence; in 1915 a well in the Barrackpore district gave 180,000 barrels of oil in sixty hours, whilst another on Parry Lands spouted unexpectedly at a depth of approximately 2200 feet, and was reported to have produced from 100,000 to 120,000 barrels before sanding up. Perhaps one of the largest gusher-yields ever measured in Trinidad was that given by a well on the Fyzabad field, practically the entire output being secured. The well flowed continuously for four days, giving approximately 500 barrels of oil hourly, and then sanded-up. Thousands of tons of sand were ejected, the road in the vicinity being buried in sand to a depth of over five feet, and it was reported that the roar of the escaping gas could be heard nearly three miles away. For the first two and a half days the oil flowed through the stand-pipe, but this was cut to pieces by the friction of the sand mixed with the oil, and the stream was then projected upwards to a height greater than that of the derrick.

Steel storage tanks, varying in capacity from 2000 to 9000 tons, and smaller ones of about 1000 tons capacity for the storage of distillates, have been erected on the fields and at the shipping ports. Concrete tanks are also in use. In some cases, open sumps have had to be resorted to, when a well has given an abnormal production and the provision for storage has been inadequate. Considerable risk, however, attaches to the use of these reservoirs on account of the very heavy rains experienced in the island. During the month of July 1917 the rainfall recorded was the highest for 28 years. Practically the whole of the oil-fields were flooded, some six inches of rain having fallen in eighteen hours, and it was during this time that an open reservoir was completely destroyed and about 2000 tons of oil lost. Another drawback is the deterioration of the oil through evaporation when it is so stored.

Water reservoirs and dams have been constructed, swamp drainage has been carried out, and excellent roads have been cut through the jungles; connections have also been made, where practicable, with the main railways.

The produce of the wells varies from a heavy asphaltic oil to a light oil of paraffin base, with a varying specific gravity from about ·940 to ·800, and containing from 5 per cent. to 45 per cent. of petrol. The oil from the Tabaquite district, which is found at very shallow depth, is the lightest; it is free from sulphur and yields from 40 per cent. to 45 per cent. petrol, and 40 per cent. kerosene, the residue consisting of high-class lubricating oil and wax. The oil from the Barrackpore district is also of a light character.

Refineries for treating the oil have been erected at several points, and pipe-lines connecting the refineries and the fields have been laid, the longest being from Fyzabad to La Carrière, a distance of some 26 miles, and from Tabaquite to Claxton Bay, about 18 miles.

Shipping facilities have been provided at Claxton Bay, Point-à-Pierre, and Point Fortin. At Point-à-Pierre an island jetty, 300 feet in length and 1¼ mile from the shore, has been constructed, and four pipe-lines, at present supported on wooden piles, have been laid, connecting the island jetty with the storage tanks, for the purpose of loading tankers with crude oil, fuel oil, and distillates.

A considerable bunkering trade has been built up in the island during recent years, and it is hoped that oil fuel will shortly take the place of coal on the railways in Trinidad. Particulars of the production of crude oil in the island are given in the section dealing with statistics.

SOUTH AMERICA. (Plate 16.)

The deposits in South America appear to possess great potential importance, but only those of Peru have been systematically worked.

In **Venezuela** both petroleum and asphalt occur, the deposits in the eastern part of the republic being a continuation of those of Trinidad.

A contract was entered into with the Venezuelan Government in November 1909 for the exploration and exploitation of the oil-fields of the northern part of the country, but previous to this the only active work had been carried out by a local company in the State of Táchira, where oil was for some years produced from shallow wells, and refined and sold in the neighbourhood.

The "Bermudez" asphalt lake, so called from the old name of the State, is situated near the coast of the Gulf of Paria, and is said to have a much larger area than that of Trinidad, while the mineral contains only 2·14 per cent. of earthy and vegetable matters; the deposit is, however, not as deep as that of the adjacent island. In 1908, 37,588 metric tons of asphalt was exported, of which 37,549 tons was from the Bermudez lake, while the remainder came from the Maracaibo region.

In 1913 a well drilled by the Caribbean Petroleum Company on the eastern shore of Lake Maracaibo yielded approximately 10 barrels of oil a day at a depth of 390 feet. Further drilling operations were then in progress in this district.

In 1915 the future of Venezuela as one of the oil-producing countries of the world was practically assured by the acquisition by the Royal Dutch Shell interests of the control of the concessions of the Venezuelan Oil Concessions (Limited), some 3000 square miles in area, in the districts of Maracaibo and Bolivar, and the commencement of active work by this group on the erection of a modern refinery on Curaçao, one of the Leeward Islands, off the north coast of Venezuela.

Concurrently the Caribbean Petroleum Company, an American company operating on the eastern side of Lake Maracaibo, continued its prospecting work with success. A six-inch pipe-line, 15 miles long, was constructed from the field to San Lorenzo on the Lake, and storage tanks were erected at the terminals of the line. One refinery, with a daily capacity of about 2000 barrels (42 gallons each), started operations in 1917, and another is now completed.

The author is indebted to the Anglo-Saxon Petroleum Company, through the courtesy of Sir Marcus Samuel, for the information that the first production in Venezuela was gained in 1916, the output for the year amounting to 2000 tons; that in 1917 it was 31,705 tons; in 1918 it reached 58,213 tons; and in 1919, 42,537 tons.

The oil is described as of a heavy asphaltic type.

Brazil.—Large quantities of a rich, dark brown, laminated, bituminous deposit, locally known as "turfa," occur in the Camamũ basin in the Province of Bahia. No signs of plant or animal remains have been found in it, but it has been suggested that it was produced by the aggregation and decomposition of vegetable matter in mangrove swamps, such as still exist in the locality. Small quantities of asphalt have been found in conjunction with the turfa. Mr. Wallace has obtained by distillation 58·48 per cent. of volatile matter from turfa dried at 212° F., and estimates that 1 ton would yield 68 gallons of crude oil of specific gravity 0·888, and 6½ lbs. of sulphate of ammonia.

In **Colombia**, asphalt is reported to occur on the northern shores and along the Magdalena River, in large quantities. Petroleum is reported from Tubera, near the mouth of the Magdalena, and thence westward all the way to the Mulato River. On the east coast of the Gulf of Darien are extensive escapes of oil and gas. A heavy oil exudes in considerable quantities along the rivers San Juan and Vulcan. In the delta of the Sinu River also a heavy petroleum with much sulphur is found. To the east of the Sinu River oil of good quality (specific gravity 0·858, viscosity 0·98, flashing-point 101° F.) with paraffin base is met with, the analysis of which gives naphtha 2·92 per cent., kerosene 31 per cent., lubricating oil 30 per cent., paraffin 3 per cent., and residuum 27·08 per cent. Very favourable reports have been made as to the richness in oil of Colombia. No less than forty petroleum springs have been found, from 1 to 3 miles from the Gulf of Uraba, near the Arboletes, one of which has a crater about 12 inches in diameter, and yields sufficient oil to fill a 6-inch pipe. A large pond of petroleum 60 feet in diameter, and from 3 to 10 feet in depth, occurs near this spring. The oil passes through a bed of coral, and is said to be very pure.

Other springs are reported to occur on the plain of Medina, at the foot of the extinct crater of Guaycaraime, within that part of the southeastern Cordilleras which terminates in the plains of Medina, about nine miles from the River Upia, a tributary of the Meta. The oil exudes from sandstone, and is free from water. Its rate of flow was estimated, by noting the time taken to fill a ditch of two cubic metres capacity, at two barrels per minute. A specimen of this oil examined by the author was dark brown in colour when viewed in a thin film by transmitted light, exhibited but little fluorescence, and had a slight odour of not unpleasant character. Its specific gravity was 0·926, its flashing-point 310° F. (Abel test), and its viscosity at 70° about two and a half times that of rape oil. It solidified at 5° F.

In 1913, English, American, and Canadian oil interests were concerned with concessions for the development of large areas where seepages of oil and asphalt are so significant as to lead to the hope of a large addition to the world's supply of fuel oil. The English interests withdrew from Colombia in the latter part of 1913.

The discovery of petroleum and natural gas at Tubera indicates the possible development of an oil-field in close proximity to the Panama Canal. The field was still in a prospecting state in 1914, but a considerable amount of drilling material and equipment was imported during that year, which indicated that prospecting had met with favourable results. It was reported that in 1914 an American company was carrying out exhaustive tests in the Loico district near the Sinu River. In 1915, although the Standard Oil Company was the only company which was carrying out active exploratory work, numerous other syndicates, especially from the United States, sent investigators into the country. A petroleum seepage, heretofore unrecorded, was found in the department bordering on the Magdalena River as far south as Girardot, where the railway connects the steamboat traffic of the river with Bogota.

Since the opening of the Panama Canal interest in the development of oil-fields in Colombia has been steadily increasing. A great deal of capital has been spent in unsuccessful efforts to find oil in commercial quantities in the Sinu region. The failure has not, however, discouraged foreign investors, and in 1916 the Tropical Oil Company, composed of Pittsburgh capitalists was organised for the development of some 2,500,000 acres in the Robert de Mares concession along the Magdalena River, in the province of Bolivar, and a number of wells were started before the end of 1916; these were completed in 1917, but met with little success.

The existence of petroleum in **Ecuador** has been known for more than two centuries, being mentioned in Velasco's *History of the Kingdom of Quito*, published in 1700, which contains an account of the operations carried on for the production of pitch at Santa Elena.

The petroleum fields of Santa Elena lie about 64 miles west-by-south of the port of Guayaquil. The principal surface indications occur at San Raimondo, on the coast; at Santa Paula, about 3 miles inland; at Achagian, 2 miles north-east of Santa Paula; and at a place midway between the villages of Santa Elena and San Raimondo. At the latter place "gum" beds, or deposits of thickened petroleum, are numerous, and the beach is found to be saturated with oil when the tide is out. In places oil oozes from the outcrop of sandstone. At Santa Paula, where sufficient oil is obtained for local use, about forty wells, varying in depth from 3 to 8 metres, have been excavated. They vary in diameter from about four metres at the surface to one at the bottom, and pass through shale, from which the oil trickles out, and is collected by skimming it off the water. It is carried in barrels, holding about 20 gallons, to the coast, on mules or donkeys. It is said to be of a very heavy character, with specific gravity from 0·97 to 0·985. A number of old dug wells also exist at Achagian, but these are no longer worked.

During 1913 negotiations were actively in progress on behalf of British and American interests with a view to securing a concession from the Government for exploiting the regions in Ecuador where the existence of petroleum is probable, as well as the oil-fields near the coast, which have yielded a small production from time to time. Investigations of the indications of petroleum along the coast and in the mountains near Quito by a Dutch syndicate were also being carried out.

The following information is given in a report,[1] dated 5th June 1916, by Consul-General Frederic W. Goding, at Guayaquil, Ecuador:—

"Bituminous seams bearing small quantities of petroleum occur in various places in the northern provinces of Ecuador, where several claims have been located. Petroleum is said to exist in marketable quantities in the Province of

[1] On file in Department of State

El Oto, near Santa Rosa, not far from the oil-fields of Peru. The known deposits, where outflows are frequently found, occur in the desert peninsula, near the port of Santa Elena, extending from Puntilla, the most western point of Ecuador, eastward at least to the town of San Vicente. The present method of collecting the oil is to excavate holes, 10 feet by 10 feet square, from 10 feet to 50 feet down to the impermeable sandstone ; by seepage there is an annual yield of about 25,000 barrels. The presence of a small oil fountain, together with considerable gas, would indicate that deep drilling would produce flowing wells.

"In 1910 a well had been sunk to 150 feet, and another in 1913 to a similar depth, passing through several small veins of oil and strong gas, while a third of 1250 feet, was nearly ready to begin operations, work with them being discontinued owing to lack of funds. Judging from the depth at which oil is found in the adjacent Lobitos field of Peru, it is believed that oil in commercial quantities will be reached here at about 1000 feet. The deposits are similar to those at Lobitos and Negritos. . . .

"The petroleum produced in Ecuador near the surface has lost some of its volatile constituents as a result of the method of collecting it. An attempt was made at Santa Elena to refine it, but was later abandoned. A small plant situated at the beach near there treats limited quantities for the asphalt only, no effort being made to save the lighter oils. An analysis made in London gave the specific gravity at 60° F., being 0·8798.

"Recently a law was promulgated here exempting from all fiscal and municipal duties and taxes the production and exportation of petroleum and its derivatives for a period of twenty years. Some mineral tar is exported each year." According to the United States Geological Survey Report for 1916 evidences of the occurrence of petroleum in commercial quantities are said to exist near Santa Rosa in the province of El Oro and Guayas.

In 1917 the Lobitos Oilfields, Ltd., acquired a considerable area of prospective oil land in Ecuador.

Argentina.—Consul Baker reported, in 1882, that the eastern slopes of the Sierras of the Andes, and the upper parts of Argentina, were said to be rich in petroleum. The oil of the province of Jujuy is black, and has no disagreeable odour. An analysis by the Government chemist is stated to have given the following result :—Light oil, of a specific gravity 0·74, 5 per cent. ; kerosene (specific gravity 0·814), 30 per cent. ; lubricating oil, 52 per cent. ; fixed carbon, 11 per cent. ; gases, 2 per cent.

The province of Salta has long been celebrated for its oil-springs and bituminous slates. One borehole is said to have yielded 300 barrels daily at a depth of 115 metres. At the close of the year 1889 there were said to be five producing wells near Mendoza, and between that time and 1893, when the number of wells had been increased to twelve, the output of petroleum in this district was reported to have been 1500 tons. The oil was used partly as fuel in the locomotives on the Argentine Great Western Railway, and partly as a source of light in Mendoza. A specimen of the crude petroleum was found by the author to have a specific gravity of 0·935, a flashing-point of 178° F. (Abel test), and a setting-point of 32° F. Recent prospecting in the district has not been attended with very favourable results.

On the Atlantic coast near Comodoro Rivadavia, Chubut Territory, petroleum was discovered in 1903 in boring for water, and a considerable amount of prospecting has been carried out. The oil, which is of a heavy asphaltic character, is found at a depth of about 1800 feet. Some of the wells have flowed.

According to Mr. J. P. Cappeau,[1] the Argentine Government, whilst drilling for water in 1908 near the town of Comodoro Rivadavia, about 850 miles southwest of Buenos Aires, obtained a considerable amount of gas at 480 feet. When Mr. Cappeau visited this field in 1910 seven wells had been drilled. The first was not deep enough to reach the oil-sand. A second one furnished a large supply of gas at 1815 feet, and a third found gas at 565 feet. A fourth, on the shore of the Gulf of St. George, gave promise of oil, but was never tested. Two other wells, about 1¼ mile from the shore, produced more than 30,000 barrels of oil by flowing and pumping.

Wells drilled near Comodoro Rivadavia have encountered very thick oil at about 1800 feet and a lighter oil at a greater depth.

In 1913 a Government Commission was engaged in exploiting the reserved producing regions, and a careful study was being made of the best methods for securing the greatest benefit to the State. In 1914, 5000 hectares (12,355 acres) of land in the Comodoro Rivadavia oil district was reserved by the Government, and 350 hectares (865 acres) was being exploited by the State. In April 1915 it was reported that the reserved area contained 8 active wells, 3 undergoing repairs, and 9 in process of drilling. Drilling in the Comodoro Rivadavia district is difficult on account of the copious flows of water encountered. The output of petroleum from this region in 1915, which was greater than in any previous year, was due to the increase of drilling activity which took place on the Government reserve during that year.

In a report of the Comodoro Rivadavia Commission, of which an abstract has been communicated to the United States Geological Survey, the following particulars are given :—" 25 wells have been completed on this tract, and 12 additional wells now drilling are expected to be finished before the close of 1916. . . . The depth of the wells ranges from 1725 to 1855 feet with the exception of No. 10, which is being made a deep test, and in February 1916 was drilling at 2500 feet. . . .

" From the field the petroleum is transported by two pipe-lines to a topping plant on the ocean front, and eventually to storage tanks which are connected with loading racks on a long wharf, recently constructed by the Petroleum Commission, and with a deep-sea loading line. . . .

" At Buenos Aires the Commission has erected two steel storage tanks with a combined capacity of 12,000 cubic metres. Petroleum is transported between Comodora Rivadavia and Buenos Aires by two steamers, the *Ministro Ezcurra* belonging to the Navy, and the *Waneta* under charter by the General Board. . . ."

As the result of a detailed study of the producing and prospective oil-fields of Argentina, the Argentine Bureau of Mines and Geology has been able to determine with considerable precision the areas in which petroleum exists.

According to a report,[2] four distinct and well-defined petroleum districts are indicated, exclusive of certain other doubtful areas. One of these, the restricted area, is in the southern extremity of the mountainous district in the Province of Mendoza ; another includes an extensive area of asphalt-showings in the northern part of Mendoza and the southern part of Neuquen ; the third and best known comprises the Patagonian coast contiguous to Comodoro Rivadavia ; and the fourth occupies a roughly triangular area, with sides approximately 100 miles in length, in the lower Andes, along the Bolivian frontier in the provinces of Salta and Jujuy.

[1] "Oil in Argentine Republic," *Fuel Oil Journal*, April 1913.
[2] " Native oil may solve Argentine Fuel Problem," *Commerce Reports*, 2nd June 1917.

The production of crude petroleum in Argentina increased from 6850 metric tons in 1912 to 116,000 metric tons in 1916; and in 1917 it reached 166,871 metric tons.

Peru.—The following account of the Peruvian petroleum deposits is mainly based upon information supplied to the author by the late Dr. H. W. C. Tweddle, by Mr. C. B. Rosenplaenter, and by other petroleum experts who have visited the country. The northern petroleum district may be said to extend about 250 miles north and south, between the town of Tumbez on t' e Gulf of Guayaquil and Point Aguja, and about 150 miles east and west, from the Pacific coast to the slopes of the Andes. The more recently developed southern district is in the departments of Cuzco and Puno, and its extent is not yet known.

The northern district includes the three fields of Zorritos, Lobitos, and Negritos.

A French company has been operating in the vicinity of Tumbez since 1897, and has drilled a number of wells, from which, in 1901, about 8000 barrels was obtained.

In 1867 Mr. Prentice, a Pennsylvanian petroleum producer, visited Peru, and subsequently drilled wells at **Zorritos**. The first is said to have yielded, by pumping, 60 barrels of oil a day at a depth of 146 feet. The second well, which was 220 feet deep, was less productive, but Mr. Prentice was satisfied of the valuable character of the territory and took steps to obtain the necessary rights with a view to its development. In 1876 the second well was deepened to 500 feet, and is stated to have then spouted to a height of 70 feet above the top of the 6-inch casing. Mr. Prentice erected a refinery, but the outbreak of war prevented further operations. This property passed into the hands of the Faustino G. Piaggio Petroleum Company, who in 1901 had twenty producing wells, yielding about 75,000 barrels a year. The wells have a depth ranging from 600 to 850 feet, and are cased with 10-inch drive-pipe, $8\frac{1}{4}$-inch, $6\frac{1}{4}$-inch, and $4\frac{1}{4}$-inch casing. About one-third of the wells have not yielded oil. The wells have been drilled in a line along the coast for a distance of about 3 miles, and are situated so close to the shore that at high tide the sea flows under the derrick floor. This position was determined by the proximity of the slopes of the Andes mountains, over which it was found difficult to move machinery. Efforts to overcome this obstacle have, however, been made, and a test-well was drilled about a mile further north, which is said to have yielded 60 barrels a day. The crude oil of Zorritos has been described by Mr. L. Weinstein (*Chemiker Zeitung*, xvi, 195, 1892). The oil examined had a specific gravity of 0·810 to 0·840, and was rich in the more volatile hydrocarbons. It yielded no solid hydrocarbons when cooled to $-30°$ C. Its elementary composition was found to be—carbon, 84·9 per cent.; hydrogen, 13·7 per cent.; oxygen, 1·4 per cent. The heat of combustion was 10,672 calories. The production of the Zorritos field in 1903 was about 50,000 barrels, and in 1910, 107,000 barrels.

There was a steady decrease in the production of petroleum in Zorritos, which is some 80 miles north of Lobitos, from 1911, when it was 64,286 barrels. In 1914 there was a slight increase, the output reaching 88,136 barrels, but in 1915 there was a decrease to 72,736 barrels. In 1916 the production was 73,852 barrels. In 1917 the production increased to 75,262 barrels. This field is controlled by Faustino G. Piaggio, of Callao, and its output, after treatment in a local refinery, finds a ready market in the cities and towns along the west coast of South America.

At La Cruz a well was drilled to a depth of over 1000 feet by the Peruvian Syndicate in 1891, but was unproductive, though at the Heath ravine, between

Zorritos and La Cruz, the Heath Company had a well which yielded some oil at a depth of 830 feet. A sample of crude petroleum from the latter well, examined by the author, had a dark brown colour, with but little fluorescence. It possessed an agreeable odour, and did not solidify at zero F. Its specific gravity at 60° F. was 0·859, and its flashing-point 38° F. (Abel test).

The claims of the Mancora Syndicate were principally situated on the hacienda Mancora, which extends along the coast from the valley of the Parinas River, forming the northern boundary of the hacienda La Mina Brea and Pariñas, to the Quebrada Secca (Siches), embracing the so-called ports of Cabo Blanco and Puerta Mancora. Two wells were drilled in 1891–92 for this syndicate at Tucillal, 2½ miles inland from Zorritos. The first was abandoned as unproductive when the drill was passing through "dark loam with broken shale and slate" at a depth of 826 feet, although at 324 feet a "very heavy vein of gas" was struck, and at about 500 feet a yield of oil amounting to about 20 gallons a day was obtained. The second well was carried to a depth of 390 feet, when the breakdown of the boiler caused a stoppage of the work. The first indications of oil were met with in this well at a depth of between 72 feet and 124 feet, and a larger quantity between 345 feet and 375 feet. When drilling was suspended the well contained 75 feet of oil. A specimen of this oil examined by the author was of a very brown colour, and had no unpleasant odour. The specific gravity was 0·940. At Siches, which lies in the centre of the hacienda Mancora, about 6 miles from Cabo Blanco, an excavation made in a "black slate, at the base of an oil-bearing sandstone of the district," quickly became filled with a "pure green oil." A specimen of the surface oil from Siches, examined by the author, was dark brown in colour by transmitted light, and fluorescent. Its odour was slight and not disagreeable ; its specific gravity at 60° F. was 0·920, and its flashing-point (Abel test) was 122° F. It did not solidify at zero F. At 70° F. its viscosity, measured by Redwood's viscometer, was 69·41 (rape oil at 60° F. = 100).

Between Zorritos and Negritos, both in importance and geographical position, is the **Lobitos** field, which has acquired its present standing within the last seven or eight years. The total production of the field increased from 162,000 barrels in 1906 to 429,195 barrels in 1909, followed by a slight decrease in 1910.

The Lobitos Oil Fields, Limited, is a British Company, formed in 1908 to acquire the properties of the Peruvian Petroleum Syndicate, Limited. The aggregate area of the company's properties at Lobitos and Restin, which is about nine miles north of Lobitos, is about 40 square miles. The author is indebted to Sir Archibald Williamson, the chairman of the company, for the information that there were on this area on the 31st December 1917, 150 producing wells, as compared with 143 on the 31st December 1916, besides 15 wells in course of being drilled.

Production in the Lobitos field is derived from two sands, the upper found between 1100 and 1400 feet, and the lower between 2000 and 2500 feet. One deep well has proved the presence of still lower sands. There is no refinery at Lobitos, the production being loaded on the company's tankers by means of an 8-inch sea-loading line and shipped to California for refining. In 1911 the production fell slightly, in 1912 it was 587,048 barrels. In 1913 there was again a slight falling off, but in 1915 there was a steady rise to 664,972 barrels ; in 1916 the production was 654,060 barrels ; and in 1917, 686,595 barrels.

The petroleum found in the hacienda La Mina Brea and Pariñas, which includes the **Negritos** field, was utilised by the Incas, probably for centuries, and in the time of Pizarro it was collected in trenches, and converted, by boiling it down, into a pitch of excellent quality, employed to line the porous earthen jars in which the Peruvians kept and transported their fermented liquors. At one time the Government is said to have derived a revenue of as much as $39,000 (Peruvian), or about £4000, per annum, for the right to collect the petroleum. The remains of these trenches are still to be seen.

The development of the Negritos field is said to have been commenced by a Peruvian firm in Lima in 1874, and in the following year the management of the drilling operations was entrusted to Mr. E. Fowkes, who drilled three wells. The first produced, at a depth of 330 feet, 400 barrels daily, and continued to flow at this rate for seven months, when it became choked. The second well spouted when a depth of 60 feet had been reached, and at 330 feet produced 70 barrels a day. The third flowed freely at the same time as the other two. From one of these wells oil and water were still flowing in 1896, and gas was being emitted. In 1888 the hacienda La Mina Brea and Pariñas was acquired, together with certain exceptional rights, by Dr. H. W. C. Tweddle, from the Alguerra family, and the London and Pacific Petroleum Company, Limited, was formed. The area of the property is 600 square miles, divided into ten pertenencias of uniform size. Probably about one-fourth of the area may be regarded as oil territory. Although there was reason to believe that the richest formation would be found at La Mina Brea, drilling was commenced at Negritos, which is 6½ miles from Talara. Up to 1901, about sixty wells had been drilled, and few, if any, proved unproductive. The wells are distributed over a fan-shaped area, extending outwards from Negritos towards the interior of the country, and they are sufficiently near together to admit of a number being pumped by one engine, but not so close as to drain each other. The wells, which have an average depth of 500 to 600 feet, were only drilled to what was believed to be the top of the oil-sand, and supplied about 1000 barrels a week. The cap of one of the wells was forced off by the pressure of the oil, and about 750 barrels of oil was ejected in ten hours. At the same time, at an adjoining well, the oil was forcing its way through the ground to a distance of 120 feet. The crude oil is of brown colour, with marked fluorescence, has an aromatic odour, and is free from water. Its specific gravity ranges from 0·834 to 0·848. Owing to the character of the "cover," the petroleum of Negritos has been better preserved than that of Zorritos, and contains a larger proportion of the more volatile hydrocarbons, the oil when taken from the wells frequently containing as much as 18 per cent. of benzine. On the other hand, the Negritos oil yields far less kerosene than the Zorritos oil. The pitch obtained by the evaporation or distillation of the Negritos petroleum is said to be quite tasteless and odourless. Peruvian oil appears usually to contain little or no paraffin. The production of the Negritos field in 1909 was 740,070 barrels, and in 1910, 773,025 barrels.

In Negritos deep drilling led to the development of wells which yielded 300 barrels a day. As the average total yield per well has in the past not exceeded 20,000 barrels, the great gain in production in 1913 caused considerable interest. Drilling in Negritos is very easy and cheap; the deeper wells requiring only about three months' work. The production of the Negritos field in 1911 was 882,698 barrels, in 1912 this was increased to 1,071,000 barrels; there was a steady increase up to 1916, when it was 1,822,733 barrels; the production in 1917 was 1,771,560 barrels.

The **Titicaca** oil-field is near Pusi, province of Huancane, where the American Titicaca Oil Company obtained oil at a shallow depth in 1906.

Prospecting has been actively carried on, and while the recorded production in 1907 was 15,000 barrels, the estimated output for 1910 was about 50,000 barrels.

According to the United States Geological Survey Reports, the oil-fields of Peru, with the exception of the small field near Lake Titicaca, continued to yield oil in increasing quantities in 1912, the total output in that year being 1,751,143 barrels, as against 1,368,274 barrels in 1911.

The year 1913 was one of the greatest prosperity, and greatest production, since the inception of the Peruvian petroleum industry, owing largely to deeper drilling. In 1914 there was a slight decline in the production, which was chiefly due to the curtailment of activity following the outbreak of the European war, and the consequent inability of the producing companies to procure adequate ocean transport.

The location of the Peruvian fields at no great distance from the Panama Canal is of great importance, and the demand for the product of these fields will doubtless rapidly increase.

At Callao and Payta large storage tanks have been erected and equipped with all the modern facilities for transferring oil to steamers in a rapid and economical manner. Similar installations have been provided by the Peruvian oil companies in the ports of Chile. There was a considerable increase in production in 1915, the bulk of the production coming as usual from the Negritos district, 6 miles south of Talara. At Talara the International Petroleum Company, Limited, has a refinery with a capacity of 2500 barrels of oil a day. In the Lagunitos field, which lies about 12 miles south of Talara, and is connected with it by a pipe-line and a narrow-gauge railroad, a number of new wells were drilled in 1915.

More oil was produced in Peru in 1916 and 1917 than in any other year in the history of the industry, which dates from 1896, the output in 1916 amounting to 340,086 metric tons, and in 1917 to 337,789 metric tons. The principal gain was in the Negritos and Lagunitos fields, which are operated by the International Petroleum Company of Canada, and supply crude oil to that company's refineries at Talara, Peru, and near Vancouver, British Columbia. It was reported that evidences of petroleum had been found in Peru, at a point along the Huallaga River about two days' journey from Yurimaguas, and that the oil was of such good quality that scientific investigation of this area was contemplated.

Chile.—In *Commerce Reports*, issue of 10th October 1916, the statement is made that recent discoveries of oil in the Territory of Magellan have created much interest, for heretofore Chilean oil has been found only in the northern and central sections of that country.

CENTRAL AMERICA.

Costa Rica.—According to a report, dated 23rd September 1915, by the British minister at Panama, a concession has been granted for the development of prospective oil-fields in the Provinces of Comarca de Limon, Guanacaste, and Comarca de Punta Arenas. In the United States Geological Survey Report for 1916 the statement is made that the operations carried out under this concession during 1916 were restricted chiefly to geological investigations, but that late in the year test-wells were commenced near Uscari, Limon, on the Amei River, in a locality where seepages of oil were numerous.

NEW ZEALAND.

The existence of petroleum and natural gas in New Zealand has long been known, and has been the subject of many reports ; notably those by Dr. J. M. Bell, late Government Geologist in the Dominion, and Mr. E. de C. Clarke. Mr. J. D. Henry's work on the Oil Fields of New Zealand, published in 1911, gives a full account of the localities in which petroleum occurs, and of the drilling operations which have been conducted.

The principal indications occur at New Plymouth, on the west coast of the north island, and on the Sugar Loaves Islands, off the coast of New Plymouth, about 200 yards south of the breakwater, known as the Taranaki district ; on the opposite side of the same island, along a belt of country extending from Horoera Point, near the East Cape, where a film of oil is said to be sometimes observed on the sea, to the Okahuatin Block, which is about 30 miles west of Gisborne (Poverty Bay) ; and at Kotuku, near Lake Brunner, South Island.

In November 1865 two companies were formed to work the **Taranaki** deposits. The Taranaki Company drilled two wells, the first, " close to the main Sugar Loaf," to a depth of 300 feet ; and the second, " on the island off the north headland," to a depth of 145 feet. In these wells, " a few oil-patches were passed through, but no appreciable quantity was obtained." The Alpha Company's well was situated a short distance from the north headland, and in this the most oil was obtained. In drilling this well a shaft was first sunk to a depth of 60 feet, and at a depth of 44 feet oil oozed from the sides. From the bottom of the shaft a borehole was carried to a depth of 180 feet, oil being obtained at 80 feet, and again at the extreme depth. The well was pumped regularly for two or three weeks, and yielded about 50 gallons of oil a week, together with a considerable quantity of water. When the pumping was discontinued, gas issued from the borehole. In 1888 Mr. Henry A. Gordon explored the Taranaki district for the Mines Department of the New Zealand Government, and reported that the indications were numerous, both inland and along the shore. In his report it is stated that " there are small quantities of petroleum, with numerous jets of carburetted hydrogen gas bubbling up here and there along the ocean beach on the north side of the breakwater, for a distance of about 300 yards. These can only be seen at low water, as the foreshore is covered with a thick deposit of iron sand. Wherever the shore is clear of this sand, traces of oil can be seen on lifting the boulders, and also in sinking down in the soft volcanic deposit, the ground is saturated to some extent with oil. The harbour engineer informed me that in carrying on dredging operations for the foundations of the breakwater, petroleum was found until the end of the breakwater was reached, and that it can always be seen on the surface of the sea between the Mikotahi and Moturoa Islands in fine weather."

In 1890 the author examined, for the New Zealand Petroleum and Iron Syndicate, which had recently been formed, a sample of petroleum collected on the beach at New Plymouth. It was of dark brown colour in a thin stratum by transmitted light, exhibited the characteristic fluorescence, and had a slight odour of a not unpleasant character. Its specific gravity was 0·971, and its flashing-point 236° F. (close test). It was found to contain no appreciable quantity of solid hydrocarbons. Subsequently a well was drilled by this company, with Canadian plant, close to the beach at New Plymouth, and at a depth of 915 feet a yield of petroleum estimated at about 4 barrels a day was obtained. This oil, on being examined by the author, was found to be quite dissimilar from that obtained on the surface. It was of a chestnut-brown colour, and was free from any disagreeable odour. Its specific gravity was

0·840 at 60° F., its flashing-point was 62° F. (Abel test), and it contained so much paraffin (solid hydrocarbons) that it solidified at 60° F. The well appears to have been drilled principally through dark sandy clay, in which petroleum occurred, and light-coloured sand, described by the New Zealand Geological Survey as trachytic. Part of a boulder of trachyte was also brought up from the borehole. A specimen of oil taken from this well by Mr. F. Brooks in 1893, and submitted by him to the New Zealand Geological Survey, gave, upon examination, results similar to those which the author had obtained, except that the flashing-point was higher, which was no doubt due to evaporation.

Later drilling met with varying but, on the whole, disappointing results, which were due in the first place to repeated mishaps. In 1906 interest was again aroused by the strike of a flow of oil at Moturoa, but no commercial production had been recorded down to 1909.

The operations which had been carried on in the **Poverty Bay** district were described in a report by Mr. H. A. Gordon, Inspecting Engineer to the Under-Secretary of Mines, dated Wellington, 20th January 1888. The first workings where oil was discovered were situated on the top of a flat range between the Waingaromia Creek and the Waiporoa River, about 1450 feet above sea-level. Several excavations had been made in this locality, the whole of which were full of water, with a thick film of oil on the top, through which carburetted hydrogen was bubbling up. On one of these pools being ignited, the oil and gas burned for a considerable time. The surface soil in the vicinity of these pools is described as "intermixed in places with paraffin, which forms a consistency having the appearance of antifriction grease." Unsuccessful attempts had been made to put down a borehole in this locality, but gas appears to have been found under considerable pressure at a depth of 110 feet. Three companies have at various times been engaged in drilling operations in this district, and much money has been fruitlessly expended. The South Pacific Company was formed in 1874, but went into liquidation without having obtained any satisfactory result. A new company, formed by some of the original shareholders, then drilled nine wells, only one of which was carried to any considerable depth. In this oil was found at 1321 feet from the surface. Sandstone with gas and oil was met with at 470 feet, and again at 780, 1119, 1260, and 1307 feet. The Minerva Company, which had been recently formed, had one well in course of drilling, and at a depth of 221 feet had struck fine sandstone bands (corresponding with those found in the South Pacific Company's borehole at 470 feet), which gave off a large quantity of carburetted hydrogen gas.

The Southern Cross Company's workings were situated on the northern and western side of the Waiapu River, about 45 miles in a northeasterly direction from the South Pacific Company's lands. This company was formed in January 1881, and drilled seven wells to depths ranging from 150 to 1820 feet. In all the wells a considerable quantity of gas was met with, and in the deepest a little oil. In the deepest well kerosene shale was passed through at 36, 85, and 115 feet; gas was met with at 171 feet; sandstone with gas and a little oil at 1006 and 1260 feet.

In **Wairarapa North County** oil shows were reported by Prof. Park in 1888, but no drilling has yet been carried out.

The **Kotuku** oil district was first discovered in 1867, though it was not generally known till 1900, since which time a considerable amount of prospecting has been carried out. Oil has been struck, and further drilling operations are now being conducted.

There was a great deal of activity in oil exploration in New Zealand in 1913, which, in addition to the formation of new oil-producing companies, included the erection of a refinery at New Plymouth, North Island, capable of refining about 500 barrels a day. The Taranaki and East Coast Oil Properties (Limited) and the Kotuku Oil Fields Syndicate were formed to exploit the Taranaki fields and the East Coast. The Royal Dutch Shell Company was also investigating this region during 1913. A good flowing well was obtained by a local company at Blenheim towards the end of the year. Interest in 1914 was centred in the Taranaki district, where six companies were reported to be engaged in development work. The wells in this district range from 2280 to 3330 feet in depth, and yield less than 25 barrels a day of high-grade paraffin-base oil, practically free from sulphur, and containing only small quantities of unsaturated hydrocarbons. The Taranaki Petroleum Company has erected a modern refinery, of a capacity of 10,000 gallons a day, to supply the local market for oil products. On the South Island the Shell interests abandoned a test-well at 900 feet after penetrating metamorphic rock. According to the United States Geological Survey Report for 1915, the Director of the Geological Survey, in reporting to the Minister of Mines, had the following to say about the future of the petroleum industry in New Zealand :—" Practically all qualified observers are agreed in the belief that the source of the New Plymouth oil is at a great depth, and that probably the principal oil horizon will not be found at a much less depth than 5000 feet. Clearly, then, the future of the field depends on the result of deep boring, and bores less than 3000 feet in depth will not be directly important in deciding whether Taranaki possesses a prolific oil-field or not. They may, however, in places be moderately profitable, and may indirectly be of great value in furnishing the structural data of which at present there is so great a lack. The area most deserving of being prospected appears to be the strip of country that extends for 15 miles south-southeast from the Sugar Loaves and contains somewhat numerous gas vents. So far as can be judged from the data at present known, the first deep bore ought to be in the neighbourhood of Moturoa, where a considerable amount of oil has already been obtained. Had the area to the south-southeast already mentioned been more thoroughly prospected by means of 2500 feet to 3000 feet bores, possibly this opinion would need modification."

The output of petroleum up to 1915 amounted to about 780,000 gallons, of which about 530,000 gallons had been refined. In 1916 and 1917 a small production of crude oil was obtained from the deep wells in the Taranaki district, near New Plymouth.

AUSTRALIA.

But little is known in respect of the occurrence of petroleum in Australia. Petroleum exudes from the ground near the mouths of the Warren and Donnelly rivers, and inland on the Fly brook and Lake Jasper, West Australia. At Albert Flat, in the Coorong district, South Australia, deposits of an elateritic nature have been known for more than half a century, but it is stated by botanical experts that this " elastic bitumen," " mineral gamboge," or " coorongite " is in truth a form of lichen. Oil oozes from the ground along the Coorong lagoon, though a boring in Albert Flat (1890) reached the Palæozoic rocks under 880 feet of Miocene, and 42 feet of recent marine deposits, without encountering any trace of oil or gas. Some inland borings near Meningie, where the Murray enters Albert Lake, have met with traces of petroleum. Indications of oil are also reported to have been met with at York Town, at the extreme end of Yorke's Peninsula, between Gulfs Spenser and St. Vincent, and it is said that gas has been found at a depth of about 2000 feet, after boring through sandstone and conglomerate, at Narrabeen, near Sydney, New South

Wales. The Australian shale deposits are referred to in the section dealing with the shale-oil industry.

In the latter part of the year 1914 an examination of the supposed oil-bearing areas of South Australia was carried out by Dr. Arthur Wade on behalf of the Government, and a full report of his work is published as Bulletin 4 of the Geological Survey of South Australia. The examination covered some 10,000 square miles of territory in four main areas, viz. Eyre's Peninsula and the west coast, Kangaroo Island, Yorke Peninsula, and the southeastern district. The conclusion reached by Dr. Wade as the result of this investigation was, that "one is bound to conclude that the chances of obtaining a supply of petroleum from the districts now under consideration is very slight indeed. The far southeast carries a faint possibility, which is based on surmise and no evidence." However, the year 1915 marked the beginning of actual drilling operations to determine whether or not oil-pools exist in the country. Effort toward this end was concentrated on the coastal district adjacent to Robe and Kingston, where surface indications of petroleum had been reported, and the reports from the Robe district towards the end of the year were that pockets of inflammable gas had been penetrated, and that at a depth of 1575 feet definite indications of oil had been encountered. The persistent efforts of the South Australia Oil Wells Company of Melbourne to test thoroughly the petroleum possibilities of the Robe district resulted in 1916 in deepening the test-well which was begun in 1915 to a depth of 3975 feet. More or less colourless and odourless gas displaying the physical properties of methane was found in a succession of black carbonaceous shales at about 3500 feet. In March 1917 this well had reached a depth of 4407 feet. Encouraging shows of oil have been encountered at 1033 feet and 4442 feet.

Up to and including the year 1916 the deposits of oil-shale in the Capertee Valley, Blue Mountains region, constitute the only source of mineral oil developed in New South Wales. Further reference to this industry will be found in the section dealing with shale-oil.

On 19th May 1920 the Australian Senate passed the third reading of the Anglo-Persian Oil Agreement. Under this agreement the Anglo-Persian Oil Company will form a refining enterprise in Australia in conjunction with the Commonwealth Government and supply oil fuel at Australian ports. The agreement has already been passed by the Australian Federal Parliament.

Queensland.—In 1913 the author was consulted by the Queensland Government in connection with petroleum and natural gas prospects at Roma; and after consultation with Mr. W. H. Dalton, F.G.S., and other geologists, advised the drilling of a test well. In 1916, under the supervision of the Minister of Mines, drilling was started on the south flank of the Carnarvon Range, and a recent report (1920) states that a large volume of petroleum gas is issuing from the Government bore at Roma.

NEW GUINEA.

Papua.—According to a report to the Government of the Commonwealth of Australia by Dr. Arthur Wade,[1] who made a geological survey of the petroliferous region of Papua in 1913–1914, evidences "of a more or less satisfactory nature" of the occurrence of petroleum exist over an area of about 1500 square miles extending along the coast from the delta of the Purari River almost to Yule Island in a belt some 8 to 12 miles in width.

[1] *Report on Petroleum in Papua*, by Arthur Wade, D.Sc., 1914.

A sample of the crude oil examined by the Imperial Institute in 1913 gave the following results :—

Specific gravity at 15° C., ...	0·802
Flash-point, ...	under 20° C.
Light petroleum, distilling below 150° C., . . .	32·5 per cent.
Kerosene, distilling between 150° and 300° C., . .	58·7 ,, ,,
Lubricating oils and solid hydrocarbons (including about 2 per cent. of paraffin wax), ...	8·8 ,, ,,

It is pointed out that the crude oil resembles typical samples of Sumatra oil examined by the author, of which particulars will be found in this work.

It was recently (May 1920) reported that the Australian Federal Government has completed arrangements for the placing of its oil-bearing operations in Papua in charge of the Anglo-Persian Oil Company. Some few years ago drilling operations were commenced in one or two places under the supervision of the geological expert of the Government, but the results were not very promising. The Commonwealth Government, however, has not lost faith in the possibilities of oil, but decided that new arrangements were necessary. Consequently a plan has been adopted, under which the British and Australian Governments jointly agree to provide a given sum for oil developments which are to be undertaken by the Anglo-Persian Company. The Company had previously made an offer to the Commonwealth Government to test and develop the Papuan field on the basis of a concessionaire, but without success. It is now acting in the capacity of a technical adviser and worker, and not as a partner.

AFRICA.

In the **Gold Coast Colony,** large quantities of solid bitumen, and deep holes filled with petroleum, are said to exist within a mile or two of the sea, in the Apollonia district. The coarse sand is in places saturated with oil, which is easily collected by making a shallow excavation. In a series of four wells drilled at Takinta, lying between Ajubanso and Ehboaso, and extending from the coast to the Tano River, three oil-horizons, all yielding a heavy description of petroleum, were encountered at depths ranging from 115 to 223 feet. Well No. 2 gave 5 barrels a day at 115 feet. A specimen of the surface oil examined in the author's laboratory was of dark brown colour, and was almost free from smell. It had a specific gravity of 0·979, and a flashing-point of 370° F. (close test).

Drilling operations were conducted near Half Assinie in 1909, and a flow of oil was said to have been obtained at a depth of 60 feet.

In 1905 and subsequent years drilling operations were conducted in Southern Nigeria in an area containing many indications of petroleum, and a number of wells were sunk, but no commercial supplies of oil were struck. In one of these, however, a good show of light oil was met with at a depth of 1643 feet. The oil has been analysed by the author with the following results :—

The specific gravity of the sample was 0·872 at 60° F., whilst its flashing-point was 115° F. (close test), which, coupled with the specific gravity, demonstrated the presence of the moderately volatile hydrocarbons of normal crude petroleum, and indicated that the oil had been obtained from a petroliferous formation, in which it had been to a large extent protected from loss by fractional evaporation. The crude oil contained 0·35 per cent. of sulphur. From the more volatile fractions 26·8 per cent. by volume of the crude oil of excellent kerosene, "water-white" in grade, of specific gravity 0·790 at 60° F., and flash-point (Abel test) 94° F., was obtained by redistillation on the Engler principle up to 300° C. The sample may be described as a crude petroleum of good quality of paraffin base, yielding the usual commercial products, with the exception of the most volatile, and being exceptionally rich in solid hydrocarbons (paraffin). Probably in practical working such crude oil would yield from 5 per cent. to 7½ per cent. of paraffin (according to melting-point).

In 1908 the British Colonial Petroleum Corporation, Limited, acquired from the Nigeria Investment Company, Limited, a license to drill for and work bitumen, petroleum, and mineral oils over an area of 225 square miles in Southern Nigeria. Two wells were sunk to a depth of 400 and 900 feet respectively, but owing to further working capital being required and the refusal of the Government of Southern Nigeria to renew the license, the field of operations was abandoned.

Several test-wells were sunk on the Ivory coast, near the Gold Coast frontier, on the Tano River, but in spite of numerous shows no useful supplies of oil were encountered.

In South Africa the numerous indications of oil in the **Orange River** and **Cape Colonies** have led to some prospecting with the drill, and a well near Barkly East, in the latter State, is said to have met with indications of oil and gas.

The prospect of obtaining oil in South Africa has been freely discussed since the last edition of this book was published, but it was not until a geological investigation was carried out by Mr. E. H. Cunningham Craig, in 1913, that any definite information was obtained. Special attention was paid in this investigation to the Ceres district, where for many years the possibility of obtaining oil had been suggested. Mr Cunningham Craig states that many reports have been written, but that the only one of note is that by Mr. J. E. Mills-Davies, who describes the geological structure excellently, and, while not holding out any definite hopes of petroleum being discovered in this district, advocates the careful investigation of the gas emanations. Mr. Cunningham Craig asserts that "None of the strata presents any of the characteristics of an oil-bearing series; not even in the shale, which is a greyish-green sandy rock, is there any trace of bitumen or ozokerite. . . . Thus it is seen that the evidence taken as indicating the possibility of petroleum being discovered has proved entirely misleading, and it is hardly necessary to add that there is not the slightest chance of oil being struck in any part of the district." According to Mr Cunningham Craig, favourable geological structure is found only in Cape Colony, and that it is to the Karroo district we must look if an oil-field is to be found. There is, however, in his opinion, a possibility that northeastern Natal, in certain areas which he was unable to visit, might furnish favourable structures.

According to Vice-Consul F. J. Flexer,[1] of Port Elizabeth, Good Hope (Cape Colony), indications of the presence of petroleum have been discovered in the district immediately surrounding Port Elizabeth, and sufficient capital has been subscribed to enable a test-well to be sunk to a depth of 1500 feet.

Somaliland.—A geological examination of the region adjacent to Berbera, on the Gulf of Aden, carried out in 1914, furnished definite evidence of the occurrence of petroleum in such quantity as to afford promise of a commercial yield. A sample of the oil obtained on excavating a pit at Daga Shabell

[1] *Commerce Reports*, 20th September 1916.

to a depth of a few feet was analysed by the author. It was an oil of reddish-brown colour and slightly camphoric odour. Its specific gravity was 0·897 at 60° F., and its flash-point 122° F. (close test). It contained 0·63 per cent. of sulphur, yielded no distillate below 150° C., but yielded 34 per cent. of distillate below 300° C. The residue contained a large proportion of solid hydrocarbons.

In 1908 some exploratory drilling was carried out in the petroliferous region of **Madagascar**, on concessions granted in the Sakalava valley, and indications of oil were met with.

During the year 1915 drilling operations were carried on in the search for oil in the Betsiriry Valley, by the Betsiriry Proprietary Oilfields, Limited, and also by the Sakalava Madagascar Proprietary Oilfields, Limited. No discoveries of commercial importance were reported, but in August of this year the author examined a sample of crude oil from No. 2 well at Maroboaly on the property of the Sakalava Company, which gave the following results :—Colour, dark reddish-brown ; odour, camphoric ; specific gravity at 60° F., ·941 ; flash-point (close test), 288° F. ; distilling below 150° C., nil ; distilling between 150° and 300° C., 10 per cent. ; residue, after distillation of a further 57 per cent. of lubricating oil, *in vacuo*, asphaltic in character ; no evidence of the presence of solid hydrocarbons in the lubricating oil distillate.

In January 1916 the Manambolo Oil Syndicate was absorbed by the Betsiriry Company. Drilling was continued on the properties of the Sakalava Madagascar Proprietary Oilfields, Limited, well No. 1 was abandoned, oil was found in Nos. 2 and 3, and drilling begun in No. 4. In September 1916 this company acquired control of properties adjoining its holdings formerly held by the Folkara Oilfields, Limited. In 1917 encouraging results were met with by the Sakalava, Limited, in test well No. 5, in Betsiriry Valley.

SECTION II.

THE GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF PETROLEUM, NATURAL GAS, AND OTHER FORMS OF BITUMEN.

In the solid, liquid, and gaseous forms, bitumen is one of the most widely-distributed of substances. It is found in greater or less quantity in almost every part of the globe, and its geological limits include the whole range of strata, from the Laurentian rocks to the most recent members of the Quaternary period.

The various forms of natural hydrocarbons have received many names, of which the most important are the following :—natural gas, petroleum, rock oil, mineral oil, maltha, asphalt, mineral pitch, and ozokerite. Local names have also been given to varieties of asphalt or solid bitumens, and these will be referred to in describing the occurrence of the substances. Deposits of oil-shale will also be mentioned in this section.

As early as 1822 Knox detected the presence of " bitumen " in a large and varied series of rocks and minerals, including greenstone from Newry and Carlingford, basalt from the Giant's Causeway and Disco Island, hornblende from Schneeberg (Saxony), augite from Arendal, and felspar from Killiney and Aberdeen. Among the few rocks in which he failed to discover this substance, Carrara marble deserves particular mention, but this only because extreme metamorphism has locally converted a once bituminous rock into pure carbonate of lime. Some graphitic granite may once have been clayey oil-sand.

Silvestri found a crystallisable paraffin in a basaltic lava at Paterno, near Mount Etna, and in the lava from that mountain. The occurrence of bitumens has been noticed in the melaphyre of Scotland, of Bohemia, of Oberstein in the Palatinate, the granite of Cornwall and Scandinavia, the traps of Connecticut, the greenstone-trachyte of Hungary, the Laurentian gneiss of Sweden, and many other of the more ancient and metamorphic rocks. Oil and gas are also distributed almost universally through unaltered, and but little-altered, strata of all ages, though their presence is less marked in the oldest rocks, which have been more disturbed and metamorphosed, and in the most recent superficial deposits, which are generally irregular and discontinuous.

Natural Gas.—The strata yielding oil and gas are geologically identical, the gas usually accumulating in the domes of the arches in the strata, or in other elevated parts of the deposits. Thus in the Trenton Limestone the gas is found in the upper portions, sometimes at a depth of 15 or 20 feet, and sometimes at three times that depth. The wells are thus supplied by a large superficial area rather than by a great depth of rock. In the almost horizontal deposits of Lima, Ohio, a well, having its bearing stratum even as little as 5 or 6 feet above that of neighbouring wells, is found to yield gas rather than oil.

The most productive wells of the United States have obtained their gas from Palæozoic rocks, through a vertical range of many thousands of feet, from the Carboniferous to the lowest Silurian, whilst in Russia it occurs in the

Tertiary series. It is worthy of note that no great gas-wells of Pennsylvania have been struck until the oil-field in which they are found has been at least partly developed, the disturbance of the equilibrium by such development and by torpedoing giving rise, it has been suggested, to conditions which allow more perfect communication between several rich portions of the strata struck by the drill.

Although gas is the invariable accompaniment of oil where conditions favour its accumulation, the latter is frequently found almost unaccompanied by it, on account of its collection in the higher portions of the strata, as already stated, or of its escape through imperfection of the covering layers. Mr. Topley thus summarised the geological conditions under which petroleum and natural gas occur :—(1) "They occur in rocks of all geological ages from Silurian upwards. The most productive areas are Palæozoic in North America, Miocene in the Caucasus." (2) "There is no relation to volcanic action." (3) "The most productive areas for oil in great quantity are where the strata are comparatively undisturbed. Oil, but in less abundance, frequently occurs when the strata are highly disturbed and contorted ; but gas is rarely found." (4) "The main requisites for a productive oil- or gas-field are a porous reservoir (sandstone or limestone) and an impervious cover." (5) "Both in comparatively undisturbed and in highly disturbed areas, an anticlinal structure often favours the accumulation of oil and gas in the domes of the arches." (6) "Brine is an almost universal accompaniment of oil and gas."

Oil and Gas Reservoir-Rocks.—Most of the porous oil and gas rocks, particularly the sandstones and conglomerates, may be regarded as merely reservoirs whose contents have been generated from the underlying strata, frequently fossiliferous and highly compressed shales, or from some other source ; but in the case of many others, more especially certain limestones, the oil and gas have usually been regarded as indigenous to the containing strata. This belief as to the origin of the oil in many of the strata in which it is now found is almost universally accepted. From observations made near Buffalo and at Chicago, T. Sterry Hunt concludes that the oil is indigenous to the Niagara, Corniferous, and Trenton Limestones. Lesley asserts the same as regards the sandstones and conglomerates of Kentucky ; and Orton considers that this is the case with the oil of northwestern Ohio. Similar observations are made as regards the asphalt of Trinidad (*Wall*), the oil of Shropshire in England (*Höfer*) that of Upper and Lower Alsace (*Andreae*), the bitumen of Seyssel (*Davies*), the asphalt of Limmer (*Credner*), the bitumen of the Lias clay and of the Wealden formation in Northern Germany (*Eck*), and the oil of the Punjab (*Medlicott*) and of Khátan in Baluchistan (*Townsend*).

In fact, for every field of which the detailed composition and structure is known, it may be asserted that the oil has originated within, or in immediate proximity to, the strata whence it flows, the yield varying chiefly with the porosity of the rock, the limpidity of the fluid, and the pressure under which it exists. The admixture of salt-water with the oil in the more compact rocks seems to facilitate the flow of the more viscous varieties.

The formation of large deposits of oil depends as much upon the presence of suitable strata to receive and retain it as upon an adequate source of supply. "So common is the occurrence of petroleum in stratified rocks, that wherever a close-grained shale occurs, there is almost always at least a small accumulation of oil directly underneath it. The same thing occurs when an impervious stratum of any other composition than shale occurs in the series" (*Orton*).

The principal deposits which possess the necessary porosity for the free discharge, if not for the original accumulation of the oil, are sandstones, conglomerates, and limestones. Shaly sandstones and slaty shales also serve as reservoir-rocks in a less degree. In limestones, a natural porosity, as in the case of the crinoidal or coarsely crystalline varieties, or a certain amount of change resulting in the formation of interspaces capable of receiving the oil, appears to be necessary for the formation of a true "reservoir-rock." Such change is usually dolomitic, and consists in the conversion of the calcium carbonate forming the limestone, into the double carbonate of calcium and magnesium, known as "dolomite," which occupies less space than the unaltered limestone. It is, therefore, characterised by the production of such numerous spaces between the dolomite crystals that the rock becomes capable of retaining a large volume of oil.

This dolomitic change appears to be incapable of occurring, save in the purer limestones. The Trenton Limestone, for instance, is thus modified only where almost free from silica, the changed parts showing about 54 per cent. of calcium carbonate, and 44 per cent. of magnesium carbonate. The major portions of the Trenton Limestone are too impure to permit of the change, and are found destitute of oil or gas.

Even in rich oil-fields the dolomite has only been formed in a small proportion of the stratum. When followed northward in Ohio and Indiana, the Trenton Limestone is found to have become dolomitic through a small thickness only of its upper beds. The changed and unaltered portions occur at short intervals, but only the former contain the oil and gas. The change usually affects from 10 to 50, and, in some cases, 100 feet of the stratum, and has occurred along a line passing into Indiana through the principal oil- and gas-fields of Ohio.

In addition to possessing a porous structure, the reservoir-rock must be entirely covered by an impervious layer, the commonest and most perfect cover being a fine-grained shale, whose imperviousness and freedom from fracture exert the most important influence on the capability of the reservoir-rock to retain its liquid or gaseous contents. Continuity of the impervious cover is essential, and the broken nature of the deposits of central and eastern Pennsylvania readily accounts for the absence of oil and gas in those districts.

In oil-bearing territory the occurrence of a porous rock beneath such a cover usually results in the formation of an oil-field. "Almost every important mass of shale in the Ohio series has been proved to be somewhere the cover of accumulated petroleum, as, for example, the Cuyahoga and Berea shales covering the Berea grit, the Ohio shale covering the Coniferous limestone, the Niagara shale covering the Clinton group, and, finally, the Utica shale covering the Trenton limestone" (*Orton*).

If not charged with oil, porous beds are found to contain water, which may be fresh when near the surface, but is salt and often sulphurous at lower depths. As the oil is removed from a stratum, it becomes replaced by water. In the case of gas-wells, however, the flooding by water does not invariably occur, many wells having been pumped for years to such an extent that a vacuum of as much as 12 lbs. per square inch is registered without any appearance of water. In gently-dipping strata of sufficient inclination, such as the Bradford sand, the gas, oil, and water form distinct horizons, the gas being uppermost and the water lowest.

As regards the capacity of the various oil strata to serve as an oil reservoir, experiments performed on the rock itself have shown that an oil-bearing pebble rock may contain one-tenth, or even one-eighth, of its bulk of oil, while the pores of the rock would permit of the ready removal of the largest supplies ever obtained, without the necessity for the channels which were at one time supposed to exist. The dolomitised portions of the Trenton Limestone have been found to possess about the same capacity. Some of the early estimates of oil-field capacities and yields were erroneous as they were based upon the older Palæozoic geological conditions. The Baku oil-fields have yielded oil which would cover their surface to a depth of 60 feet, representing about 3 per cent. of the entire thickness of strata penetrated by average depth wells. Taking Dr. Sterry Hunt's calculation of the oil contents of the petroliferous dolomite of Chicago as a basis, he has determined the probable contents of the almost universally petroliferous Waterlime stratum of Ohio. "Estimating its petroleum content at one-tenth of one per cent. and the thickness of the stratum at 500 feet, both of which figures are probably within the limits, we find the petroleum contained in it to be more than 2,500,000 barrels to the square mile. The total production of the great oil-field of Pennsylvania and New York to January 1885 is 26,000,000 barrels. It would require only three ordinary townships, or a little more than 100 square miles, to duplicate this enormous stock from the Waterlime alone." The oil-sand of the region of Baku is estimated to contain about one-fifth of its volume of oil. These estimates would account for a yield far exceeding the amount that has actually been obtained, although, as pointed out by Ashburner, small areas of the best fields of Pennsylvania have yielded as much as 900,000 barrels per square mile.

As regards the capacity of gas strata, Mr. Carll has made the following interesting calculations :—

"Although large quantities of gas had been allowed to go to waste in the Murraysville field, comparatively little had been piped from it prior to 1st November 1884. If we take this date for the commencement of the general pipe-line deliveries, the field has now (1st January 1889) entered upon the fifth year of its exhaustion. It is said by those who are qualified to judge of the matter, that an average of at least 300,000,000 cubic feet of gas per day has been drawn from the pool during the last four years. To get some conception of the enormous storage capacity of rock capable of making such an output, let us look at the following simple calculations and comparisons :—

"A standard oil barrel of 42 gallons [American] contains (42 × 231) 9702 cubic inches, or 5·6146 cubic feet. Under a rock pressure of 900 pounds or 60 atmospheres to the square inch, every cubic foot of storage room in a gas-sand should contain 60 cubic feet of gas. Hence a rock chamber capable of holding a barrel of oil would be able to hold sixty times that amount of gas or (5·6146 × 60) 336·8760 cubic feet ; consequently, a gas-well flowing 3,368,760 cubic feet of gas per day would, theoretically, relieve as large a space in the rock-reservoir as an oil-well flowing 10,000 barrels per day, and a gas-well of 33,687,600 cubic feet (some wells have been estimated as high as that) would equal an oil-well of 100,000 barrels.

"Multiplying the daily average by the number of days in four years, we have (1460 × 300,000,000) 438,000,000,000 cubic feet as the total output of gas. Reduced under 60 atmospheres, this would occupy a storage space of 7,300,000,000 cubic feet, a chamber which would contain 1,300,181,669 barrels of oil, almost four times as much as has been produced in the whole oil regions of Pennsylvania and New York since the discovery of oil in 1859. A reservoir capable of holding this enormous quantity of fluid would require to be a little over 13 miles long, 2 miles wide, and 10 feet deep."

Where the oil and gas strata are comparatively undisturbed, as in the principal districts of the United States, it usually happens that each well draws its supply from a considerable area ; indeed, so much is this the case that the owners of wells are usually compelled to continue to raise the oil without regard to the conditions of the market, to prevent its being obtained by the neighbouring leaseholders. In northwestern Ohio, for instance, wells separated by intervals of over half a mile have been found to affect each other, and a single well has been known to draw the gas from an area of several square miles.

On the other hand, certain rich wells, notably the "Manifold" well, in the Washington field, which appeared to be totally unaffected by its numerous neighbours, and the great Hutson gas-well, struck early in 1890 in the Allen township of Hancock county, Ohio, have been wholly or comparatively free from such interference.

The wells of Baku, which derive their oil from extremely loose and friable sands, are, to a great extent, independent of each other, so that less necessity for immediately raising the oil to the surface exists in that district, and a considerable number of very productive wells, belonging to the firm of Nobel and others, have been kept capped until the oil was required for use. The great Droojba well, before described, showed no appreciable action on other wells in its vicinity while it was flowing; although, when it was closed, a great disturbance occurred at Nobel's No. 14 well.

At Bibi-Eibat, near the village of Strikhoff, four wells have been producing within a few yards of each other and all from different depths. In the same district a well was sunk within a few yards of on old well, 70 feet in depth, which had furnished oil for centuries. The new prospectors, however, failed to obtain any oil until they reached a depth of 420 feet. From one of his wells at Surakhani, Mirzoeff obtained no oil until a depth of 700 feet had been penetrated, although other wells in close proximity were yielding at 100 feet.

There is, however, an evident connection between many of the wells of Baku. Three wells, for instance, belonging to Messrs. Awakoff, Palashkowski, and Nobel were found to invariably spout periodically at about the same time. Direct communication has also been found to exist between the Ararat and Sun wells in Group V of the Balakhany plateau.

The practical independence of the Baku wells, and the enormous yield of many of them, have led to a widely-spread opinion that this oil-field is divided into a number of oil-containing cavities, or, as they were described by Mr. Marvin, "subterranean lakes," yielding only to those wells which happened to directly pierce them. They may, however, be attributed with greater reason to original irregularities of deposition, lenticular sand-masses being enclosed in impervious shales, whilst subsequent deforming pressures and fractures have enormously increased the complexity of the structure, resulting in the subdivision of the field into a number of almost independent sections. This view is supported by the records which have been kept by the Nobel firm of the appearance and geological character of the strata pierced by their wells. The hypothesis that cavities exist is quite gratuitous, as the natural porosity of the strata is sufficient, as already noted, to account for a far greater yield than is practically obtained. The existence of fissures or cavities in such matter and under strong compression is inconceivable.

Professor Lesley suggested that the gas areas, which are evidently small, and are irregularly scattered and hemmed in by water and oil areas, shift their position slightly, partly on account of the pressure of the oil and water and partly from seismic changes. He considers that this movement tends towards the producing wells, and will become increasingly rapid as the gas is removed.

Structural Conditions affecting the Accumulation of Oil and Gas.—The strata from which the main oil and gas supplies have been obtained are usually unbroken and nearly horizontal, and but little disturbed.

Dr. Ashburner has found a maximum dip in the Bradford region of 69 feet per mile for the short distance of $2\frac{1}{2}$ miles; while Mr. Carll has shown that the dip of the oil-sands in the Venango belt, and the southern end of the Butler belt, rarely exceeds 34 feet per mile. A dip of even 75 feet per mile is extremely rare, even for short distances. The extensive oil-fields of Ohio and Indiana have a dip of only 1 to 10 feet per mile, those of Ohio dipping towards the north and northeast, and those of Indiana towards the northwest. Whole areas of 1000 square miles of oil land in Ohio have a dip of less than 100 feet. At Lima the dip is almost *nil*. In Baku the dip of the oil strata is said to range from 20° to 40°.

These angles, although slight, exert the most powerful influence on the accumulation of oil and gas, as is particularly exemplified in the anticlinal or terrace structure of the principal oil-districts of the world. Owing to the contractile movement of the earth, the outer crust has become creased into folds which extend for long distances and with great regularity. This creasing action has in some cases been sufficiently marked to give rise to mountain chains, but usually results in the formation of broad, low curves, whose arches are known as anticlinals or anticlines, and whose troughs are termed synclinals or synclines.

This anticlinal structure has been found markedly to influence the power of strata to accumulate oil and gas, and, given the requisite porosity and cover, forms a most important factor in their occurrence. The anticlines are themselves often crossed by subsidiary anticlines, which again largely influence the distribution of the oil and gas. Owing to difference of density, the oil and water present in the strata separate into two layers, the upper consisting of oil, which fills the anticlines, while the water remains in the synclines. Any gas which may be present rises to the summits of the anticlines. When the slow folding of the strata has been effected chiefly along certain lines of weakness, with little flexure of the intervening areas, a modified or "arrested" anticlinal structure, known as a "terrace," has resulted. The terraces may thus be regarded as flat and extended anticlines.

The terrace structure was first observed by Mr. Minshall (chap. vi. of Dr. Orton's *Rep. Geol. Surv. Ohio*, vol. vi, 1888) in the Macksburg field of southern Ohio, where the terrace is almost horizontal, and is bounded on the rise by gas, and on the descent by brine. According to Dr. Orton the terrace structure is a "frequent if not a universal element in oil production." Even in Pennsylvania and New York, more especially in the Bradford field, he considers that the oil is gathered in terrace-like expansions of the reservoir-rock. In the Findlay (Ohio) field, the gas and oil are found in two terraces, separated by a monocline for an interval of about 150 feet. The upper terrace gives "dry" gas, and the lower yields oil and water. The anticlinal structure of productive oil-fields was noticed at an early period, the "oil-break" of Burning Springs, West Virginia, whose principal wells were confined to the White Oak anticlinal, attracting particular attention. Mr. Minshall also showed that the fact of a number of wells sunk along the anticlines being unproductive, could be explained by the occurrence of subsidiary undulations along the anticlines. The productive wells were those which struck the arches of these undulations, while those which were drilled in the troughs were dry. As early as 1863 Dr. Sterry Hunt pointed out that the petroleum of western Ontario is derived from a low, broad anticline running nearly east and west.

Professor I. C. White states, as the result of an extensive inquiry concerning the great gas-wells which had been struck in western Pennsylvania and West Virginia, that "every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that had been bored in the synclines on either side furnished little or no gas, but in many cases large quantities of salt water. Further observations showed that the gas-wells were confined to a narrow belt, only a quarter to one mile wide, along the crests of the anticlinal folds. These facts seemed to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches; but the crucial test was yet to be made in the location of good gas territory on this theory. During the last two years I have submitted it to all manner of tests, both in locating and condemning gas territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt." After pointing out that, though all great gas-wells are located on the anticlinal axes, such axes do not always provide great wells, he formulates the limitations to the theory as follows:—

"(*a*) The arch in the rocks must be one of considerable magnitude. (*b*) A coarse or porous sandstone of considerable thickness, or, if a fine-grained rock, one that would have extensive fissures, and thus in either case be rendered capable of acting as a reservoir for the gas, must underlie the surface at a depth of several hundred feet (500 to 2500 feet). (*c*) Probably very few, or none, of the grand arches along mountain ranges will be found holding gas in large quantity, since in such cases the disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago have escaped into the air through fissures that traverse all the beds. Another limitation might be added, which would confine the area where great gas-flows may be obtained to those underlaid by a considerable thickness of bituminous shale."

Where the terrace structure prevails, as is particularly the case in northwestern Ohio and central Indiana, the oil and gas are naturally found over large areas, though a slight local elevation usually gives rise to a considerable accumulation, as is notably exemplified in the case of some of the wells at Lima, where the general dip of the strata is practically negligible.

In the districts traversed by anticlines, however, the yielding portions of the strata are mainly confined to the anticlines, the gas accumulating on the summit of the curves. In western Pennsylvania these gas areas are seldom more than a mile or two wide and a few miles in length. Dr. Ashburner has pointed out that though many of the largest gas-wells have been found along anticlinal axes, the exceptions, including many wells which have produced gas along the synclines, are numerous and important. It may be pointed out, however, that a synclinal between two anticlinals is equivalent to a continuous arch, in that its contents of oil and gas are equally sealed against the intrusion of water.

As regards the Eastern hemisphere, the anticlinal theory is also found to apply everywhere, evidence having particularly been collected in the case of the Caucasian and Carpathian fields, and of those of India, Persia, and Algiers. Abich has shown that it applies to the Apscheron peninsula; and Sjögren believes that the oil-producing districts visited by him at Neftjanaja and Buya-Dagh, in the Transcaspian region, both lie on anticlinals. Zincken has found that Khokand, in Russian Turkestan, yields its oil along anticlinal axes. The Carpathian deposits have also been shown to possess a complex anticlinal structure, in which oil is found at the tops of the folds, as at Boryslaw, Bobrka, and Ropienka, rather than at the lower parts. Bruno Walter has shown the application of the theory to the deposits of Bukowina; and Paul and Olszewski have found it to apply to those of Rumania. Its application to the deposits of Káhtan has been shown by Townsend, and Lyman remarks that it applies to many of the oil-fields of Japan.

Oil Lines.—In the History of Human Error an extensive chapter is requisite in connection with petroleum.

Various inconsistent and incompatible hypotheses as to the origin of the several hydrocarbons will be dealt with in another section; established principles (and, antithetically, exploded fallacies) relating to modes of occurrence may be appropriately dealt with at this point.

There is a prevalent tendency amongst minds of a certain calibre to gauge the value of hypotheses by their magnitude. By such, preference is at once accorded to views that embrace all the universe (except the relevant facts). In other words, extremes are more congenial than any compromise that involves the mental exertion of weighing evidence in each particular case presented. Hence arises the favour with which have met the wildest assertions as to underground "rivers" or "lakes" of oil, the allegations of close resemblance, generally in certain adventitious and wholly irrelevant details, between areas that have no essential points in common, *e.g.* the presence of similar superficial detritus, inducing kindred vegetation, etc. In many cases the most elementary acquaintance with geology is palpably wanting, and technical phraseology most ludicrously misapplied: geological structure and orographic form are confounded, anticlinal valleys referred to as basins or troughs, and synclinal ridges as uplifts.

The "oil-belt" hypothesis, originating with Mr. C. D. Angell in 1867, was based on a very limited range of data, and was only approximately true even for the Appalachian oil-field. Its truth lay in the geological axiom that the same composition (*i.e.* that of oil-bearing sandstone) might be expected at the same horizon for a considerable distance. Its value lay in the comparative regularity of strike in the Appalachian range, so that the productive horizons reached attainable positions along approximately parallel lines. The error lay in assuming, contrary to all observation of structural detail, that such lines were rigidly straight, instead of being somewhat sinuous, and in the purely gratuitous supposition that all the world had, in its secular contraction, undergone flexures parallel to those of Pennsylvania. This superstitious belief in the productiveness of such fields only as, irrespective of their original composition, have suffered subsequent deformation by compression along lines at 45° to the meridian, has been extended to deposits of vastly more recent date, including some of which the prevalent strike is at right angles to that of the Appalachian field. Even there, this cult of 45° has led to location of wells by compass (with or without regard to magnetic deviation), in complete disregard of the local structure.

Whilst every developed oil-field has a more or less clearly defined margin, outside of which the productive horizon has either proved inaccessible or of inadequate yield, and whilst, for areas not minutely examined, the general strike of the surrounding region may be taken as approximately that of the fields in question, it cannot be too emphatically declared that the location of wells should in all cases depend upon local structural conditions, and not upon any theoretical considerations of those conditions even at a short distance. The accurate delineation of the axes of flexure shows in most fields constant bifurcations, inosculations, and sinuosities, the ignoring of which results in disappointment, and often in abandonment of areas which have not been tested along the lines indicated by local details of structure.

Oil in Fissures and Pockets.—Some writers have laid considerable stress on the occurrence of petroleum in fissures and other cavities, deducing therefrom its derivation from deeper-seated sources, as a general law. It may, however, be doubted if such fissures and caves exist for any lengthened period under normal conditions. At any considerable depth below the surface, the rocks are everywhere under great compression, incompatible with the existence of any such spaces, except as eroded through rigid rock by the passage of water, or temporarily produced by differential movement along irregular lines of fracture. In the latter case, such cavities are generally soon filled up, either with detritus from the sides, the inequalities of which are reduced by crushing, or with mineral matter from circulating fluids. Even close to the surface, rock in certain positions is often known to expand laterally, when set free by natural or artificial removal of a portion of the mass. It is just conceivable that in some rare cases of flexured strata, parts may be in a state of tension, and that when the equilibrium maintained by the weight of superincumbent rock is disturbed by denudation, relief from the strain may be effected by the opening of fissures from the surface, but in such instances readjustment will generally consist in speedy closure of the crevices. The records of earthquakes in which men have been caught waist-deep in fissures opening under their feet, or thrown out living by a second shock, illustrate the transitory nature of such openings. Where such crevices penetrate petroliferous rocks, they may, of course, be partly filled with oil before the closing action is far advanced, and in impervious beds the oil may be able to remain in its new position under the restored pressure. The pockets in the Hamilton Shales, which furnished the earlier supplies of the Ontario fields, were doubtless filled from the subjacent Corniferous Limestone during the existence of temporary openings of the nature indicated, but borings through this to the deeper-seated Silurian limestones have not resulted in finding any larger supplies, and have thus effectually demonstrated the absence of connecting passages between the Corniferous and the lower beds. The structure of this region, looked at broadly, is a synclinal trough, the productive areas being subordinate anticlinals and domes, in which the oil has been concentrated, water occupying the surrounding depressions, and preventing its escape.

It has been gravely suggested that such synclinal curves must tend to open in fissures downwards, the lower beds being in a state of tension, and that the presence of oil under these conditions " proves " its derivation from yet deeper-seated strata. Study of exactly similar flexures on reduced scale in strongly-contorted rocks affords no support to this gratuitous assumption. The compact seams in such cases are sometimes broken into discontinuous masses, between which the softer beds are crushed, but the whole evidences intense compression, the separate blocks having been thrust apart only by the flow of the more mobile strata. Geo-synclinals are not precisely analogous to the sagging of a ceiling when the lath-nails lose hold on the joists, and the plaster develops cracks opening downwards. On the other hand, when, in a mass of strata under compression, which has determined a line of minimum resistance by the formation of an incipient anticlinal, continuance of the strain accentuates the flexure, the removal, by denudation, of the superincumbent weight at any point of the line, or (as is more commonly the case) along the course of the fold, will allow of the more rapid rise and temporary expansion of the uppermost beds so relieved, with the production of more or less short-lived fissures, which may penetrate to petroliferous deposits previously without access to the surface. Hence we find that exudations of oil almost invariably occur in valleys and on anticlinal axes, and that by far the greater number exist in the conjunction of these conditions. But these trivial oozings from shallow and temporary crevices demonstrate nothing in favour of the original charging of porous rocks with petroleum obtained through hypothetical fissures from visionary crucibles in the plutonic regions.

The Association of Salt with Petroleum.—The peculiar relations between salt and petroleum and natural gas were noticed at an early date. The petroleum industry of the United States originated in the drilling of wells for brine, and the observation that gas and oil were usually found with it; and throughout the globe the association of gas and petroleum with salt, either in solution or in the solid state, is almost universal.

The occurrence of salt in the oil districts of America, Russia, Carpathians, and India is too well known to need remark; while in Japan and China it is equally noticeable, many of the salt-workings of the latter country having been lighted with natural gas from time immemorial. The salt mines of Szalino in Hungary are similarly illuminated.

An early article by Dr. S. P. Hildreth on the saliferous rock in the valley of the Ohio, now known as the Pottsville Conglomerate, is of interest in this connection:—"All salt wells afford more or less of this interesting gas—an agent intimately concerned in the free rise of the water, and universally present where salt-water is found. Indeed, so strong is the evidence afforded by the rising of this gas to the surface, of the existence of the salt rock below, that many wells are sunk on this evidence alone. It is, without doubt, a product of the saliferous formation, as it rises in many wells without any appearance of petroleum. . . . In many wells salt-water and inflammable gas rise in company, with a steady flow. In others the gas rises at intervals of ten or twelve hours, or perhaps as many days, in vast quantity, and with overwhelming force, throwing the water from the well to a height of 50 or 100 feet in the air. . . . A well on the Muskingum, 10 miles above McConnelsville, at 600 feet in depth, afforded such an immense quantity of gas, and in such a constant stream, that, while they were digging, it several times took fire from the friction of the iron on the poles against the sides of the well, or from the scintillations from the auger, driving the workmen away and communicating the flame to the shed which covered the works."

The district of Baku was formerly highly esteemed for its rock-salt, and the Miocene oil-fields of Galicia and Rumania include valuable salt deposits. On the other hand, extensive masses of salt often exist without appearance of oil or gas in commercially noticeable quantity, as is particularly the case with the rich beds of England and Salzburg. The earlier attempts of chemists to explain the origin of petroleum frequently included the consideration of salt as a factor in the process, but modern theories usually ignore it, the brine which is present in most fields being regarded as merely the normal state of water traversing deep-lying strata, whilst the absence of salt from porous beds of marine origin is a natural result of the continual lixiviation by percolating rain-water. Petroleum can only occur in undiminished quantity where the structure precludes its escape or replacement by water, practically the same state of protection as is essential to the existence of masses of rock-salt or of concentrated brine. At the same time, the frequent connection of petroleum, salt, and dolomitised rock, suggests some obscure chemical reaction as essential to the formation of the oil from its parent organic matter, involving the presence of magnesian salts, such as concentrated sea-water would furnish.

Pressure in Wells.—The oil and gas frequently issue from the wells at great pressure, more especially when first liberated. This pressure is sometimes so great that, when the oil stratum is reached, the boring tools are expelled from the borehole, and the oil escapes in a fountain rising high above the derrick, and frequently resisting all attempts to control its flow. Such "spouting" wells or "fountains" of oil have been particularly frequent in Russia, and have often resulted in great waste, and even in ruin to the owners of the well, as described in the previous section (p. 7).

In the gas-wells of the United States the gas pressure has in many cases been very carefully measured. It may be ascertained either by placing a pressure-gauge in the freely escaping gas as it issues from the casing, in which case the pressure is described as "open pressure," or by measuring the actual pressure in the closed well, when it is termed the "closed pressure." The latter method alone, which measures the true rock-pressure, yields data which assist researches into the conditions under which the oil and gas are contained in the earth.

The strongest pressures occur in the deepest wells. The closed pressure in the Trenton Limestone in Ohio and Indiana is about 200–300 lbs. per square inch, although a much higher pressure has been registered in many wells, notably the Loomis & Nyman well at Tiffin, which showed over 600 lbs., and the Pioneer well at Findlay, which yielded its gas at 450 lbs. closed pressure. The gas-wells of Pennsylvania indicate about double the pressure of those drilled in the Trenton Limestone, 600–800 lbs. not being unusual, and even 1000 lbs. having been recorded.

Cause of the Pressure.—Three theories have been propounded as to the cause of this pressure :—

1. That it results from the weight of the overlying strata.
2. That it is due to water pressure, as in artesian wells, the percolating water which enters the stratum at its outcrop forming the "head."
3. That it is caused by the gradually accumulating gas having had no opportunity for escaping, and being thus brought into a highly compressed condition.

The first theory is evidently untenable, and is now practically abandoned. Even the most friable of the reservoir-rocks is capable of resisting the pressures of the overlying deposits ; thus, the weakest portions of the Trenton Limestone have been shown to withstand a crushing weight of 720 tons to the square foot, whereas the pressure on the stratum at the bottom of a well of over 1000 feet in depth would only be about 80 tons. The rocks are also found perfectly compact at all depths reached by the drill.

The second theory, generally known as the "hydrostatic" or "artesian" theory, has many distinguished advocates, and has been particularly upheld by those who have closely studied the great gas-fields of Ohio and Indiana ; while, on the other hand, it appears to be quite inapplicable to the fields of Pennsylvania and New York, where, if not in all other fields, the third theory is evidently perfectly tenable. This was brought into prominence by Professor I. C. White in 1887, but is strongly controverted in the reports of Dr. Orton on the oil- and gas-fields of Ohio and of Kentucky.

As a general rule, the water in the wells drilled into the Trenton Limestone in Ohio and Indiana rises to about 600 feet above sea-level, when the gas and oil have been exhausted. Thus, in a well at Lindsey, Sandusky county, Ohio, the water rose to 600 feet above tide-level when the well became "dry," while at Huntington and other districts in the Wabash valley, a rise of 615 feet above tide-level has been observed. These observations coincide with the outcrop of the Trenton Limestone on the shores of Huron and Superior, at about 600 feet above tide-level.

Dr. Orton has calculated the pressure which should be found in wells at certain depths, if produced by a head of water equal to the depth of the well below lake-level, and has found remarkable agreement with the actually measured pressures in many wells of Ohio. He considers that his results distinctly prove that "the rock pressure of Trenton limestone gas is due to a salt-water column measured from about 600 feet above tide, to the level of the stratum which holds the gas."

A notable exception to this general rule is furnished by the Simon's well in Wood county, Ohio, where a pressure of 520 lbs. has been noticed, a greater pressure than has been observed in any other part of the field. It corresponds to a head of 1090 feet of water, and cannot, apparently, be accounted for on the artesian theory. According to Dr. Orton, the great rock pressures in Pennsylvanian gas-wells may be also explained by the artesian theory.

Professor W. J. M'Gee explains the pressure of the gas of Indiana on this hypothesis as follows:—"The cause of this enormous pressure is readily seen in Indiana. The Cincinnati arch (in which the gas of the great Indiana field is accumulated) is substantially a dome about 50 miles across, rising in the centre of a stratigraphic basin fully 500 miles in average diameter. Throughout this immense basin, the waters falling on the surface are, in part, absorbed into the rocks and conveyed towards its centre, where a strong artesian flow of water would prevail were the difference in altitude greater; and the light hydrocarbons floating upon the surface of this ground water are driven into the dome, and there subjected to hydrostatic pressure equal to the weight of a column of water whose height is the difference in altitude between the water surface within the dome and the land surface of the catchment area about the rim of the enclosing basin. Accordingly the static pressure is independent of the absolute altitude of the gas-rock and of its depth beneath the surface, except in so far as these are involved in the relative altitudes of the gas-rock and a catchment area, perhaps scores or even hundreds of miles distant. Gas pressure and oil pressure may, therefore, be estimated in any given case as readily and reliably as artesian water pressure; but whilst the water pressure is measured approximately by the difference in altitude between the catchment area and well-head, that of gas is measured approximately by the difference in altitude between catchment area and gas-rock, and that of oil is measured by the same difference, *minus* the weight of a column of oil equal to the depth of the well. It follows that the static pressure of gas (as indicated at the surface) is always greater than that of oil, particularly in deep wells. It follows, also, that the pressure, whether of gas or oil, is not only constant throughout each field, but diminishes but slightly, if at all, on the tapping of the reservoir, until the supply is exhausted; and hence that pressure is no indication of either abundance or permanence of supply."

The artesian theory is somewhat supported by the fact that water rises in the wells of Ohio and Indiana as they become exhausted, for, says Dr. Orton, the cause which raises the oil and gas must be the same which operates upon the water, and can only be of artesian origin. It is, however, strongly opposed by Prof. J. P. Lesley, Mr. J. F. Carll, and others. In his letter of transmittal of Carll's *Seventh Report on the Oil and Gas Wells of Western Pennsylvania*, 1890, Lesley states his belief that the hydraulic pressure head at the Trenton outcrop in Canada could never account for the well-pressure one or two hundred miles to the south, and adds:—"Considering all the local underground obstacles to free flow, I cannot think that even the highest gas pressure should maintain itself against rock friction for even so short a distance as 20 miles."

In that report (p. 13) Mr. Carll remarks that he has never witnessed or heard of a single circumstance to support the artesian hypothesis, and states that "the theory, as applied to Pennsylvanian oil- and gas-wells, is delusive and untenable, and the cause of the great rock pressure witnessed must, therefore, be sought for in some other direction."

He further points out that if oil-wells are subject to hydrostatic pressure the flow should be constant while it lasts, and dependent on the speed with which the water enters the oil-rock reservoir. After displacing the oil, water ought to follow. Yet it is found that the output decreases gradually, and sometimes rapidly, and the wells may be pumped for years, even with gas-pumps, without being flooded by water. Gas-pumps have been used in the Triumph district since 1869, and the exhaustion is such that a vacuum-gauge at any of the wells registers a vacuum of 12 to 13 lbs. per square inch.

As regards the low pressure from the Ohio and other shales, Dr. Orton observes that the artesian theory does not apply.

The Association of Mud-Volcanos with Petroleum.—In Russia and India the relation between petroleum and mud-volcanos is very noticeable. In the former country the presence of these volcanos is usually considered a favourable indication of the presence of petroleum, as has been asserted by Prof. D. I. Mendeléeff and others. They are found in the neighbourhood of the Balakhani and Binagadi fields of the Apscheron peninsula, and are frequent in the Crimea and the Taman peninsula, Venezuela, and northern Colombia. The oil of Minbu and of the Island of Rámri in Burma also occurs in the immediate neighbourhood of mud volcanos. Wall has described the mud volcanos of Trinidad, whilst Ansted and others have described those of Pescara in Italy. In the copious literature of the subject, Galicia is not credited with any such, but Mr. W. H. Dalton observed a very fine extinct specimen, a few miles south-east of Sloboda Rungurska, and on the prolongation of the axis of that once famous oil-field. Such mud volcanos are not found in the United States and other petroleum districts where the oil strata belong to early geological periods, chiefly, if not entirely, because of the absence of incoherent material in those older beds. Prof. S. F. Peckham regards the occurrence of these volcanos, and of hot springs generally, as merely the natural accompaniment of metamorphic change, and as not possessing any significance in regard to the occurrence of petroleum. Höfer has expressed a similar opinion, and has pointed out that their ejecta are only obtained from the shallower deposits. There is less real than apparent conflict between these views. Epigenic metamorphism may, and frequently does, occur in the absence of any trace of petroleum, giving rise to thermal springs of no commercial significance. Simple hydrostatic pressure, in what may be termed natural artesian wells, produces similar mud-cones in soft material, easily removed by the rising water, a condition less common among the more compact beds of the older geological periods. But in any case such cones indicate the lines along which fluids under pressure are seeking release, and eroding their upward passage. When oil is present, such indications are not to be disregarded as guides to the structure of the region. These phenomena have but a superficial resemblance to those of true volcanic action, fluidity and pressure being the only elements in common. The "bonds" of the Plain of Bière, Vaud, and the mud-volcanos of the Mekran coast are instances in which no trace of petroleum exists.

Duration of the Oil and Gas Supplies.—As to the probable length of life of the various oil- and gas-fields, considerable doubt still exists, new districts being continually opened up and adding to the production as the older-worked fields become exhausted. The history of the oil districts of the New World, where many celebrated fields are now rapidly on the wane, or are totally deserted, points conclusively to the steady exhaustion of all the oil and gas strata which have yet been worked; and the famous fields of Baku have within the last decade shown signs of decreasing productivity, as have less important areas in other parts of the world.

There can be no doubt that the production of petroleum, whether of organic or mineral origin, is still going on in strata where the conditions are favourable; but the oil districts which have been most largely worked, and of whose geological nature we know most, appear to have long since passed from that stage, and to be now merely reservoirs, which, when denuded of their present contents, will remain barren.

Prof. J. P. Lesley, in an address delivered before the American Institution of Mining Engineers in Pittsburgh in 1886, says:—" . . . I am no geologist if it be true that the manufacture of oil in the laboratory of nature is still going on at the hundredth or the thousandth part of the rate of its exhaustion. And the science of geology may as well be abandoned as a guide if events prove that such a production of oil in western Pennsylvania as our statistics exhibit can continue for successive generations. It cannot be. There is a limited amount. Our children will merely and with difficulty drain the dregs. I hold the same opinion respecting gas, and for the same reasons, with the difference merely that the end will certainly come sooner and be all the more hastened by the multiplication of the gas-wells, and of the fire-boxes and furnaces to which it is led."

Mr. Carll thus reviews the position of the oil industry of Pennsylvania and New York at the beginning of the year 1889:—" Glancing over the chain of oil-pools which now extends entirely across the western part of the State, and overlaps both in New York and West Virginia, one cannot fail to be impressed with the fact that very few fresh or undepleted fields of production are in sight; and no very wide untested areas where others of promise may be concealed remain within the limits of the productive rocks as defined by the drill and verified by twenty-nine years of persistent investigation. . . . We have seen that all the old districts are on the decline. The drilling of many wells in developed territory, and the discovery of occasional pools of small capacity, may keep up present production, or even increase it temporarily, but there is nothing to warrant the hope that these old fields may be resuscitated and their production brought up even to that of 1886."

On page 12 of that report he states that " it is highly probable that the northern gas mains, delivering from the older and more moderately taxed rocks, will be in successful operation after the southern have practically exhausted their accumulated supplies."

Affinity of Clay for Petroleum. Dr. Orton, Mr. Topley, and others have referred to the peculiar power possessed by clay of absorbing petroleum. The first observation on the subject appears to have been that of Prof. Joseph Leidy, quoted by Dr. Orton, that:—" On the bed of the Schuylkill River, for some distance below the Philadelphia Gas Works, a deposit of clay impregnated with the petroleum-like oils that are produced in the manufacture of coal gas is in process of formation. These oily substances, which would otherwise be found on the surface of the river, are absorbed by the particles of fine clay in the water, and gradually sink to the bottom with them, there forming a petroliferous clay on the river bed."

Mr. Topley (1891) says:—" Some clays seem to have a curious affinity for petroleum, which enables them to contain more oil than we should expect. It has often been noticed that petroleum which runs to waste down a river-bank will generally float on the water, but if the banks consist of soft clay, the oil trickles down under the water, and soaks into the clay."

Dr. Orton observes that oil-bearing shale might be produced by the absorption by clay of the petroleum rising through water from submarine or underground springs, " such as occur in Central and South America."

Skey (1875) maintains that the absorption is not of a mechanical nature, but a true chemical combination, a conclusion opposed by the varying proportions of oil imbibed by clay, as found in his own experiments.

The absorptive process is probably facilitated by the spontaneous separation, in water, of the constituent oils present in all crude petroleum. Coquand thus describes the phenomena of the historic pitch-spring of Zante:—"From the bottom rise every instant bubbles of the size of lentils or peas, producing a patch of naphtha-film on the surface. Directly afterwards, threads of coffee-brown tarry petroleum radiate through the patch of opalescent film, forming an irregular aureola. Finally the bubble bursts, making a circular space of water free from film. These floating islets, consisting of three zones, and of 3 to 5 centimetres in diameter, follow the current to the mouth of the gutter. In the marsh they cling to the reeds, covering the surface with an iridescent, kaleidoscopic film. The pitch, having lost its naphtha, sinks to the bottom."

Ozokerite.—Although the liquid and gaseous petroleums may be regarded as formed in, or received shortly after their formation by, the strata in which they are found, the solid and semi-solid varieties (such as the ozokerite of Galicia, Utah, etc., and the bitumens and asphalts of Germany, France, and West Indian Islands, and parts of the United States) may be considered as formed precisely as mineral veins are produced, primarily, by oxidation and evaporation of liquid petroleum, which continually oozes from deeply-seated or better-covered deposits, into other strata or into fissures where atmospheric influence or evaporation are free to act. Where oxidation has proceeded far, a tar-spring or asphalt-rock is produced, whilst, when such change is prevented, and evaporation alone takes place, the solid constituents are merely concentrated, with the production of the substances known as ozokerite, albertite, gilsonite, grahamite, etc., of which the more important are described in the next section.

Ozokerite and allied products occur in many formations, though chiefly confined to the Tertiary and Cretaceous. Ozokerite is found in Scotland, Northumberland, Wales, Spain, Belgium, Italy, Servia, Rumania, Transylvania, Galicia, Moravia, Bohemia, Upper Austria, Thuringia, Westphalia, East Frisia, Finland, Kuban, Terek, Daghestan, Kutais, Tcheleken, Trans-Baikal, Ferghana, Trinidad, Persia, Egypt, Great Manitoulin Island (Canada), New Jersey, Oregon, Utah, Arizono, Texas, and apparently Brazil. In many cases, but chiefly in the Tertiary deposits, ozokerite is associated with rock-salt, and often with gypsum.

Asphalt Rock.—This is usually a sandstone or limestone charged with the indurated tar, generally to the extent of less than 10 per cent. It is invariably an out-cropping stratum, and is never found in borings which extend below the level of the valleys. The typical "Chester asphalt rock" of western Kentucky is produced by the slow passage of the oil from the St. Louis Limestone into an overlying stratum of sandstone about 80 feet in thickness. The body of the rock is usually found to be formed of fine, unconnected particles which become separated when the asphalt is removed by solvents. In the case of the European asphalts of Val de Travers, Seyssel, Forens, Lobsann and Limmer, the base is limestone, whilst the Californian and Kentucky asphalt-rocks are formed in sandstone.

General Distribution.—On referring to the frontispiece and other illustrations, it will be seen that whilst petroleum exists very generally distributed throughout the world, the principal deposits occur along well-defined lines, often associated with the principal mountain ranges. This relation is partly due to the necessary coincidence of lines of upheaval and strike, but chiefly to the production, in the elevatory process, of minor folds, which have arrested and collected the oil in richly productive belts, between more or less barren areas.

As fields of little or no importance alternate with, and form connecting links between, the larger and more valuable regions, the occurrence of oil will be dealt with in this section on a purely geographical basis of arrangement, irrespective of commercial relations.

Although carburetted hydrogen, as the first term in the hydrocarbon series, logically calls for mention in this work, emanations from coal-seams, whether natural or the result of human operations, are too universal to admit of reference in detail, except in cases where the yield is such as to be of commercial utility. The same rule has been observed in respect of the petroleum gases arising from wells or natural outlets in recognised oil-fields. Where, however, such gases, simple or complex, are evolved from rocks not containing coal-seams, or independent of known stores of petroleum, the fact is worthy of record, either for its bearing on the problems connected with the origin and distribution of bitumens, or as a guide in the search for new oil-fields.

On the other hand, the occurrence of bituminous rocks is so frequently associated with the presence of petroleum, asphalt, or other bitumen, that wherever the amount of such impregnation is exceptional, the fact should be noticed, whether commercial utilisation has yet been commenced or not. The exterior of such deposits is generally somewhat impoverished by its exposure to oxidising influences, and does not afford an adequate criterion of the quality of the unaltered mass within.

References, in the most condensed form, to the voluminous literature laid under contribution for the remainder of this section, would occupy more space than the text, and are perforce omitted, being replaced by the Bibliography (in vol. iv).

BRITISH ISLANDS.

Numerous indications of petroleum in England and Scotland have already been mentioned in the preceding section of this work, and need but the barest reference in their geographical order. In Ireland the only occurrences seem to be in the pores of igneous rocks that have traversed more or less bituminous strata, and absorbed and modified volatile hydrocarbons in their progress. Instances are recorded at the Giant's Causeway (Antrim) and Newry (Down).

Modification into dopplerite and kindred substances of the deeper-seated peat of some of the Irish bogs has occasionally given rise to reports of the occurrence of petroleum in those situations. The so-called butyrellite, or "bog-butter," has been demonstrated to be normal butter, with interspersed hairs from the cow, and remains of the wrappers in which it was enclosed for storage in the antiseptic peat.

In Scotland the beds of the Old Red Sandstone are highly bituminous in some parts of the Orkney Islands, Caithness, and Inverness, containing in places as much as 30 per cent. of volatile matter, and petroleum is alleged to have been found on the Orkney Mainland. Albertite occurs in the same series on Hoy, whilst in Ross-shire, over a considerable area around Dingwall, veins of this mineral occupy many of the joint-fissures of the conglomerates, sandstones, and shales. In a basalt-dyke in these beds at Cupar, Fife, the freshly broken surfaces are found to be "quite moist with naphtha, which quickly evaporates." Apparently the bitumen is due to distillation of neighbouring shales. In the succeeding Carboniferous system, the localities of Dysart (Fife), Broxburn (Linlithgowshire), and Liberton (Edinburghshire), have already been mentioned, and the oil-shales extending from West Calder to Burntisland will be described in a subsequent section. Thin seams occur in Fife at Crail, Markinch, Kinglassie, and St. Davids. Liquid petroleum and gas occur in the shale at Broxburn and Pumpherston, and ozokerite in the associated sandstone at Binny. In connection with the abundance and variety of bitumens in the Carboniferous rocks of the Forth basin, it may be remarked that the igneous rocks which traverse them have taken up some of the hydrocarbons, impoverishing the strata in their immediate vicinity. The absorbed matter exists partly as fluid petroleum in the fissures of the basalts, chiefly as ozokerite occupying the gas-blown vesicles of the amygdaloidal dolerites. Similar phenomena are recorded at Kinghorn Ness, on Inchkeith Island, and on Calton Hill, Edinburgh. Ozokerite has also been found in the peat of Loch Fyne, Argyllshire.

In England petroleum and mineral wax occur in the Coal-measures of Whitehaven, Cumberland, and carburetted hydrogen is discharged in the adjacent hæmatite mines in the Carboniferous Limestone of Cleator Moor. Ozokerite is found in the Coal-measures of Morpeth, Northumberland, and carburetted hydrogen in the Triassic salt series of Middlesbrough, North Yorkshire, with petroleum in the subjacent Permian and Lower Carboniferous (Yoredale) rocks. The Cleveland Middle-Lias ironstone is locally charged with oil-gas, and the Upper-Lias shales often contain visible oil in joints and hollow fossils. Good illuminating oil has been distilled from them to the amount of ten gallons per ton. In the West Riding Coal-measures, petroleum has been found at Hemsworth and Dinnington, and oil-shales yielding twenty to twenty-four gallons per ton occur in the measures above the Flockton "Thick" coal. In the southward extension of the coal-field, petroleum has been collected at Clowne and Riddings in Derbyshire, the short-lived flow being in some cases of commercial value as a lubricant. Recently, in a boring carried out to prove the eastward extension of the field, petroleum was met with near Kelham, in Nottinghamshire. The elaterite of Castleton exudes from the Carboniferous Limestone as a pale-yellow tar, passing to the better-known condition of dark-brown elastic "mineral india-rubber" by evaporation of volatile ingredients and oxidation. In the same region and series, discharges of carburetted hydrogen, and masses of more or less liquid bitumen have been met with in the lead-mines. The Lancashire Coal-measures yield petroleum at Wigan, West Leigh, Worsley, and Swinton, whilst the peat-oil of Down Holland Moss, Formby, as described in the previous section, is of very recent formation.

In Staffordshire oil occurs in the Coal-measures of Longton, and bitumen in Triassic sandstone at Bearwood Hill, near Burton-on-Trent. Gas is present in the Triassic salt-beds of Cheshire, and oil in the same series at Anderton, near Northwich. The petroleum of Ruabon, Denbighshire, previously mentioned, is of Permian age, whilst gas and bitumen occur in the Carboniferous Limestone of the Flintshire lead-mines. The Shropshire Coal-measures yield the oil of Wellington, Coalbrookdale, Coalport, and Pitchford, already described. Occurrences of bitumen in the Cambrian rocks, of Houghmond and Pontesford Hills, 3 miles east and 7 miles southwest, respectively, from Shrewsbury, and in the lead-veins of Snailbeach Mine, some 3 miles further in the latter direction, and in Lower Silurian rocks, are probably the residue of the Coal-measures once covering the area, but now removed by denudation. A discharge of inflammable gas in the Van Mine, Llanidloes, Montgomeryshire, in Lower Silurian beds, is less easily explained. An alleged discovery of petroleum in the Tregaron district of Cardiganshire has had no verification. Ozokerite has been observed in ironstone nodules of the Merthyr Tydvil Coal-measures at Dowlais, Glamorganshire. The Liassic petroleum of the Bristol district, and that in the Carboniferous Limestone near Ashwick, Somersetshire, call for no further remarks than those made upon these localities in the previous section. In the upper Devonian shales of Barnstaple, North Devonshire, a vein impregnated with mineral oil was found in 1871, and oil is said to have contaminated a well in the Torquay district. The Eocene lignite of Bovey Tracey contains retin-asphalt. In the Carharrack copper-mine, near Gwennap, Cornwall, at a great depth, a quantity of bitumen occurred in the veinstone and surrounding granite, and mineral pitch has also been found near St. Agnes. Early in the year 1912 a boring near Willesden was reported to have met with traces of petroleum in the Devonian series. The gas encountered in the Thames tunnel, as mentioned on p. 42, was probably derived from organic remains in the alluvial deposits. The Kimmeridge Clay, as described in a later section, has been mined in Dorsetshire for distillation, and the same beds were found to be more or less saturated with petroleum in the deep sub-Wealden boring near Battle, Sussex. Not far from this, at Heathfield, sufficient gas for local illumination is obtained from borings in the Purbeck beds, somewhat higher in the Jurassic series. Two or three miles eastward of this, these beds have been found, by distillation, to yield a wide variety of hydrocarbons, but not to commercial advantage, whilst in the yet higher Hastings Sand series a discharge of gas is recorded at Mayfield, some 4 miles north of Heathfield, and in West Sussex gas has been found in the Weald Clay at Hawkhurst, 3 miles to the east of Petworth. A discharge of gas of high-illuminating power took place from a recent boring in the Oxford Clay, near Calvert station, a few miles southward of Buckingham.

In a recent report, with a preface, dated 12th June 1918, the Director of the Geological Survey has given much valuable information on the occurrence of mineral oil and oil-yielding minerals in Great Britain.[1]

PORTUGAL.

Bituminous deposits occur in Rhætic strata, accompanied by ophite, near Monte Real, Leiria; in the region westward of Alcobaca; and near Torres Vedras. There are numerous beds outcropping from which bitumen oozes. Several wells drilled in the monoclinal beds of this region failed to disclose oil-bearing seams of commercial importance, although oil traces were frequently met with. The calcitic amygdules of the basalt of Sicario, near Cintra, are partly charged with petroleum.

SPAIN.

Asphalt occurs at the port of San Lucar de Barrameda, Cadiz, probably exuding through alluvial deposits from Triassic rocks which lie at no great depth below. The same series affords traces of petroleum at St. Elmo, near Jerez; at Conil, 25 miles southward; at Arcos, Rubi, Espera, Villamartin, and Algar. Trial-borings at Conil and Algar have as yet failed to obtain oil in commercially-valuable quantity. Bituminous sandstone of Liassic age is mined near Grazalema. Extensive deposits of oil-shale occur in the Ronda district, Malaga. Asphaltic sandstone is worked in the Upper Jurassic beds west of the Guadiaro, opposite Gaucin. The Eocene of Manilva, 18 miles northward of Gibraltar, is charged with asphalt. In Almeria asphalt is found in the Pliocene of the Sierra Alhamilla, northeastward of the capital, and in the Miocene of Tijola, Bayarque, and Cobdar, some 30 miles northward. Petroleum occurs at Cueva de la Pez, near Bayarque. The Miocene marls of

[1] *Memoirs of the Geological Survey.* "Special Report on the Mineral Resources of Great Britain." Vol. VII. Lignites, Jets, Kimmeridge Oil-Shale, Mineral Oil, Cannel Coals, Natural Gas. Part I.—England and Wales. By A. Strahan, D.Sc., LL.D., F.R.S. With Contributions by J. Pringle.

Lorca, Murcia, contain asphalt, and dysodile and elaterite occur in the highly bituminous Miocene of Hellin, Albacete. In Guadalajara, asphalt and petroleum are recorded in the Triassic sandstone of Siguenza and Molina de Aragon, and oil-shale at Valdesotas and Retiendas, 25 miles northwestward of the capital, at the contact of the Carboniferous and Cretaceous series. Petroleum is vaguely reported from the Triassic rocks of Soria, and asphalt is found in the Lower Cretaceous at several points between San Leonardo, Casarejos, Fuentetoba, Villaciervos, Villaverde, and Toledillo, lying west and northwest of Soria. Petroleum and asphalt saturate the Neocomian sandstones of a small isolated field at Huidobro, 30 miles north of Burgos, and similar conditions obtain over a considerable area on the border of Burgos and Santander, from Hoz de Arriba to Santa Gadea and Rozas. The northern extension of the same series contains oil and asphalt at Resconorio, near the top of the Luena valley, 40 miles northeast of Reinosa; at Puerto del Escudo, a few miles eastward; at Purbayon, south-southwest of Santander; and at Suances, north of Torrelavega. Westwards the Devonian sandstones of Corrada, near Pravia in Oviedo, are charged with bitumen. In Alava, asphaltic sandstone of Lower Cretaceous age occurs south of Penacerrada, 15 miles south of Vittoria, and oil has been distilled, though unprofitably, from the Oligocene limestones and sandstones lying to the northwest of Penacerrada. Asphalt is mined in the Upper Cretaceous and Eocene limestones of Maestu and Atauri, the deposits extending northeastward by Encia, Urbasa, and Salvatierra, to Bacaicou, Navarre, 23 miles westward of Pamplona. The asphalt of Torrelapaya, on the Zaragoza-Soria border, is probably of Cretaceous age. In Teruel, the Upper Neocomian contains beds of highly bituminous shale, those of Rubielos de Mora yielding, upon distillation, as much as 32 per cent. of oil. The Neocomian marls of Ribesalbes, 11 miles west of Castellon de la Plana, are of similar character. Tarry bitumen is found in the Miocene of Margalef, 30 miles west-northwest of Tarragona. The Eocene marls at Santa Catalina, near Manresa, and on the Montseny range at Campins, 34 miles eastwards, are sufficiently bituminous to have induced brief and unsatisfactory attempts at distillation, as is also the case at Vilada, Baga, and Broca, east and north of Berga. The Cretaceous limestones are charged with asphalt at Valldan, west-southwest of Berga, at Broca, and at Saldes, west of Baga. In Gerona, asphaltic shales and ozokerite are found in the Eocene of Campdevanol, 17 miles west-northwest of Olot, and petroleum at San Juan de las Abadesas, 6 miles east of Campdevanol. Oil also occurs at San Lorenzo de la Muga and Pont de Molins, west and north of Figueras.

FRANCE.

Except in Alsace-Lorraine, now restored to France, no commercial yield of fluid bitumen has been found in France, although oil-shale and asphalt-rock constitute the basis of important industries. These deposits will be described in a later section, the localities being briefly mentioned here.

In the western parts of the Basses-Pyrénées and Landes, traces of petroleum, and more or less valuable deposits of asphalt, occur at Dax, St. Pé de Leren, Castagnède, Cassaber, Saliès du Bearn, Bérenx, Salles Mongiscard, Ste. Suzanne, Orthez, St. Boës, Gaujac, Bastennes, Caupenne, Mont de Marsan, and Cazères. The Cretaceous rocks are the principal producers of the bitumen, which is believed to be really derivative from the subjacent Trias, whilst Eocene and Miocene occupy much of the surface, and it was from Miocene sands, charged with 9 per cent. of asphalt, that Bastennes at one time enjoyed a large export trade. At several points in the district local epigenic modification of the rocks has, as in southern Spain and Algeria, produced a misleading superficial resemblance to Triassic strata. Bitumen occurs at Limoges, Haute Vienne, in quartz-veins traversing Archæan gneiss, etc. Oil-shales are found in a narrow strip of Coal-measures at Faymoreau, near Puy de Serre, La Vendée, and elaterite in Lower Carboniferous beds at Montrelais, on the Loire, about 30 km. westward of Angers. Carburetted hydrogen issues from Archæan schists and diorite at Pontpéan, Ille-et-Vilaine, probably derived from adjacent lignites of Oligocene age. An ozokerite-like matter can be extracted by solvents from the peat of the Aven valley, Finistère, and from that of the Somme valley. Discharges of carburetted hydrogen are recorded from Eocene pottery clay at Vanves and Malakhoff, southwestern suburbs of Paris. A discovery of petroleum at Beuvry, near Bethune, Pas-de-Calais, was reported in 1908, and asphalt is said to occur in the Coal-measures of Aniches, Nord. Inflammable gas emanates from Triassic rock-salt at St. Laurent, Meurthe-et-Moselle, and a bituminous spring is recorded from the Lias of Fraine-on-Saintois, 11 km. south of Vézelise. Carburetted hydrogen is discharged from the Lower Carboniferous rocks of the Giromagny mines, Haute-Saône, and from many of the Triassic "salines" of the Franche-Comté. Highly bituminous shales of Liassic age occur at Saulx, Haute-Saône, at Châtillon-le-Duc (8 km. north of Besançon) and Mouthier, Doubs, and at Thizy, 14 km. north-east of Avallon, Yonne, and asphaltic limestone of the same series exists at Vassy, 9 km. east of Thizy. Extensive operations in oil-shales of the Permian or Upper Carboniferous series at Autun, Saône-et-Loire, and Buxière, Allier, will be described in a later section.

In the Puy-de-Dôme the Miocene limestones and sandstones, and the volcanic tuffs and lavas which traverse them, are saturated with viscid oil at many points around Clermont Ferrand, chiefly at Menat, Prompsat, Pont Battu, Lussat, Malintrat, Pont du Château, Cebazat, Lempdes, Cœur, Chamalières, Royat, and Flat. It may be mentioned that at some points the bitumen has filled crevices in the basal granite of the district, forming veins which would have been singularly problematical, had the parent Tertiary deposits been entirely removed by denudation. The metalliferous veins of the Archæan gneiss of the adjacent district of Pontgibaud have occasional traces of similar infiltration. Bitumen is found in Oligocene beds in the Haute Loire south of Le Puy, at Coubon, Malhac, Lausanne, Monatsier, etc. The valuable oil-shales of Vagnas, Ardèche, are of Miocene age. Carburetted hydrogen is discharged in the Jurassic iron-ore mines of La Voulte, and bitumen occurs in geodes of the somewhat older ore of Privas. In Gard, a wide range of formations yields more or less asphalt, viz. the Carboniferous, Triassic, Liassic, Jurassic, Neocomian, Cretaceous, Eocene, and Miocene. Traces of petroleum occur in the hollow fossils of Liassic limestones at Avelas. The Eocene lacustrine limestone, with seams of lignite, is highly asphaltic at St. Jean de Marvejols, Auxon, Hyeuset, les Fumades, Servas d'Olivier, and other points around Alais, and the bitumen of Barjac is from a somewhat higher horizon of the same series. At Servas the Neocomian limestone is also bituminous.

Bituminous matter is associated with the Eocene rock-salt of Saliès-du-Salat, Haute-Garonne, and of Camarade, Ariège. The Upper Cretaceous of Taurignan has traces of bitumen, which also impregnates the Eocene clays of La Bastide de Boussignac, Ariège, and colours the black Jurassic dolomites in several parts of the Pyrenees. The "burning fountain" near the Salles d'Aude, Narbonne, is due to an emission of carburetted hydrogen from much-disturbed, apparently inverted Oligocene beds. It is odourless, devoid of sulphur compounds, and burns with a red smoky flame. In Hérault, Gabian has been known since 1711 to possess a petroleum-spring, but a boring to 413 metres yielded no satisfactory result. The rocks have been assigned to the Trias, but are probably Miocene, as are also those showing traces of oil at Gaboux, Vendres, and other places southward of Béziers. Emanations of inflammable gas have been observed in the Eocene fireclay of Bollène, Vaucluse.

Asphaltic sandstones and limestones of Oligocene age, yielding 10 to 13 per cent. of asphalt, are found northwestward of Manosque, Basses-Alpes, and oil-shale has been mined and distilled on a small scale in the same region. Oil-shales of the Permian series are being worked in the Boson field, near Fréjus, Var. Jurassic shales of bituminous character form part of Mont-Braisier, between Serres and Laragne, Hautes-Alpes, and explosions, accompanied by flame, are recorded as resulting from the firing of gas, either accidentally or by the heat of oxidation of pyrites. By analogy with phenomena elsewhere known to be connected with petroleum, its presence here may be suspected, possibly in valuable amount. Gas and asphalt occur in Liassic marls northwest of Buis les Baronnes, on the Aigues above Noyons, Drôme. The "burning fountain" of St. Barthélemy, near Grenoble, Isère, is due to oil-gas emanating from Liassic marls and limestone, and utilised, as described by Tardin, in 1618. A fruitless boring was here carried to 198 metres.

Carburetted hydrogen is evolved from Miocene rocks at Prêle, near Châtillon, Haute-Savoie, and is utilised for domestic purposes; a little oil has also been found here. On the western side of the department, in Ain, and in the adjacent parts of Switzerland, occur asphalt-rocks of varying value. On the left bank of the Rhone they extend from Chavanod, by Frangy, Lovagny, Bourbouges, Volant, Challonges, and Chavornay, to Chavaroches. These (some nearly worked out) are in the Neocomian (Urgonian) limestone, which is said to be devoid of bitumen in the rest of the Faucigny Alps.

Crossing the Rhone into Ain, we find asphalt in Jurassic limestones around Belley, at Orbagnon, Lutézieux, Charencin, Cormaranche, and Pontnavey. Ascending the right bank of the Rhone, the Urgonian limestone recurs, with the famous "Seyssel" asphalt of Pyrmont, extending by Perte du Rhone and Bellegarde, to Thoiry, and up the Valserine valley from Bellegarde by Lancrau to Lelex and Forens, near Chézery. The rock of Lelex is said to have too much petroleum to be worked for asphalt, an indication of imperfect oxidation of the original oil. The Lower Miocene of this region is occasionally petroliferous, and contains three workable seams at Boge, just above Lancrau. The exploratory operations carried out by M. Pochon in 1892 consisted of a cross-cut and several galleries, with a tunnel following the slope of the principal seam. The dip is eastward, at 60° to 70°, and but little timbering is requisite. Near the surface, the sands are brown and loose, having lost the hydrocarbon they once held, but at a depth of 7 metres they are black and coherent, being protected from further oxidation. The workings present a strong resemblance to the Pechelbronn mines of Alsace, and the similarity is further observable in the character of the impregnating oil, which is blackish, semi-fluid, and (when taken from near the surface) of a density of 0·975. At Pyrmont the Miocene also is bituminous.

Alsace.—In Upper Alsace, emanations of carburetted hydrogen are on record in the iron-mines of Wickel, 27 km. west-southwest of Basel. The ore is granular hydrous peroxide of iron, probably of Eocene age, resting on Lower Jurassic rocks. Borings in the Oligocene clays of Nieder-Sept, 11 km. northwestward, found traces of petroleum, which is alleged to occur also at Ueberstrass, 2 km. northwest, and Bisel, 3 km. east, of Nieder-Sept; at Köstlach, 5 km. southeast, and Rüderbach, 5 km. northeast, of Bisel; and at

Bettendorf, 2 km. north of Rüderbach. The name of Oelbach for a brook falling into the Ill at Hirzbach, 4 km. west-northwest of Bettendorf, and 3 km. south of Altkirch, is due to films of oil, which led to brief and unprofitable operations in 1782–1785, and 1817–1820. Mineral pitch occurs in hollows and fissures of the Lower Jurassic limestone (Great Oolite) of Sentheim, 21 km. west of Mulhausen. Gas discharges have caused accidents in the copper-mines of Mollau and St. Amarin, 30 km. northwest of Mulhausen, where highly metamorphosed Lower Carboniferous sandstones are traversed by veins of granite. Traces of oil are reported in the Coal-measures of Roderen, 17 km. north of Colmar. Bitumen occurs in a vein of barytes, traversing granite at St. Pilt (Hippolyte), a short distance to the northeast, and the gneiss of Eschéry, near Markirch (Ste. Marie-aux-Mines) is bituminous. Oil is said to flow from an abandoned mine near Markirch. Globules of asphalt occur in dolomitic concretions with silver-lead ore in gneiss near the Coal-measures at Lalaye (Grube), 17 km. northwest of Schlettstedt.

In Lower Alsace, the Middle Trias limestone of Molsheim, 20 km. westward of Strassburg, contains viscous petroleum in crevices and hollows. Traces of oil have been found in the Trias, Lias, and Lower Jurassic rocks in the much-disturbed area between Wasselnheim, Zabern, Ingweiler and Wörth, on the west, and the Tertiary oil-field bordering the Rhine valley, on the east. On the margin of this region, fringing the Vosges range, bitumen occurs in the Middle Trias limestone at Weitersweiler, Rauschenburg (north of Ingweiler), and Rothbach. About half the area of the map, fig. 2, pp. 44, 45, is on Secondary rocks, and here most of the occurrences of bitumen are in the Lias, but few in the Upper Trias and Lower Jurassic. At Gundershofen iron-ore mines, in Eocene beds resting on Lias, outbursts of gas have been experienced, probably emanating from the Liassic shales.

The only profitable operations for oil are those in the Oligocene belt between Molsheim, Wörth, and Weissenburg, on the west, and the Rhine on the east. The boundary of this belt on each side is a fault of great magnitude, letting down the Tertiaries as a strip of soft easily-denuded land between the harder rock-masses of the Vosges and the Black Forest of Baden, a drop of probably 2000 metres in the Hagenau district, but somewhat less northward, about Weissenburg. Between the opposing masses of older rock, the Lower Oligocene clays and the sandstone have been compressed into a series of anticlinal and synclinal folds, of slight curvature, but sufficient to constitute a factor of the first importance in concentrating the petroleum present in the beds into alternating belts of productiveness and sterility. All but an insignificant fraction of the output of crude oil is obtained from thin seams of sand, sandstone, or sandy shale, distributed through a thickness of several hundred metres of impervious clays and marls. These oil-bearing seams are very inconstant in extension and thickness, and in their yield of oil. They appear to be lenticular in section, and rarely to cover any large areas. Consequently, lying at considerable depth, and having a low angle of dip, they rarely crop out at the surface, and thus are usually free from access of water and from loss of oil by evaporation or displacement.

A condensed account of the four-hundred-year-old industry established in this region has been given in the preceding section. Lying almost horizontally on the upturned and denuded edges of the petroliferous Lower Oligocene of Walburg, Pechelbronn, Kleeburg, etc. (a marked unconformability observed by Mr. W. H. Dalton, and not heretofore recorded), there follows, from Gösdorf near Wörth to the neighbourhood of Weissenburg, a belt of Middle Oligocene beds, consisting of fresh-water limestones, conglomerates, sandstones and clays, overlaid by purely marine clays of great thickness. The limestones and sandstones are locally saturated with asphalt, especially at Lobsann, the product of which ranks among the leading European asphalts. Conglomerate of somewhat similar character occurs southwest of Morsbronn, extending to Laubach. That of Uhlweiler, though equally consisting of pebbles and boulders of the neighbouring Jurassic rocks, is of Lower Oligocene age, and has been pierced in some of the Ohlungen borings in a position approximately that to which the dip seen in Uhlweiler would carry it.

Lorraine.—The oil-springs of Sturzelbronn and Walschbronn, 11 or 12 km. east and north-northeast respectively of Bitsch, rise in the Lower Triassic sandstone composing the bulk of the northern Vosges.

BELGIUM.

Hatchettite, sometimes accompanied by traces of petroleum, occurs in many places in the Belgian Coal-measures, especially at Strepy-Bracquegnies, east of Mons; at Fontaine l'Evêque, west of Charleroi; and at Chokier, Seraing, and Flemalle Grande, southwest of Liège. It occupies in some cases the interior of hollow concretions of iron-ore, but more generally the cavities of fossil shells or crevices in the rocks. Traces of oil are alleged to exist at Bourlers near Chimai, 45 kilometres southward of Charleroi, but whether in the Eocene or in the subjacent Devonian rock is not stated. Traces of oil are also recorded in the Liassic shales of Jamoigne, 55 kilometres westward of Luxemburg.

HOLLAND.

Apparently the sole record of native petroleum in Holland is that of its detection in the Chalk, underlying a brickfield in the neighbourhood of Maestricht. In the morasses of South Holland, North Holland, and Friesland, emissions of spontaneously inflammable gas have frequently been observed, and in some cases the supply is utilised.

SWITZERLAND.

In the canton of Neuchâtel, asphalt-rock occurs in the Upper Jurassic limestone of Purgots, near Les Brenets. At Noiraigues in the Val de Travers, Vallorbes in the Val de Joux, and Epoisats under the Dent de Vaulion, the Lower Jurassic (Bathonian) limestone is asphaltic, and was worked at the last place in the eighteenth century. The far-celebrated asphalt of the Val de Travers occurs in the Urgonian (Neocomian) limestone, of which from 10 to 12 per cent. consists of bitumen at the mines of la Presta and Bois de Croix. Similar, but less valuable, deposits in the same series occur at Auvernier, Bevais, and St. Aubin, and at Mathod, Vaud. The Aptian (Cretaceous) sandstone is also asphaltic at la Presta. The Miocene has more or less bituminous limestone at Boudry, and in the canton of Vaud this is the case over a wide area from Yverdon to Lausanne, along the northern shore of Lake Leman from St. Sulpice to Rivaz, and also at Bernex, Sattigny, and Dardagny, in the canton of Geneva. Petroleum exists in these beds near Mathod, Orbe, and Chavornay, Vaud. Inflammable gas occurs in the Liassic rock-salt of Bex, and at Montreux, Vaud. Bitumen and ozokerite are said to occur on the Neuschelbach, some 14 miles southeast of Friburg, and bituminous rock at the foot of the Gastlosen. A deposit of dysodile has been observed in the Eocene beds of Overdorf, 2 miles northwest of Soleure.

ITALY.

Though the Italian petroleum industry is of only local importance, the deposits possess considerable historic interest, as has been mentioned in the previous section.

Northern Italy.—The Triassic dolomites and shales of Lombardy are frequently bituminiferous, yielding oil and asphalt upon distillation. Beds of this character extend from Morgorabbia in Valcuvia to Ghirla and Brusimpiano, and round the southern part of Lago Lugano from Bisuschio and Besano to Melide and Arogno, recurring in Val Camonica at Esino and Vello (on Lago d'Iseo) in Val Trompia, at Sant' Eusebio in Val Sabbia, on both sides of Lago d'Idro, and thence across to L. Garda, extending over the Austrian frontier to Storo in Val Giudicaria. At Laveno and Porto Lavello on Lago Maggiore, Pellio and Viggiu on L. Lugano, Brontino near Bergamo, and Tignale on L. Garda, the Liassic shales contain a notable amount of bitumen. At Caprina near Bergamo, and Benaco on L. Garda, the Cretaceous shales are more or less bituminous, and the Miocene marl of Staghilione, 15 miles south of Pavia, contains above 16 per cent. of bitumen. The only traces of fluid petroleum in Lombardy are found in the Pliocene at Rivanazzano, 60 kilometres south-southwest of Pavia, and at San Colombano, 24 kilometres eastward of Pavia.

In the four Emilian provinces petroleum and natural gas exude, or are obtained from wells, in greater or less quantity, at more than a hundred places within the area shown in the map, fig. 1 (p. 33). The belt, embracing part of the Florence district of Tuscany, is composed ôf Eocene, Miocene, and Pliocene deposits, in rather complex recurrence, and it would be futile here to attempt to assign an age to the oil or gas of each locality, especially as, along the axial lines of anticlinal folds, oil-wells may derive their yield from a concealed formation, while gas may be evolved from great depths by fissures in this much-disturbed area. The ozokerite of Montefalo, near Savigno, in the Bolognese, occurs in Miocene rocks. Carburetted hydrogen has caused accidents in the Monte Catini mines of the Lucca district, in Cretaceous rocks. The Miocene of Sassoferrato, Urbino, has bituminous shales of doubtful value. The hot springs of Abano, southwest of Padua, evolve carburetted hydrogen, probably eliminated by the decadent volcanic heat from bituminous beds of the Cretaceous, or of a more recent period. The oil-shales of Monte Pulli, near Valdagno in the Vicentin, are of Eocene age. Artesian wells in Venice have at their first boring discharged much marsh-gas from the estuarine deposits traversed.

Central Italy.—In the Abruzzo, oil and asphalt occur in Eocene beds at Tocco, Sta. Elia, and Manopello in the Pescara valley, and in Pliocene at Lanciano. Hydrocarbon gases are evolved from the site of the classic Fucine Lake, now drained. Between Rome and Naples bituminous limestones of Cretaceous age, and petroliferous Eocene shales, with, occasionally, Pliocene deposits charged with hydrocarbons by infiltrating from subjacent beds, range southward from Filetino (about 70 km. east of Rome), by Collepardo, Veroli, Fontana, Atina, Ripi, Arce, Terelle, Roccasecca, Castro, San Giovanni Incarico, Pastena, Pico, Pontecorvo, and Cervaro, to Venafro, 90 km. northward of Naples. Bituminous shales occur in the Eocene of Laviano and Silento, Campania, and in the Triassic of Giffoni Vallepiana, northeast of Salerno. Cretaceous rocks furnished the asphalt of Puglietta, Campagna di Eboli, mined some forty years ago. The ancient *Balneum Olei Petrolii* was situated near the Stufe di Nerone, between Pozzuoli and Baiae. Emanations of petroleum occur at Cape Sorrento, and a smell of oil is at times perceptible at sea in the Bay of Naples, 9 or 10 km. northwest of Sorrento. The asphalt of Tramutola, 120 km. westward of Taranto, is of Eocene age. Both natural gas and oil are separated from the mineral waters of Salsamajore before their use in baths at that famous health resort.

Sicily.—The Tertiary rocks of Sicily are petroliferous at several points, and the oil has been used for illuminating purposes for many centuries, but no extensive industry is based thereon. Beside the historic wells of Agrigentum (Girgenti), traces of oil occur at Lercara Fridda, Polizzi, Petralia, Nicosia, Paterno, Mineo, Ragusa, and the Val di Noto (Lago Naftia). Asphalt-beds of some importance exist near Leonforte, but the most valuable deposits both of oil and asphalt lie in the districts of Ragusa, Modica, and the Val di Noto. The Cretaceous limestones of Ragusa are bituminous as well as the Miocene. The vesicles of the basaltic lava of Etna are sometimes filled with petroleum, sometimes with crystalline paraffin, taken up by the molten rock in its passage through, and partial absorption of, the Tertiary (or lower) carbonaceous strata. Parallel instances have been already mentioned, and others will fall to be noticed subsequently, of this appropriation of hydrocarbons by intrusive igneous rocks. The collection of asphalt on the volcanic Lipari Islands was an industry of importance with the ancient Carthaginians, and some of the Lipari obsidian contains traces of vaseline or a kindred paraffin.

The salt-marshes of **Sardinia** are covered from time to time with sheets of sea-weed, decomposing into an oily substance akin to petroleum. Parallel instances to this significant fact will be mentioned in due course.

ALGERIA.

As the Mediterranean Sea is, from a geological point of view, merely a picturesque incident in a region of the same general character, the oil-fields on its southern shore may appropriately be noticed here as an extension of those last mentioned.

The petroleum of the southern flank of the Dahra range, midway between Orleansville and Mostaganem, in the province of Oran, has long been known. This occurs in the lower part of the Miocene, from Mazouna, on Oued Ouarizane, for 116 kilometres westward, by the Tamda, Taghria, and Aïn Zeft ravines, and Oued Yehir, to the Cheliff at Sidi Brahim, and the coast from La Stidia to beyond Arzeu. Several wells and horizontal tunnels at Aïn Zeft and Sidi Brahim have yielded considerable quantities of dark, heavy, sulphurous oil, from a series of alternating marls and limestones, largely converted into gypsum by epigenic action. There is said to be an oozing of oil on the shore at Cape Ivi, further westward, which is probably from rocks of similar age. In the vicinity of La Stidia and Port-aux-Poules there are frequent indications of petroleum, as emanations of oil-gas at sea and inland, and oil-films on water, over a very considerable area, the most westerly point being some 8 km. southward of Arzeu. All are apparently derived from Miocene rocks. Traces of petroleum have been found in the same series at Bel Hacel, 40 km. E.S.E. of Mostaganem, and the Miocene of Oued Mebtone, 40 km. S. by E. of Arzeu, shows stains of oil. Frequent indications are seen on the Oued Kalaa, 46 km. eastward of the last-mentioned point, and the Tliouanet district, yet further eastward, has oil in many places, pits and borings having been sunk within the last twenty years at several points of more or less promising structure, but with no very important result. Similar oil-shows recur intermittently as far as Zemora and Mendes, south of St. Aimé (Djidiouia) on the Cheliff, and oil-gas is alleged to emanate at Kefeldjir (a name connoting the occurrence of gypsum), northeast of Inker-

Plate 1.

Petroleum deposits shown in red

London: Charles Griffin & Co. Ltd.

Stanford's Geog^l Estab^t, Lond.

mann. The known length of this southern belt is about 136 km. There are vague reports of similar traces at Blida, 40 km. southwest of Algiers, and bands of bitumen traverse the marls of Boghar, some 60 km. south of Blida, both localities being on beds of Miocene age. A tar-spring is reported to exist near the tomb of Oulad Sidi Aissa, about 120 km. southeastward of Algiers, in the Lower Eocene rocks. Traces of oil are also announced as found in the province of Constantine, as follows: at Beni-Ziar, southeastward of Djidjelli, in Upper Pliocene deposits; in the Lower Eocene of Ferdjiouah, midway between Setif and Constantine; in Middle Cretaceous limestones and shales in the Chebka na Sellaoua range, some 70 km. east-southeast of Constantine; and in rocks of about the same age at Claire-fontaine (Aouinet el Diab), 50 km. southward of Souk Ahras.

MOROCCO.

Oil occurs at Oulad Aissa, near Sherardo, Ain Feriba, Mazaria, Hejowa, near Ouled Slama, Satura, Kohlott, 25 km. distant, neat Khaizett.

TUNIS.

A recent official summary of Tunisian economic minerals alleges undeniable evidences of petroleum to exist at several points near the capital, from Tebourba, westward, to Grombalia, southeastward; also near Testour and Biserta.

EGYPT. (Plate 1.)

The existence of petroleum at Jebel Zeit, near the mouth of the Gulf of Suez, is matter of ancient history, and is implied in the name, which signifies Oil Mountain, the *Mons Petrolius* of the Roman geographers. To the westward the Upper Cretaceous sandstones and limestones give similar indications along a range of hills parallel to, and about twenty miles distant from, the coast. A boring near Zafarana met with oil under great pressure of gas, and natural emanations have been noticed on Jebel Atakah, southwest of Suez. The coral reefs of the Red Sea are charged in places with recent petroleum, formed in that torrid climate from the swarming organisms occupying the shallow pools. A precisely similar mode of formation has in fact been suggested for the older petroleum and gas just described, viz. the saturation of the Cretaceous surface, and of newly-deposited beds, with organic matter, throughout the period extending from the Miocene to the present day. But since traces of petroleum occur in the Eocene limestone of El Hammam (Mokattam), as well as in similar rocks to be dealt with below, it would appear that in this region conditions favourable to the production of petroleum obtained throughout the Tertiary epoch, or recurred again and again during that vast lapse of time. Petroleum has been reported as found in the hills 20 miles inland of Suakin, and in the Farsan archipelago.

The subjoined account has been furnished by Mr. A. Beeby Thompson.

The Egyptian Red Sea littoral consists of beds of Miocene limestones, massive gypsum, clays and rock-salt, Eocene marls and Cretaceous sandstones, in all of which indications of petroleum have been found at various places. These Tertiary and Mesozoic rocks are often pierced by igneous intrusions of post-Cretaceous age, forming prominent mountain ranges against which the sedimentary rocks recline. The interesting sediments extend from Suez to Kosseir, a distance of about 300 miles, and where suitably inflected and protected these rocks may yield commercial supplies of oil. Important yields of oil were obtained from the Jemsa area in a confused complex of Miocene limestones, gypsums, and rock-salt. Further south at Hurghada an exceptionally prolific oil-field has been located on a domal flexure, where oil was struck in Miocene limestones and in Nubian (Cretaceous) sandstones. Amidst recent raised beach formations overlying and concealing the Miocene at Gebel Zeit there are exudations of light oil which, as at Jemsa, may portray the existence of deeper sources. A deep well at Zeitea is said to have yielded natural gas, and pronounced indications of oil have been struck in borings on the island of Jubal at the mouth of the Gulf of Suez.

On the Sinai Coast indications of oil are found at many points in beds of Miocene, Eocene, and Cretaceous age between Tor and the Suez Canal. The darkly stained Eocene rocks of Tanka, Abu Zemina, and Nezzizat, and the oil-saturated Cretaceous sandstones of Abu Durbar deserve special mention. At Gebel Tanka and Abu Durbar oil has been obtained in borings.

Eocene marls are stained nearly black at many places and emit the characteristic odour of petroleum when struck. At other localities local impregnation is conspicuous where igneous dykes have pierced the sedimentaries. Marine oil-springs have been recorded off Gebel Tanka and Abu Durbar, and at other points ozokerite-like material has been found attached to the rocks on the coast line or cast up on the beach.

The islands in the mouth of the Gulf of Suez indicate a submerged extension of the Zeit range of hills, the higher points forming numerous islands, the most important being Ranim, Gaysum, Um el Heimet, Jubal, Towal, and Shadwan. The exposed Plio-Pleistocene domes of Um el Heimet, Gaysum, and Jubal have been penetrated by borings disclosing underlying gypsum beds of Miocene age. The islands of Ranim and Towal are covered with recent Pleistocene coral reefs with small exposures of Plio-Pleistocene beds.

An interesting outcrop of bituminous matter occurs near Helwan, a few miles south of Cairo, and this interest is not diminished by its comparative proximity to the mineral springs which have made Helwan famous.

ARABIA.

The bitumen of Wadi Gharandel, in Arabia Petræa, 40 miles southward of Suez, is in Eocene limestone, and traces of oil occur in the Cretaceous (Nubian) sandstones of Wadi el Arabah, 30 miles further southward, though this may be due to recent infiltration, as has been suggested above for the adjacent Egyptian petroleum. The same may be predicated with great probability of the indications near the southern end of the Sinaitic peninsula, and on Tiran Island, at the mouth of the Gulf of Akabah. Petroleum is said to occur at many points in the interior of Yemen. On the eastern side of Arabia, traces of petroleum occur at Benaid el Oar near Koweit, on the Persian Gulf, on the waters of which also films of oil often appear, after earthquakes or storms, between the islands of Kubbar and Garu, and again near Farsi Island (28° N., 50° 10′ E.). Deposits of bitumen are also reported as found on Bahrein Island, and oil is said to rise in the sea off Haulal Island (25° 40′ N., 52° 25′ E.), eastward of Bahrein peninsula.

Inland from Mokalla in the Hadramout, about 300 miles E.N.E. of Aden, several occurrences of oil-shales have been described by the Arabs, who brought back samples to the coast. The deposits are apparently located in a carbonaceous phase of Upper Jurassic sandstones near their junction with massive Eocene limestones. The Arabs of this region also refer to the presence of a black substance which sweats from the rocks during the heat of the day. Evidently this refers to bitumen (*A. Beeby Thompson*).

TURKISH EMPIRE.

Syria.—The asphalt of the western shore of the Dead Sea has been known from time immemorial, having been extensively exported to Egypt for embalming. The word " mummy " is, in fact, derived from the Coptic *mum*, bitumen. The " slime-pits of the vale of Siddim," so fatal to the warriors entrapped by their adhesive contents, were fed by oozings from soft Cretaceous limestones, sometimes dolomitic, sometimes gypseous, and always charged with chloride of sodium and other salts. These extend from the southern end of the Dead Sea throughout the Jordan valley to Lebanon. The chief localities are Wadi Mahawat, W. Sebbeh, and Nebi Musa, on the Dead Sea, Hasbeya, on the Upper Jordan, Sahmur and Ain-et-Tineh, on the Nahr Litany, and another Ain-et-Tineh, near Magluda, some 28 miles northeastward of Damascus. Sulphuretted hydrocarbon gases are discharged at many points on the line. The regions eastward of the northern end of the Dead Sea, and of the southern end of the Lake of Tiberias, consist in part of similar rock. On the Jebel el Dahr, between the Jordan and the Litany, the Cretaceous sandstones also yield bitumen, and oil-shale, suitable for distillation, occurs in the same series at Zehalta, Haidura, and Djezzin, in the Machada plain.

Large deposits of asphalt are reported to occur near Latakia, in the villages of Kferie, Cassab, Ghoman, Chmeisse, Khorbe, and Sonlas. Both Antioch and Aleppo have been credited with producing bitumen, possibly from a single site. Petroleum is known to exist at Alexandretta.

During the great war the Turks used as fuel in their locomotives on the Medina Railway bituminous rocks excavated in the Dead Sea area. In the district of Beersheba indications of petroleum were so pronounced that prior to the war elaborate arrangements had been completed to test the area by deep drilling (*A. Beeby Thompson*).

Mesopotamia.—An extensive oil-field ranges from Hit on the Euphrates, for 200 miles upward to El Deir, and thence as far to the northeast, to Herboul near Zakhu, and eastward from this line to beyond the Persian frontier. At many points in this vast area petroleum and gas exude with their usual concomitants, salt and sulphureous waters, often thermal, from the Miocene saline gypsiferous marls and limestones. The oil-wells of Hit, Jibbah, and Kerkuk are of great antiquity; those of Herboul, Hammam Ali, Tel Kiara, El Falha, Tuz Khurmatli, Kifri, and Mendeli are of less celebrity, but possibly of greater ultimate importance.

Armenia.—A spring of bitumen rises from the Eocene limestone within the citadel of Van, and oil is reported at Parghiri, whilst in the Muzurdagh range, on the Upper Euphrates, the Cretaceous limestones are locally charged with asphalt, and at Samosata or Someisat, 70 miles southward, Pliny mentions the occurrence of maltha or rock-tar. Petroleum is reported as found near Surmeneh, in Trebizond.

Asia Minor.—At Janartasch, on the Gulf of Adalia, Lycia, the " eternal fire " of the Chimæra has been burning for possibly 3000 years, giving rise to the legend whence our present use of the term chimæra is derived. The name is thought to be of Phœnician origin, *chamirah* = burnt. One observer records a perceptible smell of " naphtha or iodine," and soot is deposited from the flame, and utilised as a pigment, as a remedy in ophthalmia, and in other ways. The emanation is from decomposed serpentine, intrusive in Eocene rocks, and is probably oil gas. A similar, but intermittent, discharge has been noticed on the western side of Samos, at a considerable elevation. Specimens of earth, impregnated with petroleum, were some years ago submitted to the author as coming from the neighbourhood of Smyrna, and a combustible rock, capable of yielding gas, occurs at Calamitza, Crete. A sample of Cretan petroleum was shown in the Vienna exhibition of 1855. Traces of oil are recorded at Cherkose Deli, above Lake Isnik, southeast of the Sea of Marmora. Drilling was undertaken at Hora on the Sea of Marmora amidst indications, but commercial supplies of oil were never struck. At Mersina, near Adana in the Gulf of Alexandretta, there are important deposits of oil shales associated with lignites (*A. Beeby Thompson*).

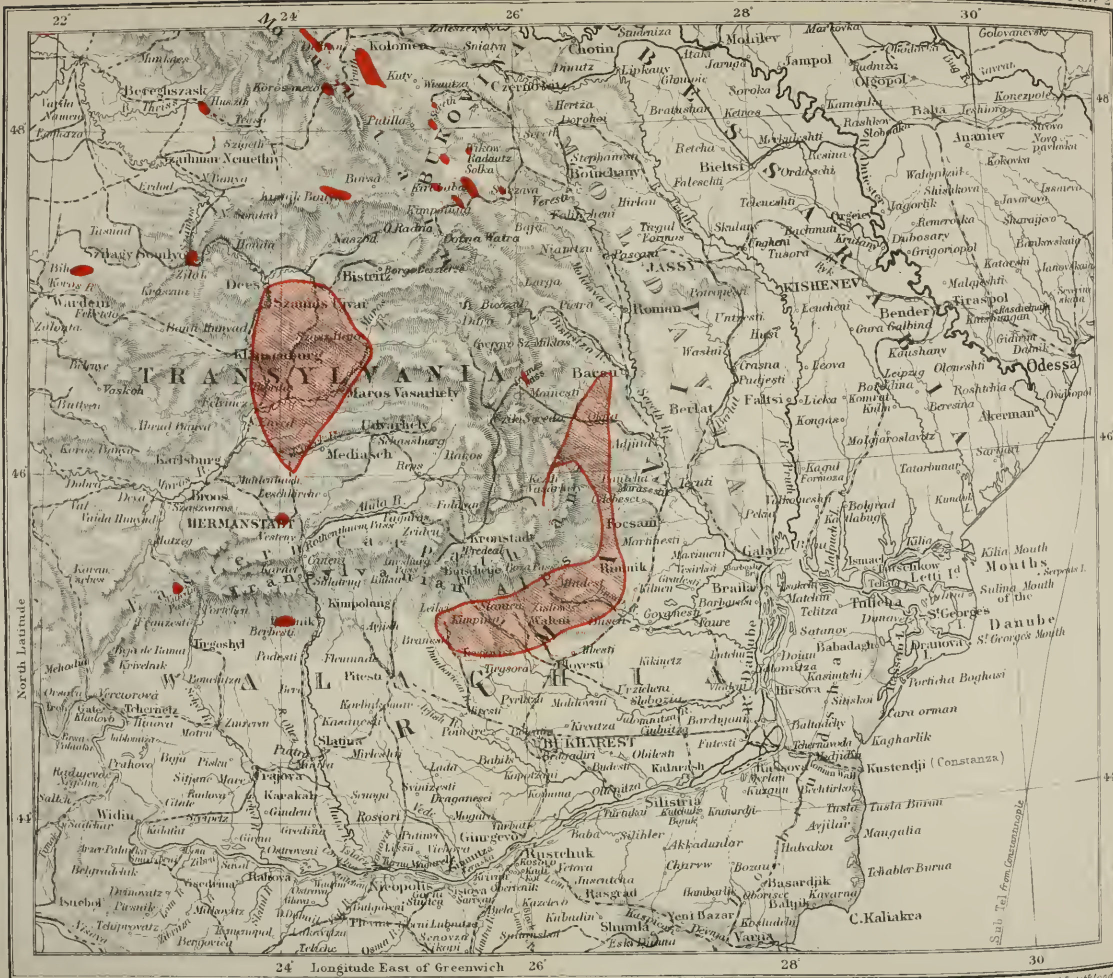
European Turkey.—A few years ago petroleum was detected in a belt of sandy deposits, apparently of Miocene age, fringing the coast of the Sea of Marmora for several miles westward of Ganos. A westward extension of this series is believed to occur near Feredzik on the Maritza. A vague report of the presence of petroleum in the Miocene beds under the Jewish quarter of Constantinople requires confirmation, but Count Marsigli, in 1681, records submarine exudations in that vicinity. At Selenitza and Rompzi, on the Voyutza, in Albania, extensive asphalt beds, of historic fame, occur in the Pliocene conglomerates. Dioscorides describes the bitumen of Apollonia (Avlona) as found floating on the River Aous, now Voyutza. Carburetted hydrogen is evolved in places, suggesting that the intermediate petroleum compounds may also be present. Petroleum and bitumen also occur on the island of Koraka, in the Gulf of Arta, opposite Salagora.

GREECE.

Oil-springs with asphaltic deposits exist on the Island of Antipaxos in Miocene rocks. At Dremisou-Maurolithari in the Parnassid, and at Galaxidi near Delphi, traces of petroleum are reported as present on the water of springs from the Cretaceous limestones. Possibly the utterances of the ancient oracle were evolved under the toxic influence of petroleum vapour. At Lintzi, the ancient Cyllene, opposite Zante, oil and bitumen exude from lignitiferous Miocene strata, and traces have been noticed on the waters of a spring near Vrochitza, in the Pyrgos district. Pausanias states that natural fires exist at Bathos, the modern Karytaenia, in Arcadia, and bitumen oozes from the Cretaceous limestones of Nauplia in Argolis, and of Maratho in the peninsula of Messenia. Occurrences of petroleum in several places on the Island of Milo are evidently the effect of the prevalent volcanic activity of the region upon bituminous strata.

The classical pitch-springs of Zante occur on the eastern side of the southern promontory of that island, in the Keri valley. A majority of authors regard the area occupied by the springs and wells as Pliocene, but there can be no question of its being of older Tertiary beds, probably Oligocene or early Miocene. Traces of oil and pitch, with bubbles of gas, are frequently observed at certain points of the bay between Keri and Cape Hieraka, and more rarely at greater distances from shore, towards the Strivati islets. Inland from Keri, temporary discharge of pitch and oil from earthquake fissures occurred at Musaki and Romirion. On the northeast coast, in and near the town of Zante, traces of petroleum occasionally appear in the Pliocene beds, and the author observed one such exudation on the shore. The Miocene rocks of Mt. Scopos are reported to smell of bitumen in places.

RUMANIA



English Statute Miles.
0 10 20 40 60 80 100

London: Charles Griffin & Co. Ltd.

Petroleum deposits shown in red

MONTENEGRO.

Petroleum of 0·874 specific gravity, accompanied by saline water and gas, exudes from Triassic shales at Bukowik, 11 kilometres southwest of the head of Scutari Lake. The series is penetrated by porphyritic rocks, and the formation of the oil may be due to the action of the heat of these intrusions upon organic matter in the shales. At Ploca and Gradac, respectively 2 and 13 kilometres northward of the lake-head, asphaltic shales of Eocene age occur in small patches amongst the Cretaceous limestones.

BOSNIA and HERZEGOVINA.

Asphalt of like age to that just mentioned occurs in crevices of the Cretaceous limestones near Metkovich and Drazevo on the Narenta. Probably the "combustible rock" of Polog near Gradac, some 54 kilometres northward, is of the same nature. The extension of these beds in Dalmatia will be described subsequently.

SERBIA.

Ozokerite-shales of Lower Miocene age occupy some 67,000 hectares of western Serbia, on the river Kolubara, about 70 kilometres south-southwest of Belgrade. In lithological character they closely resemble the contemporaneous ozokerite-shales of Galicia. Similar beds, being accessible by railway, are extensively mined for distillation near Alexinatz in eastern Serbia, 174 kilometres southwest of Belgrade.

RUMANIA. (Plate 2.)

The Rumanian oil-fields (Plate 2) may be regarded as practically continuous from the Serbian frontier on the Danube to that of the Bukowina, although the most westerly point at present known to be petroliferous lies 120 kilometres from the Iron Gates, and the most northerly nearly as far from the Stulpikani and Braiesti districts of Eastern Austria. The chief centres of operation have been mentioned in the preceding section, and, with minor points, form a nearly continuous belt from the Jalomita valley to that of the Trotush, whilst natural exudations, and a few wells and pits, extend the area known to be petroliferous across the counties of Muscel and Arges, to Valcea, westward of the Allt valley.

The petroleum occurs principally in the Miocene and Pliocene series, but the Eocene and Oligocene contribute largely to the total production, and the Neocomian and Cretaceous rocks may eventually prove to contain valuable stores of oil. These beds form a zone of hilly ground fringing the Transylvanian Carpathian Mountains on their southern and eastern flanks. They have been thrown by lateral compression into a series of anticlinal flexures, with intervening synclinals, bifurcating and inosculating in complex fashion, but parallel upon the whole to the trend of the chain of which they constitute the flanks. As a general rule, it may be said that the northern and higher-lying portion is of Cretaceous and Palæogene age, and the southern of Neogene, probably extending far beneath the alluvial plain of the Danube. But in consequence of the irregular folding of the series, newer rocks sometimes enclose uplifted areas of older, and sometimes constitute tongues of isolated patches in the synclinal hollows beyond the general course of their continuous margin. It is believed by some observers that a certain degree of disturbance and of erosion occurred between the periods of deposition of the several members, producing unconformable superposition, and thus enhancing the difficulties of determination of the age and structure of the obscure regions. The recurrence of somewhat similar lithological characters, the generic community of the fossils, the frequent neglect of detailed observation during the progress of sinking or boring operations, and the want of accurate maps of adequate scale, are further hindrances to full scientific comprehension of the geology of this most interesting and important country. Fortunately for both science and industry, the region includes large areas, the structure of which can be read at a glance by the trained eye, being "written broad" upon the landscape, and as structure is the point of primary importance in respect of petroleum, the more purely academic problems of correlation with deposits of western Europe and Russia may be left for future solution. At present the Pliocene of one author is the Miocene of another, and this, with other similar conflicts of terminology, renders it as undesirable as it is unnecessary to attempt to tabulate in stratigraphical categories the localities at which oil has been found. It may, however, be pointed out that whilst in Wallachia the Miocene and Pliocene yield the greater part of the present output, the Moldavian oil, as in the Austrian fields, is almost wholly obtained from the older Tertiaries, which occupy there a much broader area than in the southern kingdom. The want of facilities for transport may be another factor in this respect, for the Eocene belt in Wallachia is crossed by a railway but once, and at right angles, viz. in the Prahova valley, where its width does not extend 10 kilometres. In Moldavia, on the other hand, the Moinesci branch railway runs parallel to the strike, and between productive folds, for over 20 kilometres, a most palpable advantage.

The strata of the oil-fields consist chiefly of marly shales alternating with beds of sand or sandy clay, and occasional seams of pebbles. Limestone and compact sandstone are less frequently found. Gypsum and rock-salt are common, and apparently present in every part of the series. To some extent the gypsum is of recent formation by the combination of the calcareous element of the marl with sulphuric acid, due to the oxidation of pyrites. The many "sulphur springs," mostly cold, but a few thermal, result from the same action. Rock-salt most commonly, though not invariably, exists in anticlinals as the position most favourable to its preservation, protected from the direct access of surface water by the compressed marls above, and from any lateral percolation by the structure. In synclinals, partial solution may result from casual access and accumulation of water, which, however, cannot rise into the closed anticlinals. Where, on the other hand, as at Baicoi, a bed of rock-salt is raised by the dip to the surface, its dissolution, proceeding until the insoluble cover descends to seal up the remainder of the mass, leaves a more or less pronounced hollow. At Baicoi, a lake marking the site of the former outcrop of salt was described in 1878 as 11 hectares of "eternal" fire; "the peasants, making a hole with a stake, fire the stream of gas that issues, and use it to boil woad."

THE CARPATHIAN FIELDS. (Plate 3.)

Dalmatia.—Asphalt-limestone occurs in several parts of Dalmatia, and has for a century past formed the basis of a considerable industry. The Neocomian and Cretaceous series yield the greater part, but some of the overlying Eocene limestones also contain asphalt. It is worked at many points on and near the coast from Ragusa to Zara, the deposits ranging inland to near the Bosnian frontier.

Istria.—The prolongation of the Dalmatian asphalt rock is traceable on the east of the Canale dell' Arsa, southwest of Albona, and it is worked at Carpano and Pinguente. The description of the material as "coal," not only occurring as lenticular seams, but as filling hollows and fissures in the limestone, seems to indicate natural segregation of more or less pure asphalt, probably an inspissated and oxidised petroleum, and (from the conditions of formation) largely, if not wholly, of animal origin. Similar deposits, but of minor value, and chiefly utilised as fuel, occur at Herpelje, Divazza, Opschina, Sistiana, and other points in the neighbourhood of Trieste.

Carniola.—A peculiar bitumen, distinguished by the name of idrialine, occurs as veins and nodules in the cinnabar-bearing shales, probably of Carboniferous age, of Idria, and with the copper-ore of Hrastenza and Kraxen.

Styria.—Tar exudes from Miocene sandstones (Second Mediterranean stage) at Wiesmannsdorf, near the Hungarian border, between the Mur and the Drave. The series extends with northeasterly strike into Hungary, where it yields petroleum, as described below.

Croatia and Slavonia.—At Ludberg, some 69 kilometres northeastward of Agram, the Pliocene *Congeria*-marls are charged with oil, which exudes in springs. The same series yields a greenish-black oil of 0·845 specific gravity at Lepavina, about 15 kilometres southward, and a scanty yield was obtained by borings at Ribejak, between Kreuz and Glogovnica. Gas was discharged for several days from a well in these beds near Ivanich, 30 kilometres E.S.E. of Agram.

Thick tarry oil exudes from marls of Sarmatian (Miocene) age near Kutina in the Moslavina hills, some 22 kilometres eastward of Sissek. Rock-tar is said to occur in the vicinity of Novska, where both Miocene and Pliocene beds are present. At Bacindol, northeast, and Petrovoszelo, southeast, of Neu-Gradiska, the Sarmatian marls yield small quantities of petroleum, and rock-tar is reported in the Brod district a little further eastward.

Hungary.—Oil is stated to occur in the border hills between Styria and S.W. Hungary (Zala county) at Lopatinec and Zaszadfalu, probably arising from the Pliocene shales. At Szelnica and Peklenica, in the Murakoz peninsula between the Mur and the Drave, north and east of Csaktornya, the Congeria beds yield thick tarry oil, of specific gravity ranging between 0·910 and 0·960. A light, limpid, green oil is found by boring in the deeper-seated Miocene marls at Szelnica.

At Recsk, in the Matra range (Heves county), traces of oil are common in the Miocene rhyolite-tuffs, but a commercially-valuable yield is improbable under such conditions.

In the Carpathian Mountains, Eocene beds, ranging from Turzofalu in Trencsin, through Saros, Zemplin, Ungh, Beregh, and Marmaros counties, yield oil at various points of favourable tectonic structure among the complicated folds into which the vast thickness of strata present has been compressed in these and in the far more important oil-fields of Galicia, as described hereafter, the Hungarian side of the range being a comparatively narrow linear portion of the massif. The geology is less definitely ascertained on this side, partly from the minor importance of the region, and the earlier determinations of the age of the beds in which oil occurs are sometimes inconsistent with later pronunciations. In some districts, more than one series is petroliferous, as at Dragomer in Marmaros, where Miocene beds, occupying a hollow denuded in the older rocks, are also petroliferous, and perhaps parallel in respect of age with those of Boryslaw in Galicia. Carburetted hydrogen is evolved from the Miocene rock-salt, mined at Szlatina, Marmaros. At Zsibo and Szamos-Udvarhely, ozokerite and petroleum occur in sandy clays and soft sandstones of the lowest member of the Eocene group, here rising in a gentle arch through the surrounding Miocene deposits. In Bihar county, asphalt is found in sandy, lignitiferous Pliocene beds at Hagymadfalva, Tataros, Upper Derna and Bodonos, from six to eight leagues northeastwards of Grosswardein. Analyses indicate between 15 and 24 per cent. of asphalt.

The Lias of Steierdorf, Doman, Uterisch, and Reschitza (in the Banat) has valuable seams of coal and ironstone, interbedded with bituminous shales, from which an attempt was made in 1860–1866 to distil oil and paraffin. The yield, however, was too slight to be profitable, ranging from 2 to 10 per cent., with an average of 4·2. Traces of oil occur in the igneous rocks traversing the series.

Asphalt occurs in the coal-bearing beds, Upper Oligocene or Lower Miocene, of Zsil-Vajdei, in the southwest corner of Transylvania. Inflammable gas is evolved from the Miocene salt-marls of Vizakna, Tövis, Thorda, and Des, and from Eocene and Miocene beds at many points in the basin extending eastward to the Hargitta range, and drained by the Maros and its tributaries southward, and by the Szamos northward. The gas-wells and emanations of St. Benedict near Des, Sarmas, Ugra, Maros-Ujvar, "Zugo," Baassen, Kis-Kapus, Maros St. George, Szasz Regen, and the Sajo valley lie upon the principal minor anticlinals traversing the broad synclinal, the discharge of gas at Kissarmas being phenomenal. The petroleum of Kovacs and Monostor, some 50 kilometres northward of Des, is in Eocene beds. Oil-films occur on the water of thermal springs at Korond, at Szejke near Szekely Udvarhely, and at Bugyogo near Malnas.

Traces of petroleum, not as yet subjected to systematic investigation, occur over a large area of Neocomian strata at Rakottyas, Zabola, and Gelencz, near the Rumanian frontier. The oil-wells of Sösmezö, in the Ojtoz valley, date from a period prior to their inclusion in Austrian territory by the modification of the frontier-line about 1774. They appear to commence in Oligocene shales, but these are so feebly petroliferous in the greater part of their range, as to suggest the recurrence of Neocomian beds, at least at the wells, to within a small distance from the surface of this much-disturbed region. Some of the associated sandstones are charged with paraffin.

The Bukowina.—A broad belt of Neocomian and Cretaceous rocks, thrown into a series of folds, crosses the Bukowina from southeast to northwest. The Neocomian shales have proved petroliferous in each of the three major anticlinals which bring them up between synclinal folds of the Cretaceous sandstones. The first of the anticlinals extends from Stulpikani, by Kimpolung and Briaza, to the junction of the Sarata with the White Czeremosz. The second passes from near Brusturosa, by Watra Moldawitza, Roszina, Seletin, and Dichtenitz to Stebne. Then follow two or three minor folds, one showing oil at Szipot near the source of the Sereth, and the last main fold runs from near Braiesti by Sucawitza and Straza to near Kuty.

Galicia.—The Galician oil-field is perhaps the most difficult in the world for a brief yet adequate description. It consists of no less than five different geological series, four of which are petroliferous in degrees varying with tectonic structure and lithological composition. The sequence of the series is rendered inconstant by unconformabilities of greater or less importance. The same lithological conditions recur at widely separated periods, whilst synchronous deposits offer great differences of composition in closely adjacent regions. Characteristic fossils are of rare occurrence, almost the only forms being Foraminifera, of no determinative value. Lastly, the vast thickness of this heterogeneous mass of strata has been folded in a series of gigantic waves, extending from the Carpathian watershed to the border of the Podolian plain, many of the folds being overthrust, so that both flanks of arch or trough show a dip in the same direction, whilst in some places serious faulting is believed to have increased the complexity of the structure.

Warm controversy has taken place between the several geologists who have examined adjacent districts, and formed mutually incompatible views as to the sequence and age of the strata undeniably common to both, and the progress of investigation seems to exacerbate the dispute. It is amply demonstrated, however, apart from the determination of particular areas, that the Carpathian range consists of Neocomian, Cretaceous, Eocene, Oligocene and (marginally on both the Podolian and Hungarian flanks) Miocene beds. Of these the Neocomian, at the base, is an important oil-producing series. In Central and East Galicia it is always followed by Cretaceous rocks, apparently devoid of oil, but these are sometimes absent westwards. The Eocene, often very thick, is the richest oil-bearing group, and seems to extend throughout the kingdom. The Lower Oligocene affords petroleum in but meagre amount in proportion to its enormous superficial development. These four groups constitute the mountain-range, whilst on its margin northward and eastward follow the Upper Oligocene and Miocene groups. It has been a matter of debate whether the oil present in the Miocene beds is indigenous to that deposit, or due to infiltration from immediately adjacent rocks of one or other of the earlier groups. In the Boryslaw district the Miocene, with native oil and ozokerite, overlies the richly petroliferous Upper Oligocene, without any migration of the valuable fluid from the lower to the upper series, save through human operations.

From the frequent recurrence of lithological characteristics, as already mentioned, any general description of the several series is impracticable, each consisting of shales and sandstones in beds of very variable thickness and coarseness of grain. Limestones are very rare, and considerable thicknesses of rock are devoid of more than mere traces of calcareous matter. Conglomerates, though not uncommon, are seldom thick or of great extent, except those of the Upper Oligocene in the Nadworna-Sloboda district. Nor would it be less futile to attempt description or delineation on a map (of the small scale admissible) of the complex foldings of the rocks, sometimes running parallel for many leagues, often bifurcating or terminating abruptly. The axial areas are occupied on the surface now by one series, now by another, dependently on the erosion effected by the longitudinal and transverse streams of this region of copious rainfall. Frequently the belt of oil-bearing rock is of but a few metres width, the high dip producing on either side an excessive thickness of non-petroliferous beds. As a general rule, such belts constitute the floor of longitudinal valleys, a situation where the natural escape of the oil is obscured by alluvium. Where the petroliferous seams outcrop on the mountain-slopes, access of water tends to displace the oil, and exhaust the store. Copious natural outflow is consequently an unfavourable indication, proving progressive diminution of the quantity present on the side. The subjoined section, fig. 8, may be taken as typical of the Carpathian range, in which similar folds recur with constant variety in the mode of repetition.

The orography being determined by the geological structure, the general trend of the folds, curving from S.E.-N.W. in the eastern and central parts to E.-W. in the western, is indicated to a great extent by the orographical maps. The more regular the parallelism for great lengths of the strike of the rocks, the more uniform are the ridges of harder strata between the valleys eroded in the softer beds, whilst, conversely, the regions of frequent change of strike, with bifurcations of flexures, and possibly complex faulting, are marked by similarly heterogeneous drainage, in which no common direction is perceptible. In the Miocene area, however, where drainage is unaffected by marked variations of texture, the streams meander indifferently along or across the strike.

Besides yielding large quantities of petroleum, the Miocene marls are charged in places with ozokerite. The principal seat of the Galician ozokerite industry is at Boryslaw, 12 kilometres southwest of Drohobycz, and 70 from Lemberg. Workable deposits occur in the same series at Dzwiniacz and Starunia, 30 kilometres southwest of Stanislau, and traces are found at many points in the older oil-bearing beds, the residuum in most cases of evaporated petroleum.

In addition to the discharge of oil gas from most of the Galician wells, natural emanations occur in places, Iwonicz and Turosowka being noteworthy instances. The Miocene rock-salt of Wieliczka also evolves carburetted hydrogen.

Plate 3 shows the position of the chief oil-yielding districts of the Carpathian district (Galicia, Bukowina, and Northern Hungary), but its scale compels the omission of many well-known names.

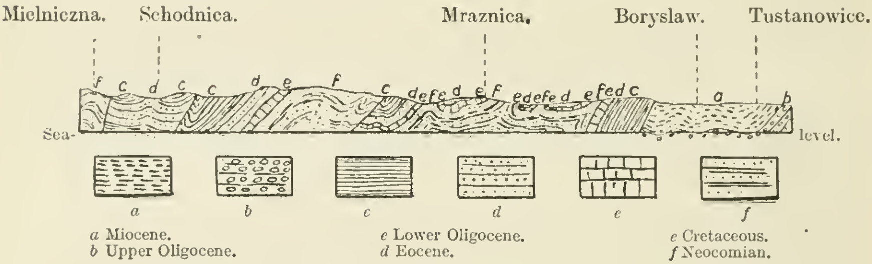
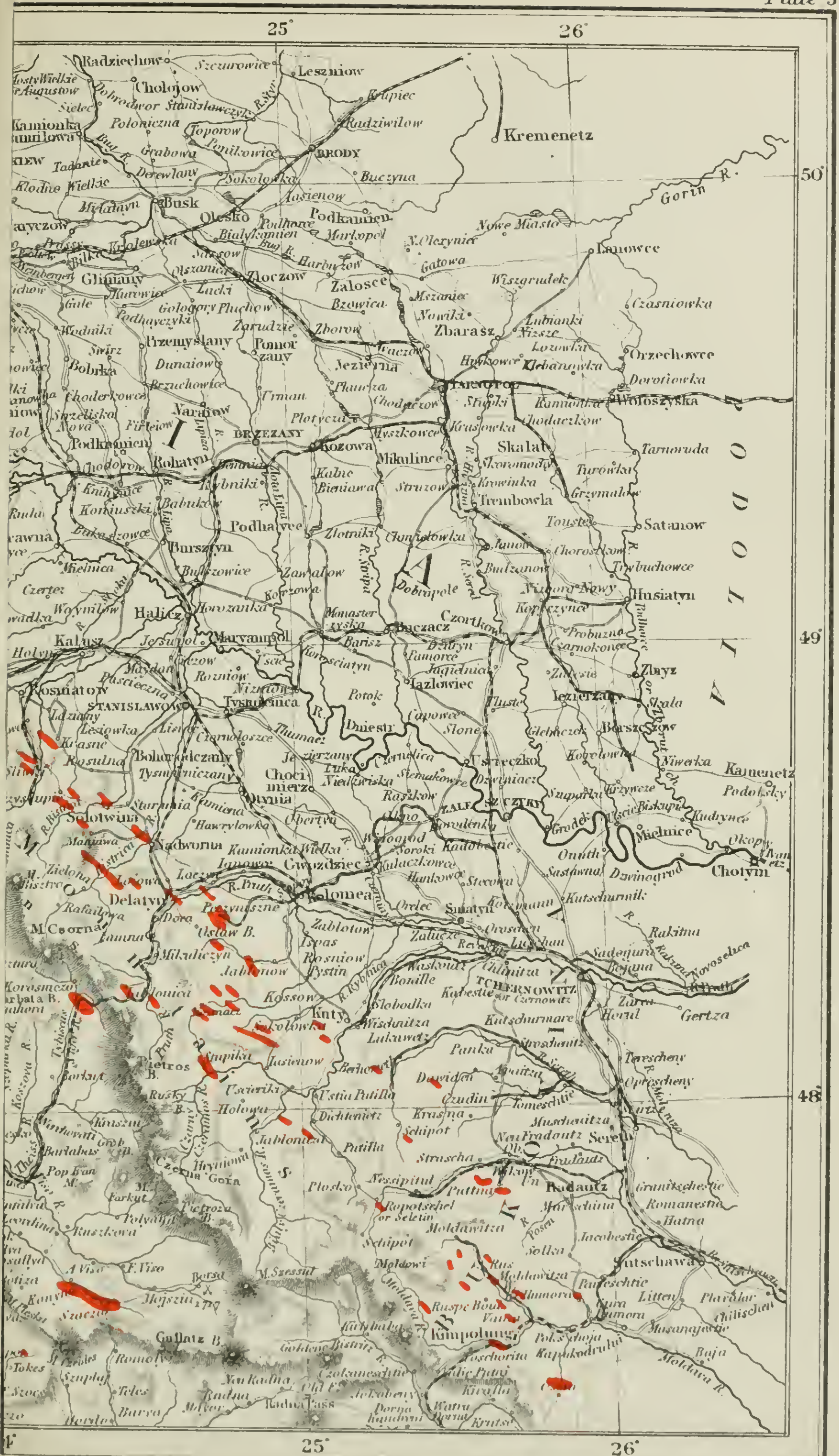


Fig. 8.—Schodnica-Boryslaw Section, 1 : 125,000.

Silesia and Moravia.—On the border between these provinces, "conchoidal rock-pitch" is said to occur at Palkowitz and Chlebowitz near Friedec, and rock-tar at Baschka, Friedland, Wermsdorf, Stramberg, Hotzendorf, and Blauendorf. Cretaceous and Neocomian rocks predominate in that region, but in the absence of detailed information, the bitumens in question cannot be definitely assigned to either series. Between Neu-titschein and Libisch are found ozokerite-marls, probably of similar age. Brownish-black viscid petroleum oozes from Cretaceous sandstones between Mallenowitz and Zlin, about 75 kilometres eastward of Brünn. The Eocene rocks extending from Ungarisch-Brod, by Boikowitz, to Bohuslawitz in the Vlara Pass, are fairly petroliferous. Tar is distilled from the Miocene lignites of a wide area, of which Czeitz, 40 kilometres southeast of Brünn, is the approximate centre. In the Carboniferous rocks of the Rossitz-Oslawan coal-field, 15 kilometres southwest of Brünn, hydrocarbon gases, petroleum, hatchettine, and valaite are recorded as of more or less frequent occurrence, and the overlying Permian shales are highly bituminous. Rock-pitch fills veins in Permian sandstone at Wiseck and Drbalowitz, near Lettowitz, 30 kilometres north of Brünn.

Bohemia.—The occurrence of petroleum, asphalt, graphite, hatchettine, and valaite, filling the cavities of fossils in the Silurian limestone and dolomite of Kuchelbad and other places in Bohemia, is of academic rather than of commercial interest, from its bearing on the problem of the origin of those minerals, as their amount is merely ancillary to that of the fuel requisite in the limekiln. Retinasphalt occurs in the Pilsen Coal-measures, and sufficient bitumen is present in some of the Permian shales of the Rakonitz, Böhmisch-Brod, and

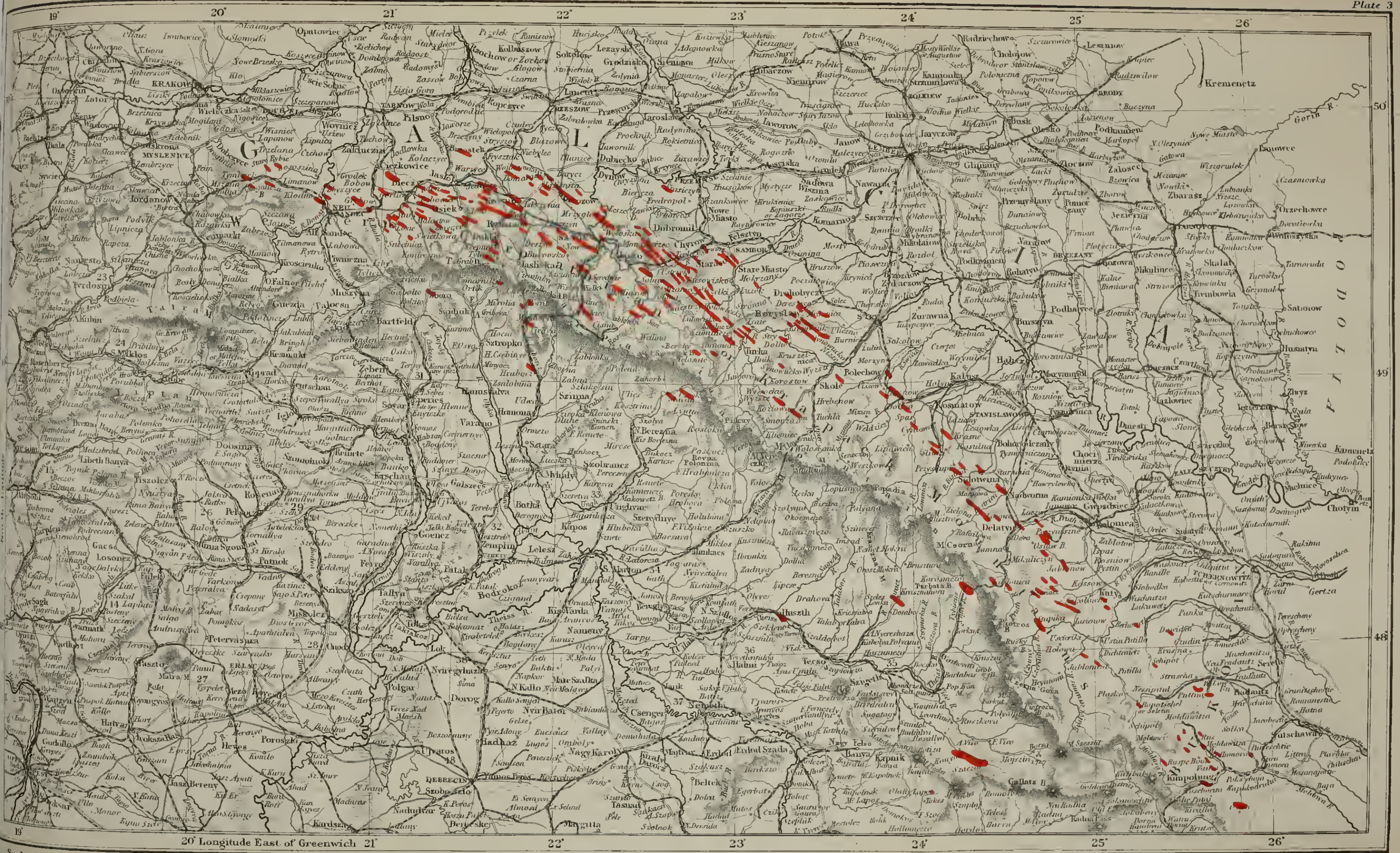
Plate 3.



Petroleum deposits shown in red

THE CARPATHIAN DISTRICT

Plate 3

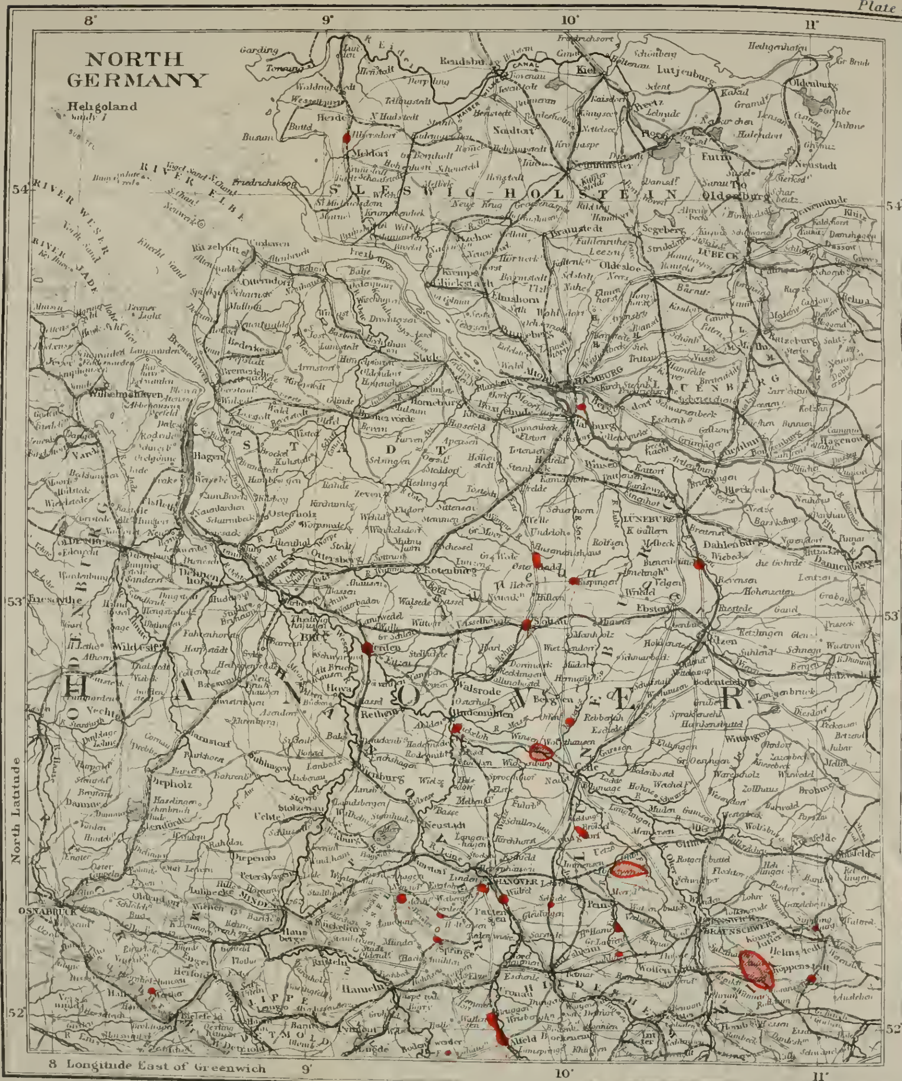


Scale of English Miles.
5 10 20 30 40 50

Stanford's Geog! Estab! London

London: Charles Griffin & Co., Ltd.

Petroleum deposits shown in red



English Statute Miles
10 5 0 10 15 20

London: Charles Griffin & Co., Ltd.

Stanford's Geog! Estab! London.

Petroleum deposits shown in red.

Hohenelbe districts to render them combustible. Tar is distilled from some of the Oligocene lignites occupying discontinuous basins from the Silesian to the Bavarian frontier, parallel to the Erzgebirge, along the southeastern foot of which a chain of lakes extended in Tertiary times.

Lower and Upper Austria.—Tar is extracted from the Miocene lignites of Thallern, on the Danube opposite Krems, large masses of pure pitch occurring in the seams. In the Erlauf Valley, scanty traces of petroleum and ozokerite occur in the Liassic coal-bearing beds of Gresten, and scanty dribblings of oil have been recorded from the Middle Triassic limestone below Nestelberg. The gas obtained by boring in the Lower Miocene clay of an area of some 850 square kilometres, extending from Linz and Eferding on the Danube southwestward to Bad Hall and Grieskirchen consists principally (79·7 per cent.) of marsh-gas, CH_4, and is odourless. The chief points at which it has been found are Wels, Eferding, and Grieskirchen, but similar gas is evolved from the historic saline springs of Bad Hall. Traces of petroleum are said to have been found at Grieskirchen, Ebelsberg near Linz, and Kleinmünchen. Carburetted hydrogen is discharged in the Hallstadt salt-mine, but the rock here is of Triassic age. Tar-yielding lignites of the Miocene period are mined at Wildshut, in the angle between the Bavarian frontier and the border of Salzburg.

The Tyrol.—Asphaltic shales of Triassic age occur intermingled with dolomitic limestones in several places northeastward of Seefeld, the chief seat of the resulting industry ; also at Leibelfingen on the Inn ; above Aschbach on the southern flank of the Wanneck ; on the Birg Lake near the Fern Pass ; in the Gurgl valley at Upper Tarrenz ; in the Lech valley between Stög and Ellebogen ; and between Reutte and the Plan Lake. The dolomites and limestones also contain asphalt in nests and veins between Leibelfingen and Telfs ; on the Lamsen north of Schwaz ; on the Geltenbergel at Wörgl ; and at Häring. The ready fusibility of the asphalt causes it to flow from the rock-faces in hot weather. From the high percentage of nitrogen, and the abundance of fish-remains (with few traces of vegetation), Murchison suggests that the shale-bitumen is principally of animal origin. At Häring, Oligocene lignites, resting on the Triassic beds, are suitable for distillation of tar. The asphaltic Trias of the Italian frontier has already been mentioned, p. 183.

GERMANY. (Plate 4.)

In the previous edition the statement was made that the principal oil-fields of Germany are in Lower Alsace and Hanover, as shown in fig. 2 and Plate 4. The description of the Alsace oil-field will now be found under France on p. 43. Distillation of oil, paraffin, and other products, from lignites and bituminous shales, also constitutes a widespread and important industry.

Bavaria.—Asphalt occurs in the Eocene limestone of the Kressenberg, about 18 km. west of Salzburg, and petroleum in Eocene marls and sandstones on both sides of the Tegernsee, that of the western slope having been famous for its medicinal properties in the fifteenth century, under the name of St. Quirinus's Oil. Although the associated water is not perceptibly saline, it has been suggested that the true source of the oil is in Triassic rocks, which are believed to occur at no great depth below the surface. This hypothesis is the more tenable since the Triassic shales and dolomites are frequently charged with similar malodorous oil and asphalt a short distance southward, on the Reitbach at Kreut, as also further westward at Vorderriess in the Isar valley, and thence by Wallgau, Krün, and Mittenwald, to Garmisch on the Loisach. The *Posi-*

donia-marls of the Lias yield oil by distillation at Aschach near Amberg, Mistelgau near Bayreuth, Geisfeld near Bamberg, and Banz near Lichtenfels. In the Höhe Rhön, separating Bavaria and Hesse, Miocene lignites, from which tar, etc., are distilled, occur beneath a protective sheet of basalt, and are worked on the Bauersberg at Bischoffsheim, and at Weissbach, Unter-Weissenbrunn, Roth, and Fladungen. An isolated extension of the Oligocene lignites of North Bohemia, mentioned above, exists at Arzberg, in the Fichtelgebirge, 14 km. westward of Eger. The peat of Redwitz, in the same range, contains in the crevices of pine-trunks modified resins, of which fichtelite is a typical variety.

Wurttemberg.—The Miocene limestone of Ehingen on the Danube is charged with viscid asphaltic bitumen. The Lias shales at Gross-Eislingen, Boll, and Ohmden, near Göppingen; between Dusslingen and Ofterdingen; at Reutlingen; at Hechingen in Hohenzollern; and at Erlaheim, Rosenfeld, and Spaichingen, yield oil by distillation. Carburetted hydrogen is evolved from the iodine spring of Heilbronn, rising from Middle Triassic rocks.

Baden.—The Lias of Niedereggensen, 22 km. northward of Basel, has its hollow fossils charged with petroleum, and the shales of the series are again productive at Badenweiler, 5 km. beyond this and at Langenbrücken, 16 km. to the northeast of Karlsruhe, whilst between these points, the stream flowing past Baden, over Permian, Trias, and Lias, bears in the older maps the name of Oelbach. On the Upper Trias, 22 km. eastward of Karlsruhe, occurs the significant name of Oelbronn, and the Lower Lias limestone of Roth-Malsch, 7 km. northward of Langenbrücken, contains oil in its hollow fossils. Petroleum oozes from the Lower Triassic sandstone of Reichartshausen, near Amorbach in the Odenwald, whilst a hill of Permian, capped with Lower Trias, bears the name of Oelberg, some 6 km. northwards of Heidelberg, and a vein of asphalt, occurring in the quartz-porphyry of Dossenheim in that vicinity, is probably due to infiltration from deposits formerly covering the area.

Rhenish Bavaria.—The Oligocene clays of Frankweiler, 5 km. northwest of Landau, are reported as petroliferous, and a recent boring at Bückelberg in the Bienwald, between Lauterburg and Kandel, met with traces of petroleum and a powerful discharge of gas. Oil is stated to occur in the same series at Böhl, midway between Neustadt and Mannheim, and also near Offstein in Hesse 9 km. southwest of Worms. An oozing of oil from Lower Triassic sandstone has been alleged to exist at Ramsen, 18 km. higher up the valley of the Eis. Northwest of this, at 10 or 12 km. distance, traces of bitumen have been noticed in the vesicles of amygdaloidal melaphyre at Bastenhaus, on the eastern side of the Donnersberg, also in the cinnabar-veins of the Stahlberg, on the northwestern side, and in like veins on the Spitzenberg, near Kriegsfeld, 10 km. northward. In the melaphyres of the Alsenz valley, the Lauter valley, and the Saar-Nahe region generally, traces of bitumen are of frequent occurrence; and the associated sedimentary rocks being of Permian age, hopes have been entertained that these were indications of subjacent Coal-measures, although there is also the possibility of their being infiltrations from Tertiary lignitiferous deposits, since destroyed by denudation.

Rhenish Prussia.—Asphalt occurs in the Lower Trias sandstone of Aussen, near Saar-Louis, and oil-yielding Miocene lignites near Brockscheid, 14 km. northward of Wittlich; in the Siebengebirge between Linz and Bonn; at Stockheim, 6 km. southward of Düren; and on the Bensberg, 12 km. east of Cologne.

Hesse and Hesse-Nassau.—Borings at Heppenheim have found oil in the Lower Oligocene sand, and the asphalt of Mettenheim, 25 km. south of Mainz, is probably desiccated petroleum of the same period. Tertiary lignites, yielding various oils, etc., by distillation, occur at Messel, 10 km. northeast of Darmstadt; in the Lahn valley; in the Wetterau, Vogelsberg, Westerwald, and Höhe Rhön; and in the Cassel-Meissner-Münden district. These range in age from Oligocene to Pliocene, their precise position, in the frequent cases of isolation, being matter of controversy beyond the scope of this work. A discharge of carburetted hydrogen is recorded from a boring in the Lias shales of the Lickweg, Schaumburg, an outlying portion of Hesse-Cassel, sometimes called Westphalian, in distinction from Schaumburg in the Lahn valley, Hesse-Nassau. Hatchettite (or ozokerite) is said to occur in these beds. At the northwest end of the Deister range, the Wealden beds are saturated with oil at Rodenberg and Nenndorf, the asphaltic and sulphurous mud-baths of the latter being much used in the first half of the nineteenth century.

Westphalia.—The Wealden shales of Werther, 6 km. northwest of Bielefeld, are highly bituminous, and the Upper Cretaceous rocks are charged with asphalt at Appelhülsen and Buldern, 16 and 22 km. respectively southwestwards of Münster, at Hangenau, and on the Baumberg, some 12 km. northwards of Appelhülsen, whilst petroleum is said to occur at Olfen, 17 km. south of Buldern, and at Walstede, 10 km. north of Hamm. The Schöppingerberg, 30 km. northwest of Münster, has veins of asphalt traversing Upper Cretaceous rocks, as has the Weseke hill, 7 km. north of Borken, and at Frankenmühle, near Ahaus, the Gault is petroliferous. A brine-well in this series at Gottesgabe, near Rheine, emitted brilliant illuminating gas for over sixty years prior to 1828.

Hanover and Brunswick.—In this region petroleum, and its inspissated residuum, asphalt, constitute extensive and valuable deposits in beds of widely varying age. The Devonian rocks of the Harz range contain bitumen on the Iberg near Grund, and the Rammelsberg near Goslar. Commercially important beds of asphaltic limestone occur in the Upper Jurassic series on the southwestern flank of the Hils range at Holzen, about 45 km. south of Hanover, the product of the Wintjenberg and Waltersberg mines being sometimes known as Vorwohle asphalt, from the point at which it reaches the railway. The Lower Jurassic has here thick beds of bituminous shale. The Triassic potash-salt of Alfeld is contaminated with traces of petroleum. To the northwest, asphaltic limestones of Upper Jurassic age occur on the northeast side of the Ith range by Duingen, Brunkensen, and Weentzen, and the Neocomian clay of the Elligser Brink is also asphaltiferous. Beyond these, the Deister range has asphaltic limestone again at Springe, and the overlying Wealden is reported to smell of petroleum at Bennigsen (eastwards). Petroleum is said to occur, in beds probably of Cretaceous age, at Wülfel, a southern suburb of Hanover. Between Badenstadt and Linden, the Cretaceous clays are asphaltic, and oil has been found in the Upper Jurassic, and also, it is alleged, in the rock-salt of the subjacent Trias. Northwest of this, between Harenberg and Limmer, the far-famed Limmer asphalt occurs in Upper Jurassic limestones at Ahlem and Belber. East of Hanover, at Sehnde, the Neocomian beds, charged with asphalt and ozokerite, overlie petroliferous Rhætic and Triassic deposits. To the southeast, at Hoheneggelsen and Oberg, oil occurs in the Wealden, whilst at Oberg there are also traces in the Jurassic, and at Oelsburg in the Lower Trias. Southeast of Brunswick, the Lower Cretaceous and Neocomian, and the Lower Jurassic on which they rest, are petroliferous at Dibbesdorf, Essedorf, Hordorf, Kremlingen, Hötzum, Siekte, Monche-Schöppenstedt and Klein Schöppenstedt. The Trias is said to contain oil at Schöningen, 33 km. east-southeast of Brunswick, and it yields asphalt at Velpke, 17 km. north of Schöningen. Traces of oil occurred in the Wealden at Horst and Wipshausen, 18 km. northeast of Brunswick. Westward of this, at Oelheim or Eddesse, is the chief centre of the production of oil, which fills crevices in the Cretaceous clay, saturates the Wealden sandstones, and occurs scantily in the Lower Jurassic, upon which these rest. Across the upturned edges of these beds lies a sandstone of Upper Tertiary age, charged with tar, and known as the Tarpits rock (Theerkuhlenfels). About 15 km. to the northwest of Oelheim, at Hänigsen and Obbershagen, the lignitiferous Tertiaries are impregnated with tar, and oil occurs in the subjacent Trias, the newer Secondary rocks being absent here. The same conditions obtain at Steinförde, Wietze, Hornbostel, Winsen and Eickeloh, northwestward of Celle. Petroleum is alleged to appear as films on water at Sulze, 15 km. north of Celle ; at Verden, 30 km. east-southeast of Bremen ; at Soltau, 38 km. further eastward ; at Beispingen, 15 km. northeastward ; at Barrl and Wintermoor, 18 and 23 km. north of Soltau ; and at Bienenbüttel, 12 km. southward of Lüneburg. In all these cases there is a total absence of geological evidence as to the age and nature of the beds underlying the superficial drifts, peat, and alluvium that cover the wide plain of North Germany, with but rare oases where a remnant of the older rocks still resists denudation. A discharge of gas at Neuengamme, near Hamburg, may arise from the same source. A deposit of ozokerite is alleged to have been found in East Frisia, and retinasphalt at Osnabruck. The well-known asphalt of Bentheim, 60 km. to the westward, occurs as a vein in Neocomian sandstone.

Schleswig-Holstein.—At Holle, 4 km. south of Heide, Dithmarschen, the superficial sands are saturated with tar. Borings have proved that under a varying thickness of alternating sands, gravels, and clays, probably in part Upper Tertiary in age, and throughout more or less charged with bitumen, the Chalk is full of petroleum, with sufficient gas-pressure to produce temporary " fountains." In 1881, an artesian well at Apenrade, in North Schleswig, is reported to have encountered a discharge of gas, supposed to be carburetted hydrogen.

Saxony and Thuringia.—In the Höhe Rhön, the extension of the Bavarian and Hessian lignites, already mentioned, affords material for distillation at Kalten Nordheim, and also in the Werra valley at Kirschhof, near Niederndorf (Vacha district). The petroleum reported as found at Sulza proved to be refined oil. Asphalt is yielded by the Permian of Kamsdorf, 6 km. east of Saalfeld, and the bituminous shales of this series, richly charged with copper and other ores, are extensively mined along a belt fringing the Carboniferous area from Gross Leinungen, 20 km. southwest of Mansfeld, eastwards to Blankenheim and Wimppelsberg near Eisleben, and thence past Mansfeld to Burgorner. Ozokerite occurs in the Coal-measures of Wettin-on-Saale, and bitumen in the Permian of Löbejün, respectively 16 km. northwest and 18 km. north-by-west of Halle. Between Halle, Leipsic, and Zeitz on the Elster, is a wide area of Oligocene beds, the lignites of which are chiefly of the " schwälkohl " variety, and constitute the basis of the Saxon paraffin industry of which this district is the principal seat. Eastward of Gerstewitz, in the centre of the field, the seam attains a thickness of 22 metres. Small isolated portions of the mass exist at Börnstedt and Helbra, 13 and 4 km. respectively southward of Mansfeld, and a larger fragment at Aschersleben, 18 km. north of that town. The Permian shales of Weissig, 10 km. east of Dresden, are strongly charged with bitumen. Carburetted hydrogen emanates from the saliferous Trias of Stassfurt, and petroleum has lately been reported as present in the rock-salt of Sondershausen, of the same period.

North-eastern Provinces.—Asphalt occurs in the Neumark district of Brandenburg, and at Dlugimost, in the district of Strasburg, West Prussia, near the Polish frontier. Here it is an infiltration into the drift sand from subjacent beds, probably Miocene, as is also the case with oil appearing as films on the surface of water at Gross Aplingen on the Vistula opposite Marienwerder, and with the gas recently reported as found at Dirschau. A belt of sandstone charged with asphalt is reported to extend between Lissen and Weigmannsdorf, in the district of Fraustadt, Posen. The region consists of Miocene beds, generally buried deeply under glacial and alluvial deposits. Bituminous shales and "pitch-coal" occur in the Cretaceous sandstones of Bienitz on the Queis, in Silesia, westward of Bunzlau.

DENMARK.

Bergmann (*Sciagraphia*, 1782) mentions Denmark as a source of asphalt, apparently referring to the Schleswig-Holstein deposits, noticed above. The veins of asphalt in pebbles of granite, etc., of Scandinavian origin, occurring in the Danish Glacial Drift, could hardly have been held, even at that period, to be a source of supply, or evidence of the proximity of the parent mass.

NORWAY.

The native-silver veins of Kongsberg, 50 miles westward of Christiania, contain masses of asphalt. Gas-discharges in the Oedegard apatite mines, near Bamle, 80 miles southwest of Christiania, are probably partly of phosphoretted hydrogen. Asphalt occurs in pegmatite veins at Narestö, Arendal. In each case the surrounding region consists of Archæan gneiss.

SWEDEN.

A discharge of carburetted hydrogen is recorded from a boring in the Trias of Helsingborg, and similar emanations are said to be common in the drifts of southern Sweden. Where these overlie the coal-bearing Lias, such discharges are easy of explanation, but this is not always the case. At Nyhamn, several miles northwest of Helsingborg, the Lower Silurian slates, full of fossils, are traversed by igneous rocks, some of the vesicles of which are charged with petroleum. This is also the case with similar rock on the Hünneberg near Wenersberg. Some 20 miles southwest of the latter, at Torpa salt-wells on the Göta, much marsh-gas is evolved from marine driftsand, overlying a floor of gneiss. In Wermland, asphalt permeates the micaschist of Nullaberg and Gammelskroppa, and fills veins in the gneiss of Warmskog and Horrsjöberg. Bitumen in a fluid or solid state is very frequently found in the veins of copper and iron ore of the Falun, Norberg, Orebro, Upsal, and Dannemora districts. A like source may with every probability be assigned to the pebbles of granite and pegmatite, veined with asphalt, that have been found at Kiel and elsewhere, south of the Baltic, as elements of the Scandinavian Drift. The bitumen was presumably derived from overlying beds, since removed by denudation, but the time of such impregnation cannot be determined, as the area has been the scene of deposition and erosion, ever since the primeval Archæan epoch. The Silurian, Liassic, and Miocene periods, all rich in bitumen-forming conditions, may each have contributed, or the whole may be of one period. Such accessions, whether absorbed by vertical porous strata, or penetrating by fissures, would escape the erosion that subsequently removed the deposit whence the infiltration descended. The frequent presence of carburetted hydrogen in these mines has been attributed, rather too sweepingly, to the decay of timber, but this, though a *vera* *causa* in some cases, is not so in mines where no timber is used. An alternative and more generally satisfactory explanation is offered by the presence of mineral bitumens, from which the more volatile constituents are being gradually set free, in consequence of alterations of temperature and pressure, due to the mining operations. Misled by the frequent presence of petroleum and solid bitumen in the hollow fossils and other spaces of the Lower Silurian limestones of Dalarne, a number of borings were effected in 1867–1869 in the neighbourhood of Osmundsberg, an isolated hill about 35 miles northward of Falun, by some victims of the then epidemic oil-fever. The failure of these to obtain any sort of yield was a foregone conclusion from the geological structure of the region. Petroleum is being formed at the present time, though probably in very limited quantity, on the shores of the Sound near Lund, by the decomposition of seaweed in sand. It is, however, unlikely that much, if any, remains unoxidised or unevaporated.

SPITZBERGEN.

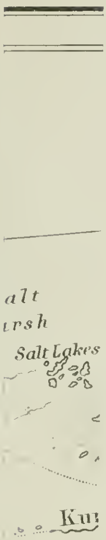
Traces of petroleum occur in the highly bituminous shales, of Rhætic age, at Capes Thordsen and Staratschin in the Ice Fiord.

RUSSIA. (Plate 5.)

Finland, Esthonia, and Livonia.—Ozokerite was discovered in 1901 on the Kemi River in North Finland, possibly the same deposit as that investigated in 1743, when a sample was doubtfully referred to the mineral kingdom. Pitch ("mumia") had been found yet earlier in the adjacent Gulf of Bothnia. Bituminous marls and limestones of Lower Silurian age form a narrow belt, parallel to the Gulf of Finland, from Odensholm Island, at the northwest angle of the Esthonian coast, to Djatlizy, about 53 versts southwest of Petrograd. The name of Pungernite was given in 1851 to a sample from this horizon, derived from a corruption of the name Paggar, the village whence it came. Discharges of inflammable gas (? carburetted hydrogen) are recorded from an artesian well at Riga, and on Kokschar Island.

Archangel and Vologda.—Indications of the presence of petroleum have been reported to exist along a line of 280 versts in a south-southeasterly direction from the Tsilma-milva, tributary to the Petchora, to beyond the Ukhta, 30 versts within the province of Vologda. These occur in Upper Devonian marls, sandstones and limestones, and have been most fully studied at the southern end of the line indicated, on the Tchuti, Ukhta, Yarega, Nepyule, Goryule, and Liyayule, western feeders of the Ijma. Evidence has recently been found of the existence of petroleum in Devonian rocks on the shores of Tchekin Bay, Novaia Zemlia. The Permian series is reported to include oil-sands near the town of Vologda.

Central Provinces and Ural Mountains.—Asphalt is reported to exude from Devonian rocks on the north side of Lake Escha, Rositen district, Vitebsk, and ozokerite, or a kindred substance, occurs in the peat-mosses of Kaluga. Subordinate shale-bands in the Carboniferous Limestones of Perm are sufficiently bituminous to burn, especially on the Kosva, about 33 versts south of Alexandrovsk, and on the railway 50 versts further south, and 22 north of Tchusov. "Combustible earth" in Orenburg, and "a remarkable rock-fire" in Ufa, are mentioned by eighteenth-century writers, and may refer to the Permian asphalt of Subowka, and the exudations of oil at Schakitau, both in the Sterlitamak district of Ufa, formerly included in the province of Orenburg. Petroleum



Salt Lakes

THE CAUCASUS

Plate 5.

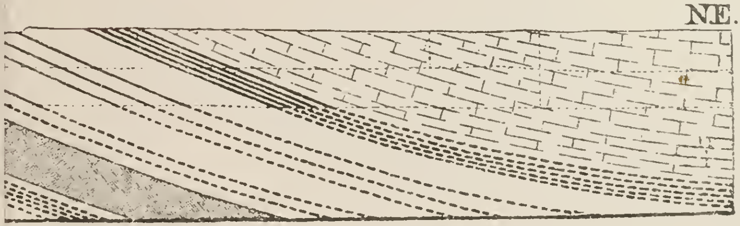
English Statute Miles

London: Charles Griffin & Co. Ltd.

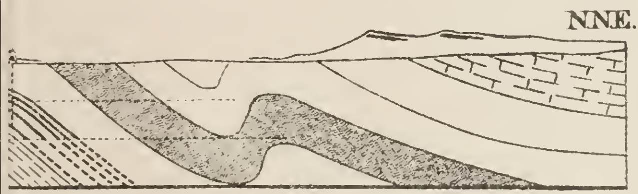
Petroleum deposits shown in red

Stanford's Geog^l Estab^t London

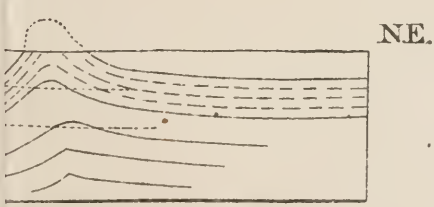
T.



ART OF ZABRAT FARM.



Y) AND PERIN-AGIT HILL.



LAN & HEKMALI.

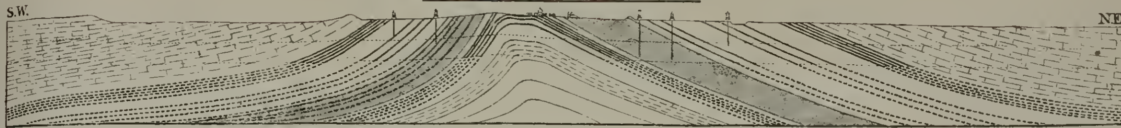
4 Versts.

Petroleum-bearing sands lying at depths down to 200 sagenes.

Part of the same beds at depths below 200 sagenes.

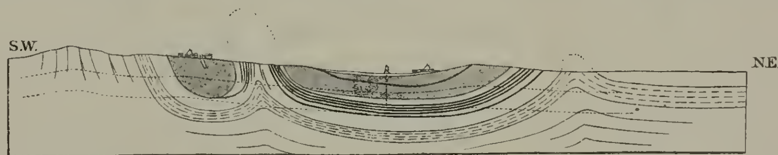
Stanford's Geog! Estab! London

CROSS SECTIONS IN THE BAKU DISTRICT.



WESTERN EXTREMITY OF THE BALAKHANY FIELD AND PART OF ZABRAT FARM.

ANTICLINAL BETWEEN PUTA (TRANS-CAUCASIAN RAILWAY) AND PERIN-AGIT HILL.



SYNCLINAL CROSSING THE VILLAGES OF KHURDALAN & HEKMALI.

1 Inch=1 Verst.

Sagenes 500 400 300 200 100 0 1 2 3 4 *Versts.*

Limestones, Clays and Sands.

Schistose-Clays, Marls and Clay-Sands.

Soft Quartz Sands and drift Sandstones.

Clays and Marls.

Petroleum-bearing sands lying at depths down to 200 sagenes.

Part of the same beds at depths below 200 sagenes.

Existing and projected boreholes.

Stanford's Geog^l Estab^t London

London · Charles Griffin & Co Ltd.

and asphaltic tar impregnate the Permian gypsum and sandstone of a large area in Kazan, Simbirsk, and Samara, from Syukieeff on the Volga and Lower Karmalka on the Scheschma to Kamischla on the Sok and Upper Orliaci on the Kinel. Gas is reported at Novo Uzensk, in Samara. Northward of this, around Sizran, the Carboniferous Limestone is charged in places with asphalt, and at Kaszpur, 7 versts south of Sizran, the Jurassic series contains seams of oil-shale. The locally prevalent belief in the presence of petroleum in Volhynia (with alleged "greasy spots on water" and traces of "ozokerite"), chiefly in the districts of Kremenetz and old Constantinov, is assigned by Prof. Lazarev to bituminous elements in the Silurian and Miocene limestones, and to doppleritic peat, no commercial value attaching to the bitumen in either case. On the other hand, traces of pure petroleum, although equally scanty and valueless, occur at Zalutcha, in Kielce (Poland), in Cretaceous marls and the overlying Miocene. This is probably derived from a more deeply-seated horizon, as neither formation is known to be petroliferous in Poland, nor, in respect of the subdivisions represented, in the adjacent Galician oil-fields.

Southern Provinces and Caucasia.—The reported discoveries of petroleum near Odessa, Perekop, and Berdiansk respectively may be fact or fiction. The Miocene beds in the first two cases rest upon older Tertiaries, in the last they abut against an uprising massif of ancient rocks, a structure by no means favourable for copious yield, even if oil be present in the series. Owing to the extraordinary prolific character of the oil-fields of the Apscheron peninsula, some notice of the principal portions of which has been given in the brief historical sketch of the Russian petroleum industry in the previous section, comparatively little experimental drilling has until lately been undertaken elsewhere in the Caucasus, but there is ample evidence that petroleum exists along the whole range, extending from the Crimea to the Caspian Sea, and beyond it far into Asia. It is practically confined to the Tertiary deposits, and consequently the area occupied by older rocks, constituting the axis of the range, separates the petroliferous ground into two belts, united at either end. On both belts, oil and gas occur at many points, as is shown by the map and sections, Plates 5 and 6.

The Kertch peninsula at the eastern end of the **Crimea** has long been known as an oil-field, but hitherto no great yield has been secured, although the entire peninsula consists of petroliferous Oligocene and Miocene beds at the surface or within accessible depth, and often with the most favourable structure for copious yield. Petroleum is already recorded from Zamorsk on the coast of the Sea of Azoff, from Misir and Karalar near Tchokrak, from the mud-volcanos of Bulganak, Enikale, and Djerjaff near Kertch, from Temesch, Karmisch, Keletcha, Djermai Kaschik, and Tchuburtma Sart in the interior of the peninsula, and from Kaschelar, Kop Kotchegen, and Tchongelek in the southern hill-range.

The **Taman** peninsula, practically a prolongation of that of Kertch, offers a series of sharp ridges, rising between swampy plains. Along these ridges, mud-volcanos are of frequent occurrence, and the plains consist largely of the mud which they have ejected, levelled by aqueous action. Petroleum is a constant accompaniment of the mud, but no large yield has yet been secured by the few borings carried out. The region is one in which three directions of compressive force have simultaneously or consecutively prevailed, producing anticlinal ridges with northeasterly, easterly, and southeasterly strikes respectively. The first, or Crimean, thrust affects the southern coast only, the second the central and northern portions of the peninsula, whilst the third, or Caucasian, is predominant at Temriuk and east of Anapa.

Passing to the northern foothills of the Caucasus, the commencement of oil-production is found at Suvorov-Tcherkess, 10 versts north of Anapa. Traces occur in this interval, and northeastward by Michaelsfeld to Varenikoff. A long narrow belt of petroliferous ground extends thence southeastwards throughout the **Kuban** province, oil being found on the rivers Tchekups, Schugo, Khops, Psebeps, Psiph, Kudako, Abin, Akhtirk, Azips, Ili, Ubin, Less and Greater Tchibia, Il, Pschepheps, Tsits, Pschekha, Tsekotch, and Belaya, a range of about 200 versts in length from Varenikoff to Mailop. The principal operations are at Kudako, Ilski, Khadijin, Nephtiannaia, and Schirvan. Probably future explorations will extend the line into the Terek province. The rivers named follow approximately parallel courses at right angles to the strike of the beds, which are of Miocene age, dolomitic limestones at the top of the series, shales and sandstones below. The actual thickness of the group, as far as oil is concerned, is less than 1000 feet, and there is a persistent northeasterly dip of 45° to 60°, so that the width of the outcrop rarely reaches, and nowhere exceeds, the thickness. The oil-horizons can of course be reached by borings on the northeast side, but at less than half a mile distance from the outcrop of the limestone, they would lie too far below the surface to be accessible with the drill, apart from the probability that at such a depth the oil would be replaced by water to a large extent, if not wholly. These conditions obtain over a considerable length of the line indicated, but towards its eastern end the belt widens to more than 10 versts, by reduction and reversal of dips, constituting a much more favourable structure. Ozokerite is reported as found at Ekaterinodar (possibly meaning an adjacent point on the above-mentioned belt) and at Kalatchin on the Little Laba, 70 versts southeast of Maikop; its occurrence in the Khadijin district is well established.

It is probable that petroleum will eventually be found in the province of Stavropol, as rich deposits were reported in 1901 as existing near Karras and Nicolaevsk, north of Piatigorsk, and not 10 miles within the **Terek Territory.** The interval between these and the nearest evidences of oil southeastward is about 150 versts, to the recently recorded exudations near Bataschev and Astemirova, the former on the railway, the latter some 13 versts east of it, 50 versts northwest of Vladikavkaz. At 28 versts eastward of Astemirova, and 35 north of Vladikavkaz, oil-traces are noticed at Upper Atchuluk, and others at Voznesensk or Mahomet-yurt, 25 versts to the north, and again on the Arkhon, 4 versts west of Vladikavkaz. The latter point is on the line of a series of exudations of oil, some of which have been exploited for local use, extending along the flank of the Black Hills from Datikh to Dilim, respectively 50 versts southwest and 80 east-southeast of Grozni, approximately on the parallel of 43° north latitude. On the opposite side of the Sunja valley, the Bataschev-Atchuluk line is continued at Karabulak and Mikhailov, 58 and 38 versts respectively west of Grozni, on the southern flank of the Grozni range. This is here single, but bifurcates a little further eastward, and terminates near the town. Its northern limb constitutes the important Grozni oil-field, inferior only in value to those of the Apscheron peninsula. The most productive part lies on the northern brow, from 10 to 20 versts west-northwest of Grozni. Across the Nephtianka valley lies the Terek range, with the river of the same name beyond it, after a most circuitous course from Vladikavkaz. On the Terek range, no trace of oil seems to have been noticed on the surface between Voznesensk and Goryatchevodsk, 13 versts northeast of Grozni, where a deposit of kir has been recorded. Further east, on the Terek above Braguni, and 25 versts east-northeast of Grozni, oil again appears, and also at Istisu, 40 versts east of Grozni. The age of the beds from which the oil is derived has been demonstrated as Miocene by irrefragable palæontological evidence. The Grozni range is a sharply-folded anticlinal, between the synclinal trough of the Nephtianka and Sunja valleys, whilst the Black Hills range, south of the Sunja, is a monoclinal of strong northerly dip. There is in the latter case another anticlinal axis at some distance southward, but it brings to the surface Cretaceous rocks, in which no petroleum is known to exist in the North Caucasus. Ozokerite occurs on the Black Hills line, on the Tchenti-Argun, due south of Grozni.

Daghestan Territory.—Petroleum appears about 3 versts east of the Sulak, and 15 south of the Tchiryurt railway station, aligning with the Black Hills range, mentioned above, at a distance of some 16 versts from Dilim. At 28 versts east-southeast of these, and 22 westward of Petrovsk, are the Kumterkale oil-springs, on a tributary of the Schura-ozen. At 15 versts above these, oil is reported as appearing at the surface in Temir-Khan-Schura. Ten versts eastward of the Kumterkale springs are the Atlibuyun oil-wells, and about the same distance beyond, and as far to the south of Petrovsk, are the exudations of Giik Salgan. Ten versts southeast of these, oil again appears at Kara-budakh-kent springs, at the same distance northward of that village. There is an interval of 60 versts to the Kaya-gent wells, 15 versts beyond which are those of Bereke, 25 versts northward of Derbent. Lastly, oil exudes from mud-volcanos on the Rubas, at Khosch Menzel, 15 versts south of Derbent. Borings have been carried to considerable depths at several of these points, but, except at Bereke, no great yield has hitherto been secured, probably on account of unfavourable structural conditions at the points selected. The structure of the region is very clear as far as concerns the beds forming the surface, but, as these rest unconformably upon lower beds of discordant strike, the anticlinal and synclinal axes of the newer series furnish no criterion of the effect of the later compression upon the subjacent masses. The surface rocks have a strike parallel to the coast, but the same cannot be asserted of the more deeply-seated beds, nor the coincidence of their axes of flexure.

Kutais.—Returning to the west-end of the Caucasus, in order there to trace the Tertiary belt on the southern flank of the range, we find the evidence of the presence of petroleum less continuous than on the northern side, largely, no doubt, on account of the limited extent of investigations effected in the less civilised districts. No trace of hydrocarbon, except in the form of coal, is recorded in the 180 miles between Anapa and Gagri, where asphaltic limestone of Cretaceous age is said to occur. Asphalt is reported from the Donetz coal-field (? Miocene), several leagues eastward of Gagri, and an interval of some 60 miles separates this from Anaklia, at the mouth of the Ingur, where petroleum is reported, apparently in Miocene rocks. Twenty-five miles further south is the Supsa oil-field, in Miocene marls and sandstones, with a large admixture of pebbles of older rocks. Oil exudes at many points in Omparété, Maghélé, Tchotchkhati, Guliani, Guriamti, Tchapeturi, Mikhel-Gabriel, Samkhto, Jacobi, Narudja, and Notanebi. The asphalt of the last, being on the railway, is worked, but no large yield of oil has been secured in any part of the field. The severe dislocations of the strata, and the high angles of dip prevailing, promote waste by natural outflow, whilst enhancing the difficulties of access to intact stores of oil. Asphaltic Cretaceous limestones occur at Nagarebi, near Kutais, and the Lias of Akhokrua near Dzmuisi, 25 versts northeastward of Kutais, contains asphalt and ozokerite. Petroleum is found in the same series at Kheiti, Khirkhonis and Somitso, in the Ratcha, and near Tedeleti in the Kvirila basin, 70 versts east-northeast of Kutais. Ozokerite also is said to occur in the vicinity of Tedeleti, and petroleum a few versts up the Tchikarula from Satchkeri on the Kvirila. The Neogene at Kvirila railway-station is stated to be petroliferous, and the Eocene rocks of Korischi, on the Khanis-tskhali, 30 versts south-southeast of Kutais, show traces of oil.

Tiflis.—In the Tiflis Government, petroleum occurs in the Middle Jurassic series, a few versts southwest of Tsona, on the Kutais border and not far eastward of Tedeleti. South of the Kur, about 25 or 30 versts below Gori, the Sarmatian limestones, in a vertical position, contain traces of petroleum, which is also reported as found near Rodionovki on the eastern shore of Lake Toporovan, possibly impregnating some absorbent igneous rock. Eastward of Tiflis, the Tertiary belt assumes a more regular course, and presents a practically continuous oil-field, extending over 150 versts southeastward, its northern edge being near the 42nd parallel of latitude on the 45th meridian, and its width at least 50 versts. Petroleum is yielded in this belt by both Oligocene and Miocene beds. The compression to which the strata have been subjected between the older rock-masses on the northeast of the Alazan and the southwest of the Kur, has produced dislocations and flexures of complex character, and the practically certain continuity of petroliferous character in the intervals between points of natural escape as oil-springs, renders it unnecessary to load this account with the names of casually noted localities, only indicated in maps of large scale. The chief centres of operation are Navtluga, two versts southeast of Tiflis ; the Signakh and Tsarski-Kolodtsi district, from 15 versts northwest to 40 versts southeast of Signakh, and extending southwestward to the Tchatma and Eldar fields beyond the Yora ; and the Scherak Steppe.

Elizabetpol and Erivan.—There is apparently but little petroleum in these provinces. The Geran field, 30 to 35 versts southeast of Elizabetpol, is the principal area, but traces occur also in the Kazakh, Djevanschir, Alexandropol, and Nakhitchevan districts. All appear to be in Miocene rocks.

Baku.—The province of Baku, or rather a few square miles in the Apscheron peninsula, has furnished matter for more abundant literary reference than any corresponding area in the world, partly by its natural phenomena, inspiring every traveller to more or less fervent eulogy, partly by its abnormally copious yield of oil. The bulk of the matter is, however, of statistical, chemical, commercial, or trivial character, and the geological structure of the region has but recently received the attention its complexity and importance merit. The age of the principal oil-bearing beds is Miocene, the deeper wells extending into the Oligocene, with much advantage. Yields from the Pliocene and newer deposits, which are unconformably superposed to the older series, are due to upward infiltration therefrom. The productive series consists of shaly marls and fine-grained calcareous sandstones, in very frequent alternations, the sandstones varying from hard rock to practically loose sand, in which compact masses of irregular size and form are more or less abundant. The oil-sands are so incoherent as to be brought up in large quantities with the oil, sometimes constituting in " fountains " 25 or 30 per cent. of the mass discharged, and precluding the use of ordinary pumps in wells that do not flow. The " sand-pump " or " bailer " requisite in such cases will be described in a later section. Masses of compact rock are occasionally hurled forth by the fountains, or by the powerful jets of gas set free by penetration of the confining strata. It is said that stones are sometimes propelled to a height of 250 metres, and the ejection of the drilling-tools is of frequent occurrence.

The upturned and denuded edges of the Oligocene are largely covered by Pliocene and later deposits, which have also suffered a certain degree of disturbance. As the movements which these later rocks have experienced were in a direction oblique to the normal strike of the older series, their undulations afford no criterion as to those of the much more disturbed beds below. The effect of the secondary pressure in a direction oblique to that of prior folds must have produced a resultant structure far more complex than the most intense action in a uniform direction. As the mass subjected to such diverse consecutive compression consisted primarily of wedge-shaped deposits of varying dimensions and compactness, with irregular powers of resistance to deformation, the complexity of its ultimate structure is necessarily much enhanced, and it is not surprising in consequence to find that wells within a few yards of each other penetrate very different sequences of strata, and strike masses of petroliferous sand wholly disconnected and diverse in depth, hydrostatic pressure, and other conditions. This complexity, however, does not involve the impossibility of ultimate explanation of the apparent chaos by calculation from properly kept records of strata traversed, records equally serviceable to science whether a boring be productive or fruitless. Total depth and yield of oil are trivial data in comparison with accurate accounts of the overlying beds.

There is a tendency to confound approximation in depth from surface with true equivalence of oil-seams, and to speak of "the" second, third, or fourth horizon as identical throughout the field, irrespective of surface-elevation, high dips, and faulting. It is evident that the topmost oil of one well may be really the deepest of another, or *vice versa*. Unless a definitely recognisable stratum affords a datum for comparison, the petroliferous seams of each well can only be numbered independently of all others. Even hydrostatic connection, evidenced by mutual relations of discharge, does not prove identity, since fractures and dislocations may have brought portions of different seams into such casual communication.

Professor H. Sjögren, of the Upsala University, in his elaborately detailed description of the geology of the Apscheron Peninsula, published in the Proceedings of the Stockholm Geological Society, considered that, on account of the disturbed condition of the oil-bearing series, no general deductions of practical value as a guide to the selection of the most suitable spots for boring could be drawn from the then existing data, nor did he regard it as safe to predict which portion of the peninsula would ultimately prove to be the most prolific. At one time the rich Romani field was held to be of very small promise. Oil is found at widely different depths even in closely adjacent wells, and the yield usually increases proportionally with the depth, whilst owing to the dislocated state of the beds, little or no hydrostatic connection exists between the productive masses of sand, each constituting a practically independent source of supply. There have been recorded, however, notable instances of direct communication between wells at some distance apart.

Improvement in drilling apparatus and in technical skill, stimulated by indications of exhaustion of the uppermost oil-seams, has resulted in constant increase in the depth at which oil has been reached, accompanied as a general rule by a proportionally greater yield. In 1862 Abich assigned 70 feet as a maximum depth ; in 1873 Trautschold extended this to 200 ; in 1884 Ragozine mentions 500 ; the first edition of this work, 1896, recorded 1450, and many recent borings have exceeded 2000 feet.

Sections of the Baku fields, generalised to an extent making them merely diagrammatic, are given on Plate 6 from a report of N. Barbot de Marni.

The gas-fields of Russia are co-extensive with oil-fields, and no attempts have yet been made to work them independently. The actual output of gas from the principal wells, and the exact pressure at which it issues, are not known, though it has been estimated that some of the Baku wells discharge their oil at a pressure of about 300 lbs. per square inch.

In view of the identity of age of the oil-bearing series of the province brief mention in geographical sequence, of the several fields or isolated occurrences as yet known will suffice to indicate the extensive area within which oil is present, except in the occasional protrusion of Eocene or Cretaceous rocks. The most westerly points calling for attention are Kinalugi, on the northern slope of the Schah-dag, and Boscha, in the Gerdiman valley southeast of Baba-dag, where occur emanations of gas, "eternal fire." Oil is said to occur on the Mugan Steppe, on both sides of the Persian frontier, but this is probably in Neogene strata, and newer than that of the rest of the province. At Schemakha; at Khilmil, 17 versts northeast of Schemakha; at a point between Marazin and Kurbantchi, 28 versts east-southeast of Schemakha, and at Djevat on the Kur, oil has been found in fair quantity, but development has not reached an important stage. It is otherwise in the rest of the area, the petroliferous ground of which is accessible by sea or railway, without prohibitive difficulties of transport, viz. in the coastal belt extending from the delta of the Kur to that of the Kuba. Petroleum is found on Kizil Agatch Bay, by Khankischlag, Bojii Promysl, Salyani, Zubov, Navagi, Alyati, Pilpilla, Schuraga, Osmandag, Djengin, Karakischlag, Nopht, Maganna, Karaibasch, Kyurgez, Lok Botan, Puta, and the Jasmal Plain to Bibi-Eibat. Off the coast are several islands formed by the ejection of mud by oil and gas rising in the sea-bed. One named Kumani, formed in 1861, has vanished, and others have had too brief an existence to receive the attention of cartographers. The most important of those still resisting the waves are Kurin, Pogorellaia, Plita, Oblivnoi, Svinoi, Los, Glinyansi, Bulla, and Duvani. These are collectively known as the Glinyanoi (Mud) Islands, and their positions are on the prolonged axes of the anticlinals of the mainland. On Apscheron, the oil-fields around Boog, Gekmal, Khurdalan, and Serai, at the base of the peninsula, are practically continuous with the far-famed belt of Binagadi, Balakhani, Sabuntchi, Romani, and Surakhani; eastward at Kala and Sviatoi (Holy) Island are separated points, and recent exploration has met with a certain measure of success about Phatmai, Masazir, and other spots north of the Balakhani zone. Beyond Apscheron, the coastal plain has oil at Kilyazi, Khidirzindi, and Kizil Burun, but under less favourable structural conditions than those obtaining to the southward, so that no important development has yet been effected, and it is believed by some authors that some at least of the oil detected occurs in Cretaceous and Jurassic rocks, uplifted at high angles, and covered unconformably by the Tertiary deposits. Although these lower rocks, extending throughout the Caucasian range, exhibit, as already mentioned, traces of bitumen here and there, they are unlikely to furnish petroleum in amount of commercial value, and in the case of Kilyazi and Khidirzindi there is reason to assign the oil they contain to downward infiltration from the Tertiary beds, even where these have been locally removed by denudation.

Of the submarine emanations of oil and gas, several occur on and near the islands already named, whilst on the northeast of Apscheron, about 3 versts off Busorna, an island was formed in 1892, and lasted a few weeks, leaving a shoal where there had previously been a depth of 50 to 60 feet. Some 5 versts eastward of this a shoal was then found to have risen from a depth of 80 feet to within 3 feet of the surface, having in its centre a hole 4 feet in diameter and 100 feet deep, full of mud in a state of ebullition from the escape of gas. Eighty versts eastward of Baku, the "Naphtha-Bank" shows projecting rocks of petroliferous sandstone, and 100 versts thence to east-southeast, mud-discharge has reduced the charted depth by 150 feet.

ASIATIC RUSSIA.

Uralsk.—An extensive oil-field exists across the lower parts of the basins of the Uil, Sagiz, and Emba, ranging inland over 100 versts from the shores of the Caspian, and stretching from near Prorwa Island on the 46th parallel of latitude nearly to the 48th. Indications of a second oil-belt are said to occur at Port Uilsk and at some ill-defined points in the upper valley of the Emba. The geological age and structure of these (which for the present may be presumed alike in both, though not yet determined with any degree of precision) may be provisionally described as a complex of Cretaceous and Permian strata, the latter outcropping along the more pronounced anticlinal flexures. Much of the surface is masked by Quaternary deposits, and the rising land of the Ust-Urt plateau southward consists of Paleogene and Neogene rocks. The oil differs from that of the Baku field by its large percentage of paraffin, and associated seams of ozokerite, but these constitute no criterion of age, in the absence of trustworthy data for stratigraphical determination.

Early drilling sites were largely based upon oil seepages associated with oil-bearing beds concealed by the Quaternary deposits. Highly successful results have attended drilling, notwithstanding the fact that complex features have been brought to light, such as massive bodies of rock-salt and gypsum, whose extent and distribution is still a subject of surmise (*A. Beeby Thompson*).

Western Siberia.—In the Turgai province, oil is reported to occur on the Djusie River, and in the Semipalatinsk dopplerite or tarry asphalt is said to cover some 80 square versts to the thickness of an inch or two, around the Alagul salt-lake, southwest of Lake Balkash.

Eastern Siberia.—Petroleum is reported in Minusinsk, and " earth-fire " on the Lower Tunguska ; the latter may, however, be of peat or coal, burning *in situ*. The Jurassic rocks on the Angara, 35 versts below Irkutsk, give rise to an oil-spring. Masses of ozokerite are cast up on the southeastern shores of Lake Baikal, and petroleum occurs in the Selengin district, but the complex geology of the region leaves the age and extent of the deposit doubtful. The oozings of oil near Koltsova, on the Amur River, 265 versts above Blagoveschensk, from amygdaloidal melaphyre, intrusive through granitic rocks, have a possible explanation in the Miocene deposits which at no distant period covered this region, and which are extensively petroliferous in the northeastern part of Sakhalin island. Traces of oil occur near the source of the Schemjetch, on the eastern side of Kamtchatka, about 55° N., 160° E., in Tertiary, and probably Miocene, beds. Springs of a fluid resembling crude oil are reported as frequent in the Tchukot region of the northeastern coast of the Yakoutsk province, and eastward on Baranov Bay and the Baranikha and Great Rivers. The source of these may be doppleritic tundra, or subjacent Tertiary rocks.

Ferghana.—Two distinct oil-horizons, of Cretaceous and Lower Tertiary age respectively, occupy a fairly wide area in common in the Andidjan, Namangan, Marghilan, and Kokand districts, the chief points of development being at Maili Su, Tchangir-tasch, the Tokebel Hills, the Sching and Unka valleys, Maili Sai, Kitchik-schai, Kanibad, Lyakan, and Kamisch Basch. The Tchimion oil contains a large percentage of paraffin, and ozokerite is mined at Kanibad and Lyakan. Traces of oil continue westward to the districts of Kostakoz and Kanibadam, on the border of the Syr Darya province.

Zaravschan.—Traces of petroleum are reported to exist on the northern slope of Khazret-i-Sultan, oozing from Tertiary clays, and in Bokhara the

Shirobodi oil is used as fuel on locomotives on the Turkestan railway. It is not clear in what region Alexander's servant Proxenus discovered petroleum on the banks of the Oxus or Amu Darya, as recorded by Plutarch, but on the Syr Darya, about 35 miles from the Lake of Aral, is a region bearing the name Mailibashi, connoting the presence of oil (maili), either native or brought thither by the river.

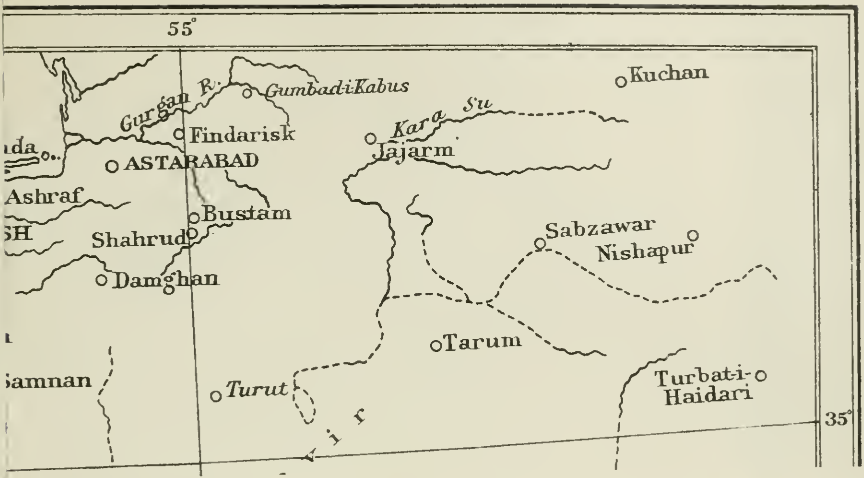
Transcaspia.—There are reports of the occurrence of oil near Merv and Sarakh Serakhs, at Derbe*nt*-nefte, a frontier-fort 35 versts from Duschak station, at Kaaka, and other points of the Kopet range. Exploitation is in progress on the Buyadag and Nephtedag, near the Caspian shore, and respectively 60 versts south-southeast and 30 south-southwest of Bala Ischem station. Strabo refers to oil occurring on the Ochus or Atrek, which is supposed to have formerly entered the Caspian 130 versts northward of its present mouth, and not far from the sites now under operation. To the west, the Island of Tcheleken is rich in petroleum and ozokerite. These Transcaspian localities have been thought to represent the Asiatic prolongation of the Apscheron oil-bearing series, of Oligocene age, but this hypothesis is wholly untenable. Their approximate alignment therewith is more apparent than real, for their strike is markedly oblique to that line. It is stated also that the rocks constituting the surface are of Pliocene or yet newer age, equivalent to those which in Apscheron unconformably overlie the productive series, and contain only oil derived therefrom by leakage. Similar derivation in Transcaspia cannot be held as an argument for equivalence of the subjacent series, and the different character of the oil, rich in paraffin, although not in itself a factor of decisive weight, is at least significant in view of the facts already set forth, of Eocene and older petroleum occurring on the Asiatic side, whilst in Georgia and Mesopotamia the Miocene or newer deposits are the chief or only source of petroleum. "Perpetual fire," as recorded at Baschkiri-Ural, near Sulp-Oul on the Mangischlak peninsula, and black oil "on Mount Irnek, on the Kirghiz-Khiva frontier," would appear to be in the same region, but these local names are undiscoverable, and no mention of the fire or of oil is made by later students of the geology of the Mangischlak, in which Palæozoic, Secondary, and Tertiary rocks present a complex mass of unconformities, foldings, and faultings.

PERSIA. (Plate 7.)

The following is an abstract of a paper by Mr. H. G. Busk and Mr. H. T. Mayo on the "Geology of the Persian Oilfields," read before the Institution of Petroleum Technologists, 15th October 1918. The abstract, and the accompanying map, have been furnished by the authors, with the sanction of the Directors of the Anglo-Persian Oilfields, Ltd.

At the present stage of geological knowledge of S.W. Persia and the Persian Gulf region, the petroliferous areas may be considered under three heads, viz. (1) The Bakhtiari country, in which the main oil-field is situated; (2) The Ahwaz-Pusht-i-Kuh country, extending to the Mesopotamian frontier and including the Khanikin-Chiah Sourk district; and (3) Qishm Island and the Persian Gulf region.

The main stratigraphic divisions in their typical development throughout these three regions are:—(1) The Asmari series (Cretaceous to Oligocene), principally massive limestones, 2000 ft. or more in thickness; succeeded by (2) The Fars series (Miocene), more than 7000 feet thick, divided into three groups; the lower, formed of some 3500 feet of massive gypsum, shales, clays, and intercalated beds of limestone; the Middle, 1000 feet of clays, shales,


55°
Gumbad-i-Kabus
Kuchan
Gurgan R.
Kara Su
Findarisk
Jajarm
ASTARABAD
Ashraf
Bustam
Sabzawar
Shahrud
Nishapur
Damghan
Tarum
Samnan
Turut
Turbat-i-
Haidari
35°

PERSIA

Plate 7

Petroleum deposits shown in red O

London: Charles Griffin & Co. Ltd.

English Statute Miles

50 40 30 20 10 0 50 100

Stanford's Geog¹ Estab¹ London

intercalated gypsum, limestone, and sandstone; and the upper, 2700 feet of clays, shales, and intercalated sandstones.

The Fars series is overlaid by (3) the Pliocene Bakhtiari series, of which the Lower group consists of 13,000 feet or more of clays, sandstone, and conglomerate, and the Upper of 2000 feet of massive conglomerates.

Oil is found principally in the Lower Fars group, vesicular shelly limestones intercalated between massive gypsum being the reservoir rocks. It also occurs indigenously in the Middle Fars group, as at Dareh-i-Qil, 30 miles N.E. of Maidan-i-Naptun, Marmatain, 10 miles E. of Ram Kormuz, and White Oil Springs, 20 miles S.E. of Maidan-i-Naftun. Of these localities, Marmatain and White Oil Springs have been tested by the drill, but neither with very satisfactory results. (In the former case the underlying gypseous group, and not the Middle Fars, was tested, whilst at White Oil Springs a small show of naturally refined water-clear oil, similar to that seeping at the surface, was struck.) Residual seepages, from the gypseous group also occur in the upper members of the Asmari series; oil is doubtfully indigenous in the latter in some cases.

The **Bakhtiari country** has been surveyed in some detail by Messrs. Busk and Weatherhead, of the Anglo-Persian Oil Company's Geological Survey. These workers have shown the geological history of this region to be one of great interest. The strata of the Fars series were deposited in quiescent conditions in a broad geosynclinal, the thickness of individual beds remaining very constant. Throughout the succeeding Bakhtiari period there was constant but gradual earth-movement, uplift and depression occurring along well-defined axes, with N.W.-S.E. orientation. The thickness of the Bakhtiari series consequently varies greatly, being greatest in the synclines and least over the anticlines. With the increase of sediment and decrease of intensity of earth-movement, the Upper Bakhtiari conglomerates, 2000 feet in thickness, spread over the finer-grained sediments of the Lower group, often resting unconformably upon the upturned edges of the latter.

The later structures, induced by post-Pliocene movements continuing down to the present day, have been to a great extent influenced and determined by the heterogeneous nature of the Asmari-Fars-Bakhtiari crust. The petroliferous gypseous group, which is extraordinarily plastic, and behaves under stress as a semi-fluid, is sandwiched between the highly rigid Asmari series below, and Bakhtiari series above. Where the gypseous group is braced by a rigid overburden of Middle and Upper Fars and Bakhtiaris the strata are kept in position and remain regularly disposed, but where denudation has sufficiently removed the protective overburden, prior to the period of maximum post-Pliocene earth-movement, minor folding, contortion, shearing, and extensive thrust-faulting of the gypsum have been developed.

Messrs. Busk and Weatherhead have shown the close interdependence between the latter structures and the details of present-day topography. The Upper fault blocks of the major thrusts, where unobstructed and allowed free movement, have moved forwards over thousands of feet, but where brought up against relict masses of Bakhtiari conglomerate, intense shearing and contortion of the gypsum, recumbent folding, incipient fan-structures of a type designated by Mr. Busk "Omega structure," and back-faulting have resulted. In some cases the over-thrust fault-block of one major thrust approaches the upper back-fault block of the next major thrust. At Maidan-i-Naftun the meeting of the opposing fault-blocks has only been prevented by the activity of the Tembi River, which has maintained its course and removed in the form of debris, etc., resulting from subaerial denudation, the opposing fault-walls correspondingly with their advance by the tectonic process.

The Maidan-i-Naftun main oil-field is situated well out on the N.E. flank of the Maidan-i-Naftun anticline, so that there is no danger of wells reaching the fault-plane of the Tembi thrust-fault, which replaces the S.W. limb of the anticline, or even of entering the zone of isoclinal folding associated with—normally, in such structures—and overlying the thrust-plane. The Tembi fault hades at the surface at an angle of 83°, that is to say, it dips at the surface at 7°, but the hade decreases with depth, as does the displacement, the fault eventually dying out, thus rendering the fault-plane convex in cross-section. The maximum displacement is 12,000 feet. The field is characterised by minor folding, but lies in the " open " portion of the Maidan-i-Naftun anticline, which to the N.W. is pinched up into Omega form. The main producing oil-zone is struck at from 1100 feet to 1400 feet.

The **Ahwaz-Pusht-i-Kuh** region presents similar tectonic features, but disturbance has been less intense. Except to the N.W., in the foot-hills of the Pusht-i-Kuh range, exposures are isolated and intermittent, and the chief problem that confronts the geologist is stratigraphic correlation with type areas. The Ahwaz range is a low and irregular anticlinal line of hills rising out of the Mesopotamian alluvial plain, and striking W.N.W. and E.S.E. through Ahwaz ; it is the farthest recognisable outlying fold of the Iranian mountain chain. The fold has been traced for a distance of over 100 miles N.W. and S.E. of Ahwaz. A test-well was drilled in 1913 east of the Karum River, in the neighbourhood of Ahwaz, on the N.E. flank of an asymmetrical but well-developed dome. An approximate correlation with the known stratigraphic sequence was adopted, based on general lithological characters. The lowermost two or three hundred feet of beds exposed were classed provisionally as a lower sub-group of the Upper Fars. Later they were recognised as belonging to the Middle Fars passage group, a correlation which has recently been confirmed by the survey of the more remote northwesterly extension of the fold.

As already explained, faulting or overthrusting is not developed when the gypseous group is braced by a sufficient overburden of Upper Fars and Bakhtiari strata. This condition is well illustrated at Jebel Mishdakh, 40 miles N.W. of Ahwaz, where faulting of the exposed gypseous group has occurred along the axial plane, but dies out rapidly to the N.W., as the gypseous group pitches below superincumbent Middle and Upper Fars beds.

Other favourable structures, comprised in local domes resulting from undulations of pitch of the axes of the Ahwaz and Mishdakh folds, exist N.W. of Ahwaz ; the best of these is the Sinn el Abbas dome on the Karkheh River, which is both a more extensive and a less sharply asymmetrical structure than any in the immediate neighbourhood of Ahwaz. At the foot of the Pusht-i-Kuh range, in the Dalpari-Deh-Luran district, the whole Fars succession outcrops against the flanks of great Asmari limestone domes. The gypsum group is isoclinally folded and disturbed to a great extent. At its base is a conspicuous thick bed of limestone, below which, apparently conformably, a group of thin limestones, or marls, and dark blue clays, overlies the Asmari series. Both gypsum and limestone groups are petroliferous, and the prospects of this area are regarded as very favourable.

Qishm Island and the Persian Gulf Region.—Qishm is the largest island in the Persian Gulf, and is situated near its entrance, opposite the coast between Lingah and Bunder Abbas ; it is more than 60 miles long, and has an average breadth of from 8–10 miles. The rocks exposed are those of the Hormuz series, the Upper group of the Fars series, and the Pliocene Tersai series.

The Upper Fars beds, a calcareous phase, occupy the greater part of the ground, and are disposed in a series of gentle domes, approximately symmetrical qua-qua-versals, along an axis running through the length of the island.

The Hormuz series constitutes a roughly circular inlier with steep or vertical uppermost beds at the margin. Two distinct rock-groups are included, a basal Namakdan group with massive rock-salt, laminated shales, and dolomitic limestone, and an upper pyroclastic Pusht-Tumba group of volcanic agglomerates and gypseous tuffs, etc. Dr. Pilgrim, who made the first geological examination of Qishm Island, in 1904, assigned to the Hormuz series a post-Cretaceous, pre-Nummulite age. His account of the island is to be found in his Memoir on the Persian Gulf region (*Mems. Geol. Surv. India*, vol. xxxiv).

There has since been a certain amount of controversy concerning both the stratigraphy of Qishm Island and the nature of the tectonic processes responsible for the Hormuz inlier and the Upper Fars domes. The key to the stratigraphy has been found in a study of the adjoining Persian mainland. By this means the pre-Oligocene age, at least, of the Hormuz series has been established.

Four theories as to the origin of the Hormuz inlier and the Upper Fars domes have been advanced. (1) That they have been produced by two successive earth-movements of slight intensity, operating at right angles to one another ; (2) that the inlier and domes are respectively breached and unbreached examples of "Salt-plug" action of a type similar to that exhibited by certain domes in Transylvania and Texas which are believed to owe their origin to the self-extrusion of underlying salt-masses ; (3) that they are due to laccolitic igneous intrusion ; and (4) that the domes may be accounted for by the consolidation and compression of Fars strata about pre-existing bosses of older rock. The evidence to hand appears to accord best with the second explanation, but further work, on outside areas, is required before a final judgment can be arrived at.

A test-well located on the apex of the Salukh dome, adjoining the Mamakdan Hormuz inlier at the N.E. end of the island was started up in 1915. The advantages of this dome are :—(1) That it provides a lower initial horizon in the Upper Fars group than any of the other five domes of the island ; and (2) that it possesses the only oil-seepage, the latter occurring near the apex. Owing to political disturbance consequent on the war, the Qishm test-well has not yet been completed as a deep test. After passing through the Upper Fars beds, the drill entered first the normal middle and then the normal gypseous Lower Fars group as developed on the adjoining mainland. Its depth in January 1919 was a little over 2000 feet. Several light shows of gas and oil have recently been encountered.

The record of the well has thus confirmed the solution of the stratigraphy of the island arrived at from a study of the mainland, namely, concealed progressive overlap, the Middle Fars group overlapping the Lower, and the Upper the Middle, against the older Hormuz series.

Brief reference only can be made here to the geology of the Persian Mainland in the Gulf region.

A general stratigraphic correlation has been effected from the Indian frontier into central S.W. Persia. Blanford's " Mekran " series, the continuity of which he traced from Cape Mouze to Bushire, a distance of 1200 miles, in 1872, includes the Miocene Gaj and Pliocene Hinglaj of the Mekran coast, and the Miocene Fars and Pliocene Tersais of the Persian Gulf. The continuity of the " Gypsiferous " series, which included the Fars and Bakhtiari series, throughout S.W. Persia, was proved by Loftus in 1849–1852, and that of the Fars and Bakhtiari series from the Bakhtiari country S.E., along the coast to Gwadur on the Mekran by Pilgrim in 1904–1905.

A test-well which is being drilled on the Chandragup dome, 100 miles west of Karachi, is thus designed to test strata which are approximately the stratigraphic equivalent of the petroliferous Lower Fars group of Persia ; incidentally, both are approximately to be correlated with the petroliferous Pegu series of Burma, and with the oil series of Assam.

Lateral variation along the general line of strike has been traced in the Fars groups by Mr. Lister James between the Bakhtiari country and the neighbourhood of Bushire. The coastal facies is reduced in thickness and of deeper-water type than that of the Bakhtiari country.

The main tectonic feature of the Persian-Mekran region is the E. and W. running system of folds, parallel with the coast. The folding movement began in late Pliocene times and has continued down to the present day.

Slight seepages or traces of oil are recorded at a number of localities, and from several geological horizons in the Lingah-Bunder Abbas region, *e.g.* from the Eocene and Oligocene Hummulitic series, and even from the Carboniferous Oman series.

Other than that of Salakh, however, only one small seepage is known from rocks of the Fars series. Seepages in the gypseous group are not known nearer than Daliki, N.E. of Bushire.

The conditions of deposition of the coastal Fars facies do not appear to have been so favourable for the accumulation of oil in large quantities as were those obtaining in the Bakhtiari country.

Of other areas in the Persian Gulf region known or believed to be more or less favourably circumstanced as regards oil prospects, mention may be made of Bahrein Island. This island lies in an arm of the Persian Gulf, on the Arabian side, west of the peninsula of Qatar. The only rocks exposed are compact Eocene limestones with flints and saliferous marls. The structure is that of a gentle elongated dome. Near the apex is an important asphalt deposit emanating from the limestones.

BALUCHISTAN and AFGHANISTAN.

Oil is reported as found at Shoran, 20 miles north of Gandawa, and traces occur in the sulphur-mines of Sunnee, a like distance further northward. In Sewestan, the Lower Eocene limestones are petroliferous at several points of favourable structure, especially in the Khátan, Harnai, and Spintangi districts. There are many similar evidences in the little-known region between Shah Makhsud, on the Helmund, southwest of Kandahar, and the Khyber Pass.

BRITISH INDIA.

Northwestern India.—Traces of petroleum appear on water in the alluvial plain of the Indus, some 9 miles south-southwest of Sukkur in Scinde, where the underlying rocks are presumably Eocene. A boring in the same series at Sukkur found gas, but no yield of oil. On the western border of the Punjab, the Eocene sandstones of the Sherani Hills are charged with petroleum at Moghalkot, 12 miles southeast of Takhti Suleiman. On the Basti brook, west of the Indus, some 10 miles south of Isakhel, tar oozes from some anomalous strata, supposed to be of Triassic age. Thirty miles northeastward of this, oil flows from the upturned edges of the Eocene limestones at Barakutta or Jabba, and again some 28 miles southeastward of Jabba, at Duma, Hanguch, and Chinnur, and a dozen miles southeast of the last at Sulgi or Umb. A wide belt of Upper Tertiary separates this from the corresponding belt northeastward,

Plate 8

Petroleum deposits shown in red.

London Charles Griffin & Co. Ltd.

Stanford's Geog' Estab' London

which extends from Sheikh, near Kohat, by the Panoba gorge, 37 miles eastward, by Dando Hill on the Indus, Dulla, Churhut, Boari, Japir, Gunda, Basala, and Lundigar, to Chirpar and Rata Otur, respectively 6 miles southwest and 11 northeast of Rawal Pindi. As the Upper Tertiary area is interrupted by anticlinal uplifts, the Eocene petroliferous series may be accessible at intervals between the belts of continuous outcrop, and an alleged occurrence of oil near Makhud on the Indus appears to be an instance of such. The "sacred fire" of Jualamuki, 120 miles east-northeast of Lahore, is probably an emission of gas on a line of fault in Eocene beds. Bitumen is reported as found in the Serra mountains of the Hazara district, and at Iskardo in Kashmir. In Kumaon, asphaltic exudations occur scantily in Palæozoic limestones, some 25 miles north-northwest of Almora. Traces of oil are alleged to exist in the Coal-measures of South Rewa State, some 80 miles southward of Benares.

Peninsula.—Films of oil have been noticed in the sea over the mud-bank at Calicut, and oily mud was found in constructing the bridge over the Kallai River. The mud-banks of Alleppy (Travancore) are also oily, and their changes of form and situation suggest an origin similar to that of the mud-islands of the Baku coast, described above, p. 207.

Assam (Plate 8).—In Assam, both Eocene and Miocene beds contain oil; the former, including important coal-seams, has been more fully explored in respect of its extent, whilst the Miocene is by far the richer in petroleum, a copious yield having been secured from nearly every boring. Operations have been restricted to limited areas in the Makum coal-field and at Digboi, respectively 16 miles east and 18 northeast of Jaipoor. East and west of this centre, evidences of petroleum have been detected over a long range, from near the junction of the Dapha brook with the Dihing river, down to the Disai, a small tributary of the Brahmaputra flowing past Jorhat (see Plate 8). Petroleum also occurs in the Miocene sandstones on the Barak and Surma rivers in Cachar, Jaintia, and Sylhet, whilst inflammable gas is discharged from salses in the Tipperah hills, and furnished the "sacred fire" in Chittagong.

Burma.—The Burmese oil-fields form an inland series along the Chindwin and lower Irawadi valleys, and a coastal belt from Akyab to Ramri and Cheduba. The most northerly point, as yet known, on the former line (which exceeds 400 miles in length) is Yenan, on the Yu, near the junction of that river with the Chindwin, on the 24th parallel of north latitude. Indin, on the Myit-tha, some 75 miles distant to south by west, has similar exudations. Near Kalewa on the Upper Chindwin, on the Zanabok and Pinkadin brooks in the Lower Chindwin district, and at Yebyu, 10 miles northwestward of Pauk, are reported other discharges of oil. Feeble discharges have been noticed on the Yaw River below Kyinlin, and southward on some of the tributary streams of the Yaw and Salin rivers, but in no case is the structure favourable for a yield of commercial value, and the same with similar exudations in the southwest part of the Minbu, and the northern part of the Thayetmyo districts. East of the Chindwin, traces of oil are reported near Shwebo. The Yenangyat field is the most northerly of the main oil-fields, followed, to the south, by the Singu, and this by the Yenangyaung field, which is subdivided into the Twingon, Khodoung, and Beme tracts. The Minbu, Yethaya, Banbein-Padonkpin, Prome, and Yenandoung fields complete the chain, the last point lying about 12 miles southwestward of Myanoung, and near the 18th parallel. In the coastal belt, petroleum is found on the left bank of the Koladyn, opposite Akyab, in the Baranga Islands, and at many points of Ramri, Cheduba, Round, Flat, and False Islands. There are also vague reports of the occurrence of some form of bitumen on the adjacent west coast of the mainland. In every case the productive rocks appear to be of Lower Miocene age, brought within reach, if not actually outcropping by sharp anticlinal flexures, forming inliers in the surrounding Upper Miocene and Pliocene areas.

SIAM.

A black, viscid oil is reported as occurring sparingly near Muang Fang, on the Mekhok, at the northern frontier of Siam. Traces of petroleum are reported to have been found in the province of Gerbi.

MALAY PENINSULA.

The existence of "large oil-fields" in Kedah and Selangor is based on rumours as yet unconfirmed.

ANAM.

Traces of petroleum are found in the Miocene coal-fields of Yenbai, about 170 miles up the Songka (Red River), Tonking.

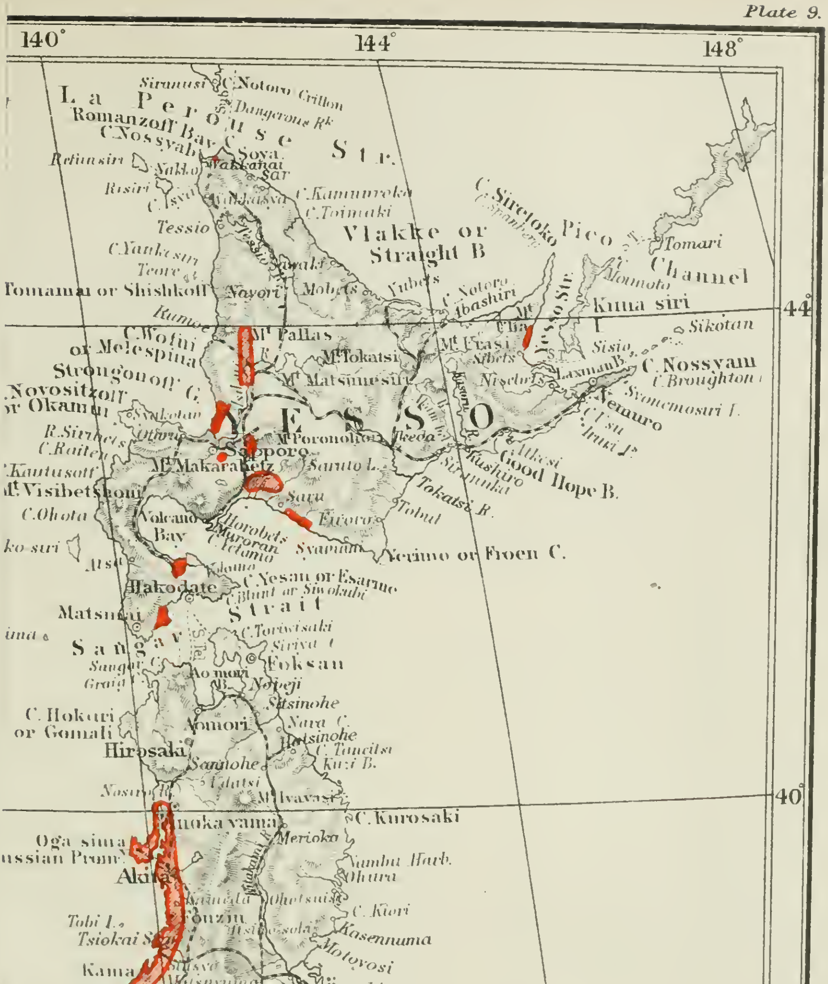
EASTERN TURKESTAN, THIBET, and CHINA.

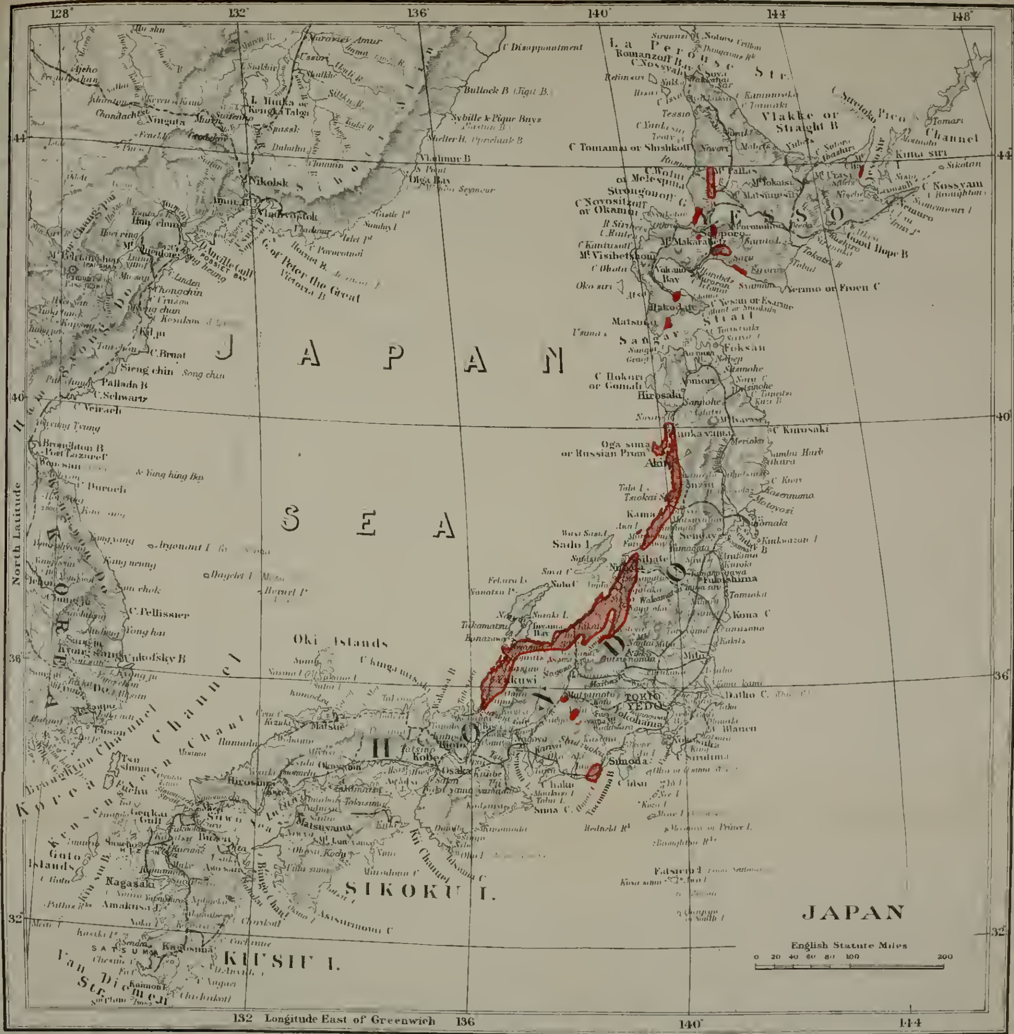
Traces of petroleum are reported from near Kutcha, from the hills north of the Barkul Salt Lake, and from Dikhon near Urumtchi. Oil is recorded also at the northern foot of the Nan Shan range, 70 miles southwest of Suchau in Kansu. Traces of petroleum occur in Carboniferous rocks in the Yen valley in Shensi, at and for some miles below Yen-chang-hsien, and thence to Tsing-kien, and again at a spot some 24 miles southeast of Hsia-hsien, rejoicing in the concise name of Hou-chia-yao-fu-kou. In the adjacent province of Shansi, petroleum is reported at Kiang-tchu in the southwest, and Tai-tong-fu in the north. The historic brine-wells of Szechuen yield a certain amount of oil in the Chungking, Tse-liu-tsin, Kong-tsin, and other districts, and large volumes of gas at many points. The latter has been utilised from time immemorial for domestic and commercial purposes. The oil is found at a comparatively shallow depth, but the associated brine being of inferior strength, boring is generally carried to far lower horizons, from which are obtained copious discharges of gas, and a concentrated solution of salt. The deeper-seated gas is, however, chiefly sulphuretted, with little or no carburetted, hydrogen, and the same may be the case with the slighter yield from the higher strata, merely "enriched" by its contact with the petroleum. The age of the series is apparently Triassic. Oil is also alleged to occur at Tai-li-chen (Fu-chu-ku) and Haitha, in Kwangsi, and at Kayo-chau, in Shantung.

In Mongolia, thick tarry oil exudes from Mesozoic beds on the southern flank of the Djais range, and also to the north on the Orkhu Lake, where it forms a series of fairly large hillocks of asphalt. The name Maïli (oil) is given to the western end of the Jais range.

JAPAN. (Plate 9.)

Extensive oil-fields of Upper Tertiary age exist in both Yesso and Nippon. In the former island, four divisions—Kitami, Ishikari, Ifuri, and Oshima—are known to be petroliferous, and there is reason to believe that Teshiwo, Hitaka, and Nemoro will eventually be added to the list. A belt 250 miles in length, and reaching at the southern end the width of 50 miles, extends along the


140°
144°
148°
44°
40°
La Perouse Str.
Romanzoff Bay
C. Notoro
Crillon
Dangerous Rk
Soya
Wakkanai
Tessio
Vlakke or Straight B
C. Siretoko
Pico Channel
Tomari
Kuna siri
Sikotan
C. Nossyam
C. Broughton
Nemuro
Mt Pallas
Mt Tokatsi
Mt Matsimesiri
YESSO
Sapporo
Mt Makarabetz
Mt Poronohori
Good Hope B.
Tokatsi R.
Tobui
Yerimo or Froen C.
Volcano Bay
Muroran
Hakodate
C. Yesan or Esarme
Strait
Sangar
Foksan
Aomori
C. Hokuri or Gomali
Hirosaki
Sannohe
Mt Ivavasi
C. Kurosaki
Merioka
Akita
Oga sima
Tobi I.
Tsiokai San
Kosennuma
Motovosi



Petroleum deposits shown in red

London. Charles Griffin & Co., Ltd.

Petroleum deposits shown in red.

London: Charles Griffin & Co. Ltd.

Stanford's Geog! Estab! London.

western coast of Nippon from the Ogasima peninsula (lat. 40° N.) to Itoigawa. A short interval divides the latter from a small area on Toyama Bay (see Plate 9). Another separated field occurs on the south coast around Sagara, and traces are recorded at Mabana in Kadzusa, southeast of Tokyo. In the north of Formosa, petroleum occurs on the Toakhohan river, from 22 to 42 miles southward of Tamsiu harbour, and at Byoritsu, while other deposits are reported in the interior further to the south.

EASTERN ARCHIPELAGO. (Plate 10.)

Philippine Islands.—Traces of petroleum and gas are recorded in the Capiz province of Panay, southeastward of Dumarao, and again in the Masinao valley (Iloilo province), 40 km. northwest of the capital. Productive wells exist on the west coast of Cebu at Toledo, further evidence reaching to Asturias on the north and Alegria on the south, and recurring at Villaba on the west coast of Leyte. These probably indicate a more or less continuous oil-field, including the intervening islands of Guimaras and Negros, and presumably coterminous with the coal-bearing Tertiary series. Oil is also said to have been found at Macabebe and Manalan, province of Pampanga, and at Santo Tomas, province of Batangas, as well as on Manila Bay, in Luzon, and at Kotta Batu, in Mindanao.

Borneo.—The northern coast of Borneo, from Sampanmango point to Sarawak, consists of Tertiary coal-bearing beds, in which petroleum occurs at several points. The Sekuati river, near Ganda Head, is the most northerly at present known; then follow Gantisan, Timanam, Qualla Lama, the islands of Mengalon and Labuan, the shores of Bruni Bay, the Tutong and Miri rivers, and lastly the Sadong district of Sarawak. Probably future investigation will detect oil at intervening points. On the east coast, petroleum and gas are found in Upper Tertiary beds on Tarakan Island, at the mouth of the Sesajab, in Tidung, and in Kutei on Sangkuliran Bay, around the lower part of the Mahakkam, and in Balik Papan Bay. In southeast Borneo, oil occurs on the Negara below Tandjong; at Balangan, southeast of Amunthai; in the Riam Kiwa valley, 60 miles east-northeast of Bandjermasin; and at Warukin, Martapura.

Sumatra.—Extensive oil-fields exist on the east coast of Sumatra, from Edi in Atjeh, to the Lepan River in Langkat, some 70 miles southeastward, the belt being some ten miles in width. The series, consisting of coarse-grained loose sandstones and marly shales, is probably of Upper Tertiary age. Samples of the oil submitted to the author show a low specific gravity, and an unusually large proportion of the more volatile hydrocarbons, evolving inflammable vapour even at zero F. Oil is reported as found by boring in the kingdom of Siak, and a spring is noticed in the Eocene conglomerates on the Mahi, a tributary of the Kampar, 3 or 4 miles west of Kottabaru. In Palembang again is an extensive and valuable oil-field of Upper Tertiary age, ranging from the northern margin of the province, 100 miles westward of the capital, to the vicinity of Lahat, 80 miles southward, and eastward to the Ogan River. This includes the Lahat and Muara Enim wells. Traces of oil are recorded in the West-Coast province of Kollok, 11 miles east of the Sinkara Lake, in Eocene marls, and "naphtha" is vaguely stated to occur in the Ipu region of Benkulen province.

Java.—Petroleum may be said to occur intermittently throughout the length and breadth of Java, though several provinces are devoid of any trace of it. The volcanic agencies in operation at many points of the island effect on the one hand the destruction of much of the oil within the sphere of their influence, doubtless accentuating their energy thereby, whilst on the other hand the adventitous distillation of oil from coal-seams, in regions of somewhat lower temperature, may give rise to delusive hopes of a commercially-valuable store in the rocks which have absorbed the condensed products of this local and casual action. It is scarcely necessary to add that the richest fields are those far remote from the volcanic foci. At the same time it must be borne in mind that volcanic scoriæ and dust are distributed by winds far beyond the range of any detrimental action of volcanic heat upon oil-containing rocks, and that such may exist under a considerable thickness of deposits, igneous only in origin, and not in mode of accumulation. Equally, of course, explorers may disregard the proximity of eruptive rocks of prior age to the oil-yielding Miocene, except as marking the horizontal or downward limit of the series. The petroliferous area around Lebak in Bantam has as yet been little tested, and the occurrences in Cheribon, Tegal, and Pekalongan are apparently of no commercial value. The principal oil-field of Java may be said to begin in Samarang, ranging through Rembang and Surabaya to Madura and the smaller islands which represent the eastward extension of the latter. With the vigorous research of the present time, the already extensive industry will probably increase rapidly, and hamlets not unknown to the topographer may in the course of a year become important centres of production. Possibly the southern coast regions of Java may have a like future to that so favourably opening in the north, but at present there are reported only traces of oil in the districts of Bandjar Negara, Banjumas ; of Grogol, Surakarta, and of Lodaijo, Kediri.

Samaauw.—Exudations of petroleum occur in a mud-volcano near Kawua, at the north end of the island.

Timor.—In the Portuguese section of this island, petroleum and gas have been noticed at four distant points, and future exploration will presumably result in the discovery of intermediate places of discharge. At Okussi, some 25 miles southwestwards of Delli, asphalt exudes from porphyritic rocks, probably dykes traversing bituminous beds below the surface. Forty miles east of this, in Laculubar, perennial fires are produced by emanations of gas over 500 square feet. There is a strong petroleum odour, but the flame is without smoke, and no liquid oil has been detected. Half a mile south-southeast, and 1000 feet lower, there are several oil-springs, some of large size, in the Samoro or Mutika valley at Pualaka. At Daifavassie, 20 miles further eastward, occur tarry exudations from highly bituminous shales, utilised by the natives as fuel. Ten miles beyond this, and two miles from the coast, at Bibiluto or Babelota, in the Raisute plain, oil and gas are discharged from the pseudo-volcano Korrara, an eruption of which in 1856 is said to have destroyed a village. The frequent recurrence of earthquakes in these regions removes such disasters from the category of the abnormal, but renders the continued existence of valuable stores of petroleum somewhat problematical. The mechanical ejection of inflammable fluids by seismic agencies is not to be confounded with the thermal effect of true volcanic action. Some 17 miles north-eastward of this is the Quiarida oil-spring, on the shore between tide-marks, and oil again occurs at Ata-Lélé, 7 miles inland from Quiarida. Petroleum is also found at Alas, near the Dutch frontier on the south coast, and at Weinitas on the Fatu Kabun. In the complex series constituting the region, extensive Quaternary coral-reefs largely mask the Jurassic, Triassic, and Permian rocks, recognised as such by local accumulations of fossils, and apparently abutting against the Archæan core of the island. The seat of the oil appears to be in the Triassic beds, but some may be of Permian origin.

Celebes.—Petroleum is reported at Taguntolo, Bay of Tomori ; at Baroko,

CANADA

Plate II

English Statute Miles
100 50 0 100 200 300

London Charles Griffin & Co.,Ltd.

Petroleum deposits shown in red.

Stanford's Geog' Estab', London

in the Duri district of Masereng Pulu ; and at Doda, in the Manudju district of Mandhar. The island of Muna, off the southeast coast, is also said to be petroliferous.

Moluccas.—Asphalt impregnates Cretaceous shales on the west coast of Buru, at Fogi, Mai-Tai, and Bilkofan, and rock-tar is found in the Tertiary deposits of the north coast of Ceram, on Bula Bay, and in the Nif valley. The reported occurrence of oil in Batjan has not been confirmed.

New Guinea.—Oil is alleged to occur at a short distance from the mouth of the Buti river, on the north coast near the 139th meridian. About 200 miles southwest of this, oil saturates parts of a coal-bearing series on the Iwaka River, south of the Nassau range, at lat. 4° 21′ 30″ S., long. 136° 52′ 30″ E., about 40 miles from the sea.

Ladrone Islands.—Discharges of carburetted hydrogen are reported as occurring on Guam.

BRITISH AMERICA. (Plate 11.)

Yukon.—An alleged occurrence of oil at the mouth of Forty-mile Creek may be a trivial exudation from the lignitiferous Tertiary deposits, resting on the ancient gold-bearing rocks.

British Columbia.—Bitumen is reported as oozing from coarse volcanic agglomerate of Miocene age at the Tar Islands, off the east coast of Moresby, Queen Charlotte Islands. Oil is said to have been found at Steveston and New Westminster, and hopes are entertained, though apparently upon no very adequate grounds, of the extension thence of a belt of petroliferous rocks, along the lower part of the Fraser valley, and to the region of the Tulameen and Similkameen rivers, whilst the existence of parallel belts in North Vancouver, and in the Cassiar and Cariboo districts, is a further vague anticipation. Exudations of oil from the lower Cambrian rocks of some of the eastern tributaries of the Flathead River, a few miles from the junction of the Alberta-Columbia border with the United States frontier, have been assigned with practical certainty to Cretaceous rocks, over which the vastly more ancient series has been thrust in an almost horizontal plane.

Alberta.—In the vicinity of the last-mentioned indications, but upon the eastern side of the watershed, the Cambrian rocks are again apparently petroliferous on a feeder of Waterton Lake. A fair yield of oil was struck in the Cretaceous beds at Pincher Creek, some 30 miles north of Waterton Lake.

Very important gas-fields have been developed at Medicine Hat and Bow Island, where wells of several million cubic feet daily capacity are struck at depths of 1000 to 2000 feet in beds of Cretaceous age. Their limited exploitation is solely due to the restricted uses of gas within a radius that justifies the construction of pipe-lines. Calgary and neighbouring cities are supplied with natural gas extensively.

Many indications of petroleum have been reported along the Alberta foot-hills of the Rocky Mountains, and in 1914 a fairly good well of light-density oil was struck about 30 miles from Calgary. The excitement following this strike led to considerable prospecting and drilling activity, but although many shows of oil were encountered in wells no important oil-field was brought to light. Practically all the foot-hill country of interest is characterised by sharply inflected and disturbed strata of Cretaceous or Tertiary age (*A. Beeby Thompson*).

The drift-sands at Big Egg Lake, 25 miles northwest of Edmonton, are saturated with tar, presumably derived by filtration from the subjacent Upper

Cretaceous (Laramie) sandstones. At Victoria and Athabasca Landing, the Cretaceous shales have yielded heavy discharges of gas at various depths.

The Dakota sandstone at the base of the Cretaceous series is saturated, over an area of at least 1000 square miles, with inspissated petroleum, and is often mentioned as the Tar Sand. It rests unconformably on the Devonian limestones and shales, which are also petroliferous to a slight extent within the province, and abundantly so both northwards in Mackenzie and southward in Ontario and the United States, so that the idea has found favour in some minds that the tar of the Dakota sandstone is derivative from the Devonian series. But the latter, where seen along the Athabasca and its tributary valleys, cut down through the soft Cretaceous rocks, is devoid of any trace of bitumen except in fissures recently filled by oozings from the overlying sandstones. It may be added that, as will be mentioned later, the Dakota beds are petroliferous in other regions, where no such derivation is conceivably possible. The area occupied by the Tar Sand is undefined on the south and west, where the higher Cretaceous beds cover it to a depth not yet pierced by boring. Eastward it is approximately bounded by the 111th meridian, whilst northward, on the Peace River, the overlying Clearwater Shales appear to rest directly on the Devonian floor, the limit of the Dakota being problematical beyond its disappearance near latitude 57° 45′, 80 miles below Fort McMurray.

Occurrences of petroleum in the Devonian are noticed on the Clearwater River at Methye portage ; on the 59th parallel at 100 miles west of the mouth of the Peace River ; and on Slave River 30 miles below the Peace. The Tar Sand comes into view at 30 miles above Fort McMurray, and extends to at least 80 miles below it, being also traceable from 10 to 20 miles eastward in tributary streams. Gas and tar are emitted from a spring in the Clearwater Shales on the Peace, 30 miles below the mouth of the Smoky River, and the nodules in the shales contain streaks of bitumen. Similar nodules occur on the north shore of Little Slav Lake, and another tar-spring is alleged to occur here near the mouth of Martin River. The discharge of tar and gas from a boring at the mouth of Pelican River on the Athabasca stopped operations at a depth of 837 feet, the Dakota series having been entered at 750 feet.

Saskatchewan.—The Cretaceous shales discharged a heavy flow of gas for several years at Langevin, near the Alberta border.

Mackenzie.—Tar and pitch occur on the north side of Great Slave Lake, a spring rising about a mile and a half off shore, some 27 miles westward of Pointe Brulée, and another on the shore of the bay eastward of the point. A third spring is reported on the long arm northeastward. These exude from cavernous dolomites, limestones, and shales of Devonian age. On the Mackenzie River, valuable pitch-springs occur at 70 miles above the mouth of the Liard, and at the mouth of Hareskin River (Fort Good Hope). At 53 and 68 miles below the fort the shales and limestones are saturated with petroleum. The oil-field thus indicated is at least 650 miles in length ; its width is a matter for future investigation.

Manitoba.—The Cretaceous rocks on the Assiniboine, 80 miles west of Winnipeg, are impregnated with petroleum, and oil is said to have been found in boring at Springfield, some 10 miles eastward of the city, in a region of Lower Silurian (Trenton) rocks. Near Dauphin, on the other hand, neither oil nor gas occurred in a boring through 422 feet of Cretaceous and 321 of Devonian rocks. The structure of the Palæozoic masses, where so concealed by independent overlying beds, must necessarily remain unknown till revealed by a long series of carefully recorded borings through the obscuring series.

Ontario.—Gas discharges occur in the silver-mines of the Port Arthur district, Lake Superior, from veins in the Animikie (Pre-Cambrian) group. In the upper copper-bearing series of the same region, probably of Lower Silurian age, are chert masses, containing minute globules of bitumen, which have apparently formed nuclei for the aggregation of the silica. Veins of bitumen, traversing the mass, seem to be due to the discharge of such chambers as were intersected by the fissures. On Great Manitoulin Island in Lake Huron, the Trenton Limestone yields petroleum at Pike Lake and Wequamakong, and the overlying Utica shales, from Cape Smith westward to Shiquinandah and the small island north of Maple Point, are highly bituminous, oil exuding in several places. Far to the north of this, on the Abittibe river, from 40 to 50 miles south of its mouth in Hudson's Bay, the Devonian limestones are reported to be petroliferous, and nearly as far to the southward lie the several oil-fields of west Ontario, occupying, with the associated gas-fields, a large proportion of the peninsula between Lakes Huron, Erie, and Ontario. The chief source of the petroleum is the Devonian series, of which the Corniferous limestone is the most productive member, though the earlier exploitations were confined to the overlying Hamilton beds, consisting of shales with variable limestones and dolomites. With the local exhaustion of the Devonian, deeper boring has found slight amounts of oil, but valuable supplies of gas, in the Middle and Lower Silurian, the following being the complete sequence :—

Chemung group, Portage group, Hamilton beds, Corniferous Limestones,	Devonian.
Onondaga Salt group,	Upper Silurian.
Guelph, Niagara, and Clinton Limestones, Medina Sandstone,	Middle Silurian.
Hudson River beds, Utica Shale, Trenton Limestone,	Lower Silurian.

The gas is principally derived from the Medina and Trenton, but rich yields have been met in the higher beds. The important production of oil is confined to Lambton county, of which Petrolea is at once the geographical and commercial centre, the field extending southeast to Bothwell in Kent and northwest to Sarnia on the frontier river St. Clair. Minor yields of oil are obtained in Essex (including Pelee Island), Kent, Middlesex, Oxford, and Huron, and traces are found in the cavities of limestones in Norfolk, Haldimand, and Wentworth. The production of gas is of commercial importance in Essex and Welland, but useful amounts are obtained in Elgin, Lincoln, Peel, York, Simcoe, Ontario, Hastings, and some other counties. Discharges of gas from drift-gravels during the sinking of wells are not uncommon, and have given rise to delusive hopes of valuable yield. The gravels serve as reservoirs to store feeble emanations from the subjacent rocks, the overlying Erie Clay preventing escape till pierced artificially, when a rapid delivery soon exhausts the small accumulation. The "Burning Spring" below Niagara Falls is due to a flow of gas from the Niagara Shales, which underlie the limestone of the Falls. The Trenton limestone of the two isolated areas near Ottawa contains petroleum in its hollow fossils and other cavities at Pekenham, 30 miles west-southwest, and in Lancaster, 60 miles east-southeast of the capital. A little gas had been found at Barnsville, eastward of Lancaster, and glossy asphalt in Cornwall to the southwest. Oil has lately been found at Ramsay's Corner, 8 miles from Ottawa. The gas-spring at Caledonia, Prescott, has been known for a century or more.

Quebec.—Gas has been found at Maisonneuve, near Montreal, in the Utica Shale, and in considerable quantity in the Hudson River beds at St. Hyacinthe, 30 miles eastwards. Yet further east, at Actonvale, and north of this at Drummondville, the rocks of the Quebec group contain traces of the bitumen ungrammatically termed anthraxolite by Professor Chapman, in the form of minute globules casually distributed through the mass, and evidently an inspissated condition of some originally fluid hydrocarbon. At St. Justin and St. Barthélemi, near the head of Lake St. Peter, gas has been found at insignificant depth in the Trenton, and also at St. Pierre, a few miles northeastward. Some 20 miles east of this, borings at St. Grégoire and Beauséjour have found abundant gas in both Medina and Hudson River beds. At Lotbinière and St. Nicholas, the latter series again contains bitumen-granules, and at Pointe aux Trembles the Utica Shale is charged with petroleum. At Sillery, Quebec, and the Island of Orleans, the Lower Silurian slates and conglomerates contain traces of bitumen, and at Beauport, 4 miles northeast of Quebec, the Trenton limestone has large geodes of glossy bitumen, whilst petroleum occurs in the same rock on Rivière de la Rose, 20 miles northeastward, as is also the case over at least 170 square miles around Tremblay, on the Saguenay river, 100 miles northward of this. Intermittent attempts at economic development of the Gaspé oil-field cover some forty years, with no commercial success as yet. The Upper Silurian limestones and Lower Devonian sandstones and shales are both petroliferous, and in fairly favourable structure for commercial operations. The valleys of the Dartmouth, York, St. John, and Malbey rivers show exuding oil at many points, and the vigorous researches now in progress have every prospect of a successful result.

Dr. J. A. L. Henderson has furnished the author with the following description :—

New Brunswick and Nova Scotia.—The Palæozoic geological basin of eastern New Brunswick is flanked by the Bay of Fundy Coastal Range on the south, and extends northward into the Province of Quebec, its northern margin lying a few miles north of Gaspé. In it the beds of the Cambrian, Ordovician, Silurian, and Lower and Middle Devonian were laid down within the same trough and, in general, simultaneously with the sediments of similar age in New York and Pennsylvania. After the Shickshockian disturbance and uplift of Upper Devonian times, however, the New Brunswick and Gaspé basin has been severed from that of the interior of the continent. The uppermost Devonian beds and the lowest Carboniferous beds (Albert Shale series), subsequently deposited, cannot therefore be correlated with beds of similar age in the interior oil-fields, nor can the later Lower and Middle and Upper Carboniferous and Triassic, which form the present surface rocks of New Brunswick.

The oil- and gas-bearing formations known within this basin are the Lower Carboniferous Albert Shale series of New Brunswick and the Lower Devonian sandstones of Gaspé in Quebec. The Albert Shale series consists chiefly of calcareous non-bituminous shale, blue-grey or dark in colour, containing numerous interbedded oil- and gas-bearing lenticular sandstones, thin-bedded limestones, sometimes bituminous, many beds of oil-shales, and veins of the solid bitumen, albertite. They are exposed in many localities, owing to intense local faulting, folding, and erosion, near the southern margin of the basin in New Brunswick, where numerous surface evidences of their solid, liquid and gaseous, petroleum content can be observed. Their thickness in the Stony Creek gas- and oil-field, nine miles south of Moncton, is about 2900 feet, but their maximum thickness is probably, where undenuded, in excess of 4000 feet. Gas has also been struck in very small quantity in boring in the conformably underlying Upper Devonian. The albertite vein of the Albert Mines has a length of 2800 feet, with a maximum width of more than 16 feet, and occupies a fissure with an almost vertical northerly dip, traversing the crest of a steep anticline, intersecting the shales and oil-bearing sandstones along its east-westerly course. It was worked to a depth of about 1600 feet on the incline, before being abandoned on account of the competition of natural oil from Pennsylvania.

The Albert Shale series was extensively eroded and folded during a period of uplift immediately following its deposition, and lies unconformably beneath the later beds of Carboniferous age at present occupying the surface. Its exploration and exploitation are, therefore, difficult.

The Middle and Lower Devonian rocks lie probably unconformably beneath the Albert series. At Gaspé, near the northern margin of the basin (as mentioned on page 82), these beds yield oil of unusually high quality. In southern New Brunswick no oil or gas has so far been found in these rocks, represented by the much disturbed, highly fossiliferous shales, sandstones, and conglomerates near St. John.

The folds within the basin exhibit a general east-northeasterly trend. Where exposed, the Albert Shales are highly folded against Pre-Cambrian buttresses occurring in the south, and their attitude will probably become more gentle in the northern area with distance from these disturbing factors. The overlying later Carboniferous rocks are very gently folded, and exhibit a number of flat anticlines.

Traces of Petroleum have been met with at Cheverie, Hants, Nova Scotia, and on Lake Ainslie in Cape Breton Island, both in Carboniferous rocks of an horizon slightly higher than the Albert Shale. Oil-shale of about the same age is reported from McAdams Lake, north of the east bay of Bras d'Or Lake, and in the yet higher Coal-measures of Pictou occurs an oil-coal.

Newfoundland.—The petroleum-bearing deposits of the western coast of Newfoundland range lower in the geological series than those of any other known oil-field, being in the Lauzon limestones and Levis sandstones of the Quebec group (Lower Silurian). These occur at Port-au-Port Bay, and from Bonne Bay to Sandy Bay (Parsons Pond). The series is overlaid from Port-au-Port to Bonne Bay by a group of volcanic rocks, predominantly serpentine, in which, opposite Fox Island, occur veins of bitumen, doubtless derived from the sedimentary rocks traversed. In the Carboniferous sandstones, unconformably following the Lower Silurian on the outer coast of the Port-au-Port peninsula, albertite occurs at Clambank Cove. Oil-shales are found in the Lower Carboniferous rocks of the Humber river. On the east coast of the northern peninsula at Cap Rouge are black Devonian shales with nodules containing petroleum.

GREENLAND.

Petroleum is said to have been detected in McCormick Bay, a small inlet on the south coast of Prudhoe Land.

UNITED STATES. (Plate 12.)

The author is indebted to Mr. George Otis Smith, Director of the Geological Survey of the United States, for the following geological and geographical description (dated 6th March 1919) of the oil- and gas-fields of the United States. Special attention has been given to it by Mr. O. B. Hopkins, with whom other oil and gas geologists of that Survey have co-operated in the preparation of the sections, as follows :—

New York, Ohio, and Indiana, . .	Mr. D. D. Condit.
Pennsylvania and West Virginia, .	Mr. G. R. Richardson.
Kentucky, Illinois, and Iowa, . .	Mr. E. W. Shaw.
Arkansas, ...	Mr. H. D. Miser.
Michigan, Wisconsin, Minnesota, Colorado, and Montana, . . .	Mr. E. T. Hancock.
Kansas and Missouri, and Oklahoma (in part), ...	Mr. A. E. Fath.
Wyoming and California, . . .	Mr. W. B. Emery.
Nebraska, South Dakota, and New Mexico, ...	Mr. N. H. Darton.
North Dakota, ...	Mr. A. J. Collier.
Washington, Oregon, and Nevada, .	Mr. J. P. Buwalda.
Idaho, Utah, and Arizona, . . .	Mr. F. B. Clark.
Connecticut, New Jersey, Maryland, Virginia, North Carolina, Georgia, Florida, Alabama, Texas, Louisiana, and Alaska	Mr. O. B. Hopkins.

The history of the petroleum industry in the United States has already been described (pp. 85–96). The distribution of the productive fields and the important localities where oil and gas have been found are shown in Plate 12. The following table gives a brief summary of the industry in the different fields of the United States, shows the amount of oil marketed, the amount left in the ground, and the percentage of exhaustion at the close of 1918, and the percentage of gasoline extraction in the different fields at the present time.

Available Oil remaining in Ground, as estimated by the U.S. Geological Survey (Barrel of 42 gals.)

Oil-Fields.	Marketed Production in 1917.	Marketed Production in 1918 (Preliminary Estimate).	Total Marketed Production to end of 1918.	Available Oil left in Ground, January 1919.	Percentage of Exhaustion.	Present Average Gasoline Extraction, per cent.
Appalachian (New York, Pennsylvania, West Virginia, Kentucky and Eastern Ohio).	24,932,205	25,300,000	1,221,737,000	550,000,000	68	28·0
Lima (Western Ohio and Indiana).	3,670,293	3,100,000	448,404,000	40,000,000	92	20·0
Illinois, . .	15,776,860	13,300,000	298,159,000	175,000,000	63	22·0
Mid-Continent (Oklahoma and Kansas).	144,043,596	139,600,000	990,573,000	1,725,000,000	36	24·0
North Texas, .	10,900,646	15,600,000	78,971,000	400,000,000	16	33·0
North Louisiana, .	8,561,963	13,000,000	90,902,000	100,000,000	47	28·0
Gulf (coastal Texas and Louisiana).	24,342,879	21,700,000	303,954,000	750,000,000	28	1·5
Wyoming, . .	8,978,680	12,370,000	39,793,000	400,000,000	9	40–50
California, . .	93,877,549	101,300,000	1,114,000,000	2,250,000,000	33	12·0
Alaska, Colorado, Michigan, Montana, etc.	230,930	230,000	10,651,000	350,000,000	3	..
Total, .	335,315,601	345,500,000	4,598,144,000	6,740,000,000	40½	..

Connecticut and New Jersey.—The Triassic deposits, which crop out from north to south across the west-central part of Connecticut and in a northeast-southwest direction across the northern part of New Jersey, consist dominantly of red sandstones and sheets and dikes of trap rock with subordinate beds of black bituminous shale and thin beds of coal. Asphalt, presumably derived from the black shale or coal, is found in cavities in the amygdaloidal trap rock at a number of places in Connecticut and at Newark, New Jersey. Asphalt in small amounts is found in beds of marl of Cretaceous age at Vincentown, Burlington county, New Jersey. Amber is found in the Cretaceous fire-clay at South Amboy, New Jersey.

New York.—The western part of the State of New York has a number of more or less connected gas-fields, drawing their supply from various members of the Palæozoic series, but principally from the Devonian, Silurian, and Ordovician formations. Oil-producing areas are limited to the southern edge of the State adjacent to Pennsylvania where the Bradford sands of Devonian age are productive. The pre-Carboniferous rocks consist of the following sub-divisions :—

Chemung shales and sandstone, Portage beds, Genesee shales, Tully beds, Hamilton shales, Marcellus shales, Corniferous or Onondaga limestone, Oriskany sandstone, Lower Helderberg limestone,	Devonian.
Cayugan series, Niagara (mostly limestone), Clinton limestone, Medina series (sandstone and shale), Oswego sandstone,	Silurian.
Lorraine shale, Utica shale, Trenton limestone, Black River limestone, Chazy series, Beekmantown limestone,	Ordovician.
Potsdam sandstone,	Cambrian.

The Trenton limestone furnishes gas to a number of towns in Oswego, Jefferson, Onondaga, and Oneida counties, and formerly was the main supply of natural gas in New York State. Lately a number of important gas-pools have been discovered in the Medina sandstone, in Niagara, Erie, and Genesee counties, which supply Buffalo and other towns, and at present this is the most important gas horizon in the State. The Medina is believed to be equivalent to the so-called " Clinton " sandstone which is the reservoir-rock for the large gas accumulations in central Ohio. In Chautauqua county small supplies of natural gas at shallow depths are obtained from the Upper Devonian shales. The Chemung group at the top of the series yields considerable oil and gas in Cattaraugus and Allegany counties, being an extension, though not of great area, of the Bradford field of Pennsylvania.

Pennsylvania and West Virginia.—The oil- and gas-pools in Pennsylvania and West Virginia are situated in the midst of the Appalachian field and constitute its most important part. In these States the productive territory occupies a zone about 350 miles long and 50 miles wide, extending northeast and southwestward across the Allegheny Plateau. Oil and gas occur in lenticular beds of sandstone interstratified with shale that constitutes by far the greater part of the stratigraphic section. The productive beds are of Carboniferous and Devonian age and are outlined in the following table :—

Generalised Section of Main Oil and Gas Sands in Pennsylvania and West Virginia.

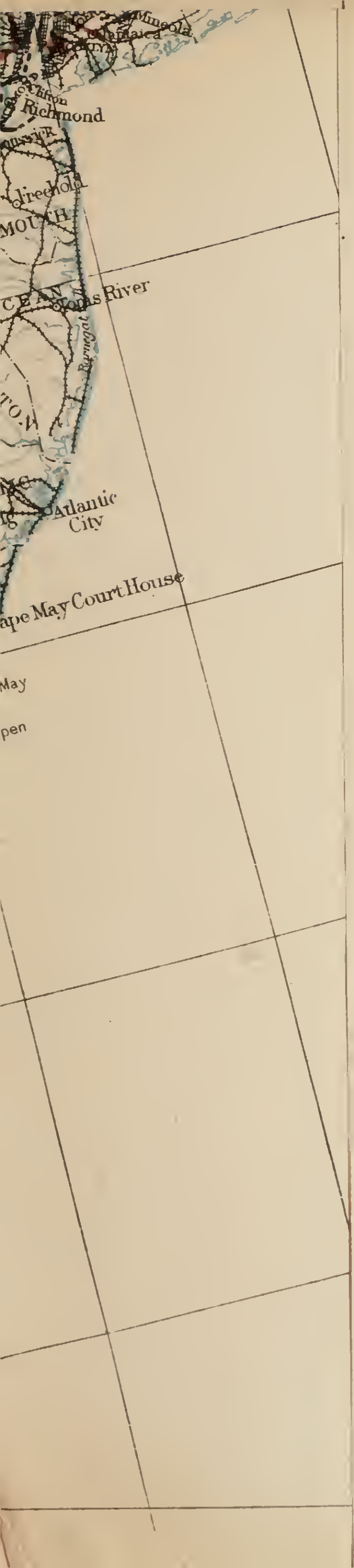
Carboniferous.	Formation.	Producing Sands.
(Pennsylvanian)	Conemaugh,	Dunkard.
	Allegheny,	Burning Springs.
	Pottsville,	Salt.
(Mississippian)	Mauch Chunk,	Maxton.
	Pocono,	Keener.
		Big Injun.
		Squaw.
		Weir.
		Berea.
Devonian		Hundred foot = Gantz and fifty foot.
(Upper Devonian)	Catskill and Chemung,	Thirty foot.
		Snee.
		Boulder.
		Gordon or Third.
		Fourth.
		McDonald or Fifth.
		Bayard.
		Elizabeth.
		Warren.
		Speechley.
		Tiona.
		Bradford.
		Sheffield.
		Kane.

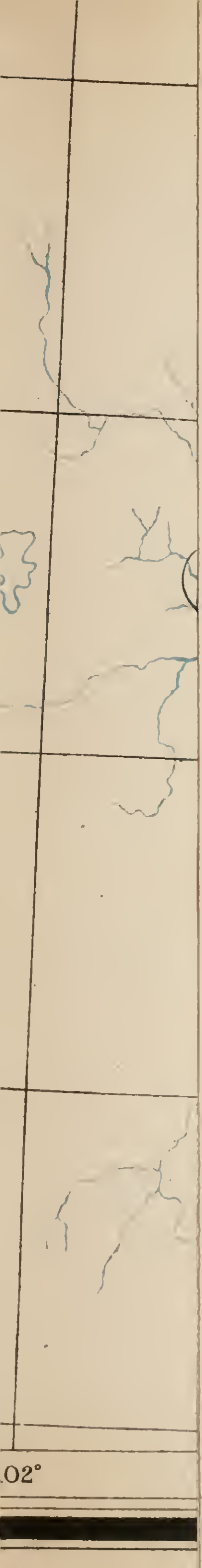
The interval between the Dunkard and the Kane sands is approximately 3500 feet. The sands above the Big Injun are not generally productive in Pennsylvania, and those below the Fifth have not proved to be of great value in West Virginia. It is possible that the "Clinton" sand of Silurian age and even the Trenton limestone of Ordovician age, both of which have yielded immense quantities of oil and gas in Ohio, may yet be found productive in Pennsylvania and West Virginia, but on account of the eastward increase in thickness of the strata and because of the general synclinal structure, mentioned below, these deep-lying sands have not yet been reached by the drill, not even in two wells which were recently sunk more than 7000 feet deep.

A major unconformity separates the Pennsylvanian and Mississippian series of the Carboniferous system. This is marked by the variable thickness and local absence of the Mauch Chunk formation and by the increase in thickness of the Pottsville from less than 200 feet in western Pennsylvania to nearly 4000 feet in southern West Virginia. There is also a marked change in the character and thickness of the Upper Devonian rocks. The sands of Catskill and Chemung age, shown in the table, in eastern Ohio, merge into shale. And the total thickness of the Upper Devonian strata decreases from more than 5000 feet in northern West Virginia to about 500 feet in central Ohio. These variations in the stratigraphy have a pronounced bearing on the occurrence

Chadron
AWES
SHERI
X BUTTE
Alliance
ORRILL
Bridgeport
GAR
PLATTE
E
Osh
EYENNE
UNION
Sidney
Chap
DEU
Jul
SEDGWI
PLATTE
PHILLI
Hol
GTON
YUMA
Wra
Riv.
Arikaree
S. Fork Repub
Burlington
T CARSON
N. Fk. of
O
HEYENNE
Cheye
Eads
Sheridan Lak


DOMINION
WASHINGTON
OREGON
IDAHO
MONTANA
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
NEVADA
UTAH
COLORADO
CALIFORNIA
PACIFIC
YELLOWSTONE NATIONAL PARK
GLACIER NATIONAL PARK


Mineola
Jamaica
Clifton
Richmond
Freehold
MOUTH
CEAN
Toms River
Barnegat
Atlantic City
Cape May Court House
May
pen


.02°

UNITED STATES S.W.

PLATE 12

Scale 2,50

APPROXIMATELY 40 MIL

25 0 25

25 0 25 50

1914

First published

Original compilation under the di

AND GAS F

ED UNDER THE SUPERVISI

Corrected to March, 191

added Februa

LEGEN

ld.

eld.

il locality.
oduction, but area
ow as defined field)

as locality.
oduction, but area
ow as defined field)

gas wells.
unimportant)

showing

n)

showing

on)

78°

77°

UNITED STATES S. E.
PLATE 12
ARKANSAS
TENNESSEE
KENTUCKY
NORTH CAROLINA
SOUTH CAROLINA
GULF OF MEXICO
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR
UNITED STATES
1914
First published in 1890
OIL AND GAS FIELDS IN 1916
PREPARED UNDER THE SUPERVISION OF JOHN D. NORTHROP
Corrected to March, 1917, additional data added February, 1919
LEGEND
Defined oil field
Oil and gas field (Oil predominant)
Defined gas field
Gas and oil field (Gas predominant)
Productive oil locality. (Commercial production, but area too small to show as defined field)
Productive oil and gas locality. (Commercial production, but area too small to show as defined field)
Productive gas locality (Commercial production, but area too small to show as defined field)
Oil and gas seep, or showing in wells (No production)
Scattered gas wells (Production unimportant)
Oil seep, or showing in wells (No production)
Trunk oil pipe lines.
Gas seep, or showing in wells (No production)
Principal ports from which foreign shipments of crude petroleum were made in 1916

of oil and gas. The sands cease to be productive where they merge with shale, and because of the variation in thickness the oil-bearing beds are not parallel to the surface strata. Consequently the deep-seated structure, which generally is of controlling influence in the accumulation of pools, is different from that of the surface rocks.

The oil- and gas-sands are offshore delta and current-distributed lenticular deposits that were laid down in a shallow inland sea. The long dimensions of the lenses are parallel to the ancient shore-lines, but the beds of sand are of extremely varied outline, determined by the irregular distribution of sand and mud when the rocks accumulated. In thickness the sands range up to 200 feet, but their average is nearer 50 feet. They are medium or fine-grained feldspathic sandstones, irregularly cemented by quartz and calcite, and locally streaked with conglomerate lenses composed of well-rounded pebbles of quartz. The pay streaks are the more porous, softer portions of the sand, contrasted with the harder and "tighter" parts, which range from a fraction of a foot up to 30 or 40 feet, and average between 5 and 10 feet thick. The cap rock is shale or well-cemented sand. These sandstone lenses, which are gently folded and interbedded with great thickness of carbonaceous shale, form ideal conditions for the accumulation of oil and gas.

The Appalachian oil- and gas-field lies in the geosyncline that extends between the Cincinnati uplift on the west and the zone of steeply-folded rocks of the Allegheny Mountains on the east. The syncline is a spoon-shaped trough in which the rocks rise northwestward, northward, and southeastward from the lowest part of the basin situated in West Virginia near the southwestern corner of Pennsylvania. Superimposed on this larger structure are a series of small non-persistent anticlines and synclines of irregular outline. The axes of the folds, conforming with the regional trend, extend northeast and southwest. The folds decrease in intensity westward from the eastward margin of the field, and west of the axis of the geosyncline the folding becomes so gentle that the rocks are only warped into irregular wrinkles. Farther west in Ohio the folds practically disappear and give way to an eastward dipping monocline.

The most productive oil-belt occurs contiguous to the central axis of the geosyncline, and the largest accumulations of gas are found along its outer margins. But pools of oil and gas of varying size, separated by non-productive areas, are irregularly distributed throughout the field. The pools are characteristically elongated in outline, and their longer dimensions are prevailingly parallel to the regional trend. The locations of most of the gas-pools have been distinctly determined by structure. They occur chiefly along the crests of anticlines or along the up-dip termination of lenses of sandstone, where they merge with shale. The influence of structure on oil accumulations is also pronounced. In the absence of gas, some oil-pools occur on the crests of anticlines; where much gas is present oil occurs on the flanks of anticlines below the gas and above edgewater. Other oil-pools occur on terraces marked by changes in the rate of dip. In the absence of water in the rocks, petroleum tends to occur in the synclines. But in many pools the effect of structure is not so evident, and lithology has been a controlling factor. The location of many of the oil- and gas-pools in Pennsylvania and West Virginia, and particularly their shape and delimitation, is fundamentally affected by the position, outline, and porosity of the lenticular reservoir-rocks. These factors account for the irregular shape of many of the pools and for their not uncommon occurrence "off structure."

The petroleum from Pennsylvania and West Virginia is a high-grade paraffin oil that has an average specific gravity not far from ·800 (45° Baumé). It yields distillation products of the highest grade at the lowest refining cost, and commands the highest price paid for American crude petroleum.

The following average analysis of gas delivered to Pittsburgh is typical of Pennsylvania and West Virginia dry gas: methane, 80 per cent.; ethane, 19 per cent.; nitrogen, 1 per cent. Such gas yields some gasoline by the absorption process, but much larger quantities of gasoline are made from casing head gas, which has added considerably to the value of the oil and gas production from Pennsylvania and West Virginia.

The total production for Pennsylvania and West Virginia from 1859 down to 1917 has been approximately one billion barrels. For Pennsylvania the maximum annual amount was obtained in 1891, when approximately 33 million barrels were produced. Since then there has been a fairly uniform decrease down to 1916, when the yield amounted to only $7\frac{1}{2}$ million barrels. It is estimated that about 85 per cent. of the recoverable amount under present operating conditions has been exhausted from Pennsylvania. In West Virginia apparently the reserve is not quite so much depleted.

The production of oil in these States is characterised by the longevity of the pools rather than by large wells. Although gushers were numerous when pools were first opened up, there have been no phenomenal wells. Some of the best wells in West Virginia, in the Shinnston pool in Harrison county, for instance, are credited with initial production between 450 and 550 barrels an hour, but the flow rapidly declined, and the best well in the Shinnston pool required nine years to yield 165,000 barrels. In the McDonald pool, one of the best in Pennsylvania, a single well produced more than 2,000,000 barrels in sixteen years. A number of wells have produced steadily for more than forty years, and in the Bradford field, in northern Pennsylvania, a large number of wells have produced continuously since the opening of the field more than thirty years ago. In that field, with several thousand producing wells, the average production per well is a quarter of a barrel a day. The "settled production" of wells in central and southern Pennsylvania averages not far from one barrel a day, and in West Virginia it is possibly between 2 and 3 barrels daily. A recent development in the Bradford field is the introduction of waterflooding, whereby territory which was considered practically drained has been made to yield large quantities of oil.

In the production of natural gas Pennsylvania and West Virginia are the most important States in the Union. The value of natural gas produced in these States in 1915 amounted to more than $67,000,000.

Maryland.—Small pellets of amber are found in the Magothy formation of Upper Cretaceous age at Cape Sable, at the mouth of the Magothy River, in Anne Arundel county, Maryland. The amber is associated with lignitised stems and leaves in thin beds of clay and sand. Its occurrence is only of mineralogic interest, as it has no bearing on the presence or absence of petroleum.

Virginia and North Carolina.—The Triassic deposits which are found in narrow synclinal basins from near Richmond, Virginia, southward almost across the State of North Carolina, contain at places beds of workable coal and beds of carbonaceous shale at different horizons. The beds of carbonaceous shale will doubtless yield some oil if distilled at high temperatures, but no tests have been made to determine the amount. It is unlikely, because of the structure of these areas, that oil-pools will be developed in them.

Georgia.—Showings of oil have been reported from the Trenton limestone of Ordovician age from near Dalton and near Rome in the northwestern part of the State of Georgia. There is little encouragement, however, for believing that oil will be found in commercial quantities in this area of Palæozoic rocks.

Recently considerable interest has been taken in the oil possibilities of the Coastal Plain of Georgia, which forms the southern part of the State. A deep well has been drilled near Waycross without favourable showings of oil or gas.

Florida.—So far no authentic discovery of oil has been made in Florida, although seepages of oil have been reported from a number of places and shows of oil and gas have been reported from a number of wells. It is probable that the shows of oil and gas are due to the decomposition of plant and animal remains buried in the surface muds. Deep wells have been drilled for oil near Wakulla, 10 miles south of Chipley, one-half mile southeast of Greensboro, near Kissimmee, and south of Titusville.

The surface rocks in Florida range in age from late Eocene to recent. The oldest rocks, representing broad areas of uplift, occur near Ocala and Marianna. The succession of beds lying beneath the exposed rocks has not been completely determined, but recent studies by Dr. J. A. Cushman have shown that the late Eocene limestone near Ocala is immediately underlain by limestone of Lower Cretaceous age, with a large part of Eocene and Cretaceous time unrepresented. The age of the beds which underlie the surface rocks near Marianna is not known, but the entire Eocene section as found in the adjoining area is believed to be present. So far, drilling has not shown the rocks underlying the peninsula of Florida to be petroliferous.

Alabama.—There is no commercial production of oil in Alabama and only one small producing gas-pool. There are, however, two areas in which oil is likely to be found: (1) In the area lying northwest of a line connecting Birmingham and Stevenson, comprising the northwestern part of the State, and (2) the Coastal Plain area lying south of the latitude of Montgomery.

The northwestern part of the State offers the best possibilities. In its northern part, which forms the southern border of the Cincinnati uplift, escapements of oil and gas and outcrops of bituminous limestones and sandstones are common. Showings of oil have been found in sec. 30, T. 7 S., R. 6 W., in Morgan county, at Atwood in Franklin county, near Hamilton in Marion county, near Cordova in Walker county, and a number of other scattered localities. Oil shows have been found in rocks ranging in age from Ordovician to Pennsylvanian. The only productive gas-field in the State is found in this area near Fayette, in which the gas is derived from the Pottsville formation of Pennsylvanian age.

In the Coastal Plain area, comprising the southern part of the State, the Cretaceous and Tertiary formations dip gently to the south toward the Gulf, but at a few places this general dip is interrupted by more or less pronounced folds. The most conspicuous is the Hatchetigbee anticline in Clarke and Choctaw counties. Seepages of gas and salt-water led to drilling many years ago on or near this fold; more recently two deep wells have been drilled on this fold without yielding sufficient results to encourage further exploration, although showings of oil and gas were reported from one of the wells. Other folds occur near Lower Peachtree Landing, in the northeastern part of Clarke county, and in Geneva and Houston counties, but on them there have been no developments. Showings of gas in wells near Mobile have led to the drilling of a number of additional unsuccessful wells there.

Tennessee.—Tennessee has not yet proved a large producer of oil and gas, and a study of the rocks does not lend much encouragement to its ever becoming a large producer. To date nearly all of the oil and gas found has come from the Cumberland Plateau or the Highland Rim in Scott, Fentress, Overton, and Putnam counties. The oil appears to be associated more or less closely with the Chattanooga black shale of Devonian (?) age, coming in thin sandstones above or from crevice limestones above or below. The Chattanooga shale underlies the Highland Rim at shallow depths, the productive wells being from 19 to 600 feet deep, the oil coming from the Mississippian rocks overlying the black shale or from the Ordovician rocks below. Wells have reached a production as high as 600 barrels a day, but have usually been short-lived. At one time (1896), a pipe-line was laid into the Riverton field. The field soon played out and in 1906 the pipe-line was taken up. During recent years many holes have been drilled on the plateau in Scott and adjoining counties. Wells near Oneida and Glenmary, in Scott county, have found a little oil, but the productive area in each case has not proved large and the wells have been short-lived. The wells have had depths of from 1200 to 2800 feet, and have found oil at various horizons, principally from the limestones a short distance above the black shale. There is usually some gas associated with the oil and some of the wells yield gas only. The oil is of from 36 to 38 degrees Baumé, with from ·14 to ·17 per cent. of sulphur. It appears to come from fractured dolomite or fine-grained sandstone. It appears probable that considerable oil exists in Tennessee, as oil seepages and gas springs are common, but experience indicates a lack of suitable reservoirs, the sandstone of Kentucky and the more northern States having apparently thinned out near the northern edge of Tennessee.

Kentucky.—The oil- and gas-fields of Kentucky are widely scattered over the State, but no commercial pools have been found in the broad area covered by the Cincinnati uplift in the central north portion of the State and none in the northern end of the Mississippian embayment along the western border of the State. The main gas-fields are the Menifee and the Inez fields, the former in particular now being largely exhausted of its gas. Noteworthy occurrences of both oil and gas, as yet of little importance, are scattered widely between the producing fields, a large number of which are relatively small.

The oil in Kentucky is found mainly in the "Corniferous" limestone which is more or less dolomitic and which lies a short distance below the Ohio or Chattanooga black shale, the arrangement and other facts furnishing strong circumstantial evidence that the shale was the source of the oil. Some oil has been found above the shale and some in other porous beds not far below, and some has been found in higher sandstones of the Pennsylvanian and Mississippian series, particularly in the eastern end of the State.

The most noteworthy convergence of beds known in the State is a result of the westward thinning of all or practically all formations east of the Cincinnati uplift. Unconformities occur here and there throughout the Devonian and Carboniferous groups, the main unconformity being between the Mississippian and Pennsylvanian. The structure of Kentucky is dominated by the Cincinnati uplift, the Appalachian uplift along the southeastern border of the State, and the Gulf embayment depression at the western end. The remainder of the State may be divided into two sedimentary basins in which Pennsylvanian and Mississippian formations outcrop. The oil- and gas-pools of the State show more or less marked relation both to structure and to lithologic features of the beds. The most productive field, known as the Irvine field in Esthill county, lies on a very well-developed anticline which is faulted along its northern margin. The oil-field of Lee county is almost connected with the Irvine field, but shows almost no relation to structure. The oil-fields of Allen county occur on fairly well-marked domes, but some of the oil is in synclines and in places where there is no marked deformation.

The oil of Kentucky is classified commercially as of two grades, though there is no distinct line of demarcation, the gravity ranging from about 30 to 37 degrees Baumé. The past production of Kentucky has been small relative to other Appalachian States, but has grown rapidly in the last few years since the Esthill and Allen counties fields have been developed. The future of the State depends to a considerable extent on certain unique features that control prospecting, particularly the fact that the undiscovered pools are probably small and widely spaced and that tests are relatively inexpensive. It seems probable that new pools will be discovered from time to time for many years to come, and that the future production of the State will be between 100 and 200 million barrels.

Ohio.—The oil- and gas-fields of Ohio, as shown, Plate 12, lie in the eastern half and northwest quarter of the State and cover an area of approximately 3000 square miles, nearly half of which is gas territory, while the other half yields both oil and gas. The principal gas-field, known as the "Clinton," extends northward through the central part of the State. The productive areas to the east of this belt comprise a part of the great Appalachian oil-field. The productive area, extending diagonally across the northwestern part of the State, is a part of the field generally known as the "Trenton" or "Lima-Indiana" field. The fields of Ohio have been in process of development for nearly half a century, and many areas are approaching exhaustion. This is notably true of the Lima-Indiana oil-field, which is estimated to be 92 per cent. exhausted, and also of the central Ohio gas-field.

The productive rock in the Lima-Indiana field is the "Trenton" limestone, together with lower beds of the Ordovician. The reservoir-rock is cavernous crystalline dolomite. The overlying Silurian beds, though not productive in this part of the State, are of great importance in its central part, where a sandstone known as the "Clinton" is the reservoir-rock. In the eastern part of the State, forming a part of the great Appalachian coal basin, the Clinton sand is 2000 to 5000 feet below the surface, and the oil and gas production is derived from numerous shallower sandstone beds in both the Lower and Upper Carboniferous series. Among the most important of these, listed in ascending order, are the Berea, Big Injun, Keener, and Big Lime, Salt and Cow Run sands, as named by the drillers. There are in all more than 15 sands productive at one place or another, and in some instances several sands may be found productive in the same well. The eastern Ohio region is generally known as the "shallow sand territory," for the reason that the production is so largely derived at moderate depths. In some of the pools wells that obtain their production from depths of 100 to 200 feet have been pumped continuously for forty years.

It is thus seen that the Ohio fields derive their product chiefly from limestones of Ordovician age, from the "Clinton" sandstone of Silurian age (possibly the same as the Medina sandstone of New York State), and from Lower and Upper Carboniferous strata. The stratigraphic relations are represented in the following generalised sections, the first of which is representative of the Cleveland gas-field and the second of the Woodsfield district, southeastern Ohio (see fig. 9). It should be mentioned that the Ohio shale group represented as 1200 feet thick in the Cleveland district, thickens greatly to the southeast, and in the Woodsfield district is probably at least 3000 feet thick. In western Pennsylvania this shale contains sandstone lenses known as the Venango oil-sands, which are highly productive, but they thin to the west and are missing in Ohio.

GENERALISED SECTION OF ROCKS IN THE CLEVELAND GAS-FIELD, OHIO.

System.	Group or formation.		Thickness in feet.	Character.	Driller's description.
Quaternary (Pleistocene series).	Glacial drift.		10–100	Boulders, pebbles, sand, and clay.	Drift.
Carboniferous (Mississippian series).	Berea sandstone.		10–150	Medium to coarse-grained white, buff, or brown sandstone.	Berea grit.
Devonian or Carboniferous.	Bedford shale.		60–80	Bluish-gray to reddish shale, with some thin layers of limestone.	Ohio shale, 1100–1400 feet.
	Ohio shale group.	Cleveland shale.	50–120	Massive hard black bituminous shale with a few bluish layers in lower portion.	
		Chagrin shale.	850–1200	Soft bluish-gray clay shale, with some concretionary layers.	
Devonian.		Huron shale.		Black and bluish shale in upper and lower portions, with a band of gray shale near middle.	
	Olentangy (?) shale.		80	Gray calcareous shale.	
	Delaware limestone.		500–700	Blue and gray limestone, becoming dolomitic in lower part. Contains a 30 to 50 foot bed of white quartz sandstone 350 to 450 feet below top.	Big lime [includes Newburg sand and some "stray" sands in lower 300 feet], 1125–1825 feet.
	Columbus limestone.				
Unconformity —	Monroe formation.				
	Salina formation.		400–600	Shale, dolomite, anhydrite or gypsum, and rock salt.	
	Niagara limestone.		400–600	Dolomite and limestone.	
Silurian.	"Clinton" formation.		150–250	Calcareous shale and thin-bedded limestone, with sandstone layer in lower part.	[Includes Little lime], 75–150 feet. Clinton sand, 0–60 feet. 25–75 feet.
	"Medina" shale.		300–400	Red clay shale with thin layers of sandstone.	Medina red rock.
Ordovician.	Shale and limestone of Cincinnatian age.		1100–1250	Dark shale with thin layers of limestone, especially in upper part.	Slate and shells.
	Trenton (?) limestone.		(?)	Limestone.	Trenton lime.

The oil from the Carboniferous strata is almost without exception of high quality, being of a paraffin base and of high gasoline content. The specific gravity ranges from 37 to 50 degrees Baumé, and on the whole the quality is nearly equal to the best Pennsylvania grade of oil. The "Clinton" oil does not command as high a price as the oil from the Carboniferous strata, being of similar specific gravity and of paraffin base, but yielding less kerosene and gasoline. The "Trenton" oil is least valuable of all, being 19 to 35 degrees Baumé gravity and having the objectionable feature of containing considerable sulphur.

Throughout Ohio the strata lie nearly flat or are at most inclined at a rate of 75 to 100 feet to the mile. The general rate of dip is 10 to 15 feet to the mile, with local areas of steeper inclination, alternating with the nearly flat areas, thus giving a terraced effect. Less commonly there is a reversal in direction of dip, producing small anticlinal folds.

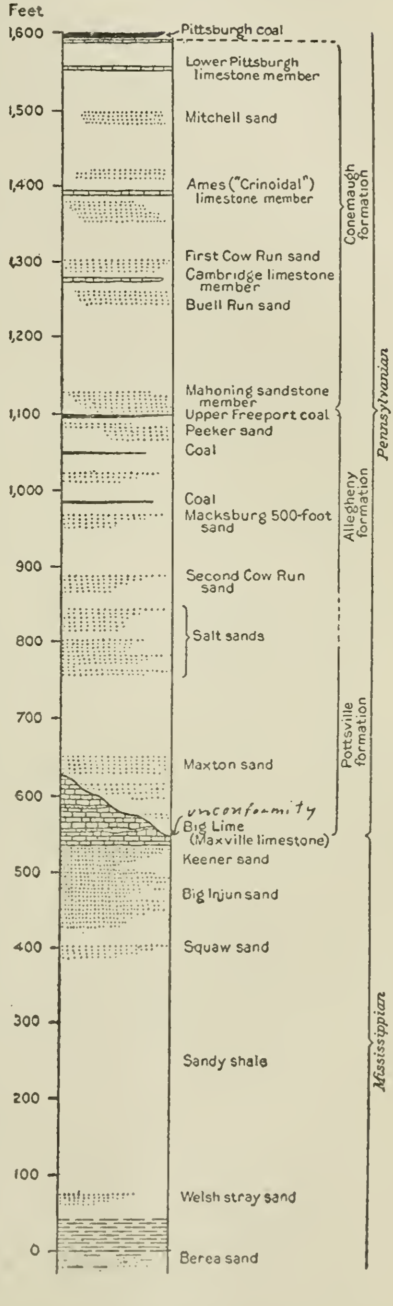


FIG. 9.—Generalised section showing oil-sands and accompanying beds in Woodsfield quadrangle, Ohio.

An inspection of the geologic map of Ohio will show that the oldest exposed rocks are of Ordovician age and outcrop in the south-western part of the State over what is known as the Cincinnati uplift. The axis of this arch extends north across the western part of the State through the west end of Lake Erie. About midway a branch arch extends westward into Indiana. Along this broad flat arch and its westward branch is situated the Lima-Indiana oil-field of northwestern Ohio and the adjacent portion of Indiana. From the Cincinnati arch eastward the strata dip gently toward the Appalachian synclinal basin. This basin has numerous minor structural wrinkles which have to a large extent influenced the accumulation of oil and gas in the commercial pools.

Indiana. The State of Indiana has been an important producer of oil and gas for many years, the most important area being the Lima-Indiana or "Trenton" field, which covers hundreds of square miles in the northeastern part of the State and extends eastward into the adjacent portion of Ohio. The importance of the field will be realised from the fact that the total production of oil marketed from it to the close of 1918 is estimated at 418,404,000 barrels. The field, like most others in the eastern part of the United States, is approaching exhaustion and is estimated to be 92 per cent. exhausted. In the southwestern part of the State there are smaller areas productive of oil, and in this general region the possibilities of extending the areas now productive and of discovering new productive areas are most hopeful.

The oldest rocks exposed in the State lie in the southeastern part on the west slope of a broad flat arch known as the Cincinnati uplift along the axis of which Ordovician strata are exposed. The "Trenton" limestone of this group is the productive stratum in the Lima-Indiana field which lies along an extension of the Cincinnati uplift. A branch of this arch extends westward across the northern part of Indiana to the city of Chicago, and small pools of oil have been discovered along it at numerous places. From this arch the rocks slope southward and westward into the Eastern Interior Coal Basin, which occupies the southwestern part of Indiana and adjacent parts of Illinois and Kentucky. Throughout the State the strata dip very gently, the rate being in general only a few feet per mile, or locally at a rate of as much as 100 feet per mile. Locally terraced structures or anticlinal folds are found. Glacial drift covers the rock exposures over much of the State, but where it has been found possible to do structural mapping in the "Coal-measures" strata in the southwestern part, it has been found that the occurrences of oil and gas bear a definite relation to structural features.

In the Lima-Indiana oil- and gas-field the "Trenton" limestone and underlying strata are the principal oil-bearing strata. In the central part of the State the Niagara limestone of Silurian age is a source of oil at a few localities, while in the southwestern part Devonian limestones are the principal productive strata. Shales of the latter system and sandstones in the overlying Carboniferous beds are also productive to a lesser extent.

Michigan.—The oil and gas yielded by the rocks of this State are of comparatively small importance, the structure being unfavourable for large accumulations of either, even where the rocks are of the same age and nature as those elsewhere productive. A small production of natural lubricating oil comes from a few shallow wells near Port Huron, Saint Clair county, and these wells also yield a small volume of natural gas. Minor quantities of natural gas have been reported from the Trenton limestone in Munroe county and the adjacent part of Washtenaw county, and from the Devonian of Wayne, Macomb, and Allegan counties. Both oil and gas have been reported from the Carboniferous of Washtenaw, Muskegon, and Berrien counties. In the northern peninsula asphalt is found in Delta county, and occurrences of oil have been noted from the Lower Silurian (Chazy group) of Mass City and Rockland in Ontonagon county.

Illinois.—Since 1903 Illinois, particularly the southeastern part of the State, has proved highly petroliferous, but before that date the existence of large sources of oil in this region remained generally unsuspected in spite of small yields of oil and gas from shallow wells in certain isolated districts. Oil-fields occur not only in the main southeastern region but scattered throughout the southern half of the State, and small quantities of both surficial and deep-seated gas have been found in various parts of the State.

The main oil-bearing sands belong in the upper part of the Mississippian series, but notable quantities have been produced from other beds above and below. The greater part of the oil from Illinois comes from sandstones in the

Chester group, but one of the sands in the main field, known as the McClosky, is an oolite of Ste. Genevieve age, composed of very pure calcium carbonate. The various oil-bearing sands occur through a thickness of strata aggregating about 1500 feet. The sands themselves are of somewhat irregular thickness and pinch out entirely at many places, due both to limited areas of deposition and to erosion, which has led to the development of numerous unconformities. The main unconformity is between the Mississippian and Pennsylvanian series, but more or less widespread unconformities occur in several places in the Chester and other groups.

The main oil-fields of the State occur along a broad uplift, known as the La Salle anticline, the west limb of which is somewhat steeper than the east. Most of the individual oil-fields occur on domes and other minor upfolds along the crest of the main anticline, but their limits do not correspond closely with the structures. A considerable number of anticlines and domes in the State that have been tested have failed to yield oil and gas in commercial quantities.

The oil of Illinois is somewhat heavier than Pennsylvanian oil and contains considerable asphalt. For the most part it ranges in gravity from 31° to 38° Baumé. The production in Illinois is declining rapidly. From 1910 to 1914 it produced between 20 and 30 millions of barrels annually, but the production has now declined to about half that amount. The total production of the State to date is about 300,000,000 barrels. It is estimated that the State may produce in the future from discovered and undiscovered fields 150 to 175 million barrels.

Wisconsin.—Small quantities of asphalt occur in cavities in the Devonian limestone in one or two localities, and thin layers of bituminous shale have been found interbedded with the lead and zinc-bearing limestones in the southwestern part of the state ; but these occurrences do not as yet have any commercial importance.

Minnesota.—Some gas was discovered in a sandy layer in the glacial drift about 75 feet below the surface in Freeborn county. Similar occurrences of gas have been reported from other counties in the State—for example, Faribault, Mower, Waseca, Blue Earth, Nicollet, Goodhue, Dakota, Washington, Ramsey, Hennepin, Chisago, Stearns, Bigstone, and Traverse. The source of the small amount of gas in these localities may in some cases be the underlying beds, but it is more probably the decomposition of vegetable remains in the superficial deposits.

Iowa.—Commercial oil- and gas-pools are as yet unknown in Iowa, although small quantities of surficial gas, sufficient to furnish a number of houses, have been found in various parts of the State. Discharges of carburetted hydrogen from the "forest-bed," intercalated between the first and second Glacial boulder-clays, have supplied small demands for longer or shorter periods in Louisa, Muscatine, Polk, Dallas, Sac, and Hamilton counties, while in Nevada township, Story county, and in other localities, gas has been found in Pennsylvanian and older formations.

Missouri.—The oil and gas developments in this State are located along its western border and are very limited in extent and productivity. Oil of low grade has been found at Kansas City, Jackson county, near Belton in Cass county, and near Stotesbury in Vernon county, and although the production records date back to 1889, the total production of the State to the end of 1916 amounted to only a few thousand barrels. Natural gas is of more value, and the development of this resource dates back to 1872 or before. The principal production is found at Kansas City, Sheffield, and near Martin City, all in Jackson county, near Parkville in Platte county, and near Belton in Cass county, where the domestic needs of small communities are supplied. Scattered wells in Bates and Johnson counties have sufficient yield to satisfy the domestic needs of two or three families each. The total production for the State in 1916 was estimated at 69,236,000 cubic feet, with a value of $17,594.

The source of the oil and gas is principally the rocks of the Cherokee formation at the base of the Pennsylvanian series of this region, which is found at depths ranging from 200 to 600 feet. The future developments in Missouri will probably be confined to the northwestern part of the State, and in view of the low productivity of the sands already developed, there is little hope of encountering greater supplies in future developments. The State will probably continue as in the past to produce small quantities of oil and sufficient gas to supply small quantities for local domestic needs, but beyond this there is little prospect.

Arkansas.—Petroleum has not been found in commercial quantity at any locality in the State.

Seven asphalt deposits are known in the lower part of the nearly horizontal Trinity formation of Lower Cretaceous age in Pike and Sevier counties. The petroleum yielding the asphalt was probably derived from the closely folded Carboniferous rocks which underlie the Trinity. The deposit 2½ miles south-southeast of Pike, in Pike county, has produced asphaltic sand that has been used in paving streets in Little Rock, but this is the only deposit from which asphalt has been shipped. An albertite-like mineral, impsonite, occurs as veins or fissure fillings in closely folded Carboniferous shales near the west end of Fourche Mountain a few miles north of Mena.

Gas is obtained from wells in Massard Prairie near Fort Smith in Sebastian county, in Coops Prairie near Mansfield in Scott and Sebastian counties, and near Van Buren in Crawford county. It supplies the towns of Mansfield, Huntington, Fort Smith, Van Buren, and Kibler. The production in 1916 was 2,387,935,000 cubic feet. The wells have been drilled on or near the crests of anticlines and the gas is obtained from sandstone beds in the Atoka formation of Pennsylvanian age. This formation is several thousand feet thick and consists mainly of shale, but partly of sandstone. The three productive areas mentioned above are in the Arkansas Valley which is a gently folded east-west synclinorium lying between the Ouachita Mountain uplift to the south and the Ozark uplift to the north.

Gas in small quantity has been found near Vick, Bradley county; Batesville, Independence county; and Fayetteville, Washington county.

Louisiana.—The productive oil-fields of Louisiana are found in the northwestern part of the State, mainly in Caddo, De Soto, and Red River parishes, and in a narrow belt parallel to the coast, stretching from Calcasieu to Iberia parish in the southern part of the State. The productive gas-pools are found in the northwestern part of the State associated with the oil-pools, and also near Monroe and Bastrop in its northeastern part, and near Houma in its southeastern part.

The oil and gas in northern Louisiana are found in a sandy phase of the Eagle Ford shale, in the Annona chalk and Nacatoch sand, all of Upper Cretaceous age. The Eagle Ford yields most of the high-gravity oil, as well as a large percentage of the gas; the Annona yields oil of varying gravity, and the Nacatoch yields gas over a wide area and low-gravity oil in the neighbourhood of Vivian and Hosston in Caddo parish. The oil and gas in southern Louisiana are believed to be derived in large part from beds of Miocene age and from masses of secondary dolomite overlying salt cores.

The rocks of Louisiana, broadly speaking, dip to the south and southeast. This normal dip is interrupted here and there by folds of greater or less magnitude. The Sabine uplift is the dominant structural feature of northwestern Louisiana on which are found all of the producing oil-fields of that part of the State. The axis of this broad, gently folded uplift extends from near Mooringsport south-southeast to near Coushatta. The oil is found in small folds transverse to the axis of this broad uplift. The large gas-field near Monroe and Bastrop is located on a broad, flat terrace, from which the rocks dip relatively steeply to the east and southeast. The oil near the coast is found in small isolated fields, unusually covering more than a square mile in area, which are associated with steeply folded domes underlain by salt cores.

The oil from the northern fields is largely of high gravity, ranging from 38° to 45° Baumé; that from the southern fields is of low gravity and is used largely as fuel.

Texas.—The oil-fields of Texas are widely distributed and fall naturally into three belts: (1) The coastal belt, which extends from Beaumont to San Diego and is the continuation of the coastal fields of Louisiana; (2) the Cretaceous belt, which extends from Mooringsport in Louisiana southwest to San Antonio; and (3) the north-central fields, which extend from near Wichita Falls south almost to Brady, in McCulloch county. Outside of these productive areas, shows of oil and gas, asphaltic sands, and bituminous shales have been found widely distributed over the State under varying geological conditions.

The oil from the coastal fields is derived from late Tertiary formations, and in many instances from secondary limestone or dolomite overlying salt cores; the oil from the Cretaceous belt is derived from beds of substantially the same age as that in northwest Louisiana, from different horizons in the Taylor marl and Navarro clay of Upper Cretaceous age; the oil in the north-central field is derived from a wide range of horizons, probably from near the base of the Permian, from various horizons in the Pennsylvanian and possibly from the Mississippian and Ordovician (Ellenberger limestone). The principal producing horizons are in the lower part of the Pennsylvanian, as found in the Ranger and Electra fields.

The oil-fields of the coastal belt are associated with small, closely folded domes with salt cores, called salt domes. The oil is found in the steeply dipping beds on the flanks of the domes, in the secondary limestone or dolomite capping the salt core, or in the gently folded sands which overlie the core. In the Cretaceous belt, the beds dip gently toward the coast, and the oil-pools are found either in small local folds, which disturb this normal dip, or in lenses of sand in dominantly clay beds of Taylor and Navarro age. The structure of the north-central fields is more complex. The Bend series, of Mississippian or Lower Pennsylvanian age, is folded into a broad arch which extends from the Llano-Burnett uplift in central Texas, north to Red River, the crest of the arch becoming lower to the north. The surface rocks in this area, of Upper Pennsylvanian age, dip gently to the northwest or west, except where interrupted by gentle folds, the relation of which to those in the Bend series has not been determined.

The oil from the north-central fields, as well as most of that from the Cretaceous area, is of high gravity and is refined; the oil from the coastal fields is of low gravity and is used largely as fuel.

Oklahoma.—Since 1915 Oklahoma has been the leading producer of oil in the United States. Within its borders are about 1000 square miles of producing territory which represents the central and major part of the Mid-Continent fields. This territory is divided into two districts, the leading one being located principally in the northeastern part of the State, but includes also pools in the east-central and north-central parts. The other district is located principally in the southwestern part of the State and includes also a few small pools in the south-central part.

The oil and gas of the northeastern district comes principally from the rocks of Pennsylvanian age, although some is obtained from rocks of Mississippian and Permian age. The productive beds of the Pennsylvanian occupy various positions through an interval of approximately 3000 feet, but the greater part of the production comes from the porous beds of the Cherokee shale at the base of the Pennsylvanian series in this region. Of these porous beds the Bartlesville sand is not only the most prolific, but also is the most widespread, being productive over large parts of Nowata, Rogers, Washington, Tulsa, Osage, Pawnee, Creek, and Payne counties.

In this district the productive sands range in depth from a few hundred feet in Nowata and Rogers counties on the east to nearly 3500 feet in Kay County on the west. Of the individual fields the Cushing pool in western Creek county ranks first in its prolific production, which during the first half of 1915 amounted to nearly 250,000 barrels daily, most of which came from the Bartlesville sand. Glenn Pool in eastern Creek and western Tulsa counties was the leading development from 1907 to 1910, during which period it produced more than 19 million barrels annually. The land in Osage county is tribal land belonging to the Osage Indians, still under the guardianship of the Federal Government. The oil royalties derived by the Osages have made them the richest people on earth. The Ponca City, Blackwell, Marvine, Billings, Garber, and Barnes pools in Kay, Noble, and Garfield counties in the northwestern part of this district are its more recent developments.

In the southwestern district the oil comes from rocks of Permian, Pennsylvanian, Cretaceous, and possibly Ordovician age. The Healdton pool in western Carter county is by far the most prolific, with a monthly production of more than 1,000,000 barrels during most of 1916. Other fields of this district include the Wheeler and Fox pools in Carter county, Loco and Duncan in Stephens county, Walters in Cotton county, Lawton in Comanche county, Cement in Caddo county, Gotebo in Kiowa county. Several small pools in Marshall county are the only ones in the State to obtain their production from the rocks of Cretaceous age.

The northeastern district, together with eastern Kansas, lies on the west flank of the Ozark Uplift, and the rocks of this region slope gently westward at a rate of 20 to 80 feet per mile, forming a general monocline. On this is superimposed many local anticlines and domes, which are the controlling features in the accumulation of the oil and gas in the more prolific fields. There are, however, numerous occurrences due to locally porous conditions, as lenticular sands. As a rule the anticlines and domes are not pronounced, the dips of the strata generally amounting to less than 1°. The Cushing pool supplied the largest wells of the district, many of them exceeding 5000 barrels daily when drilled in, and one of them had an initial production as high as 14,000 barrels daily. In the shallow sand district of Nowata and Rogers counties the initial productions of wells run as low as 2 or 3 barrels.

The regional structure in the southwestern district is distinct from that of the northeastern district. The comparatively local Arbuckle and Wichita Mountain uplifts are here the controlling features beyond whose borders lie the anticlines and domes which control the oil and gas occurrences. These anticlines and domes are similar in magnitude to those of the northeastern district, the dip of the strata generally amounting to less than 1°.

The oils of Oklahoma vary from 22° to 48° Baumé. This variation is principally regional, the lighter oils coming from the northeastern districts and the heavier ones from the southwestern districts. The oil of the Cushing pool, because of its large content of the lighter constituents, is the most valuable of any of the larger pools. The heaviest oils come from the Wheeler field in the southwestern district, where all the oils are not only of the heavier type but they contain also larger quantities of sulphur, which lowers its market value to about two-thirds that of the oils of the northeastern district.

The development of new pools in Oklahoma will probably continue for many years. The western part of the Osage Indian tribal lands in Osage county is still undeveloped, because of governmental restrictions, and this county therefore has considerable territory to be developed in the future. Along the west side of the northeastern district there remains considerable undrilled territory which probably is oil-bearing, but here the surface rocks, which are of Permian age and consist of soft sandstones and shales, do not lend themselves readily to geological investigations, and therefore the locating of new pools will not be rapid. The southwestern district has great possibilities, but here also the locating of new pools by geological surveys is not promising, for not only do the surface rocks consist of soft lenticular beds of shales and sandstones of Permian age, but they are separated from the oil-bearing Pennsylvanian rocks by a marked unconformity.

Kansas.—The developed oil- and gas-fields of this State occupy about 400 square miles, scattered through the southeastern and east-central counties. Those fields which occur in a belt from Miami and Franklin counties on the north, through Allen, Wilson, Neosho, Labette, Montgomery, and Chautauqua counties to the south boundary of the State, comprise the shallow-sand district where the producing rocks range from 300 to 1600 feet in depth. The oil-fields are generally not distinct from the gas-fields, and will therefore not receive individual treatment.

The initial productivity of oil-wells in this district ranges generally from two or three barrels to 25 and 50 barrels, although 1000-barrel wells have been drilled. The gas-wells have initial capacities ranging from a few hundred thousand to five million cubic feet per day. A few wells with initial capacities of more than fifty million cubic feet daily have been drilled. The active development of this shallow-sand district began in 1889 and is still in progress.

Lying farther west is the Butler county district, discovered in 1914. It is known for its prolific deep oil-sands found at a depth of about 2500 feet, and the development of these sands in 1916, 1917, and 1918 represented the leading development of the Mid-Continent field. Many of the wells produced in excess of 10,000 barrels a day when drilled, and for many months the daily production of the district exceeded 100,000 barrels. Several other noteworthy fields have been developed in Greenwood and Cowley counties, of which the more important ones are located near Sallyards, Virgil, Beaumont, Winfield, and Arkansas City.

The producing sands are of Pennsylvanian age and range from the lowest to the highest parts of this series, which is represented by 3000 to 3500 feet of sediments. The principal producing sands of both the shallow and the Butler county districts belong to the Cherokee shale, the lowermost formation of the Pennsylvanian series in the State.

Eastern Kansas lies on the west flank of the Ozark Uplift, and the rocks of this region slope gently westward at a rate of 15 to 20 feet per mile, forming a general monocline. On this is superimposed many local folds or anticlines, which are the controlling factors in the accumulation of the oil and gas in the more prolific fields. There also are numerous fields in which the oil and gas are controlled by features other than structure, such as local porous zones or lenticular sands.

The oils range in gravity from 25° to 41° Baumé. The heavier oils as a rule are obtained from the shallowest sands of the shallow-sand district, and the lighter oils from the deeper sands.

Undoubtedly Kansas contains many undiscovered oil- and gas-fields, although large ones similar to the Butler county district can hardly be hoped for. Extending north-northeast from the Butler county fields is a belt of folding, the anticlines and domes of which it had been hoped would furnish other oil- and gas-fields of promise, but drilling has shown that several of these anticlines are not only barren, but also that they are underlain at shallow depths by a buried crystalline mountain ridge, the presence of which has almost completely discouraged further prospecting in this region. It is possible that oil and gas may occur on either side of this buried mountain ridge, and the discoveries of oil late in 1918 and early in 1919 near Elbing and Peabody, in northwestern Butler and southeastern Marion counties, are very encouraging.

The western half of the State is covered by Cretaceous and Tertiary sediments which are separated from the underlying oil- and gas-bearing Pennsylvanian series by a great unconformity. Investigations have shown well-developed anticlines in the Cretaceous series, but developments thus far have not proved it to be oil- and gas-bearing. It is also possible that in places where these rocks are comparatively thin, oil and gas will be discovered by deep drilling into the underlying Pennsylvanian series.

Nebraska.—In the report of the State Geologist of Nebraska for 1903, mention is made of the occurrence of oil in small quantities in Rock and Brown counties; other "discoveries of petroleum" in the State having proved to be merely iridescent iron films floating on water. Presumably this condemnation extends to the "shows" of oil found in boring at Ponca in Dixon county, at Decatur in Burt county, and on the North Platte River near the Wyoming border. Deep borings in Omaha, Lincoln, Brownville, and near Stockville, the latter on a prominent anticline, have failed to find oil or gas.

South Dakota.—Small amounts of gas have been found in several wells drilled for artesian water in Cretaceous rocks at and near Pierre in Hughes county, and in the adjoining Sully county. The gas is found in dark shale, or in gray sandstone (Dakota) immediately beneath the shale. It has been utilised to some extent at Pierre.

Many wells in the central and eastern parts of the State have reached bed rock (granite or quartzite) without finding traces of oil or gas. Deep borings north and south of the Black Hills yield water but found no oil or gas. An anticline in the southwestern part of Shannon county has been drilled recently, but all the sedimentary rocks have not been penetrated.

North Dakota.—A small amount of gas collected from the waters of artesian wells drilled in Cretaceous rocks is used for domestic purposes at Edgeley, Lamoure county, and the towns of Westhope and Lansford in Bottineau county are supplied with gas from shallow wells in the glacial drift above the Pierre shale of Cretaceous age.

Small samples of an oil resembling gasoline are said to have been obtained from a well in the Tertiary Fort Union formation at Minot, Ward county, and small flows of gas are reported near Crosby and Nesson, Williams county and Sanish Mountrail county, from wells in the same formation.

The rocks of North Dakota generally lie so flat that anticlines or domes are not easily detected. The Glendive anticline which crosses the State line from Montana in Bowman county, the Nesson anticline, and the probable anticline at Minot practically complete the list of such structures as far as they are known.

Montana.—The only commercial production of oil in Montana is from the Elk Basin field on the Montana-Wyoming State line in Carbon county. Showings of oil in the form of seeps and films on water have been reported at various localities, but no other accumulations of commercial importance have yet been found. Natural gas is produced on a small scale at Havre, Hill county; near the mouth of Cedar Creek, about 10 miles southwest of Glendive, Dawson county; at Baker, Fallon county; and about 20 miles northwest of Baker. Natural gas is also known to occur in small quantity at Hardin, Bighorn county. Showings of gas have also been found in Carbon county, and especially along the Great Northern Railroad near Malta, and for some distance west from Havre.

In general, it may be said that the main oil- and gas-producing sands of Montana occur in the lower part of the Upper Cretaceous, including the Eagle sandstone and sandy beds in the lower part of the Colorado shale.

Natural gas appears to have accumulated where the formations including the above beds have been gently arched. The occurrences of gas west of Havre are in sands of the Colorado shale, on what is known as the Sweetgrass Arch. In the vicinity of Glendive and Baker the gas comes from similar beds, on what is known as the Glendive Anticline, a long fold extending from the Yellowstone River southeast to the extreme northwest corner of South Dakota. The large flow of gas at Havre is from the Eagle sandstone, where the beds have been folded and faulted.

Wyoming.—Oil has been discovered at many places in Wyoming, and its occurrence in commercial quantity is not confined to any particular part of the State. Thus, in central Wyoming there are the Lander, Pilot Butte, and Maverick Springs fields in Fremont county, the Salt Creek field in Natrona county, and the Big Muddy field in Converse county. Gas in large amount has been discovered in the Poison Spider district in Natrona county, and at Big Sand Draw in Fremont county. In the eastern part of the State a field of considerable promise was discovered in 1918 near Lance Creek in Niobrara county, while in the same year another pool of large potentiality was brought in on Rock Creek, Albany county, in the southeastern part of the State. In Lincoln county, which lies in the opposite corner, oil has been produced from the Fossil field. In the northern part of the State in Bighorn Basin lie the Elk Basin, Byron Basin, Greybull, Hidden Dome, Warm Springs, Grass Creek, and other fields.

Production has been obtained principally from rocks of Cretaceous age, and the Torchlight, Peay, and Wall Creek sands which belong to the Frontier formation of this system have been by far the most prolific producers. The Shannon sandstone in the upper part of the Cretaceous, and the Cloverly formation toward the base of the system, also yield oil and gas in considerable amount. Recent discoveries in rocks of Carboniferous age suggest that important pools may be developed from beds in this system. The accompanying table summarises the stratigraphic occurrence of oil in Wyoming.

The accumulation of oil in Wyoming appears in a large measure to be controlled by anticlinal folding, and while all anticlines in which oil-sands are sealed are by no means oil-bearing, experience has demonstrated the fact that anticlinal structure affords a greater chance of success than do other types of structure. In general the anticlines of Wyoming are large, pronounced, and very readily determinable folds.

Oil produced from the Cretaceous rocks is of high grade and comparable in character to Pennsylvania oils. In Bighorn Basin the average gravity of the Cretaceous oils is about 15° Baumé, but at Salt Creek the gravity is 40° Baumé or less. The oil produced from Carboniferous rocks is heavy and dark brown to black in colour. Oil from this zone in the Lander field ranges from 22° to 24° Baumé.

The first reported commercial production in the State was that of 1894, when 2369 barrels were produced. It was not until 1912 that the production reached a million barrels annually, but since that time the increase has been rapid, and it is estimated that in 1918 about 12,000,000 barrels were produced —the largest production yet recorded for the State. To the close of 1918, approximately 38,500,000 barrels of oil had been brought to the surface, and it is estimated by the U.S. Geological Survey that on 1st January 1919 there was left in the ground an available supply of about 400,000,000 barrels.

Colorado.—About 97 per cent. of the oil marketed in 1916 came from the Florence district in Fremont county. The remaining 3 per cent. came from the Boulder district in Boulder county. Oil is also known to exist in small quantity in the Rangely district, Rio Blanco county, in the De Beque district, Mesa county, and in a few other localities of minor importance. A small volume of natural gas was obtained from oil-wells and used locally in the Boulder and Florence oil-fields. The remaining natural gas produced in Colorado came from individual wells which furnished only enough gas for one to three families. Thick belts of rich oil-shale occur in the northwestern part of the State, mainly in Rio Blanco, Garfield, and Mesa counties. These beds will doubtless form the basis of a large industry.

For stratigraphic distribution of oil- and gas-yielding sands, see table of formations under the State of Wyoming.

The structure of the Florence field is monoclinal, and the dips within the producing area range from 3° to 6°. The oil occurs in joints and fissures in the Pierre shale in a zone about 2500 feet in vertical thickness. In the Boulder field the gentle southeasterly dip of the Pierre shale is modified to some extent by gentle north-south or northwest-southeast folds. The producing wells occur in a north-south belt closely related to an anticlinal fold in the Pierre shale.

The Florence field yields a paraffin oil of dark olive green to reddish brown colour. The mean specific gravity of 48 samples is 0·8709 (equivalent to 30·7° Baumé). The oil is generally heavier at the north end of the field than at the south end, but within the productive zone of shale there is no relation between depth and specific gravity. The oil contains practically no sulphur. In the Boulder field the wells on the top of the anticline produce gas and light oil, which vary in gravity from 40·2° to 40·9° Baumé. Those farther down the limbs of the anticline produce heavier oil mixed with water.

New Mexico.—Oil and gas have not as yet been obtained in notable amounts in New Mexico. Indications of oil have been found at many localities in the State and numerous holes have been bored. Wells at Dayton in the Pecos Valley have yielded a small amount of oil, and it is claimed that oil occurred in borings near Seven Lakes, 40 miles northeast of Gallup. Indications of oil have been reported in Cretaceous rocks in San Juan, Guadalupe, Socorro, Colfax, Union, and Bernalillo counties. Very small seeps of oil occur at a point 6 miles north of Santa Rosa, but deep holes bored in that vicinity have been unsuccessful.

The oil area at Dayton appears to be restricted, for the oil-sand has only been found in a few holes close together, and the amount obtainable from the best well apparently is very small. The horizon is in the Permian sandstones included in the great succession of limestones, sandstone, and gypsum beds

[*To face p.* 240.

s.]

ek and River.[8]	Douglas.[9]	Moorcroft and Newcastle.[10]	Boulder, Colo.[11]	Florence, Colo.[12]
	White River. o.g.			
ion.	Fort Union.			
	Lance.			Laramie (?).
ls.	Fox Hills.	Fox Hills.	Fox Hills.	Trinidad (?).
	Pierre.	Pierre.	Pierre. Hygiene. o.g.	Pierre.
nan.	Parkman (?).			(o.)
ion. o.	Shannon(?). +		(o.)	
a. o.	Niobrara.	Niobrara.	Niobrara. o.	Niobrara.
	Benton. +o. g.	Carlile.	Benton. o.?	Carlile.
reek. o.	Wall Creek (?).			
		Greenhorn.		Greenhorn.
		Graneros.		Graneros.
. +	Mowry.	Mowry. o.		
	(o.?)			
	"Cloverly," o. +	Dakota. +	Dakota.	"Dakota." +

SECTIONS SHOWING OCCURRENCE OF OIL AND GAS IN SOME OF THE ROCKY MOUNTAIN FIELDS.

[Correlations approximate and sections incomplete. o., oil; g., gas; +, seeps or small production of oil or gas.]

System or Series.	Group.	Spring Valley and Labarge.[1]	Grass Creek[2] and Oregon Basin.	Shoshone River.[2]	Greybull.[3]	Basin.[4]	Lander.[5]	Wyoming.[6]	Central Wyoming.[7]	Salt Creek and Powder River.[8]	Douglas.[9]	Moorcroft and Newcastle.[10]	Boulder, Colo.[11]	Florence, Colo.[12]
									White River. +		White River. o.g.			
Tertiary.		Wasatch. +o.	Wasatch.	Wasatch.			Wind River.	Wasatch. +	Wind River. +?					
		Evanston.	Fort Union.	Fort Union.	Fort Union.	Undifferentiated Fort Union and Lance.	Absent or concealed.	Laramie. Fort Union.	Fort Union.	Fort Union.	Fort Union.			
Tertiary (?).			Lance.	Ilo (Lance).	Ilo.				Lance.	Lance.	Lance.			Laramie (?).
		Adaville.	Meeteetse.	Meeteetse.	Montana, undifferentiated.			Fox Hills.	Lewis.	Fox Hills.	Fox Hills.	Fox Hills.	Fox Hills.	Trinidad (?).
	Montana.		Mesaverde.	Gebo.	Eagle.	Mesaverde.	Mesaverde.		Mesaverde. Teapot. + Parkman.	Pierre. Parkman.	Pierre. Parkman (?).	Pierre.	Pierre. Hygiene. o.g.	Pierre. (o.)
					Pierre.			Fort Pierre.	Steele. Shannon.	Shannon. o.	Shannon(?). +		(o.)	
		Hilliard.	Cody.	Colorado.	Basin.	Cody.	Mancos.	Niobrara.	Niobrara.	Niobrara. o.	Niobrara.	Niobrara.	Niobrara. o.	Niobrara.
									Carlile.	Benton.	Benton. +o. g.	Carlile.	Benton. o.?	Carlile.
Cretaceous.		Frontier. o.	Frontier. o.		Benton.	Frontier.			Frontier.	Wall Creek. o.	Wall Creek (?).			
	Colorado.			(+) (+)	Torchlight.	Torchlight. + (+)		(+)	Wall Creek. + +			Greenhorn.		Greenhorn.
					Peay.	Peay. +g.			Peay. +			Graneros.		Graneros.
		Aspen. o.	Mowry.	(o.)	(o. g.)	Mowry. +o.	(+o.)	Fort Benton.	Mowry.	Mowry. +	Mowry.	Mowry. o.		
			Thermopolis. g.	(o.)		Thermopolis. +			Thermopolis.		(o.?)			
		Bear River. o.	Cloverly.	"Cloverly." g.	Cloverly. o. g. Greybull.	Cloverly.	Dakota.	Dakota. +	Dakota. +		"Cloverly," o. +	Dakota. +	Dakota.	"Dakota." +
							Lower Cretaceous (?).	(+)	Lower Cretaceous. Shale. Conglomerate. +	Dakota (?). +		Fuson. +.		
												Lakota.		
Cretaceous (?).		Beckwith.	Morrison.	Morrison. g.	Morrison.	Morrison.	Morrison.	Como.	Morrison. +	Morrison. +.	Morrison.	Morrison.	Morrison.	Morrison. +
Jurassic.		Twin Creek.		Sundance.			Sundance.	Shirley.	Sundance. +	Sundance. +.	Sundance.	Sundance.		
Triassic.							Chugwater. +o.	Triassic.	Chugwater. +		Chugwater.			
Permian.							Embar. o.	Permian.	Embar.				Lykins.	
Pennsylvanian.								Carboniferous.	Tensleep. +		Forelle (?). Satanka (?) Casper. +		Lyons.	
									Amsden.				Fountain.	

[1] Veatch, A. C., "Geography and Geology of a Portion of Southwestern Wyoming, with Special Reference to Coal and Oil," *U.S. Geol. Survey*, Prof. Paper 56, pp. 157–158. 1907. Schultz, A. R., "The Labarge Oilfield, Central Uinta County, Wyo.," *U.S. Geol. Survey Bull.* 340, p. 364, 1908.

[2] Hewett, D. F., "The Shoshone River Section, Wyo.," *U.S. Geol. Survey Bull.* 541, pp. 89–113, 1914, and unpublished data.

[3] Hintze, F. F., "Basin and Greybull Oil and Gas Fields," *Wyoming State Geologist's Office, Bull.* 10, p. 40, 1914 [1915].

[4] Lupton, C. T., "Oil and Gas near Basin, Big Horn County, Wyo.," *U.S. Geol. Survey Bull.* 621, pp. 157–190, 1916.

[5] Woodruff, E. G., "The Lander Oilfield, Fremont County, Wyo.," *U.S. Geol. Survey Bull.* 452, 1911.

[6] Knight, W. C., "A Preliminary Report on the Artesian Basins of Wyoming," *Wyoming Univ. Exper. Sta. Bull.* 45, 1900. Knight, W. C., and Slosson, E. E., "The Dutton, Rattlesnake, Arago, Oil Mountain, and Powder River Oilfields," *Wyoming Univ. School of Mines*, Petroleum Series, Bull. 4, 1901.

[7] Hares, C. J., "Anticlines in Central Wyoming," *U.S. Geol. Survey Bull.* 641, p. 238, 1916.

[8] Wegemann, C. H., "The Salt Creek Oilfield, Natrona County, Wyo.," *U.S. Geol. Survey Bull.* 452, pp. 37–83, 1911; "The Powder River Oilfield, Wyo.," *U.S. Geol. Survey Bull.* 471, pp. 56–75, 1912.

[9] Barnett, V. H., "The Douglas Oil and Gas Field, Converse County, Wyo.," *U.S. Geol. Survey Bull.* 541, pp. 49–88, 1914.

[10] Barnett, V. H., "The Moorcroft Oilfield and Big Muddy Dome, Wyo.," *U.S. Geol. Survey Bull.* 581, pp. 83–117, 1914. Darton, N. H., "Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains," *U.S. Geol. Survey*, Prof. Paper 32, pp. 334, 364, 379–388, 1905.

[11] Fenneman, N. M., "Geology of the Boulder District, Colo.," *U.S. Geol. Survey Bull.* 265, pp. 76–98, 1905.

[12] Washburne, C. W., "The Florence Oilfield, Colo.," *U.S. Geol. Survey Bull.* 381, pp. 517–544, 1910.

on the underground extension of the east slope of the cuesta of Sacramento mountains. Many deep wells drilled for artesian water in other parts of Pecos Valley have failed to show any indications of oil.

There are many structures favourable for oil in various parts of New Mexico, but there is no evidence that oil or gas are included in the underlying strata.

Arizona.—Petroleum has not yet been discovered in commercial quantity in Arizona, perhaps because the probably favourable regions have not been tested.

The Plateau region in northern and northwestern Arizona is not unfavourable for oil accumulation, which is attested by the fact that oil has been found under similar geologic conditions just north of the State line in Virgin River district and in the San Juan field in southern Utah. The oil in both these areas occurs in rocks of Pennsylvanian age similar in character to those widely present in northern Arizona. The structure is known to be favourable for oil accumulation in parts of northern Arizona where beds of Carboniferous age lie beneath the surface within reach of the drill.

The oil from the San Juan field in Utah is of light gravity, testing as high as 40·7° Baumé, while that from the Virgin River field is much heavier, 22·5° Baumé. In view of this wide range in gravity, predictions as to the gravity of petroleum which may be found in Arizona are unwarranted.

Utah.—Oil and gas have not yet been produced in large quantities in Utah, but indications of petroleum are known at several widely scattered areas in the eastern and southern portions of the State. The western desert and the central mountainous portions may be considered as unfavourable territory, although gas has been found in the Lake Bonneville beds surrounding Great Salt Lake.

Asphalt or tar sandstones are known at many places, namely, in Rozel Hills, north of Great Salt Lake; at Thistle, on the Denver and Rio Grande Railroad in Utah county; near Vernal and Whiterocks, Uinta county; northeast of Sunnyside, in Carbon county, and in Emery, Wayne, and Garfield counties. Oil-seeps are known in San Juan county and along the Colorado River in southeastern Utah, and oil has been discovered by drilling in the Bluff field in San Juan county and in the Virgin River field in Washington county.

Oil-shale is known to be present in the Uinta Basin, northeastern Utah, and in the Wasatch and Gunnison plateaus in central Utah. These shales contain great quantities of oil which may be recovered by distillation. Several varieties of hydrocarbons are also present in the Uinta Basin.

Indications of petroleum and related hydrocarbons in Utah range stratigraphically from the Bridger formation (Tertiary) to the Pennsylvanian, inclusive. The gilsonite and other hydrocarbons occur in Bridger, Green River, and Wasatch formations. The oil-shale is Green River in age. The Tar sandstone in the Uinta Basin and at Sunnyside is probably Wasatch in age. Indications of petroleum are reported in the Nugget sandstone (Triassic) and in the Park City formation (Permian) on the south flank of the Uinta Mountains. The Nugget sandstone in many places is highly saturated with asphaltic substances and the Park City contains cavities filled with hydrocarbons, such as asphalt, gilsonite, and related hydrocarbons.

In southeastern Utah, asphaltic saturated sandstones are reported in the Vermillion Cliff (Triassic) in Castle Valley, Emery county. Oil is reported in the Permian in the Virgin River field, several sandstones in the Goodridge (Pennsylvanian) are oil-bearing in the San Juan field, and oil-seeps are reported in the Shinarump conglomerate (Triassic) and in the Pennsylvanian in the Green River desert, Emery and Wayne counties. The only other known occurrences of petroleum in beds older than Cretaceous in southeastern Utah are several oil-seeps reported along the Colorado River, probably in rocks of Carboniferous age. From the above descriptions of the known occurrences of petroleum in eastern Utah it seems possible that the Upper Carboniferous, and in places the Triassic rocks, may yield commercial petroleum.

The structure in eastern and southern Utah is composed of several major folds, among which are the Uinta Basin (synclinal) and San Rafael Swell (anticlinal), on the flanks of which minor folds are developed that may yield petroleum.

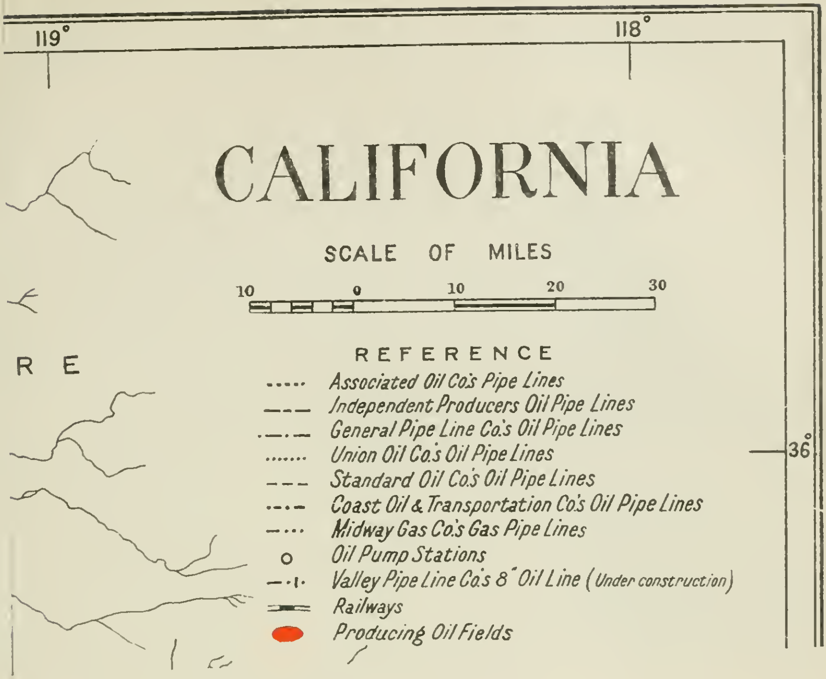
Nevada.—Eocene oil-shales averaging 10 to 50 gallons of petroleum per ton occur near Elko, Carlin, Palisade, and points in Pine Valley south of Palisade. Two plants for treating the shale in commercial quantities for petroleum were under construction early in 1919 at Elko. Solid asphaltic material, apparently a final residue of petroleum which once impregnated the beds, is present at numerous localities in Carboniferous rocks north and east of Ely.

Drilling in the Eocene shales and elsewhere in the State has not met with success.

California (Plate 13).—The productive oil-fields of California are at present confined to the southern half of the State and may in a general way be grouped into two divisions: (1) the San Joaquin Valley division, embracing the Coalinga field in Fresno county, and the Lost Hills, McKittrick, Sunset, and Kern River fields in Kern county; (2) the coastal and southern division, including the Santa Maria, Lompoc, and Summerland districts in Santa Barbara county, the Montebello, Whittier, Puente Hills, Newhall, Salt Lake, and Los Angeles City pools in Los Angeles county, the Fullerton field in Orange county, and the Santa Paula field in Ventura county, with small production in San Luis Obispo, Monterey, and Santa Clara counties. Of these the San Joaquin Valley division is far and away the more important. The fields in it are located in the foothills of the Coast Ranges and the Sierra Nevada, at the very edge of the desert valley bottom. The fields of the coastal and southern division are located on the western side of the Coast Ranges in a zone of prevailingly semi-arid climate. In general the fields in both divisions are fairly well served by railroad transportation and have pipe-line connections affording direct shipment to coast and railroad loading stations. Bakersfield is the principal town in the Valley division, while Los Angeles is the principal centre of the coastal and southern division.

Studies so far have tended to demonstrate that rocks older than Cretaceous in age are not petroliferous in California, and the same is true in the main of Cretaceous rocks. There are, however, surface indications of petroleum in the highest beds of the Upper Cretaceous at some localities in the eastern foothills of the Diablo Range, and commercial production is obtained over a small area from these beds in the Oil City field of the Coalinga district. With this exception, the production of California comes entirely from beds younger than Upper Cretaceous, and it is a noteworthy fact that oil in economic amount has been obtained only in areas where there is a sufficient thickness of shale rich in the remains of minute organisms, diatoms, and foraminifera to have furnished oil in such quantity. There are two thick diatomaceous shales in the Tertiary in San Joaquin Valley—one of Oligocene age, known variously as the Kreyenhagen or Oligocene shale, and one of Miocene age, commonly called the Monterey shale. Other less prominent zones of diatomaceous shale also occur in the Valley fields. In the coastal and southern division similar shales full of organic remains are present in the Miocene and have been referred to the Monterey in some areas, though elsewhere, especially in the older reports,

Plate 13


119°
118°
CALIFORNIA
SCALE OF MILES
10 0 10 20 30
R E
REFERENCE
Associated Oil Co's Pipe Lines
Independent Producers Oil Pipe Lines
General Pipe Line Co's Oil Pipe Lines
Union Oil Co's Oil Pipe Lines
Standard Oil Co's Oil Pipe Lines
Coast Oil & Transportation Co's Oil Pipe Lines
Midway Gas Co's Gas Pipe Lines
Oil Pump Stations
Valley Pipe Line Co's 8" Oil Line (Under construction)
Railways
Producing Oil Fields
36°

Petroleum deposits shown in red.

London: Charles Griffin & Co., Ltd.

they have been given local names. As in the Valley division, so in this division, diatomaceous shales are not wholly confined to the Miocene. Economic accumulations of oil are found under favourable structural conditions in sandstone beds either in the shale series, or associated with them. In addition to diatomaceous shale the Tertiary beds of California, which are measured in thousands of feet, embrace clays, sands, and gravels which are poorly consolidated, especially in the upper part.

Drilling in California has demonstrated that in the main oil has collected in anticlinal folds, but, on the other hand, synclinal—that is, downfolded—areas cannot be condemned on structure alone, for there are examples in California of successful production from such areas. Commercial production has also been encountered in what may be termed open anticlines—that is, folds in which the oil-bearing beds are exposed at the surface but from which oil is obtained down dip. A notable example of production from such a structure is that of the Oil City field of the Coalinga district. This field is developed on an anticline which trends obliquely to the main uplift of the Diablo Range and pitches toward the southeast into San Joaquin Valley, a type of structure typical of the Valley fields.

Surface indications of petroleum are numerous in the developed areas of California and have been directly responsible for much of the development in the State. Such indications consist of oil-springs and seeps, tar sands, brea deposits, and burned bituminous rocks. Gas emanations are rare. Oil-seeps are known in San Diego county in the southern part of the State and in Humboldt county in the northern part, but drilling in these counties has not yet developed oil in commercial quantity. In Santa Cruz county are peculiar sandstone dikes heavily impregnated with bitumen.

The gravity of California oil varies through a wide range. Some of the highest gravity oil reported is a small production from the Coalinga field which ranges between 42°–48° Baumé, though the average gravity from this field is 33° to 34° B. At the other extreme is the 10° gravity oil of the Casmalia field, Santa Barbara county, which is so viscous as to render commercial production next to impossible. In general the gravity of California oil ranges between 15° and 25° Baumé.

The production of petroleum in California has been enormous, totaling more than 1,000,000,000 barrels to the close of 1918. The first recorded yearly production was 12,000 barrels in 1876, and from that time on production had rapidly increased, especially since 1900. The maximum recorded production was that of 1918, estimated at more than 101,000,000 barrels. Though, perhaps, this will constitute the peak of production, the future of the California oil industry is assured for many years to come. It is estimated by the U.S. Geological Survey that on 1st January 1919 there was left in the ground in California an available supply of 2,250,000,000 barrels of oil.

Idaho.—Petroleum has not yet been discovered in commercial quantity in Idaho, and the chances for such a discovery appear to be small.

Indications of petroleum are known along Snake River Valley, in southeastern Oregon and western Idaho. Petroliferous sandstone (Tertiary in age) is exposed in this region and showings of oil have been reported from wells, but indications of gas are much more numerous than signs of oil. Several deep wells, showing considerable gas pressure, have been drilled, but the deepest one, 3650 feet, at Ontario, Oregon, did not reach the base of the Payette (Tertiary) formation.

The structure of the Snake River plain in Idaho is not pronounced. Broadly it is a shallow syncline with only minor irregularities.

Washington.—The western one-third of the State, comprising the Coast

Ranges and Puget Sound-Cowlitz Valley depression, is underlain by folded marine strata chiefly of Tertiary age. Oil-seeps are reported at many points, and numerous test-wells have been sunk. At one or more localities on the coast between Grays Harbor and Cape Flattery small quantities of oil and gas have been encountered, but commercial quantities have not been struck. Favourable indications have led, however, to continued prospect drilling at numerous points.

In eastern Washington numerous attempts have been made to secure oil from Tertiary freshwater strata, without notable success. Gas has been encountered in small quantities near Rattlesnake Mountain, southeast of Yakima, and is also reported near Colfax in Whitman county.

Oregon. The rocks of the Coast Ranges of western Oregon are mainly folded Tertiary and Cretaceous marine strata, similar in a general way to those of the Coast Ranges of California, in which the California oil-fields are situated, but large bodies of the Monterey shales and other organic strata to which the origin of the oil in California is usually ascribed do not appear to be present. Oil-seeps have been reported at many points, and many prospect-wells have been drilled, but no important amounts of oil or gas have been found.

The Cascade Mountains are mainly lavas, and the plateaus of eastern Oregon are underlain by similar Tertiary volcanics associated in some areas with Tertiary lacustral and terrestrial strata. In the Blue Mountains Cretaceous and older rocks are exposed. Considerable drilling has been done in the lacustral and terrestrial beds in the Malheur and John Day regions. Not more than traces of oil have been reported. Small quantities of gas have been secured in the Malheur region.

Alaska.—Petroleum seepages are known in Alaska at four localities, all on the Pacific seaboard. These, named from east to west, are Yakataga; Katalla, on Controller Bay; Iniskin Bay, on Cook Inlet; and Cold Bay, on Alaska Peninsula. A petroleum residue has been found near Smith Bay, on the Arctic coast, and seepages are reported to occur near Wainwright Inlet, about 100 miles west of this locality. At Katalla, Cold Bay, and Iniskin Bay there has been some drilling for oil, but the Katalla field is the only productive one in Alaska.

The oil on Cook Inlet is found in Jurassic rocks, and that near Yakataga oozes from marine beds of Miocene age, in which it may or may not be indigenous.

The Katalla field is marked by a series of seepages and gas springs distributed through an eastward-trending belt about 25 miles long and from 4 to 8 miles wide. This zone skirts the north shore of Controller Bay. To the east it extends into the alluvial flats of Bering River, and to the west into the flats of Copper River. An oil seepage has been reported still farther west, on Hinchinbrook Island, but this occurrence has not been verified. The field lies in part on the southern slope of a densely timbered highland, whose summits reach 1200 to 2000 feet above the sea, and in part on the flats adjacent to the shore line. Drilling has been done at several localities in this belt, but the productive wells are limited to that part of it lying between the town of Katalla and Bering River. In all about 26 holes have been drilled in the Katalla field, of which at least a dozen have struck some oil. The deepest well is about 1600 feet deep, but the geology of the field is so complex that the actual depth is not significant of the position of an oil-pool. Some natural gas was encountered in the drilling.

The surface rocks are a series of intensely folded and faulted shales, sandstones, and conglomerates, with some small basalt or diabase dykes and sills. The general structural trend is about N. 20° E., and the line of seepages lies

Petroleum deposits shown in red

London · Charles Griffin & Co Ltd

Stanford's Geog^l Estab^t London

diagonal to this trend. As much of the field is masked with a dense growth of vegetation, details are lacking on the minor features of structure. Certain seepages or groups of seepages are closely associated with faults or with subordinate anticlines. No definite law of association of the petroleum with tectonic features, however, has yet been established. West of Katalla, seepages belonging to the same belt have been found in surface rocks of more or less metamorphosed graywackes and slates.

The shale, sandstone, and conglomerate series is of Tertiary age and probably older than the Tertiary Coal-measures of the Bering River field, which lies about 25 miles to the northeast. All these Tertiary beds are undoubtedly younger than the metamorphosed graywackes and slates, which may be of Mesozoic or Palæozoic age.

MEXICO. (Plate 14.)

Petroleum is stated to occur in abundance in Lower California, chiefly on the eastern shore and on Carmen Island. The States of Durango and Chihuahua are vaguely reported to possess evidence of the presence of petroleum, presumably in insignificant amount. Springs of oil and deposits of asphalt occur on Lake Chapala in Jalisco. In the Guadalupe suburb of the city of Mexico, films of oil rise on a spring flowing from volcanic rocks, and 3 litres a day is sold for external application, a trade fully two hundred years old. A diatomaceous earth, charged with petroleum, occurs at Salitre de Mendez in Toluca. Petroleum and asphalt occur in the vicinity of Huauchinango in Puebla, probably a continuation of the Vera Cruz deposits presently to be referred to. The deposits of Real del Monte in Hidalgo ; of Matamoros, Azucar, Chiautla, and Acatlan in Puebla ; of Tlaxcala ; of Tlaquitenango in Morelos ; and of Huetamo and Otzumatlan in Michoacan, described as "carbon-mineral," are presumably asphaltic matter. Highly bituminous shales, yielding on distillation a thick brown offensive oil, occur a short distance west of Tlaxiaco in Oaxaca. These are shown by their abundant fossils to be of Middle Neocomian age. Near Port Angel and Pochutal, in the same State, a light oil is found in dug wells of about 100 feet deep. There is, however, little probability of a yield of commercial value, as the district consists of granite-gneiss, granulite, quartzite, marble, and other rocks, of probably Archæan age, covered by sandy and loamy matter, partly derived directly from disintegration *in situ* of the subjacent rocks, partly rearranged as river- and lagoon-deposits. These appear to have been locally saturated with oily hydrocarbons from the decomposition of organic matter in the lagoons.

Immense quantities of asphalt, known as chapopote by the "Indians," occur mingled with petroleum in most of the eastern States of Mexico, and these have led to extensive and successful drilling operations. In Tamaulipas and northwestern Vera Cruz, the beds in the neighbourhood of the surface deposits of asphalt are found to be grey Cretaceous shales, or Tertiary sandstones, often pierced by volcanic rocks and dykes. The borings have passed through some two or three thousand feet of these beds before encountering the main producing horizon in the dolomitised Neocomian limestone. In the Tuxpam canton some production has also been obtained at shallow depth in the Tertiary sandstones. Recent developments include large productions in the Tamesi and Panuco River basins, at Ebano, Topial, and elsewhere ; at San Diego de la Mar, on the Tamiahua lagoon, what was probably the largest production ever recorded came from the Neocomian limestone, although unfortunately the whole was lost by fire. Further south in the Buenavista valley, a tributary of the Tuxpam, a production of 60,000 barrels a day has been obtained from a well drilled to the main limestone. The surface shows extend southward into the valley of the Tecolutla and its tributaries, and a considerable yield has been obtained from the wells at Furbero, west of Papantla, also drilled through the Cretaceous shales into Neocomian limestone. The asphalt and oil of Jalacingo, being on the southeastward extension of these beds, are probably of like geological source. Petroleum, accompanied with gas, is said to flow from Cretaceous limestones some 30 miles southward of the port of Alvarado, in southern Vera Cruz. Eastward of this, the wide Tertiary basin of the San Juan, Coatzacoalcos, and Tanchoapam rivers has surface-exudations of asphaltic oil along several well-marked lines at Sayultepec, Jaltipan, Trujillo, Ixhuatlan, Moloacan, Los Changos, San Cristobal, Pajapa, Sayula, Medias Aguas, etc. Several fields have been developed in the Isthmus of Tehuantepec, the conditions of occurrence approximating closely to those met with along the coast of Texas. The chief productive horizon is a dolomitic limestone associated with large masses of gypsum and rock-salt.

Petroleum is obtained from Tertiary beds in the districts of Macuspana in Tabasco, and Pichucalco in Chiapas, and extensive beds of asphalt are reported to exist on the upper course of the Grijalva, in Chiapas, probably in the Cretaceous rocks there predominant. Oil is alleged to occur also in Yucatan.

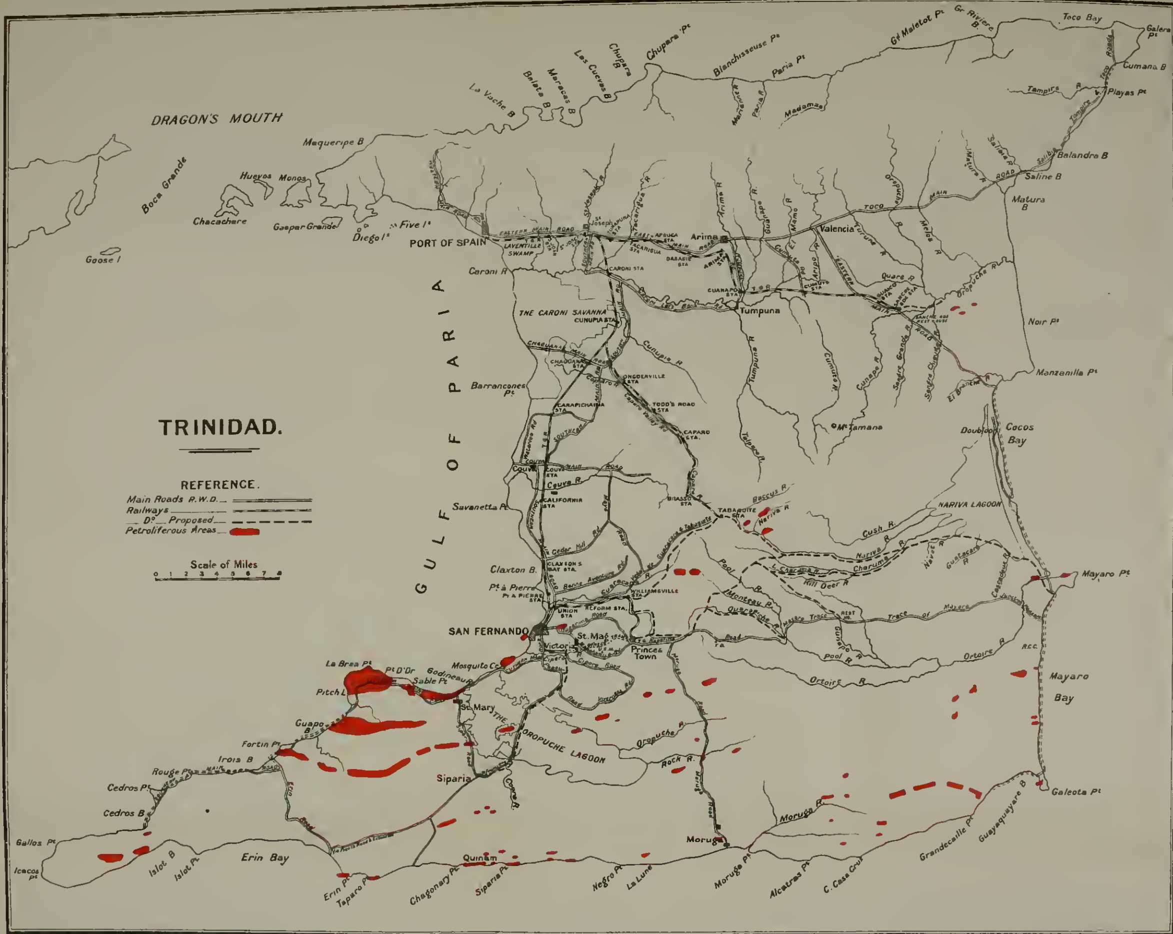
HONDURAS.

In the Republic of Honduras, indications of petroleum are reported in limestone (presumably of Neocomian age) near Comayagua, in the Guare mountains.

WEST INDIES.

Cuba. Indications of petroleum exist in every province of the island of Cuba, the product occurring principally in the desiccated form of asphalt or chapopote. The deposits are found either in, or in close proximity to, serpentine and syenite masses, which occur at many points in the island, but it is probable that the oil is merely the product of distillation and absorption from bituminous beds traversed by these intrusive rocks.

The most westerly occurrences are found near Bahia Honda, in Pinar del Rio province, where the serpentine massif is succeeded northwards by Eocene deposits. Asphalt is quarried in the vicinity of Mariel, the deposits being in some cases more than 50 feet in thickness, while similar beds also occur near Banes. In the province of Havana, chapopote is found occupying fissures in the metamorphic and magnesian rocks at various points in the neighbourhood of the capital, but the substance is now mined in only one locality, about 5 miles from Bejucal, where it occurs in Cretaceous limestone, whilst at Campo Florida, fluid asphalt oozes from the joint-planes of syenite, and the solid mineral occurs at the junction of Cretaceous marl and serpentine. Similarly in the province of Matanzas, it occurs at the junction of serpentine and limestone, some 9 miles northwest of the capital, and extensive deposits occur on the shores and beneath the waters of Cardenas Bay, extending for many miles. The asphalt is sufficiently brittle to be broken by pointed bars, suspended from lighters, and the fragments are collected by divers into scoop nets. In the Lagunillas district, some 9 miles southwestward of Cardenas, petroleum is found in small quantity, and asphalt occurs in serpentine some 20 miles eastward of this, whilst shales impregnated with bitumen are recorded nearer the coast. A small yield of oil and gas has been obtained in the west of Santa



Petroleum deposits shown in red.

London: Charles Griffin & Co. Ltd.

Stanford's Geog' Estab', London

Clara province, about 8 miles north of San José de los Ramos, the wells being sunk in beds chiefly of volcanic origin, though the supply of both products appears to come from the serpentine rocks below. Springs of fluid asphalt occur in serpentine about 15 miles northwest of the capital, and solid deposits on the Sagua River near Ranchuelo, and again about 30 miles from Sagua la Grande southwestwards. At Camajuani, 18 miles eastward of Santa Clara, is another asphalt flow, and again far to the southeast on the province border near Santo Esperito, and northward of this near Mayajigua. In Puerto Principe, the continuation of the last-mentioned deposit occurs across the Jatibonico in the Moron district, whilst in Santiago the only spot described is about 8 miles southward of Puerto Padre, though fluid asphalt is reported as found between Holguin and Mayari. Rumours of the occurrence of oil near Manzanillo, Guisa, Guantanamo, and other points in Santiago are as yet unconfirmed.

Hayti.—Indications of petroleum have been met with in two localities in this island, namely, at a point 3 miles north of Azua, where a heavy oil rises on a small stream, and further east, on the coast near San Cristobal, 10 to 15 miles west of the town of Santo Domingo. Recent successful operations here have been mentioned in the previous section (p. 140). The productive rocks are of Cretaceous age.

Porto Rico.—Exudations of petroleum are said to occur at several points on this island, possibly derived from the beds of bituminous lignite which are found in the Tertiary beds at the southwest corner of the island.

Barbados.—The petroleum-deposits of Barbados are almost entirely confined to the Scotland district, on the eastern side of the island, the petroliferous rocks being a series of Miocene sandstones and shales, known locally as the Scotland beds. The most northerly occurrence is that of the Morgan-Lewis estate, about 1½ miles north of St. Andrews, where shallow wells have yielded a small quantity of petroleum, as is also the case in the Turner's Hall Wood estate, about 3 miles to the southwest. Tarry Gully, a short distance south of the latter, derives its name from the quantities of petroleum-saturated earth found here. Oil is also produced in the Baxters district from shallow wells, and on the Friendship and Groves estates, a short distance to the southwest. On the latter, a large quantity of " manjak " or desiccated tar occurs at about 4 feet from the surface. A little heavy oil has been obtained on Barrow Gully, about three-quarters of a mile further south, while manjak and oil occur at Springfield, in the Lloyd oil-wells on the coast, and at St. Joseph, further inland. Manjak is also found at Burnt Hill on Conset Bay, some distance to the south, outside the Scotland district, in shales of like age.

Grenada.—Oil is said to rise in the sea round this extinct volcano, probably the result of distillation by volcanic agency from deep-seated bituminous deposits.

Trinidad (Plate 15).—Mr. E. H. Cunningham Craig has contributed the following account :—

Petroleum occurs throughout some 600 square miles in the southern half of the island of Trinidad.

Three main oil-bearing horizons have been detected, and these are known as :—

The La Brea Oil-bearing Group—Upper Miocene or Pliocene.

The Rio Blanco Oil-bearing Group—Miocene.

The Galeota Oil-bearing Group—Eocene.

The uppermost is confined to a small area on and near the western coast. It has yielded oil, in large quantity, but of high specific gravity and sulphurous.

The Rio Blanco Group has yielded the bulk of the oil so far won in Trinidad. It occurs some 1600 feet below the La Brea Group, and yields an asphaltic oil, which varies considerably—in quality—in different districts. In some localities the group is carbonaceous, containing lignite seams and no oil.

The Galeota Group, some 3500 to 4000 feet below the Rio Blanco Group, is exposed along the southern anticline near the southern coast, and at Mayaro Point, on the eastern coast. It yields an asphaltic oil of fairly high grade.

There are other oil-bearing horizons of less importance as regards yield of oil, but which produce valuable light oils of paraffin base.

Descriptions of the various oil-fields are given in Reports by the Government Geologist, published as Council Papers in the years 1904–1907.

Mr. A. Beeby Thompson has furnished the following additional particulars :—

Petroleum manifestations are displayed on an unusual scale along the crests of some of the main flexures that persist for long distances in a general E.-W. direction. Important oil-fields have been developed on the succession of Tertiary folds prevailing between the Pitch Lake at La Brea and Point Fortin. Around the Pitch Lake itself many highly productive wells have been drilled, whilst a few miles inland, in the Forest Reserve area, extraordinarily prolific wells have been struck at a number of localities. All the oils from this area are of the heavy black asphaltic type, but in the Guayaguayare area fair producers of lighter oils were struck. In the Tabaquite district an interesting field has been opened in Cretaceous beds where oils of exceptionally light density have been uniformly obtained from sandstones embedded in black shales.

The Tertiary oils are mostly secreted in friable sands amidst a succession of soft clay shales ; consequently great quantities of sand are usually expelled with the oil when new sources are penetrated. Cretaceous oils are drawn from consolidated sandstones which do not disintegrate to any extent on the expulsion of their contents.

Northeast of San Fernando, commercially important deposits of manjak have been mined. The mineral forms large veins in the compact clays of the region. Manjak is also found in the Williamsville district.

Westwards to Point La Brea, the Upper Miocene beds contain asphalt in considerable quantities, and liquid petroleum issues from this series near the famous Pitch Lake. This has been thought to be the largest and most important deposit of solid or semi-solid bitumen known, but is said to be far exceeded in area, though not in depth, by one in Venezuela. It has an area of 134 acres, and is found to be sufficiently firm in places to support a team of horses. The deposit is worked with picks to a depth of a foot or two, and the excavations soon become filled up by the plastic material rising from below and hardening. The depth of the deposit is not accurately known, and in pits dug some little distance from the edge of the lake the flow of bitumen has been found too great for the depth to exceed 12 feet. The surface is not level, but is composed of irregularly tumescent masses of various sizes, each said to be subject to independent motion, whereby the interior of each rises and flows centrifugally towards the edges. As the spaces between these separate masses are apparently filled with water, they are prevented from coalescing. The softer parts of the lake constantly evolve gas, which is stated to consist largely of carbon dioxide and sulphuretted hydrogen, and the pitch, which is always found honeycombed with gas-cavities, continues to exhibit this action for some time after its removal from the lake. Springs of petroleum rise in the sea westward of the lake, and asphaltic deposits are found in many places along the shore, as far as Point Guapo, which is partly composed of highly bituminous Miocene sandstones. Similar rock occurs on Irois Bay and in the Erin district on the southern shore of the island. The name parianite has been somewhat unnecessarily assigned to the Trinidad pitch.

SOUTH AMERICA. (Plate 16.)

Guiana.—A work of the eighteenth century refers to the bitumen of Surinam. Considerable deposits of asphalt are known to exist in the Wainé River district of British Guiana, but their origin and association with true petroleum deposits remains to be proved. Shallow wells failed to disclose any information of value. In the Essequibo delta natural gas has been observed in borings, but may be associated with modern deltaic deposits rich in organic matter. Finds of asphalt have been reported on the coast. In Dutch Guiana (Surinam) exudations of amber-coloured oil are reported on the Surinam River, six miles from Kabele. Seepages of oil are said to exist on the Marowijne River some 100 miles from Albina. Similar manifestations of oil continue into French Guiana southeast of the Marowijne River deposits of Dutch Guiana (*A. Beeby Thompson*).

Venezuela.—A large part of Venezuela is rich in asphalt, and the deposits have recently received scientific investigation. The Miocene series seems to be the origin of many of the indications, but the Cerro de Oro (possibly Cretaceo-Tertiary) system is important as a petroliferous group.

An oil-spring exists at the mouth of the Orinoco, and others are vaguely reported in the Delta ; asphalt-deposits and mud-volcanos occur on the islands of Pedernales, Pesquero, and St. Clair. The " Bermudez " asphalt lake lies on the north bank of the Guanoco River, near the mouth of the Cano San Juan, and other indications of petroleum occur on the lower part of the Guanipa. Mud-volcanos and other indications of petroleum are found in the neighbourhood of Maturin on the Llanos. Petroleum also exudes at various points to the north ; near Manicuare, opposite Cumana, on the island of Cubagua, and in Margarita : an asphalt deposit is vaguely reported near Puerto Cabello. The States of Falcon and Zulia are rich in asphalt and petroleum, and the Andine States of Trujillo, Merida, and Tachira have large stores of oil and asphalt.

Colombia.—The sedimentary rocks of Colombia correspond closely with those of Venezuela, but occurrences of petroleum seem to be limited to beds older than the Eocene. Deposits of asphalt, and emissions of oil and gas, probably from the Guadas Beds (equivalent to the Cerro de Oro system of Venezuela), are more or less continuous from the mouth of the Magdalena to the Gulf of Darien, ranging inland for several miles. Large mud-volcanos and pools of oil have been described by Humboldt and later explorers of this singularly rich region. Southward, Cretaceous and Neocomian rocks provide oil shows at very many points in the Magdalena valley, and in the eastern cordillera of the Andes. There are asphalt deposits and petroleum springs near Simiti, in the department of Bolivar near the left bank of the Magdalena, and on the tributaries of the opposite side ; the latter extend southward into the department of Santander, and near Pamplona on the Venezuelan frontier, a small local industry has long existed in the illuminating oil of the Villeta Beds (Cretaceous). Higher up the Magdalena valley, in the departments of Cundinamarca and Tolima, there are many occurrences of petroleum, most noteworthy of which seem to be the extensive deposits of asphalt near Chaparral, on the Saldano tributary. Springs of oil are also reported to exist at more than one point on the edge of the San Martin and Casanare Llanos.

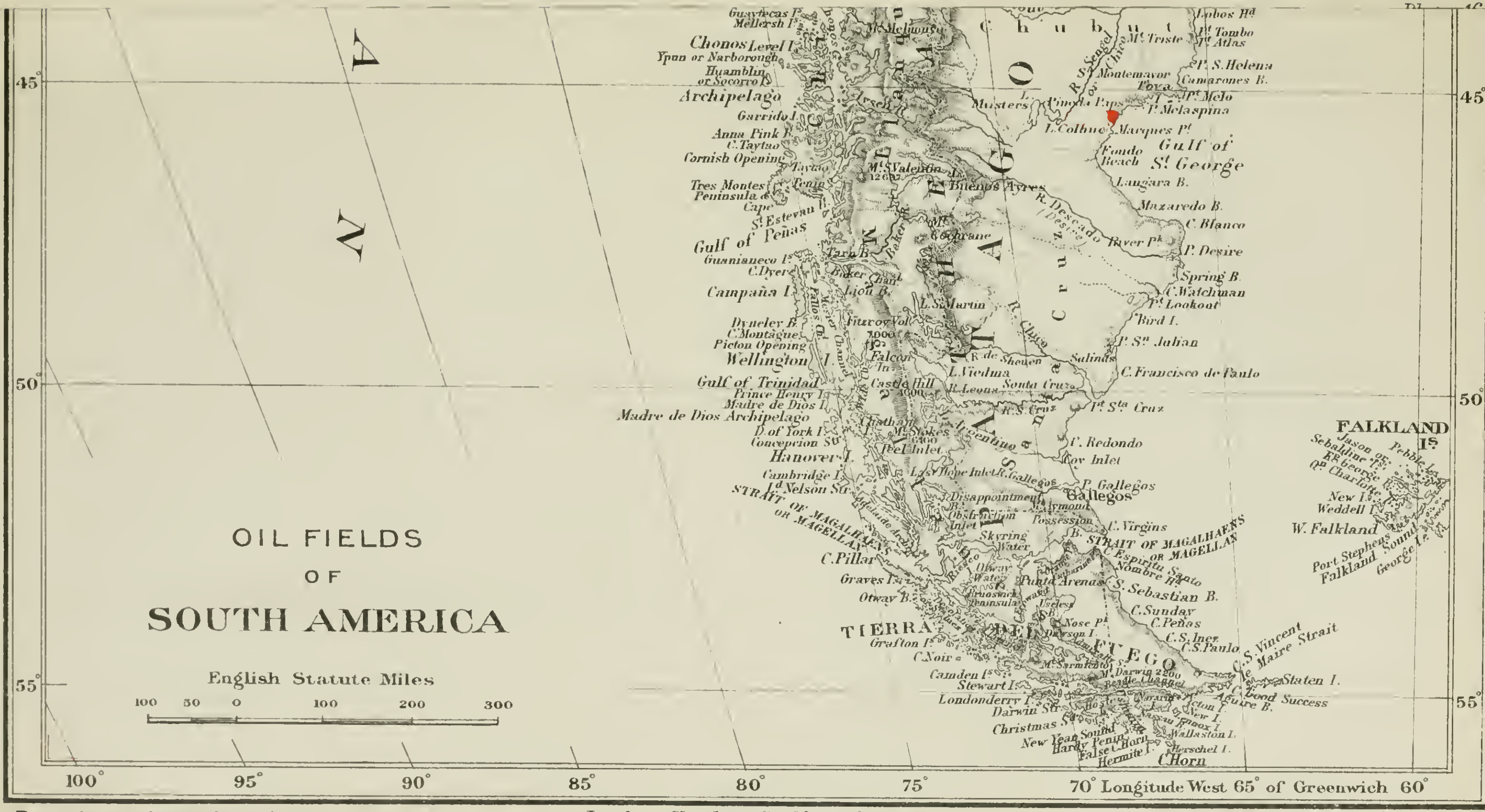
Ecuador.—The oil-fields of Santa Elena lie between 50 and 80 miles westward of the port of Guayaquil. The principal surface indications occur at San Raimondo, on the coast; at Santa Paula, about 3 miles inland, and at Achagian, 2 miles northeast of Santa Paula; but traces exist for 30 miles eastward of Point Santa Elena, and southward to Puna Island. Oil is said to exude from dioritic rocks a day's journey northward of Quito, and on the east flank of the Andes an oil-spring is reported as found on the southern side of the Pastazza River, about 130 miles east-by-north of Guayaquil. Asphalt is raised on the Cojitambo hill, some 13 miles northeastward of Cuenca.

Peru.—According to Mr. A. Beeby Thompson, the Negritos-Lobitos oil-fields yield oil from lenticular bodies of consolidated sands and grits enclosed in bodies of sandy shale. Although the productive series is well exposed as a more or less uniformly dipping group only occasionally do the sandstones betray obvious evidence of petroleum. At Salinas, La Brea, and a few other localities mud-volcanos and petroleum exudations have guided the search of geologists, but elsewhere drilling alone has disclosed the areas of enrichment. Strike-faulting has caused the repetition of the sequence at intervals, and a somewhat complicated system of oblique faulting has isolated areas or caused differential movements that profoundly modify the depths of wells and economic results in neighbouring sections. The oil occurs in beds of Tertiary age (Eocene) unconformably overlying metamorphosed Cretaceous or Jurassic rocks and unconformably overlain by successive late Tertiary and often highly-calcareous raised beaches little disturbed from the horizontal.

Asphaltic limestone occurs north of Balza, and near Quemia, Cocabamba district, Luya province. Petroleum saturates limestone in the Huallanca region at Huacota, Huagta-huaru, Huata-guaro, and Colpa, and elaterite is associated with the cinnabar at the Chonta mines. Cerro di Pasco, again, shows traces of oil in several places, and asphalt forms dykes traversing the limestone of Huari and Soaro, Tamra province. Occurrences of petroleum are reported in the Angascaca ravine of Mito, Jauja province, and in the Sacsamarca ravine of Huancavelica, whilst La Brea in the Chumpi district, Parinacochas province, has an oil-spring of some dimensions, and an oil-field has recently been developed between Pusi and Arapa, in the Huancane province, northeast of Lake Titicaca.

Bolivia.—Significant and extended indications of petroleum have been located in the long stretch of Eastern Andean foot-hill country between the Argentine frontier near Yacuiba to beyond Buena Vista or even Santa Cruz. Numerous seepages of high-grade sweet oils occur amidst strata of Tertiary, Secondary, and Devonian age, often where important tectonic dislocations have facilitated the egress of contained hydrocarbons. The oil is thought to originate in rocks of Devonian age amidst a succession of black bituminous shales and micaceous sandstones. Naturally somewhat involved structures characterised this area, but on the large scale great strike-faults cause the sequence to be repeated, each such upthrust representing one of the ranges. Anticlinal structures exist, but the unyielding nature of many of the beds has prevented the formation of simple folds and generally led to the creation of faults and overthrusts. Most of the seepage oils have a density between ·790 and ·880, and in two shallow wells sunk on favourable flexures at Charaguas and Sararenda small quantities of similar grade oil were struck (*A. Beeby Thompson*).

Chile.—Petroleum has been met with in northern Chile, in the province of Tarapaca, south of Patillos. In the southern part of the republic an extensive area southward of the Maullin River is said to have indications of natural gas



Petroleum deposits shown in red

London: Charles Griffin & Co., Ltd.

Stanford's Geog[l] Estab[t], London.

Petroleum deposits shown in red

from Tertiary deposits. Oil is also reported to have been met with at Puerto Porvenir and Agua Fresca in the Magallanes Territory.

Argentina.—The Argentine provinces of Salta and Jujuy have large areas of petroliferous Neocomian rocks, chiefly dolomites and conglomerates. Oil and asphalt exude from these at Yavi Chico, on the Bolivian frontier, at 65° 30′ W.; Tejada, 60 miles south of this; Abra de la Cruz, 29 miles eastward of Tejada; Garrapatal, 21 miles east-northeast of Jujuy; Laguna de la Brea, 42 miles further in the same direction; Cerro de Calilegua, 30 miles northwest of the last; and Tartagal, on the frontier at 63° 44′ W. Near the Chilian frontier petroleum and asphalt have been produced by natural distillation in shales of the Rhætic series, extending for nearly 300 miles along the Andean slope, from about 40 miles north of Mendoza to the Neuquen district. In the Cacheuta mines, a few miles south of Mendoza, oil occurs in the veins of seleindes of silver, copper, etc., and also at the Chalahuen copper mines, Neuquen. There are said to be petroleum springs rising in the Barrancas valley in the latter province. Eastward of this belt, the Lower Jurassic limestones of the upper part of the Salado River (about 35° south latitude and 70° west longitude) are charged with oil, and veins of asphalt traverse the Cretaceous beds of the Sierra de Loncoche, 20 miles southward.

The oil of Comodoro Rivadavia in the Chubut Territory is apparently derived from Upper Cretaceous rocks.

Brazil.—A barrel of a mineral resembling ozokerite reached Italy from Rio de Janeiro about 1850, but no record is preserved of its place of origin, presumably Brazilian. The recorded outburst of inflammable gas from the gneissose rocks of the Morro Velho gold-mine, Minas Geraes, is a further instance, analogous to several already mentioned, of the appearance of hydrocarbons in anomalous, or at least unexplained, positions, although here it is just conceivable that there has occurred some infiltration from an inland extension of the deposit next to be described, furnishing organic material to be subsequently reduced, by hydrothermal metamorphism, to simple carburetted hydrogen. Impure bitumen exists at Morro do Taio, Santa Catharina, and at Piropora in São Paulo, probably in outlying portions of the great belt of bituminous shales of Eocene age that extends intermittently from Porto Alegre along the coast to near the mouth of the Amazon, a range of 18 degrees of latitude. The granite and other ancient rocks against which the system abuts landwards reach the coast in occasional spurs, between which the Tertiary deposits occupy bays of 20 to 50 miles in depth. Oil-shales suitable for distillation, and locally termed turfa, probably occur more or less throughout this vast area, but have been specially noticed at the following points. On the River Itahipe, northward of Ilheos, turfa deposits occur near the spur of crystalline rocks that here reaches the coast. The island of Joas Thania on the Marahu River, about 80 miles southward of Bahia, has rich turfa, and traces of petroleum have been noticed in dioritic intrusions through the shales, further up the river. Fifty miles northward of this, turfa of good quality is found on Tinhare Island. The next notable areas are in Alagoas, at Riachadoce and Camarajibe, respectively 25 and 45 miles north of Maceio. On the Parahyba del Norte, petroleum is alleged to occur below São Paulo, at Jesus de Tremembe, and oil-shales in the Sierra de Araripe, Ceara.

AFRICA.

The oil-bearing regions of Algeria, Tunis, and Egypt have already been dealt with (pp. 184–186) in connection with the European areas of which they constitute outlying portions.

West Africa.—The occurrence of oil in the sea off Cape de Verde Islands is probably due to bitumen in the deep-seated beds traversed by the volcanic rocks which compose the group, and the reported indications in Madeira have presumably a similar origin. Petroleum occurs in considerable quantity in the Cretaceous sandstones, shales, and limestones clinging, as isolated patches of varied extent, to the western flanks of the ancient crystalline massif which forms the bulk of the African continent. A vaguely-reported discovery of oil in the little Portuguese territory of Guiné, southward of Senegambia, probably belongs to this category, as do two separated petroliferous areas on the Gold Coast, viz. at Tachinta in the Apollonia district, and Commenda in Elmina, respectively 60 miles westward of Axim and 26 miles eastward of Sekondi, both covering several miles in length, and extending well inland. The extensive deposits of mineral pitch in the Ijebu district of Southern Nigeria have led to prospecting with the drill, and oils of both asphalt- and paraffin-base have been found. Petroleum is reported as found on the equatorial island of St. Thomas (a volcanic mass), also on the Mongo and Wuri rivers in the Cameroons, in the Fernand Vaz district of French Congo, and further inland on the Nguni and Ogowai rivers. The oil and bitumen of Dande and Libollo, in Angola, are of Cretaceous age, which is probably the case with those east of Mucula, and of the Congo region generally.

Cape Colony.—Traces of petroleum occur in the Calvinia, Fraserburg, Carnarvon, Hanover, and Barkly East districts, where igneous dykes have traversed bituminous beds of Triassic age, and absorbed the petroleum distilled by their heat from the surrounding strata. The supposed existence of oil in the Bokkeveldt (Ceres district) is an error, though small discharges of marsh-gas are recorded. Presumably the same is the case with like reports as to Mossel Bay. Both areas consist of Lower Palæozoic rocks. In the Karroo, again, the announcements of oil-discoveries are, in all probability, based on similar phenomena to those of Carnarvon, etc.

Orange Free State.—Ozokerite is stated to occur on the Vaal near Christiania, and reports of petroleum come from Boshof, Ladybrand, Ficksburg, Harrismith, Bethlehem, Lindley, and Heilbron, and of gas from near Kroonstad. All are due to similar igneous action on feebly-bituminous shales.

Transvaal.—Traces of oil are reported about 60 miles northwestward of Potchefstroom, and bituminous shales, of Lower Mesozoic age, occupy a wide area in the Wakkerstroom, Piet Retief, and Ermelo districts, extending to some 28 miles eastward of Middelburg, but the frequent indications of petroleum are almost invariably in the vicinity of dykes or sheets of igneous rock, if not actually exuding from such intrusive masses.

Rhodesia.—There are said to be traces of petroleum near the confluence of the Umzingwani and Limpopo rivers.

Portuguese East Africa.—The occurrence of a recent vegetable substance on the shores of Lake N'hangella, inland of Inhambane, led to the report of a valuable deposit of elaterite, and later to boring for petroleum, but no true bitumens are known to occur in the district.

Somaliland.—Oil-impregnated strata of probable lower Jurassic age occur about 10 miles east of Bihendula, some 30 miles inland from Berbera, where, in shallow shafts. light-density oils of a paraffin base are obtained in sandstones dispersed amidst a red clay series. Oil indications are also reported from Eg Malah district some 70 miles S.E. of Berbera (*A. Beeby Thompson*).

Madagascar.—Petroleum is reported on the western side of Madagascar, on the Ankavandra coast, consisting of Eocene deposits, and also in the valleys of the Ranobe and Manambolo rivers, and their tributaries rising in the Bemaraha range, the rocks of which are of various Mesozoic horizons. A petroleum-spring is alleged to exist north of the Betafo volcano, one of the newer series, and not long extinct. As the surrounding region consists of crystalline schists, granites, and earlier volcanic rocks, the report requires confirmation. The Jurassic coal-field of Ambavatoby, on the northwest coast, yields some small oil-springs.

AUSTRALIA.

West Australia.—Oil is reported as found on the coast of the southwestern corner of this State, near the mouths of the Warren and Donnelly rivers, between Cape Leeuwin and Point d'Entrecasteaux, whilst for some miles inland the Permo-Carboniferous shales and sandstones are more or less charged with petroleum, especially on Fly Brook and Lake Jasper, and with asphalt on the Fitzgerald. Large pieces of bitumen are cast up on the coast after storms.

South Australia.—Petroleum occurs in the Miocene shales of Leigh's Creek (on the railway at 31° S.), and on the Gawler between Kapunda and Adelaide. On the Coorong, a lagoon extending some miles along Encounter Bay, there exist deposits of an elastic bitumen (which has been termed coorongite), raising expectations of the discovery of petroleum in an unaltered condition. There appears to be sufficient reason for suspecting this to be a recent vegetable substance, but, as a fact, small quantities of oil and gas have been found by boring on Salt Creek near Meningie at the mouth of the Murray, and at Bordertown. Similar beds are said to yield oil at Ethel's Cove near Normanville; at D'Estre Bay; in the interior of Kangaroo Island; and on the coast of Kongorong. In the northern territory, kerosene shale has been found on the coast near Cape Wilberforce.

Tasmania.—Kerosene shale occurs in the Carboniferous of the northwest part of this State, some miles up the Inglis valley, inland of Table Cape. Oil-shales of similar age, occurring from the Don valley, past the Mersey River to the Tamar estuary on the east, are utilised for the production by distillation of kerosene and lubricating oils.

Victoria.—Bitumen occurs in the Miocene of Portland and in the Pliocene of Western Port, while the Permo-Carboniferous is petroliferous on Coal Creek, and near Traralgon on a small tributary of the Latrobe River. Highly bituminous shale or albertite occurs in the same series near Cape Patterson, and exudations of oil are found near Bridgewater, about 100 miles north-northwest of Melbourne.

New South Wales.—Petroliferous deposits, in the form of Tertiary lignite saturated with hydrocarbons, occur on the coast northward of Cape Howe, at Twofold Bay and Boonda, and inland at Kiandra. A white mineral wax of kindred origin occurs on the coast about 40 miles north of Boonda. Kerosene-shale is extensively mined at various points in the east of this State, in a somewhat sinuous belt extending from Clyde, near Jervis Bay, northward by Joadja, Hartley Vale, Ilford, and Barigan to Ulan, along the western outcrop of the Productive Coal-measures, whilst on the corresponding eastward outcrop, kerosene shale is mined near Murrurundi and Greta. The shale has been termed torbanite and wollongongite, but, besides being needless, both names are open to the graver objection of erroneous connotation. The Torbane-Hill mineral is not identical with that of New South Wales, and the specimen described by Professor Silliman under the second name came from Hartley, the kerosene-shale of Wollongong being of somewhat different nature. Ozokerite occurs at Coolah, and bitumen oozes from the sandstones of Coonabarabran, respectively 150 and 190 miles northwestward of Newcastle. Elaterite is found with the kerosene-shale of Reedy Creek, southeastward of Wallerawang, and gas has been obtained at Narrabeen, near Sydney. In the northeast of the State gas has also been obtained in considerable quantity at Grafton from rocks of Triassic age.

Queensland.—Kerosene-shales, apparently similar to those dealt with above, are found on Widgee Creek, on the northern flank of the McPherson range, separating this State from New South Wales. Boring in the Triassic rocks of Roma secured a repetition of the Grafton gas-well. The Tertiary basin of the Dawson River has oil-shales on the Central Railway between Duaringa and Wallaroo.

NEW GUINEA.

Papua.—The following statements are taken from a report by Dr. Wade,[1] who carried out a geological survey of the region for the Government of the Commonwealth of Australia in 1913–14:—

"The Upoia beds which characterise the whole area between the Vailala and the Purari are chiefly argillaceous in character, with sandstones and thin unfossiliferous limestones as subordinate features. It is this series which carries the chief evidences of petroleum. The beds are probably Miocene in age, and may even extend downwards into the older Tertiaries."

NEW CALEDONIA.

Traces of petroleum occur in thermal springs (30° C.) at Koumac on the northwest coast, between Tonnerre Point and Cape Dewerd. These springs rise in magnesian schists of Silurian age, traversed by intrusive masses of serpentine and diorite, and the oily matter is due to decomposition of recent organisms, abundant in the tepid water.

NEW ZEALAND.

Oil-shales of Cretaceo-Tertiary age occur at Awatere, near Mongonui, and Waimate, Bay of Islands, Auckland. The Cretaceous series, but of a lower horizon, is also the productive rock, though not richly charged with oil, in a belt extending southwestward from East Cape for a length of at least 90 miles. Petroleum rises from the sea-bed off Horoera Point, westward of East Cape, and at many points on the inland course indicated. Operations have been confined chiefly to the vicinity of the Waiapu and Waiporoa rivers, the latter region being sometimes called the Poverty Bay district, though over 20 miles inland from the mouth of the River Waikohu, of which the Waiporoa is a tributary. The most distant point on the belt at which indications are recorded seems to be about 25 miles west-northwest of Gisborne. Dopplerite and elaterite occur in places as results of evaporation and oxidation of the exuded oil. In Wellington emanations of carburetted hydrogen take place from the Cretaceous rocks of Blairlogie, Langdale, Ika, Aohanga, and Akitio, in Wairarapa North county. The New Plymouth oil-field in Taranaki consists of clays of Pliocene age, largely intermixed with volcanic detritus in the upper part, and with occasional beds of sand and conglomerate below. Inland, over a large area of Miocene rocks, extending past Egmont and Inglewood, evidences of the presence of petroleum are found in the contamination of water-wells, etc.

In the South Island, petroleum is found at Lake Brunner in Westland in the Lower Tertiary series; and oil-shales at D'Urville Island in Marlborough, and at Blueskin, Kaikorai, Waikaia, and Orepuki in Otago. Similar material is also reported from the Chatham Islands.

[1] *Report on Petroleum in Papua*, by Arthur Wade, D.Sc., 1914.

SECTION III.

THE PHYSICAL AND CHEMICAL PROPERTIES OF PETROLEUM AND NATURAL GAS.

Early Views as to the Nature of Petroleum.—Although our information respecting the chemical composition of petroleum has been almost entirely gained within the last sixty or seventy years, a considerable amount of empirical knowledge of the substance was possessed by chemists at an earlier date, and there was much speculation as to its origin. In his *Sylva Sylvarum* (1627), Francis Bacon states that the original concretion of bitumen is a mixture of a fiery and watery substance, and observes that flame "attracts" the naphtha of Babylon "afar off." Macquer[1] defines bitumen as a mineral substance yielding on distillation "a great deal of Oil very like Petroleum," and states that it is "nothing but an oil rendered consistent and solid by being combined with an acid." In Chapter XVI of his work he says that bitumen belongs as much to the vegetable as to the mineral kingdom, and that the solid bitumen appears to be a vegetable oil combined with a mineral acid. In describing the analysis of vegetable bodies, Macquer states that bitumens (of which he regards amber as a type) are the resinous and oily parts of trees or plants modified by prolonged lying in the earth. Bergmann[2] considered petroleum to be an instance of a small proportion of water combined, by means of an acid, with the principle of inflammability. He enunciates[3] the view, yet maintained by some, that the liquid bitumens are often, if not always, produced by the action of subterranean heat upon solid bitumens. The most explicit of the earlier publications on petroleum is that of Hatchett.[4] At that time, he states, it was generally admitted that bituminous substances are not of mineral origin, "but have been formed from certain principles of substances belonging to the organised kingdoms of nature." He further observes that the elementary principles of bitumen "are carbon, hydrogen, sometimes azote, and probably some oxygen," and from the correspondence between this composition and that of the vegetable and animal oils and resins, he is of opinion that metamorphic action has produced bitumen from them.

Hatchett divides bituminous substances into naphtha, petroleum, mineral tar, mineral pitch, asphaltum, jet, pit coal, bituminous wood, turf, and peat, and states that when *naphtha*, the light, thin, often colourless oil, loses its lighter parts by exposure to the air, it yields *petroleum*, which, on further exposure, gives *mountain* or *mineral tar*. Continued exposure produces *mountain* or *mineral pitch* or *maltha*, which in cold weather becomes brittle, but is soft and somewhat tenacious when warm. By further induration *asphaltum* is produced. These changes are ascribed to loss of hydrogen accompanying the evaporation of the material, and "consequent disengagement of carbon." He refers to

[1] *Chemistry*, i, ch. 11. 1764.
[2] *Physical and Chemical Essays*, translated by Cullen, iii, 252. 1784–1791.
[3] *Op. cit.*, iii, 283.
[4] *Trans. Linn. Soc.*, iv, 129–154. (1798.)

the occurrence of bitumens in the limestone of Matlock and other districts, and to the bituminous odour of freshly broken Portland stone. In his "Observations on the change of some of the proximate principles of vegetables into bitumen, with analytical experiments on a peculiar substance which is found with the Bovey coal,"[1] Hatchett gives further reasons for regarding bitumen as of vegetable and not animal origin. He considers that the Bovey coal of Devon represents an intermediate product in the conversion of vegetable matter into bitumen.

Although petroleum was used to some extent by the ancients as fuel and for lighting purposes, its most important application was in medicine, the "white" naphtha being the most highly prized, although the less fluid descriptions, such as *Barbados tar*, and the solid or semi-solid forms known as *Jews' pitch, mumia, pissasphaltum*, and *pisselæum* were largely used in the preparation of ointments.[2]

The intimate relation between the different descriptions of petroleum was well known to the earlier chemists, and Bergmann[3] states that the differences in colour and tenuity exhibited by petroleum depend for the most part on the "degree of exsiccation" and on the various substances mechanically mixed with it. Prolonged exsiccation produces a mass thick and tough, or solid and dry. Hatchett, as quoted above, makes a similar statement.

Kirwan[4] states that the fine, thin, fragrant, colourless oil, which issues out of white, yellow, or black clays in Persia and Media, and is as inflammable as ether, changes colour and thickens, and "degenerates into petrol" if exposed to the air, although it is not decomposed by distillation. He further observes that this colourless oil or "naphtha" has a specific gravity of 0·708, and that it dissolves resins and balsams, but not gum-resins nor elastic gums, and is insoluble in spirit of wine or ether.

For many purposes petroleum was redistilled,[5] but the product was regarded as inferior to the natural "white" oil, and was looked upon by James about the middle of the eighteenth century as an adulteration. Kirwan[6] states that the petroleum is rendered finer by distillation with water, a resinous residuum being left; and he refers to its distillation with a volatile alkali.

Towards the close of the eighteenth century attention began to be directed towards the chemical examinations of petroleum, but the researches were mainly confined to the ultimate analysis of the oil until the middle of the last century, and the result of such analysis indicated little beyond the proportions of carbon and hydrogen contained in petroleum from various districts. In 1788, Winterl[7] examined a brown petroleum from southern Hungary, and noticed the formation of acicular crystals soluble in alcohol on exposure to the air. In 1791 von Martinovich[8] examined the oil of Galicia. The next publication of importance in respect to the chemistry of petroleum appears to have been that of de Saussure, who, in 1817,[9] examined the naphtha of Amiano, then employed in street lamps in Parma. In 1837 Boussingault[10] gave an account of the properties of the bitumen of Pechelbronn, while in 1833, Professor B. Silliman, sen.,[11] described the petroleum of Pennsylvania. The first to under-

[1] *Phil. Trans.*, 1804, 385–410.

[2] James, *Medical Dictionary*, 1743–1745, articles "Asphaltos" and "Bitumen;" also Chambers' *Universal Dictionary*, 1738.

[3] *Op. cit.*, iii, p. 283.

[4] *Mineralogy*, 210. (1784.)

[5] *Encyclopædia Britannica*, 3rd edition, 1797, article "Petroleum." Aikin's *Dictionary of Chemistry and Mineralogy*, 1817, article "Bitumen."

[6] *Mineralogy*, 211. (1784.)

[7] Crell's *Chemische Annalen*, i, 493. (1788.)

[8] *Chem. Ann.*, i, 72. (1791.)

[9] *Bibl. Univ.*, iv, 116.

[10] *Ann. Chim. Phys.*, 2, lxiv, 141.

[11] *Amer. Journ. Sci.*, 1, xxiii, 97.

take the systematic examination of petroleum, and some of the commercial products obtained from it, was Professor B. Silliman, jun., who, in a report dated 16th April 1855, addressed to Messrs. Eveleth, Bissel, and Reid,[1] gave the results which he had obtained with the "rock oil or petroleum" of Venango county, Pennsylvania. He fractionated the crude oil by distillation, and on examining the distillates he came to the conclusion that certain of the bodies which they contained were products of distillation, and were not present in the crude oil. Prof. Silliman studied the action of the various reagents on the fractions, the behaviour of the distillates when cooled, the value of the different oils as illuminating agents and lubricants, and their suitability for employment as a source of gas.

PHYSICAL PROPERTIES.

Crude petroleum varies greatly in character, some descriptions being of pale colour and highly mobile, while others are viscid and almost black.

Odour.—Of most of the samples of crude oil the odour is not unpleasant; that of some, *e.g.* the majority of the Rumanian crude oils (Edeleanu and Tanasescu [2]), and the Cuban oils (Stokes [3]) is agreeable, but the oils of Lima (Ohio), Algeria, and Petrolea (Canada), as well as the heavy oil of Texas (Spindle Top), have an offensive smell, attributable to the presence of sulphur compounds, and the Wyoming oils also have a somewhat disagreeable odour. It may be mentioned that Kast and Lagai [4] consider the unpleasant smell of some oils to be due to unsaturated hydrocarbons rather than to sulphur compounds.

Specific Gravity.—According to the author's experience, the specific gravity appears to range from 0·771 (Washington, U.S., and Sumatra) to 1·06 (Mexico). Höfer [5] finds that American crude oil varies from 0·785 to 0·936, but a sample from Wyoming was of as high a specific gravity as 0·945. Nawratil [6] states that the specific gravity of Galician crude oil varies from 0·799 (*Kleczany*) to 0·902 (*Harklowa*). The specific gravity of the petroleum from the flowing wells of the Baku district during the year 1889 ranged from 0·854 to 0·899.[7] The oil from Petrolia, in Canada, usually has a density of 0·859 to 0·877. The lighter oils generally yield the larger proportion of kerosene.[8] Mabery and Dunn find that Engler's conclusion that the specific gravity of petroleum varies inversely with the depth of the well is not supported in the case of the sandstone oils of southern Ohio, the oil from the 500-feet sand being nearly as light (specific gravity 0·7971) as that from the 1500-feet sand of the Berea Grit (0·7939). The latter sand also contains the heaviest oil of all (0·8274). Some descriptions of crude petroleum have undoubtedly been subjected to a process of selective filtration through porous strata, whereby they have been deprived of some of their original constituents, on the principle which has recently formed the subject of experimental investigation by Dr. David T. Day, of the United States Geological Survey.

[1] Republished 1871 in *Amer. Chemist*, ii, 18.
[2] *Monit. Int. Pétrol. Roum.*, 1903; *Journ. Soc. Chem. Ind.*, 1287 (1903).
[3] *Eng. and Min. Journ.*, lxxiii, 347; *Journ. Soc. Chem. Ind.*, 541 (1902).
[4] *Dingler's polytechn. Journ.*, cclxxxiv, 69 (1892).
[5] *Petroleum-Industrie Nordamerika*, 1877.
[6] *Dingler's polytechn. Journ.*, ccxlvi, 423.
[7] Mr. Rydén has informed the author that at Kudako (Russia) a description of crude petroleum is found, which has the low specific gravity of 0·650.
[8] *Amer. Chem. Journ.*, xviii, 215; *J. Soc. Chem. Ind.*, xv, 533.

Table VII, A, B, C, give the specific gravity of crude petroleum from wells of various depths in the districts of Campina and Bustenari, Rumania.

TABLE VIIA.—SPECIFIC GRAVITY OF THE CRUDE PETROLEUM PRODUCED AT CAMPINA

The samples of oil were taken direct from the wells.

No. of Well.	Depth of Well in Metres.	Specific Gravity at 15° C.	No. of Well.	Depth of Well in Metres.	Specific Gravity at 15° C.
1	302·00	0·8268	27	175·66	0·8291
7	384·90	0·8399	29	189·86	0·8299
8	175·00	0·8602	30	277·90	0·8204
12	396·00	0·8605	33	314·50	0·8260
20	158·10	0·8310	36	536·00	0·8540
22	304·38	0·8328	39	229·00	0·8223

Average 0·8360.

TABLE VIIB.—SPECIFIC GRAVITY OF CRUDE OIL PRODUCED AT BUSTENARI.

No. of Well.	Depth of Well in Metres.	Specific Gravity at 15° C.	No. of Well.	Depth of Well in Metres.	Specific Gravity at 15° C.
2	161·90	0·8580	22	171·00	0·8604
7	237·10	0·8510	23	151·10	0·8561
10	179·50	0·8460	24	226·20	0·8570
11	221·60	0·8542	26	145·00	0·8540
12	368·28	0·8410	27	236·71	0·9225
14	345·00	0·8564	28	168·15	0·8565
15	174·30	0·8520	29	171·50	0·8505
16	381·30	0·8281	30	173·80	0·8620
17	173·00	0·8550	31	200·30	0·8421
18	182·55	0·8450	33	159·00	0·8510
19	145·30	0·8540	37	198·00	0·8530
20	157·45	0·8534	41	283·80	0·8345
21	167·70	0·8600			

Average 0·8541, or excluding Well No. 27, 0·8513.

TABLE VIIC.—SPECIFIC GRAVITY OF CRUDE OIL OBTAINED FROM HAND-DUG SHAFTS AT BUSTENARI.

No. of Shaft.	Depth of Shaft in Metres.	Specific Gravity at 15° C.	No. of Shaft.	Depth of Shaft in Metres.	Specific Gravity at 15° C.
1	87·00	0·8525	14	152·65	0·8555
7	140·00	0·8458	19	128·15	0·8518
8	178·50	0·8517	25	163·90	0·8480
10	135·50	0·8740	33	144·00	0·8438
10	152·00	0·8645			

Average 0·8541.

The following table, which records results obtained in the author's laboratory, shows the **specific gravity** and **colour** of a number of crude oils from various localities, the **flashing-point** and **viscosity** being also given in some cases :—

TABLE VIII.—PHYSICAL PROPERTIES OF CRUDE PETROLEUMS.
CANADA, ETC.

Locality.	Specific Gravity.	Flashing-point (Abel Test).	Colour.
		F.	
Canada (Petrolea), ...	0·858	..	Dark brown.
,, New field, ...	0·840	Below 60°	Reddish-brown.
,, (Gaspé), 1, ...	0·881	180°	Brown.
,, ,, 2, ...	0·856	65°	,,
,, ,, 3 (1057 ft.), .	0·853	54°	Dark brown.
,, ,, 4 (906 ft.), .	0·877	90°	,,
,, ,, 5, ...	0·939	280°	Black.
,, ,, 6, ...	0·921	210°	Brown.
,, ,, 7, ...	0·948	..	,,
,, ,, 8, ...	0·871	104°	,,
,, ,, 9, ...	0·894	..	,,
,, ,, 10 (2361 ft.), .	0·847	46°	,,
,, ,, 11,. . . .	0·844	60°	,,
,, ,, 12 (1946 ft.), .	0·861	183°	,,
,, ,, 13, . . .	0·795	20°	..
,, ,, 14, . . .	0·828	Below 0°	..
,, New Brunswick, 1, .	0·857	40°	..
,, ,, 2, .	0·852	Below 50°	Reddish-brown.
,, ,, 3, .	0·862	95°	..
,, ,, 4, .	0·855	84°	..
,, ,, 5, .	0·838	Below 60°	Dark reddish-brown.
Newfoundland, 1, ...	0·843	134°	Very dark brown.
,, 2, ...	0·805	0°	,,
,, 3, ...	0·798	Below 50°	Bright red.
Manitoulin Island, ...	0·870	,, 60°	Dark reddish-brown.
Labrador, ...	0·914	274°	Almost black.
Alberta (Calgary), ...	0·750	..	Pale amber.

TABLE VIII.—*continued.*

AMERICA.

Locality.	Specific Gravity.	Colour.
Pennsylvania, Bradford, 1, ...	0·810	Reddish-brown.
,, ,, 2, ...	0·819	,,
,, Parker (Clarion), . .	0·797	,,
,, Karns City, . . .	0·789	,,
,, Thorn Creek, . . .	0·802	,,
,, Stoneham, . . .	0·802	Dark amber.
Washington, 1, ...	0·790	Yellow.
,, 2, ...	0·777	,,
,, 3, ...	0·798	Amber.
,, 4, ...	0·798	Yellow.
,, 5, ...	0·800	Amber.
,, 6, ...	0·804	,,
,, 7, ...	0·792	Yellow.
,, 8, ...	0·819	Amber.

TABLE VIII.—*continued.*

AMERICA—*continued.*

Locality.	Specific Gravity.	Colour.
Washington 9, ...	0·775	Yellow.
,, 10, ...	0·820	Amber.
,, 11, ...	0·801	,,
,, 12, ...	0·816	Brown.
,, 13, ...	0·814	,,
,, 14, ...	0·828	,,
,, 15, ...	0·792	Dark brown.
,, 16, ...	0·788	Yellow.
,, 17, ...	0·771	,,
,, 18, ...	0·801	Amber.
,, 19, ...	0·799	,,
,, 20, ...	0·780	Dark Brown.
,, 21, ...	0·777	Yellow.
,, 22, ...	0·771	,,
,, 23, ...	0·786	,,
,, 24, ...	0·772	,,
,, 25, ...	0·772	,,
,, 26, ...	0·797	Amber.
,, 27, ...	0·792	,,
,, 28, ...	0·814	,,
,, 29, ...	0·808	,,
,, 30, ...	0·820	Dark brown.
Ohio, Macksburg, ...	0·829	Reddish-brown.
,, Lima, ...	0·839	Brownish-black.
Wyoming, 1.	0·912	Very dark brown.
,, 2, ...	0·912	,,
,, 3, ...	0·912	,,
,, 4, ...	0·910	,,
,, 5, ...	0·944	Brownish-black.
,, 6, ...	0·911	Very dark brown.
,, 7, ...	0·945	Brownish-black.
California (Pico Cañon), ...	0·844	Dark brown.
,, (Puente), ...	0·880	Black.

TABLE VIII.—*continued.*

Locality.	Specific Gravity.	Locality.	Specific Gravity.
California—		Pico Cañon district, 15, . .	0·854
Pico Cañon district, 1, . .	0·827	,, ,, 16, . .	0·837
,, ,, 2, . .	0·835	,, ,, 17, . .	0·846
,, ,, 3, . .	0·831	,, ,, 18, . .	0·853
,, ,, 4, . .	0·838	,, ,, 19, . .	0·842
,, ,, 5, . .	0·837	,, ,, 20, . .	0·837
,, ,, 6, . .	0·828	,, ,, 21, . .	0·841
,, ,, 7, . .	0·844	,, ,, 22, . .	0·850
,, ,, 8, . .	0·839	,, ,, 23, . .	0·842
,, ,, 9, . .	0·836	,, ,, 24, . .	0·844
,, ,, 10, . .	0·847	,, ,, 25, . .	0·840
,, ,, 11, . .	0·827	,, ,, 26, . .	0·846
,, ,, 12, . .	0·832	,, ,, 27, . .	0·843
,, ,, 13, . .	0·828	,, ,, 28, . .	0·865
,, ,, 14, . .	0·859	,, ,, 29, . .	0·927

The colour of all these samples was brown.

TABLE VIII.—*continued.*

AMERICA—*continued.*

Locality.	Specific Gravity.	Flashing-point (Abel Test).	Colour.
		F.	
California, 1,	0·792	Below 50°	Yellow.
,, 2,	0·976	270°	Dark reddish-brown.
,, 3,	0·923	76°	Dark brown.
,, 4,	0·852	Below 50°	Reddish-brown.
,, 5,	0·895	,, 55°	..
,, (Coalinga district), 1,	0·779	,, 60°	Straw-coloured.
,, ,, 2,	0·940	116°	Dark brown.
,, ,, 3,	0·836	Below 60°	Dark reddish-brown.
,, ,, 4,	0·979	276°	Dark brown.
Colorado (Boulder district), 1,	0·806	Below 55°	Reddish-brown.
,, ,, 2,	0·814	,, 60°	Light red.
Texas, 1,	0·927	224°	..
,, 2,	0·923	178°	..
,, 3,	0·911	60°	..
,, Spindle Top,	0·876	Below 60°	..
,, Hardin county,[1]	0·970	240°	Dark brown.
,, Sour Lake,[1]	0·964	250°	,,
,, Saratoga,	0·946	212°	..
Louisiana,	0·829	101°	..
Kansas, 1,[1]	0·852	55°	Dark brown.
,, 2,	0·927	224°	Black.
Indiana, 1,	0·917	260°	Very dark brown
,, 2,	0·922	264°	,,
,, 3,	0·935	240°	,,
,, 4,	0·938	258°	..
,, 5,	0·949	206°	..
,, 6,	0·848	130°	..
Indian Territory, Chelsea, Cherokee Nation, 1,[1]	0·855	18°	Dark brown.
,, ,, ,, 2,[1]	0·862	25°	,,
,, ,, Bartlesville,[1] 1,	0·859	30°	,,
,, ,, ,, Osage Nation, 2,[1]	0·886	210°	,,
,, ,, ,, 3,	0·877	64°	..
,, ,, ,, (1420 feet), 4,	0·856	Below 50°	..
,, ,, ,, (1750 feet), 5,	0·872	102°	..
,, ,, Muscogee,[2]	0·825	35°	Amber.
Wyoming, Salt Creek, Well No. 1,[1]	0·909	148°	Reddish-brown.
,, ,, ,, 7,[1]	0·905	125°	,,
,, ,,	0·826	Below 60°	Black.
,, Tisdale's Ranch,[1]	0·916	200°	,,
,, Arapahoe,	0·861	128°	Very dark brown.
,, Lander, 1,	0·935	110°	,,
,, ,, 2,[1]	0·910	Below 50°	..
,, Bonanza,	0·862	136°	Reddish-brown.
,, Iba shaft,	0·890	210°	Very dark brown.
,, Douglas Field,	0·959	260°	..
Alaska, Burls Creek,	0·942	234°	Dark reddish-brown.
,, Johnstone Creek, 1,	0·964	200°	Dark brown.
,, ,, 2,	0·879	178°	,,
,, Poul Creek (lowest),	0·970	250°	,,
,, ,, (top, west),	0·881	67°	,,
,, ,, (upper),	0·914	156°	,,
,, Catalla Meadow, 1,	0·929	240°	,,
,, ,, 2,	0·901	156°	..
,, ,, 3,	0·874	156°	..
,, ,, 4,	0·869	152°	..
,, ,, 5,	0·961	266°	..
,, Bore-hole at Catalla, 120 feet (1902),	0·802	Below 60°	Dark red.

[1] Fluid at 0° F.

[2] Solidifies at 0° F.

TABLE VIII.—*continued.*

AMERICA—*continued.*

Locality.	Specific Gravity.	Flashing-point (Abel Test).	Colour.
		F.	
Alaska, Bore-hole at Catalla, 355 feet (1902), . .	0·790	Below 60°	Dark red.
,, Oil Creek, ...	0·855	108°	Dark brown.
,, Morrison Creek, . .	0·991	270°	,,
,, Argyll (Icy Bay), .	0·962	310°	,,
,, Yakogelty, . .	0·937	246°	,,
,, Crooked Creek, . .	0·921	172°	,,
Mexico, 1, ...	0·975	200°	..
,, 2, ...	0·939	63°	..
,, 3, ...	1·06	300°	..
,, 4, ...	1·04	310°	..
,, 5, ...	0·993	98°	..
,, 6, ...	0·810	130°	..
,, 7, ...	0·874	111°	..
,, 8, ...	0·882	126°	Brownish-red.
,, 9, ...	0·942	294°	Black.
,, 10,[1]	0·946	262°	..
,, 11,[2]	0·970	300°	Chestnut-brown.
,, 12	0·842	144°	..
,, 13, ...	0·809	Below 50°	Reddish-brown.
,, 14, ...	0·879	,,	Very dark brown.
,, 15, ...	0·883	,,	,,
,, 16, ...	0·970	148°	Black.
,, 17, ...	0·965	140°	,,
,, 18, ...	0·814	Below 60°	Amber.
,, 19, ...	0·960	70°	..
Mexico, 20, ...	0·992	100°	Black.
,, (Isthmus of Tehuantepec, 1,	0·959	234°	..
,, ,, ,, 2,	0·933	254°	..
Colombia, 1,[3]	0·926	310°	Dark brown
,, 2, ...	0·963	226°	Rich red.
Ecuador, 1, ...	0·953	..	Deep brownish-red.
,, 2, ...	0·928	80°	,,
Peru, 1, ...	0·859	38°	Dark brown.
,, 2,[4]	0·940	248°	Very dark brown.
,, 3,[4]	0·920	122°	Dark brown.
,, 4, ...	0·840	Below 60°	Reddish-brown.
,, 5, ...	0·843	,,	,,
,, 6, ...	0·860	,,	,,
,, 7, ...	0·830	,,	,,
,, 8, ...	0·866	,,	,,
,, 9, ...	0·841	,,	,,
,, 10, ...	0·842	,,	,,
,, 11, ...	0·870	,,	,,
,, Negritos, . . .	0·843	,,	,,
Argentina,[5]	0·935	..	Black.
,, Garrapatal, . .	0·975	330°	..
,, Aybal, ...	0·995	270°	..
,, ,, ...	0·996	300°	..
,, (Rivadavia). . .	0·930	65°	Dark reddish-brown.
Bolivia, 1, ...	0·808	78°	Reddish-yellow.
,, 2, ...	0·892	224°	Dark reddish-yellow.
,, 3, ...	0·863	78°	..
Venezuela, 1, ...	0·868	Below 60°	..
,, 2, ...	0·878	,,	Dark reddish-brown.
,, 3, ...	0·855	62°	Light brown.
,, 4, ...	0·887	194°	Dark brown.

[1] Viscosity at 70° F. 73·11 (rape oil at 60° F. = 100) ; solidifies at zero F.
[2] Viscosity at 140° F. 198·7 (rape oil at 60° F. = 100). [3] Solidifies at 5° F.
[4] Fluid at 0° F. [5] Solidifies at 32° F.

TABLE VIII.—*continued.*

RUSSIA.

Locality.	Specific Gravity.	Flashing-point (Abel Test).	Colour.
		F.	
Balakhani, 1,	0·879	..	Dark brown.
" 2,	0·873	93°	"
Surakhani,	0·780	..	Pale yellow.
Grozni, 1,	0·884	Below zero.	Dark brown.
" 2,	0·874	"	..
" 3,	0·894	52°	..
" 4,	0·927	176°	..
Guri, 1,	0·955	82°	Brownish-black.
" 2,	0·968	274°	"
Tiflis,	0·976	320°	Almost black.
Ilsky, 1,	0·853	..	Dark brown.
" 2,	0·942	..	Brownish-black.
Kudako, 1,	0·860	..	Very dark brown.
" 2,	0·936	..	Brownish-black.
Kertch (Crimea),	0·887	..	..
Black Sea,	0·826	Below 30°	..
" Anapa,	0·900	Below zero	Dark brown.
" Suvorov,	0·914	36°	..
Maikop,	0·827	Below 60°	Reddish-brown.
Gurieff, 1,	0·839	" 65°	Dark reddish-brown.
" 2,	0·869	"	Brownish-red.
" 3,	0·903	210°	Reddish-brown.
" 4,	0·908	240°	"
" 5,	0·904	212°	"
" 6,	0·876	Below 65°	Brownish-red.
" 7,	0·880	100°	"
Tcheleken Island, 1,	0·839	Below 60°	..
" 2,	0·850	"	..
" 3,	0·873	82°	..
" 4,	0·841	Below 60°	..
" 5,	0·859	110°	Dark reddish-brown.
" 6,	0·878	Below 60°	"
" 7,	0·843	"	"
" 8,	0·841	"	"
Island of Sakhalin,	0·922	340°	Dark reddish.
" (Nutovo)	0·903	208°	Reddish-brown.

TABLE VIII.—*continued.*

GALICIA.

Locality.	Specific Gravity.	
	Lowest.	Highest.
Eastern end of belt, Sloboda-Rungurska,	0·830	0·868
Intermediate portion of belt, Ustrzyki district,	0·835	0·844
Western end of belt, Wietrzno district,	0·846	0·859

Locality.	Specific Gravity.	Flashing-point (Abel Test).	Solidifying-point.	Colour.
Potok,	0·798	Below zero.	Below zero.	Dark brown.
Kleczany,	0·802	28°	"	Orange.
Kobylany,	0·853	34°	"	Dark reddish-brown.

TABLE VIII.—*continued.*

GALICIA—*continued.*

FIFTEEN WELLS IN THE DISTRICT OF SLOBODA-RUNGURSKA.

No.	Depth in Metres.	Specific Gravity.	No.	Depth in Metres.	Specific Gravity.
1	213	0·842	9	202	0·863
2	194	0·868	10	280	0·837
3	189	0·835	11	305	0·839
4	164	0·850	12	280	0·837
5	225	0·838	13	282	0·864
6	275	0·845	14	250	0·830
7	282	0·844	15	311	0·839
8	274	0·833			

FIVE WELLS IN THE USTRZYKI DISTRICT.

No.	Depth in Metres.	Specific Gravity.	No.	Depth in Metres.	Specific Gravity.
1	183	0·835	4	232	0·836
2	173	0·844	5	229	0·841
3	183	0·841			

TABLE VIII.—*continued.*

BURMA, ASSAM, AND BALUCHISTAN.

Locality.	Specific Gravity.	Solidifying-point.	Flashing-point (Abel Test).	Viscosity by Redwood's Viscometer (Rape Oil at 60° F. = 100) at 90° F.
		F.	F.	
Upper Burma (Yenangyaung)—				
,, ,, Twinza wells, 1,	0·887	82°	110°	10·21
,, ,, ,, 2,	0·937	Fluid at 0°	150°	25·86
,, ,, Drilled well, .	0·869	80°	62°	..
,, ,, ,, .	0·870	78°	80°	..
,, ,, ,, .	0·875	82°	83°	10·07
,, (Pagan district), 1, .	0·837	60°	..	5·91
,, (Pakokku ,,), 2, .	0·832	70°	70°	5·54
,, (Minbu), ...	0·999	35°	294°	703·06
Padoukpin (west of Thayetmyo), 1, .	0·854	72°	80°	6·38
,, ,, ,, 2, .	0·859	76°	110°	7·81
,, ,, ,, 3, .	0·870	80°	126°	8·78
Arakan I. (Ramri), mud-volcano, 1, .	0·818	..	..	..
,, ,, native pits, 2, .	0·866	..	..	..
,, ,, ,, 3, .	0·890	Below 10°	125°	10·21
,, ,, ,, 4, .	0·834	,,	45°	..
,, ,, ,, 5, .	0·825	20°	62°	..
Baranga I. (Eastern), ...	0·835	..	..	..
,, (Western), ...	0·888	..	..	..
Assam, 1, surface-oil, ...	0·933	..	..	..
,, 2, ,, ...	0·940	..	212°	14·2
,, 3, from drilled well, Digboi, .	0·858	..	43°	..
,, 4, ,, ,, Makum,[1]	0·944	Fluid at 0°	180°	..
,, Budderpore, ...	0·980	..	214°	..
Baluchistan, from drilled well, Khátan,[2]	1·000	..	280°	..

[1] Dark reddish-brown ; viscosity at 70° F. 44·5 (rape oil at 60° F. = 100)
[2] A black viscid oil.

TABLE VIII.—*continued.*

MISCELLANEOUS.

Locality.	Specific Gravity.	Flashing-point (Abel Test).	Solidifying-point.	Colour (by Transmitted Light).
		F.	F.	
Rumania, 1, ...	0·859	123°	..	Dark brown.
,, 2, ...	0·845	Below 20°	..	,,
,, 3, ...	0·860	75°	..	,,
,, 4, ...	0·861	72°	..	,,
,, 5, ...	0·839	87°	..	,,
,, 6, ...	0·890	80°	..	,,
,, 7, ...	0·896	85°	..	,,
,, 8, ...	0·882	57°	..	,,
,, 9, ...	0·846	..	..	,,
,, 10, ...	0·899	24°	..	,,
,, 11, ...	0·829	Below 65°	..	..
,, 12, ...	0·823	,, 60°	..	..
,, 13, ...	0·855	..	..	..
,, 14, ...	0·844	Below 60°	..	Dark reddish-brown.
,, 15, ...	0·888	,,	..	,,
,, 16, ...	0·876	,,	..	..
Hungary (Kriva-Olyka), .	0·907	188°	..	Reddish-brown.
Germany (Oelheim), . .	0·913	..	..	Brownish-black.
,, (Wietze-Steinförde), 1,	0·951	200°	15°	..
,, ,, 2,	0·943	150°	12°	..
,, ,, 3,	0·941	122°	..	..
,, (Horst), 1, . .	0·910	98°	..	Very dark brown.
,, ,, 2, . .	0·872	84°	..	,,
,, ,, 3, . .	0·918	128°	..	Dark brown.
France (Alsace), . . .	0·873	37°	10°	Very dark brown.
England (Derbyshire), . .	0·857	..	..	Black.
,, (Somersetshire). .	0·816	175°	..	Straw-coloured.
Spain (Huidobro), . .	0·921	270°	..	Dark reddish-brown.
,, (Conil, near Cadiz), .	0·837	110°	..	Pale reddish-brown.
Italy (Montechino), . .	0·787	13°	..	Straw.
,, (Miano), 1 . . .	0·867	36°	..	Bright red.
,, ,, 2, ...	0·832	21°	..	,,
,, (Neviano), drilled well, .	0·805	44°	Below 0°	Amber.
,, (Galetta well), . .	0·908	190°	,,	Dark red.
,, (Ozzano), drilled well. .	0·807	Below 0°	,,	Amber.
Sicily (Nicosia), . . .	0·933	228°	Below 0°	Amber.
Zante, 1, ...	1·020	..	..	Black.
,, 2, ...	1·005	..	..	,,
Algeria, 1, ...	0·921	60°	..	Dark brown.
,, 2 (12 feet deep), .	0·924	..	32°	,,
,, 3 (surface), . .	0·981	218°	32°	,,
,, 4 (Ain Zeft, 1100 feet),	0·888	Below 50°	..	..
,, 5, ...	0·879	36°	..	..
,, 6, (Tliouanet), .	0·820	50°	..	..
,, 7, ,, . .	0·825	80	..	..
,, 8, ...	0·814	..	..	Dark reddish-brown.
Tunis, ...	0·965	260°	..	..
Morocco, 1, ...	0·871	Below 60°	..	Dark reddish-brown.
,, 2, ...	0·849	,,	..	,,
,, 3, ...	0·870	106°	..	,,
Gold Coast (Apollonia), 1, .	0·979	370°	..	Dark brown.
,, ,, 2, .	0·972	350°	..	..
,, Nigeria, . .	0·872	115°	..	Dark reddish-brown.
Ivory Coast, . . .	0·959	136°	..	..
Somaliland, ...	0·897	122°	..	Dark reddish-brown.
Red Sea, ...	0·945	146°	..	Black.
,, Gemsah, . . .	0·823	Below 60°	..	Dark reddish-brown.
Persia, 1.	0·777	..	..	Straw-coloured.
,, 2, ...	1·016	170°	45°	Dark brown.

TABLE VIII.—*continued.*

MISCELLANEOUS—*continued.*

Locality.	Specific Gravity.	Flashing-point (Abel Test).	Solidifying-point.	Colour (by Transmitted Light).
		F.	F.	
Persia, 3,	0·846	69°	..	Dark brown.
,, 4,	0·900	154°	..	..
,, 5, (Tchiah Sourkh), drilled well,	0·815	Below 60°	..	..
,, 6,	0·839	,,	..	..
,, 7,	0·863	67°	..	Reddish-brown.
Java, 1,	0·881	90°	..	Dark brown.
,, 2,	0·881	62°	Below 0°	,,
,, 3,	0·844	71°	..	..
Sumatra (Langkat), 1,	0·771	Below 5°	..	Light brown.
,, ,, 2,	0·789	,, 0°	..	,,
,, ,, 3,	0·857	46°	Below 0°	Reddish-brown.
,, (Iliran Palembang), 1,	0·964	236°	..	..
,, ,, ,, 2,	0·980	256°	..	..
,, ,, ,, 3,	0·925	96°	..	..
,, ,, ,, 4,	0·934	112°	..	..
,, (Muara Enim), 1,	0·833	Below 10°	..	..
,, ,, 2,	0·923	338°	..	..
,, ,, 3,	0·813	Below 0°	..	..
Borneo (Labuan),	0·965	216°	Below 0°	Dark brown.
,, (Sarawak),	0·924	198°	..	..
,, (Kutei), 1,	0·859	..	..	..
,, ,, 2,	0·865	65°	..	..
,, ,, 3,	0·856	Below 60°	..	..
,, ,, 4,	0·856	,,	..	..
,, ,, 5,	0·848	,,	..	..
,, ,, 6,	0·851	,,	..	..
Timor, 1,	0·825	105°	10°	Dark brown.
,, 2,	0·817	Below 60°	..	Reddish.
Philippine Islands (Cebu), 1,	0·809	..	..	Dark brown.
,, ,, 2,	0·838	54°	..	..
,, ,, 3,	0·819	80°	..	..
,, (Leyte),	0·926	166°	..	..
Trinidad, 1,	0·980	330°	..	Dark brown.
,, 2,	0·961	190°	..	,,
,, 3,	0·952	..	..	,,
,, 4,	0·914	90°	..	..
,, 5 (Aripero),	0·938	60°	..	Very dark brown.
,, 6 (La Brea),	0·971	76°	..	,,
,, 7,	0·873	164°	..	Dark brown.
,, 8,	0·920	Below 60°	..	Dark reddish-brown.
,, 9,	0·912	,,	..	,,
,, 10,	0·814	..	..	Brownish-red.
Barbados, 1,	0·945	240°	..	Dark brown.
,, 2,	0·957	..	..	,,
,, 3,	0·950	284°	..	,,
,, 4,	0·946	248°	..	,,
,, 5,	0·971	300°	..	,,
,, 6,	0·951	280°	..	,,
,, 7,	0·971	268°	..	,,
,, 8,	0·878	195°	..	..
,, 9 (600 feet),	0·872	100°	..	..
,, 10,	0·941	85°	..	..
,, 11,	0·895	100°	..	..
Madagascar (Maraboaly),	0·941	288°	..	..
New Zealand (Taranaki)—				
,, 1, surface oil,	0·971	236°	..	Brownish-black.
,, 2, drilled well,	0·840	62°	60°	Chestnut-brown.
,, (Gisborne, Waitangi well),	0·885	124°	..	..

TABLE VIII.—*continued.*

JAPAN.

Locality.	Specific Gravity.	Colour.	Locality.	Specific Gravity.	Colour.
Urase lease,	0·840	Dark brown.	Nütsu lease	0·932	Dark brown.
Kubiki ,,	0·823	Dark reddish-brown (fluorescent).	Amaze ,,	0·841	Reddish-brown (marked fluorescence).
Kamata ,,	0·927	Dark brown (marked fluorescence).	Enshyu ,,	0·792	Light reddish-brown.
Miyagawa ,,	0·807	Brown.	Akita ,,	0·917	Dark brown.

Some information as to the physical characters of various descriptions of crude petroleum will be found in the previous sections, especially as regards the less-known deposits.

Höfer gives the following particulars of some of the commercial products of the distillation of petroleum :—

TABLE IX.—PHYSICAL PROPERTIES OF COMMERCIAL PRODUCTS FROM PETROLEUM.

Light Oils.

	Boiling-point. ° C.	Specific Gravity.
Petroleum ether (Keroselene, Rhigolene, Sherwood oil),	40 to 70	0·650 to 0·660
Gasoline,	70 to 80	0·640 to 0·667
Petroleum naphtha (Petroleum benzine),	80 to 100	0·667 to 0·707
,, ,, (Ligroïne),	100 to 120	0·707 to 0·722
,, ,, (Cleansing oil),	120 to 150	0·722 to 0·737

Burning Oils.

	Boiling-point, 150° to 300° C.
Kaiser oil,	0·780 to 0·800
Illuminating oil (American),	0·800 to 0·810
,, (Russian),	0·820 to 0·825
Standard white oil,	0·808 to 0·812
Prime white oil,	0·800 to 0·806
Astraline,	0·850 to 0·860

Heavy Oils.

Solar oil,	0·860 to 0·880
Mixing oil,	0·880 to 0·890
Spindle oil, I.,	0·895 to 0·900
,, II.,	0·900 to 0·906
Machine oil, I.,	0·906 to 0·910
,, II.,	0·910 to 0·915
Cylinder oil (bright),	0·915 to 0·920
,, (dark),	0·920 to 0·950
Vulcan oil,	0·910 to 0·960

According to Veith,[1] the American petroleum ether of commerce has a specific gravity of 0·63 to 0·65, while that obtained from Galician oil has a specific gravity of 0·65 to 0·66. Evers states that certain oils obtained during the compression of oil-gas, and known technically as "hydrocarbon," are sold

[1] *Das Erdöl* . . ., 369 (1892).

as petroleum-ether. The "benzin" of the United States Pharmacopœia is the portion of the distillate from American petroleum having a specific gravity between 0·670 and 0·675, and boiling between 50° and 60° C. The "petroleum-benzin" of the German Pharmacopœia consists of the colourless, non-fluorescent portions of petroleum, having a specific gravity of 0·640 to 0·670, and distilling almost entirely between 55° and 75° C. Petroleum-naphtha is required by the New York Produce Exchange to be "water-white and sweet," and of density from 68° to 70° Baumé (specific gravity 0·707 to 0·690). Further information respecting the various products of petroleum met with in commerce will be found in the section dealing with the refining of petroleum.

The coefficient of expansion of petroleum, more especially in connection with the behaviour of heavy distillates and residues from petroleum, has been very fully treated by Dr. Holde.[1] Dr. Engler[2] gives the following (Table X) as the coefficients of expansion of a number of typical crude oils. Generally speaking, the expansion varies inversely with the density, the exceptions which occur being attributable to the chemical nature of the oils.

TABLE X.—COEFFICIENTS OF EXPANSION OF CRUDE PETROLEUM.

Origin.	Pennsylvania.	Canada.	Schwabweiler (Alsace).	Virginia.	Schwabweiler (Alsace).	Wallachia.	Eastern Galicia.	Rangoon.	Caucasus.	Western Galicia.	Ohio.	Baku (Benkendorf property).	Oedesse (Hanover).	Pechelbronn Pit Oil.	Wallachia.	Oberg (Hanover).	Weitze (Hanover).
Coefficient of expansion × 1,000,000	840	843	843	839	858	808	813	774	817	775	748	784	772	792	748	662	647
Sp. Gr. at ?°C. × 1000.	816	828	829	841	861	862	870	875	882	885	887	890	892	892	901	944	955

W. Markownikow and W. Ogloblin[3] calculated the expansion-coefficient from the specific gravity of the oil—between 0° and 39·8° C.—the results obtained with a sample of North American oil being as follows:—

Density at 15° C. × 1000.	Coefficient of Expansion × 100,000.
Under 700	90
700–750	85
750–800	80
800–815	70
Above 815	65

Sainte-Claire-Deville's experiments[4] were limited to temperatures between 0° and 50° C. As all researches hitherto show[5] that the coefficients of expansion of liquids vary as the temperature rises, the formula for solid bodies—viz. $V=V_0\ (1+at)$—is only of use to give an approximate result between agreed temperatures in conjunction with the specific gravity. Gintl's results, as recorded by Höfer,[6] agree with those of Markownikow and Ogloblin in con-

[1] *Mitth. k. techn. Versuchsanst. Berlin*, xi, 45–68 (1893). [2] *Loc. cit.*, 643.
[3] *Ber. deutsch. chem. Ges.*, xvi (Ref. from *J. Russk. Ph.-Kh. O.*, xv, 1, 237). 1883.
[4] *Comptes Rend.*, lxvi, 442; lxviii, 349, 485, 686.
[5] Landolt and Börnstein, *Phys. Tabellen*, 99, 100 (1894).
[6] *Das Erdöl, etc.*, 1888.

firming the relation between the specific gravity and the expansion-coefficient of oils. They are given in Table XI.

TABLE XI.—RELATION OF COEFFICIENT OF EXPANSION TO SPECIFIC GRAVITY.

Origin.	Density × 1000 at 0° C.	Density × 1000 at 50° C.	Coefficient of Expansion × 100,000.
West Virginia (White Oak),	873	853	46
,, (Burning Spring),	841	808	81
Pennsylvania (Oil Creek),	816	784	82
Canada,	870	851	44
Burma (Rangoon),	892	861	72
Russia (Baku),	954	920	71
Eastern Galicia,	870	836	81
Western ,,	855	852	77
Rumania (Ploiesti 1),	862	829	80
,, (,, 2),	901	869	73
Italy (Parma, Neviano de' Rossi),	809	772	96
Hanover (Oberg),	944	914	66
France (Pechelbronn),	912	880	73
France (St Gabian),	894	861	69
Zante,	952	921	67

A. Bartoli and E. Stracciati [1] tested the fractions obtained from crude petroleum, including the saturated hydrocarbons from pentane, C_5H_{12}, to hexadecane, $C_{16}H_{34}$, and obtained the following results :—

TABLE XII.—COEFFICIENTS OF EXPANSION OF PETROLEUM FRACTIONS.

Hydrocarbon.	Boiling-point.	Specific Gravity at 0°.	Average Coefficient of Expansion between 0° and 30°
C_5H_{12}	+ 30°	0·64025	0·0015890
|	|	|	|
$C_{16}H_{34}$	+ 278–282°	0·82873	0·0008045

With the exception of a few isolated cases,[2] no thorough investigation had been made into the expansion of mineral lubricating oils until the experiments described below were conducted by the Charlottenburg Versuchsanstalt, although the subject is of practical importance as facilitating the estimation of the specific gravity at different temperatures, and the comparison of the relation between increase of fluidity and increase of volume. The question of fluidity has a direct bearing on the value of lubricating oils ; and the coefficient of expansion, besides its interest in this particular, also throws light on other peculiarities observable in mineral oils, particularly the part played by solid hydrocarbons.

Experiments on expansion had hitherto been based upon the formula $V = V^1 (1 + at + bt^2 + ct^3)$, the constants, a, b, and c, having different values at different temperatures, as shown by Kopp and others.[3] Preliminary experiments were

[1] *Gazzetta Chimica*, xv, 417 (1885).

[2] Albrecht, *Annalen für Gewerbe und Bauwesen*, xxx, 234 (1892) ; and Veith, *Das Erdöl und seine Verarbeitung*, 1892.

[3] Landolt and Börnstein, *Physik. Tabellen*, 1894.

made to ascertain the relative advantages of the determination of the coefficient by weighing a constant volume at different temperatures, and by direct measurement of the increase in volume; the most suitable form and dimensions of dilatometers and pyknometers (specific-gravity bottles), and the method of applying heat so as to produce and maintain a constant and equable temperature throughout the oil under test being also investigated. The use of a dilatometer with a bulb holding 30 cubic centimetres, and a tube of a diameter of 1·7 to 1·8 millimetres, was decided on, the thermometer for the experiments being graduated to $\frac{1}{10}$° C. This made estimation to the fifth decimal place possible. Table XIII shows the effect on the coefficient resulting from error in the dilatometer or pyknometer and thermometer.

TABLE XIII.—EFFECT OF INSTRUMENTAL ERRORS IN THE DETERMINATION OF THE COEFFICIENT OF EXPANSION.

Instrument.	Cubical Contents.	Difference in Temperature between Observations.	Error of Instrument.	Error of Thermometer.	Error of Coefficient of Expansion.
	c.cm.	° C.	c.cm.	° C.	
Dilatometer,	10	20	0·5	0	0·000025
	25	20	0·5	0	0·0000010
	24	12	1·0	0	0·0000030
	30	10	1·0	0	0·0000030
	30	4	1·0	0	0·0000076
	24	13	0	0·1	0·0000056
			milligramme.		
Pyknometer,	1·5	15	1	0	0·0000600
	1·5	30	1	0	0·0000200

The formula used was

$$a = \frac{V_1 - V + V_1[1 + c(t - 20)](t_1 - t)c}{V[1 + c(t - 20)](t_1 - t)},$$

c being the coefficient of expansion of the glass tube, taken as $= 0{\cdot}000025$, the dilatometer being calibrated at 20° C. This resolves into :—

$$a = \frac{V_1 - V}{t_1 - t} \cdot \frac{1}{V[1 + c(t - 20)]} + c \cdot \frac{V_1}{V}.$$

Of which the divisions

$$\frac{1}{[1 + c(t - 20)]} \text{ and } \frac{V_1}{V}$$

may be disregarded in making the calculations, bearing in mind that leaving out $\frac{V_1}{V}$ causes an error of -1 to -2 units in the seventh decimal, and that the omission of $\frac{1}{[1 + c(t - 20)]}$ has the following effect :—

When $t - 20 = 10$ the error is $+1$ to 2 units in the seventh decimal.
,, $t - 20 = 20$,, $+3$,, ,,
,, $t - 20 = 40$,, $+6$,, ,,

The formula, thus simplified, becomes

$$a=\frac{V_1-V}{(t_1-t)V}+c,$$

differing only slightly from that of Kohlrausch :—

$$a=\frac{V_1-V}{t_1-t}\cdot\frac{1}{V}+c\cdot\frac{V_1}{V}.$$

The experiments to ascertain the best form of apparatus for obtaining a constant and regular temperature were carefully and elaborately made, both water-bath and vapour-bath systems being tried. Preference was ultimately given to the former, the currents circulating in the vapour-bath apparatus, and the partial condensation on the dilatometers and thermometers preventing an equalisation of temperature, and resulting in incorrect readings. The water-bath was kept at an almost constant temperature by the vapour of boiling ether, carbon bisulphide, chloroform, etc., according to the heat required.

In fig. 10, A is a cylindrical copper vessel, with a non-conducting jacket, for boiling the ether, etc., and B is an inner water-bath to contain the dilatometers *c*, and thermometer. A metal plate, *d*, protects the under surface of B from splashes from the boiling liquid, and by means of an Allihn's condenser, *e*, the vapour is condensed, the liquid flowing back into A. The whole is heated by immersion in an oil-bath, C. Ten dilatometers can be employed at a time. Uniformity in the temperature of the water is maintained by revolving the lid of the bath. When the thermometer has registered the same temperature for a quarter of an hour—the oil in the dilatometer being at a constant level during the same period—the increase in volume is read off, the bath-lid being raised for this purpose, and a slight correction for the resultant cooling effect of the air. In transparent oils, the lower meniscus is read ; in opaque oils, the upper meniscus. The dilatometer is filled with oil by suspending it upside down, as shown to the left of the figure, in a basin containing the oil, and exhausting the air from the inside by means of a fine tube connected with an air-pump, so that the oil rises steadily in the dilatometer without the production of air-bubbles. Any bubbles caused by the withdrawal of the suction-tube must be carefully removed by the aid of the air-pump. The inside of the dilatometer tube is cleansed by careful wiping with a plug of wadding. To empty the dilatometer, the above proceeding is reversed, the oil being expelled by air forced in through the capillary tube, ether being afterwards employed to remove all traces of the oil. The difference between the temperature of the vapour-chamber and that of the water-bath is only about 0·1° C., and this is reduced, by stirring, to a few hundredths of a degree. In order to avoid error, readings are taken before and after stirring, and the mean is taken for the subsequent calculation.

The results given in the tables which accompany the paper by Holde show that the variations in the expansive properties of mineral lubricating oils of different origin are but slight. The rule that increase in specific gravity is accompanied by decreased expansion holds good in general. The presence of paraffin (solid hydrocarbons) has the effect of reducing the specific gravity of the oil (owing, according to Dr. Albrecht, to its extraordinarily high rate of expansion on liquefaction in liquid hydrocarbons), the coefficient of expansion being raised at the same time.

The German oils have a comparatively high rate of expansion at low temperatures, but do not expand more than the Russian oils at a higher temperature (between 30° and 50° C.); whereas the coefficient of expansion of the Scottish oils, and such American oils as are rich in paraffin, increases with the temperature, and exceeds that of the German and Russian oils. The thick blackish oils of various origins which were tested gave irregular results in the confirmatory experiments, the discrepancies being accounted for partly by the irregular distribution of the solid particles in suspension, and probably also by differences in consistency, especially in the case of one sample, which appeared to be solely composed of residues. It does not appear from the

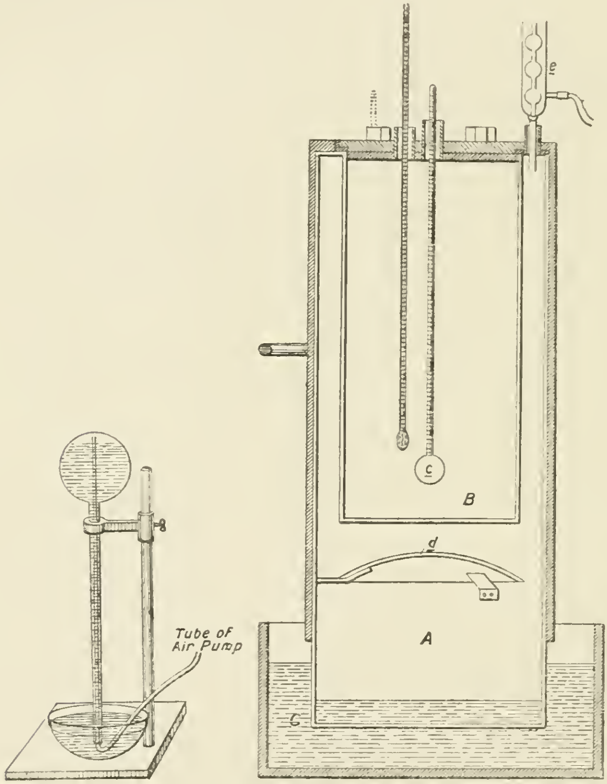


Fig. 10.—Dilatometer.

tables already referred to that any simple relation exists between change of fluidity and expansion. As was to be expected, the variations of fluidity were greater in oils containing paraffin (solid at low temperatures) than in the oils free from paraffin.

The presence of solid paraffin and asphalt has a peculiar influence on the fluidity of the oil, particularly when the temperature of the sample is reduced, as these bodies require a long time to separate completely, and the establishment of normal testing-conditions is consequently difficult. The general characteristics deducible from these experiments may be summed up as follows:—

The heavy viscous mineral lubricating oils of various origins, of a minimum specific gravity of 0·908, show very little variation in the rate of expansion between 20° and 78° C., the coefficient ranging between 0·00070 and 0·00072.

Those containing paraffin, and solid below 20° C., such as the German oils, have between 12° and 20° C., on the melting of the paraffin, a higher coefficient, viz. 0·00075 to 0·00081. Dr. Albrecht found the difference of the coefficients somewhat greater, viz. 0·0004 for German, 0·0007 for Russian, and 0·0005 for American oils.

The less viscous oils, for lighter machinery, of specific gravity lower than 0·905 at 15° C., have a higher coefficient than the first class, viz. 0·00072 to 0·00076 between 20° and 78° C.

The completely fluid oils exhibit, with rising temperature, a gradual increase in the rate of expansion. The oils containing paraffin have a decreasing coefficient with increasing temperature until fully fluid, when they follow the above rule.

In the case of kerosene, the practice in the trade in the United Kingdom is to add to or subtract from the specific gravity at 60° F. 0·0004 for every 1° F. above or below that temperature. Tables founded on a formula of Gay-Lussac are in use in America for calculating the alterations in volume of crude petroleum under variation of temperature.

According to the author's experience, the following corrections for each 1° F. should in practice be made :—

For products lighter than kerosene, 0·00040 to 0·00048.
,, kerosene, 0·00040.
,, gas oils, 0·00036.
,, lubricating oils, 0·00034.

Calorific Value.—The elaborate researches undertaken in 1869 by Sainte-Claire-Deville [1] on the physical properties of crude oils from the principal oil-districts then in operation, showed that the oil of Baku possessed a higher calorific power than that of other districts, and that the practically ascertained heating-power was lower than that found by calculation from the known composition of the oil. Some of his results for crude oils are given in Table XXII.

Determinations of the calorific values of various descriptions of Texas crude petroleums, made in the laboratory of the University of Texas Mineral Survey, have furnished the following results (Table XIV) :—

TABLE XIV.—Calorific Values of Texas Crude Oils.

Source of Sample.	Calories.[2]	B.Th.U.[2]
Lucas Well, Spindle Top, Jefferson county, . . .	10,874	19,574
Higgins Oil and Fuel Co., Spindle Top, Jefferson county,	10,992	19,785
Sour Lake, Hardin county, ...	10,201	18,362
Sour Lake, Hardin county, ...	10,305	18,694
Northeast of Fort Stockton, Pecos county, . . .	9,655	17,387
Near Dunlay, Medina county, ...	9,372	16,807
Dullnig Wells, Bexar county, ...	8,531	15,356
Walsh Tract, Bexar county, ...	9,177	16,518

[1] *Comptes Rend.*, lxvi, 442 ; lxviii, 349, 485, 686 ; and lxxii, 191.

[2] The Calorie is the heat required to raise the temperature of one kilogram of water from 0° to 1° C. The British Thermal Unit (B.Th.U.) is the amount of heat required to raise the temperature of a pound of water from 50° to 51° F. Calories (kilogram-degrees C.) per kilogram multiplied by $\frac{9}{5}$, or 1·8, give the calorific value in B.Th.U. (pound-degrees F.) per lb. of combustible.

The calorific value of a large number of crude oils, fuel oils, and distillates are given in Table XV, A to E. With the exception of the *net* values for petrol by Watson and Thomas, the calorific value was in all cases determined in some type of bomb calorimeter.

The method employed to obtain the *net* values by Watson and Thomas was to carburet air with the vapour at a suitable temperature to ensure complete vaporisation, the mixture being then burnt in a Boys' gas calorimeter, the instrument officially recognised by the Metropolitan Gas Referees.

It will be noted that with distillates of the same class there is a close agreement in the heating value when referred to weight of fuel: it follows that when referred to volume, the commercial unit in the case of the lighter distillates, the advantage is considerably in favour of the distillates of higher density.

TABLE XV.—CALORIFIC VALUE OF PETROLEUMS AND PETROLEUM PRODUCTS.

XVA.—CRUDE OILS (W. INCHLEY).[1]

Description.	Specific Gravity.	Calories per kilogram.	B.Th.U. per lb.
American, . . .	..	10,912	19,650
Canadian, . . .	0·859	10,797	19,420
Caucasian, . . .	..	10,328	18,600
Java, ...	0·867	10,654	19,180
Russian, . . .	0·871	10,833	19,500
Texas, ...	0·947	10,517	18,945

XVB.—HEAVY FUEL OILS.

Description.	Specific Gravity.	Calories per kilogram.	B.Th.U. per lb.	Authority.
American—				
Texas, . .	0·919	10,670	19,200	Redwood
,, . .	0·923	10,755	19,360	,,
,, . .	0·935	10,748	19,345	,,
,, . .	0·941	10,957	19,720	,,
,, . .	0·928	10,750	19,350	Brame
,, . .	0·934	10,900	19,630	,,
"Anglo-American,".	0·889 (20°)	10,780	19,400	H. Moore
Mexican, . .	0·949 (20°)	10,350	18,630	,,
Argentine, . .	0·942	10,680	19,220	Brame
Chile, . . .	0·9518 (20°)	10,110	18,200	H. Moore
Assam (Digboi), .	0.890	10,312	18,562	,,
Borneo, . . .	..	10,371	18,670	Redwood
,, . . .	..	10,340	18,600	,,
,, . . .	0·915	10,780	19,400	Brame
,, . . .	0·939 (20°)	10,360	18,650	H. Moore
Burma, . . .	..	10,794	19,430	Redwood
,, . . .	..	10,924	19,660	,,
,, . . .	0·924	10,520	18,950	Brame
,, . . .	0.900	10,610	19,100	
Persian, . .	0·894 (20°)	10,550	18,990	H. Moore
Russian (Ostarki), .	0·914	10,990	19,780	Brame
,, ,, .	0·920	10,580	19,040	,,
,, ,, .	0·906	11,170	20,100	W. Robinson
Shale Oil Fuel, .	0·880	11,570	19,030	,,
,, ,, .	0·803	11,150	20,070	,,
Venezuela, . .	0·955 (20°)	9,683	17,430	H. Moore

[1] *Engineer*, 1909.

XVc.—Diesel Engine Oils (J. S. S. Brame).

Specific Gravity.	Calories per kilogram.	B.Th.U. per lb.
0·8615	11,095	19,970
0·863	11,070	19,925
0·869	10,980	19,760
0·889	10,940	19,690
0·890	10,890	19,600
0·893	10,925	19,665
0·896	10,790	19,420
0·905	10,780	19,400
0·927	10,715	19,290
0·945	10,660	19,190

XVd.—Kerosenes.

Description.	Specific Gravity.	Calories per kilogram.	B.Th.U. per gal.	Authority.
American—				
"Royal Daylight," .	0·797	11,167	159,000	W. Inchley
,, ,, .	0·797	11,170	160,200	W. Robinson
"Tea Rose," . .	0·8055	11,100	160,500	Brame
"Homelight," .	0·807 (22°)	10,960	159,200	H. Moore
"White Rose," .	0·800	11,140	160,400	,,
Kerosene, . .	0·780	11,163	156,500	W. Inchley
"Petrolite," . .	0·814 (20°)	11,020	161,465	H. Moore
Russian-Baku, . .	0·825	11,270	167,000	,,
,, ,, . .	0·8248	11,060	164,000	Brame
,, ,, . .	0·825	11,270	167,360	W. Robinson
Rumanian, . . .	0·8172	10,900	159,500	Brame
"Oil Engine" Oils—				
Flash-point 104° F.,	0·816	11,225	164,870	,,
,, ,, 118° F.,	0·8155	11,170	163,960	,,
,, ,, 124° F.,	0·815	11,130	163,280	,,
(Shale),, ,, 86° F.,	0·768 (20°)	11,250	155,520	H. Moore

XVe.—Petrols.

(B. Blount, *Inst. Automobile Engines*, pp. 1–6, March 1909.)

Description.	Specific Gravity.	Calories per kilogram.	B.Th.U. per lb.	B.Th.U. per gal.
Anglo ·760, ...	0·739	11,162	20,092	148,480
Shell, ...	0·717	11,252	20,254	145,220
Pratt's, ...	0·717	11,229	20,212	144,920
Carless Capel "Standard," .	0·700	11,302	20,344	142,400
Carless Capel "Morvil," .	0·718	11,200	20,160	144,760
Carburine, ...	0·717	11,187	20,137	144,380
Russian, ...	0·705	11,232	20,218	142,530
Net Calorific Values (W. Watson and J. S. G. Thomas, *I. Inst. Automob. Engs.*, 434, 1909).				
Bowley's Special, . .	0·684	10,660	19,190	131,500
Carless, ...	0·704	10,420	18,760	132,300
Express, ...	0.707	10,420	18,040	127,600
Ross, ...	0·714	10,370	18,670	133,600
Pratt, ...	0·719	10,340	18,610	134,100
Carburine, ...	0·720	10,380	18,680	135,000
Shell (ordinary), . . .	0·721	10,400	18,720	135,300
Dynol, ...	0·725	10,290	18,520	134,600
Simcar benzol, . . .	0·762	9,490	17,080	130,400
0·760 Shell ("Crown"), .	0·767	10,140	18,250	140,300

TABLE XVI.—Calorific Power of various Descriptions of Petroleum, etc.

Description of Oil.	Specific Gravity at 0° C.	Chemical Composition.			Coefficient of Expansion.	Amount of Water evaporated per unit of fuel.	Calories per kilogram.
		Carbon.	Hydrogen.	Oxygen, etc.			
Heavy petroleum from West Virginia,	0·873	83·5	13·3	3·2	0·00072	14·58	10,180
Light ,, ,, ,,	0·8412	84·3	14·1	1·6	0·000839	14·55	10,223
,, ,, ,, Pennsylvania,	0·816	82·0	14·8	3·2	0·00084	14·05	9,963
Heavy ,, ,, ,,	0·886	84·9	13·7	1·4	0·000721	15·30	10,672
American petroleum,	0·820	83·4	14·7	1·9	0·000868	14·14	9,771
Petroleum from Parma,	0·786	84·0	13·4	1·8	0·000706	13·96	10,121
,, ,, Pechelbronn,	0·912	86·9	11·8	1·3	0·000767	14·30	9,708
,, ,, ,,	0·892	85·7	12·0	2·3	0·000793	14·48	10,020
,, ,, Schwabweiler,	0·861	86·2	13·3	0·5	0·000858	15·36	10,458
,, ,, ,,	0·829	79·5	13·6	6·9	0·000843	..	..
,, ,, Hanover, Eddesse,	0·892	80·4	12·7	6·9	0·000772	..	..
,, ,, ,, Wietze,	0·955	86·2	11·4	2·4	0·000641	..	..
,, ,, East Galicia,	0·870	82·2	12·1	5·7	0·000813	14·23	10,005
,, ,, West Galicia,	0·885	85·3	12·6	2·1 (N.O.)	0·000775	14·79	10,231
Shale-oil from Ardèche, Vagnas,	0·911	80·3	11·5	8·2 (O.S.N.)	0·000896	12·24	9,046
Coal-tar from Paris gas-works,	1·044	82·0	7·6	10·4	0·000743	12·77	8,916
Petroleum from Balakhani,	0·822	87·4	12·5	0·1	0·000817	..	11,700
Light petroleum from Baku,	0·884	86·3	13·6	0·1	0·000724	16·40	11,460
Heavy,	0·938	86·6	12·3	1·1	0·000681	15·55	10,800
Petroleum-residues from the Baku factories,	0·928	87·1	11·7	1·2	0·00091	..	10,700
Petroleum from Java,	0·923	87·1	12·0	0·9	0·000769	15·02	10,831
Heavy oil of pine (Landes),	0·985	87·7	10·4	2·5	0·000685	14·75	10,081

Veith[1] gives the calorific value of various petroleums, etc., in Table XVI.

Specific Heats.—Mabery and Goldstein[2] have carried out a lengthy experimental investigation of the *specific heat*, and *latent heat or heat of vaporisation*, of certain petroleum hydrocarbons, and have published the following results and conclusions. It was found by the authors that impurities lowered the specific heat considerably.

Although the paraffin series of hydrocarbons afford the best field for study of an homologous series, very little has been done in the direction of ascertaining the specific heats of these bodies.

In a study of distillates separated from Pennsylvania petroleum, by Bartoli & Stracciati, the specific heats of the following hydrocarbons were determined:—

TABLE XVIIa.—Specific Heats of Hydrocarbons.

	Temperature	Specific Heat.
Hexane C_6H_{14},	16°–37°	0·5042
Heptane C_7H_{16},	16°–37°	0·4869
Octane C_8H_{18},	12°–19°	0·5111
Decane $C_{10}H_{22}$,	14°–18°	0·5057
Tetradecane $C_{14}H_{30}$,	..	0·4995
Hexadecane $C_{16}H_{34}$,	15°–22°	0·4963

The following table shows the results of from three to six determinations for each hydrocarbon made at the temperatures 0° and 50°.

TABLE XVIIa.—*continued.*

	Boiling-point.	Specific Heat.
C_6H_{14},	68°	0·5272
C_7H_{16},	91°	0·5005
C_7H_{16},	98°	0·5074
C_8H_{18},	125°	0·5052
C_9H_{20},	151°	0·5034
$C_{10}H_{22}$,	162°	0·4951
$C_{10}H_{22}$,	172°	0·5021
$C_{11}H_{24}$,	195°	0·5013
$C_{12}H_{26}$,	214°	0·4997
$C_{13}H_{28}$,	226°	0·4986
$C_{14}H_{30}$,	242°	0·4973
$C_{15}H_{32}$,	260°	0·4966
$C_{16}H_{34}$	275°	0·4957
Commercial gasoline,	..	0·5135
Crude Ohio petroleum,	..	0·4951

TABLE XVIIa.—*continued.*

Specific Heats of Methylene Hydrocarbons.

	Boiling-point.	Specific Heat.
C_6H_{12},	68°	0·5062
C_7H_{14},	98°	0·4879
C_8H_{16},	119°	0·4863
C_9H_{18},	135°	0·4851
$C_{10}H_{20}$,	160°	0·4692
$C_{11}H_{22}$,	190°	0·4819
$C_{12}H_{24}$,	212°	0·4570
$C_{13}H_{26}$,	232°	0·4573
$C_{14}H_{28}$,	244°	0·4708
$C_{15}H_{30}$,	263°	0·4708

[1] Veith, *Das Erdöl*, 1892.

[2] "On the Specific Heats and Heat of Vaporisation of the Paraffin and Methylene Hydrocarbons." C. F. Mabery and A. H. Goldstein, *Amer. Chem. Journ.*, vol. xxviii, pp. 67–78 (1902).

It appears from these results that there is generally a decrease in specific heat with increase in molecular weight.

Furthermore, the normal hydrocarbons, such as heptane, C_7H_{16}(b.p. 98°), and decane, $C_{10}H_{22}$ (b.p. 172°), have higher specific heats than their isomers, such, for example, as isoheptane, C_7H_{16} (b.p. 91°), and isodecane, $C_{10}H_{22}$ (b.p. 162°).

The same variation also appears in the methylene series, with high values for certain members that probably indicate different structural relations.

The authors call attention to the materially lower values given by the methylene hydrocarbons as compared with the values for the paraffin hydrocarbons; and question whether this is due to greater compactness in the methylene molecule or to some quality of its ring structure.

TABLE XVIIa.—*continued.*

Specific Heats of a Series of Hydrocarbons separated from the High-boiling Portions of Pennsylvania Petroleum and belonging to the Series C_nH_{2n}.

	Boiling-point.	Specific Heat.
$C_{16}H_{32}$,	173°	0·4723
$C_{18}H_{36}$,	202°	0·4723
$C_{20}H_{20}$,	223°	0·4706
$C_{23}H_{46}$,	260°	0·4612
$C_{24}H_{48}$,	272°	0·4586

TABLE XVIIa.—*continued.*

Specific Heats of several Hydrocarbons separated from Texas Petroleum.
Series C_nH_{2n-2}.

	Boiling-point at 50 mm.	Specific Heat.
$C_{14}H_{26}$,	127°	0·4447
$C_{15}H_{28}$,	142°	0·4439
$C_{16}H_{30}$,	162°	0·4426
Series C_nH_{2n-4}.		
$C_{21}H_{38}$,	218°	0·4560
$C_{25}H_{46}$,	273°	0·4650

The latter results cannot be accepted as trustworthy, for the quantities of the hydrocarbons were very small, and the oil began to crystallise at 0°. There is no doubt that the specific heats of these hydrocarbons are smaller than those of the preceding series.

TABLE XVIIb.—Specific Heat of Crude Oils, etc.

	Specific Gravity.	Specific Heat.
Pennsylvania,	0·8095	0·5000
Berea Grit,	0·7939	0·4690
Japanese,	0·8622	0·4532
Texas (Lucas well),	0·9200	0·4315
Russian,	0·9079	0·4355
Wyoming,	0·8816	0·4323
California,	0·9600	0·3980
Texas,	0·9466	0·4009
Ohio,	..	0·4951 } Shown
Commercial gasoline,	..	0·5135 } above.

These values show that the specific heat of the crude oils is an important property from a practical point of view. It also appears that there is no close agreement between specific heat and specific gravity.

Pennsylvania oil stands at the head, and Berea Grit, with a much larger proportion of volatile constituents, is next.

Of the heavier oils, it appears in general that the specific heats are much lower, but with no definite relation.

Professor J. S. S. Brame has determined the specific heats of a number of typical samples of petroleum products handed to him by the author, together with that of a sample of Young's paraffin oil, and has obtained the following results :—

TABLE XVIIc.—Specific Heats between 12° and 25° C.

	Sp. Gr. (at 15° C.)	Sp. Ht.	Sp. Gr. × Sp. Ht.
Motor Spirit.			
Anglo-American Oil Company, Ltd.—Heavy ("Taxibus"),	0·7375	0·465	0·343
,, ,, Light ("Pratt's Perfection"),	0·7240	0·483	0·350
Asiatic Petroleum Company, Ltd.—"Shell," Heavy ("760 Benzine"),	0·7675	0·450	0·346
Asiatic Petroleum Company, Ltd.—"Shell," Light ("720 Benzine"),	0·7215	0·490	0·352
Kerosene.			
Anglo-American Oil Company, Ltd.—Water white,	0·799	0·457	0·365
,, ,, Standard white,	0·8035	0·450	0·362
Russian,	0·8248	0·435	0·358
Rumanian,	0·8127	0·444	0·361
Shale oil (Young's paraffin oil),	0·804	0·472	0·379
Fuel Oil.			
Russian,	0·914	0·448	
Burma,	0·897	0·433	
Texas,	0·927	0·436	

In reference to these results, Prof. Brame points out that for the heavy oils there does not appear to be any defined relationship between specific gravity and specific heat, which is in agreement with Mabery and Goldstein's experience, but that with motor spirit and kerosene of the same grade there certainly does appear to be a good relationship ; indeed, a factor for dividing into the specific gravity can be suggested which would give approximate values for the specific heat. This factor is for kerosene 0·362, and for motor spirit 0·348. It will be noted that shale distillate gives an abnormal value.

Scheller and Gheorghiu [1] used a novel method of burning naphthalene in a Mahler bomb calorimeter, the surrounding fluid being the oil under examination. The following values were obtained for Rumanian petroleum and unrefined products :—

Crude Oils.—Policiori, 0·4724 ; Campina (rich in paraffin wax), 0·4675 ; Campina (poor in paraffin wax), 0·4667 ; Bustenari, 0·4625.

Products.—Light benzine (0·7215 sp. gr.), 0·484 ; heavy benzine (0·7464 sp. gr.), 0·4679 ; petroleum oil (0·8142 sp. gr.) 0·4652 ; gas oil (0·8642 sp. gr.), 0·4619 ; light spindle oil (0·9143 sp. gr.), 0·4597 ; refined lubricating oil I. (0·9100 sp. gr.), 0·4579 ; II. ditto (0·9100 sp. gr.), 0·4567.

According to Karawajeff [2] the mean specific heat of various fractions

[1] *Petr.*, viii, 533 (1913); *J.S.C.I.*, 126 (1913). [2] *Petr.*, ix, 550 (1914).

increases rapidly with the temperature; thus with specific heat approximating to 0·48 at 100° C., at 400° it approximates to 0·60. Between 100°–400° C. the specific heat with the majority of petroleum products can be expressed as a linear function of the temperature, thus sp. ht. $=0{\cdot}4825+0{\cdot}000385(t-100)$.

The specific heats of heavy petroleum fraction, as determined by N. Karawajeff showed that most heavy oils possess a value of ·48 at 100° C. and 60° at 400° C.

H. E. Wales[1] gives the following values for the specific heat of Californian petroleums at 20° C. Three oils yielding no distillate below 300° C., 0·3999–0·4389; five oils yielding no distillate below 150° C., 0·4419–0·4788; four other oils, 0·4474–0·5016.

Heat of Vaporisation.—The heat of vaporisation of hydrocarbons is an important physical property about which information is very scanty.

The following tables give the mean of several observations for members of the paraffin and polymethylene series of hydrocarbons:—

TABLE XVIIIa.—Heat of Vaporisation.

	Boiling-point.	Heat of Vaporisation in Calories.
Hexane C_6H_{12},	68°	79·4
Heptane $C_{17}H_{16}$,	88°	74·0
Octane C_8H_{18},	125°	71·1

TABLE XVIIIb.—Determinations for certain Methylene Hydrocarbons.

	Boiling-point.	Heat of vaporisation in Calories.
Hexamethylene C_6H_{12},	68°–70°	87·3
Dimethylpentamethylene C_7H_{14},	90°–92°	81·0
Methylhexamethylene C_7H_{14},	98°	75·7
Dimethylhexamethylene C_8H_{16},	118°–119°	71·7

These indicate rapid falling off in latent heat with increase in molecular weight.

RESULTS OF FRACTIONAL DISTILLATION.

The **boiling-points** of crude oils, and the amounts of distillate obtained at specified temperatures, differ considerably, as shown in Table XIX, the first part of which is by Engler and Levin,[2] the second by Engler,[3] the third by Kramer,[4] and the fourth by Gintl.[5]

The first part of Table XX relating to Galician crude petroleum is based upon results obtained in the laboratory of the author, while the other two parts are given upon the authority of Nawratil.[6]

[1] *J. Ind. and Eng. Chem.*, vi, 727 (1914).
[2] *Dingler's polytechn. Journ.*, cclxi, 32 (1886).
[3] *Dingler's polytechn. Journ.*, cclx, 337 (1886).
[4] *Sitz. Ver. Beförd. des Gewerbefl. Preuss.*, 294 (1885).
[5] Karmarsch and Heeren, *Technologischies Wörterbuch.* Ed. iii, Kick and Gintl, 618 (1876).
[6] *Dingler's polytechn. Journ.*, ccxlvi, 328 (1882).

TABLE XIX.—Boiling-points of Crude Petroleum, and Amounts of Distillate at various Temperatures.

1.

Oil from	Specific Gravity at 17° C.	Distillation commenced at – C°.	Per cent. by Volume distilling at ° C.										
			Below 130°.	130° to 150°.	150° to 170°.	170° to 190°.	190° to 210°	210° to 230°.	230° to 250°.	250° to 270°.	270° to 290°.	290° to 300°.	Above 300°.
Pennsylvania, 1,	0·8175	82°	15	6	5	5	5	5·75	4·75	6	4·75	2	40·75
Pennsylvania, 2,	0·8010	74°	24·5	7	4·5	4·5	6·5	5	4·75	3·25	4	2·5	33·5
Galicia (Sloboda-Rungurska),	0·8235	90°	16	10·5	10·25	6·5	6·5	7	6·75	6	3·5	0·5	26·5
Baku (Bibi-Eibat),	0·8590	91°	16	7	6·5	6·5	5	5	5	5·5	3·5	1	39
,, (Balakhani),	0·8710	105°	3·75	4·75	5·5	4·75	5·25	5	7	4·75	5·5	1·75	52
Alsace (Pechelbronn),	0·9075	135°	..	3	4·4	5·4	4·5	6·6	7·3	7	10·3	4·5	47
Hanover (Oelheim),	0·8990	170°	..	..	..	4·75	5·25	6	4	5	5	2	68

2.

Product.	Average Percentage Yield from Oil of				
	Pennsylvania.	Galicia.	Rumania.	Alsace.	Baku.
Light oil,	10 to 20	3 to 6	4	..	5 to 10·6
Burning oil,	60 to 75	55 to 65	60 to 70	35 to 40	36 to 60
Residue,	5 to 10	30 to 40	25 to 35	55 to 60	36 to 60

TABLE XIX.—*continued.*

3.

Oil from	Specific Gravity.	Distillates obtained below ° C. 150° Per Cent.	150° Sp. Gr.	250° Per Cent.	250° Sp. Gr.	300° Per Cent.	300° Sp. Gr.	Above 300° Per Cent.	Above 300° Sp. Gr.	Residue and Loss.
Tegernsee (Bavaria)	0·812	20·04	0·726	26·12	0·782	14·02	0·825	35·91	0·856	3·07
Alsace, . .	0·888	1·30	0·720	16·37	0·778	17·07	0·824	47·88	0·903	16·28
Oelheim (Hanover),	0·885	0·74	0·750	11·05	0·805	9·75	0·852	73·91	0·910	3·92
Pennsylvania, .	0·814	14·34	0·725	25·35	0·811	13·75	0·820	40·99	0·850	5·57
West Galicia, .	0·842	14·21	..	16·93	..	12·30	..	47·58	..	8·95
Wallachia, . .	0·857	14·32	..	22·59	..	13·86	..	39·51	..	9·72
Baku, . .	0·880	0·63	0·762	21·73	0·811	15·55	0·825	57·97	0·903	4·12
Kuban, . .	0·930	2·30	..	10·60	..	3·20	..	64·40	..	9·50

4.

Oil from	Specific Gravity.	Light Oil.	Burning Oil. I.	Burning Oil. II.	Paraffin.	Tar.	Coke and Loss.
Pennsylvania, . . .	0·824	15·00	47·00	20·00	..	12·00	6·00
Canada, ...	0·845	20·00	50·00	19·00	3·00	5·00	2·00
Rangoon, ...	0·885	4·01	40·70	36·99	6·07	4·61	7·62
Red Sea, ...	0·912	2·50	30·00	57·00	5·22	3·70	1·60
Siary (Galicia), . . .	0·827	8·50	44·85	24·22	..	13·25	9·18
Boryslaw (Galicia), . .	0·842	9·38	52·49	12·57	11·40	2·48	11·10
Bukowina, ...	0·84	10·00	25·70	18·30	12·40	23·60	10·00
Rumania, ...	0·846	10·00	61·28	20·60	2·23	..	5·89
Baku, ...	0·865	8·50	40·70	18·30	5·00	15·00	12·50

TABLE XX.—Results of Fractional Distillation of Galician Crude Petroleum.

No.	Locality.	Sp. Gr. of Crude Oil.	Specific Gravity of Distillate. A.	B.	C.	D.	E.	Commercial Products. F.	G.	H.
1	Sloboda-Rungurska, .	0·845	0·724	0·763	0·792	0·821	0·841	12·0	35·9	41·6
2	,, ,, .	0·860	0·743	0·771	0·789	0·825	0·835	8·8	37·4	40·0
3	Ustrzyki district, .	0·846	0·764	0·782	0·803	0·823	0·842	9·6	38·4	44·3
4	,, ,, .	0·912	0·786	0·829	0·867	..	..	2·6	17·4	58·6
5	Harklowa, . .	0·901	0·760	0·806	0·846	0·878	..	7·5	32·5	51·8
6	Lanczyn, . . .	0·875	0·720	0·756	0·791	0·828	0·856	8·4	36·5	50·3

A. First tenth by volume.
B. Second ,, ,,
C. Third ,, ,,
D. Fourth ,, ,,
E. Fifth tenth by volume.
F. Percentage by weight of petroleum spirit.
G. ,, ,, kerosene.
H. ,, ,, intermediate and heavy oils.

TABLE XX.—*continued.*

Locality.	Kleczany.		Ropa.		Ropa.		Wojtowa.		Libusza.		Sekowa.	
Formation,	Cretaceous, 189 metres.		Cretaceous, 63 metres.		Cretaceous, 60 metres.		Eocene, 160 metres.		Eocene, 137 metres.		Eocene, 114 metres.	
Colour,	Reddish-yellow.		Brownish-red.		Reddish-brown.		Greenish-black.		Greenish-black.		Greenish-black.	
Specific gravity,	0·779		0·808		0·800		0·835		0·837		0·837	
Distillate,	Specific gravity.	Per-centage.	Specific gravity.	Per-centage.	Specific gravity.	Per-centage.	Specific gravity.	Per-centage.	Specific gravity.	Per-centage.	Specific gravity.	Per-centage.
100,	..	12·30	..	1·90	..	9·30	..	1·60	..	4·30	..	2·00
100 to 150,	0·742	31·20	0·738	24·70	0·735	18·20	0·764	11·90	0·745	14·70	0·747	20·00
150 to 200,	0·775	14·60	0·773	18·00	0·773	12·80	0·792	14·60	0·803	17·80	0·783	15·70
200 to 250,	0·783	9·60	0·810	12·40	0·805	10·80	0·822	16·90			0·823	11·20
250 to 300,	0·802	9·30	0·841	11·60	0·838	10·60	0·849	18·80	0·841	11·40	0·857	10·50
300 to 350,	0·837	5·20	0·865	9·80	0·868	12·30	0·862	13·70	0·856	9·90	0·879	8·60
350 to 400,	0·852	9·60	0·885	15·90	0·880	24·60	0·895	20·40	0·878	20·80	0·907	10·90
Above 400,	0·895	8·00	..	4·60					0·915	15·70	0·914	18·50
"Petroleum gum,"	..	0·05	..	0·10	..	0·10	..	0·20	..	0·60	..	0·10
Coke,	..	0·05	..	0·60	..	0·80	..	1·10	..	3·00	..	1·50
Loss,	..	0·10	..	0·40	..	0·50	..	0·80	..	1·80	..	1·00
	..	100·00	..	100·00	..	100·00	..	100·00	..	100·00	..	100·00

TABLE XX.—*continued.*

Locality.	Formation.		Colour.	Specific Gravity.	Light Oil, to 150° C.	Petroleum Distillate, 150° to 300°.	Lubricating Oil above 300°.	Coke and Loss.
					Percentage.	Percentage.	Percentage.	Percentage.
Ropa, .	Cretaceous,		Reddish-brown	0·853	11·40	39·80	46·50	2·30
Wojtowa,	Eocene,	114 m.	Greenish-black	0·820	12·40	43·60	41·50	2·50
Libusza,	Cretaceous,	140 m.	,,	0·842	13·30	32·80	49·40	4·00
Starunia,	Salt-layer,	36 m.	,,	0·845	10·90	34·90	50·90	3·30
Lipinki,	Eocene,	133 m.	Greenish-black	0·850	20·90	30·30	44·00	4·80
Siary, .	,,	124 m.	Brownish-black	0·853	11·30	31·90	52·30	4·50
,, .	,,	189 m.	Blackish-brown	0·847	20·00	31·20	43·30	5·50
Pagorzyn,	,,	111 m.	Brownish-black	0·849	9·80	45·40	40·60	4·20
Mecina, .	,,	230 m.	Greenish-black	0·853	19·60	33·10	42·90	4·40
Kleczany,	,,	57 m.	Dark green	0·870	3·40	38·60	54·50	3·50
Kryg, .	,,	170 m.	Brownish-black	0·876	8·00	32·60	53·20	6·20
Harklowa,	,,	114 m.	,,	0·898	6·70	28·20	58·20	6·90
,,	,,	111 m.	,,	0·902	5·70	30·10	56·70	7·50

Table XXI gives the proportions of some of the commercial products obtained from typical specimens of crude petroleum, examined in the laboratory of the author. The process of distillation was in each case substantially the same, and the results are, therefore, fairly comparable, but on the large scale, an increased yield of kerosene, due to "cracking," would in many instances be obtained. In the last column of the table the percentages of coke obtained on distillation to dryness are recorded, and it will be seen that these vary considerably, the extremes being 0·1 and 26·3.

According to the author's experience, the largest proportion of solid hydrocarbons is found in the crude oils of Burma and in some of those of Borneo, whilst in others from the same locality in the latter country there is very little. A large proportion is also found in the oils of Assam, Java, Timor, Cuba, Alsace, Algeria, New Zealand, Maikop, and Tcheleken. The oils of the United States usually give a moderate yield, in common with those of Canada, Galicia, Rumania, Persia, Egypt, and Lower Burma, whilst those of Baku, Peru, Mexico, and Trinidad contain, as a rule, very little.

TABLE XXI.—COMMERCIAL PRODUCTS OF CRUDE PETROLEUM.

a, Specific gravity ; *b*, Percentage of petroleum-spirit (benzine) ; *c*, Kerosene ; *d*, Intermediate and lubricating oils, with solid hydrocarbons ; *e*, Coke.

	a	*b*	*c*	*d*	*e*
America :—					
Pennsylvania, Bradford, . .	0·810	20·0	50·0	25·3	1·12
,, Parker (Clarion), .	0·797	21·0	74·1	..	1·36
,, Karns City, . .	0·787	32·0	64·4	..	..
,, Thorn Creek, .	0·802	21·0	74·3	..	1·4
,, Stoneham, . .	0·802	15·0	75·0	6·6	1·8
,, Washington, .	0·788	18·1	71·1	0·8	0·1
Ohio, Macksburg, ...	0·829	11·0	49·0	35·7	1·8
,, Lima, ...	0·839	83·0		6·9	4·1
Texas, ...	0·923	98·5		1·1	..
,, ...	0·927	94·5		2·5	..
Colorado, ...	0·806	18·0	39·7	36·8	0·6
Indian Territory, ...	0·825	8·5	45·0	40·6	0·6

TABLE XXI.—*continued.*

a, Specific gravity ; *b*, Percentage of petroleum-spirit (benzine) ; *c*, Kerosene ; *d*, Intermediate and lubricating oils, with solid hydrocarbons ; *e*, Coke.

	a	*b*	*c*	*d*	*e*
Indian Territory,	0·970	..	..	95·8	4·8
,,	0·859	4·4	38·0	50·3	3·8
Wyoming,	0·911	2·5	27·5	53·0	11·0
,,	0·862	..	18·6	79·0	0·8
,,	0·910	1·9	24·4	56·3	11·5
California, Pico Cañon,	0·844	15·0	45·0	32·0	..
,, Puente,	0·880	12·5	22·0	42·6	10·2
Alaska,	0·869	..	19·0	78·6	1·7
,,	0·914	..	9·0	87·6	2·7
,,	0·800	24·8	53·9	16·7	1·2
Canada, Petrolea,	0·858	2·5	57·5	..	4·08
,, Gaspé,	0·847	8·75	48·0	40·0	2·75
,, ,,	0·795	22·1	34·3	42·0	0·8
,, ,,	0·828	15·9	41·3	40·5	1·4
New Brunswick,	0·857	2·0	23·5	67·0	5·3
Newfoundland,	0·843	..	37·6	58·6	2·1
,,	0·805	18·0	38·1	41·0	1·2
,,	0·808	12·7	55·2	28·7	1·0
Alberta (Calgary),	0·750	78·0	19·5	2·5	..
Mexico,	0·874	..	37·0	62·25	0·5
,,	0·882	..	27·75	66·0	..
,,	0·970	..	..	88·5	6·5
,,	0·939	2·6	15·6	66·3	12·1
,,	0·986	..	..	81·7	15·7
,, Isthmus of Tehuantepec,	0·959	..	..	91·3	6·7
,, ,,	0·933	..	..	90·0	4·0
Barbados,	0·951	..	..	94·0	5·0
Trinidad,	0·914	2·0	17·0	72·3	8·6
,,	0·814	44·0	36·0	22·0	..
Colombia,	0·926	..	..	91·3	7·45
Ecuador,	0·928	2·14	15·61	70·89	8·82
Peru,	0·859	11·0	42·0	41·5	..
Argentina,	0·935	..	..	86·77	..
,,	0·930	..	2·0	15·0	83·0
Russia—					
Balakhani-Sabuntchi,	0·873	6·3	32·5	57·1	3·0
Surakhani,	0·780	48·9	43·9	..	..
Grozni,	0·884	20	20	50	5·9
,,	0·874	19·2	16·4	56·7	5·9
Ilsky,	0·853	20·0	40·0	35·0	..
,,	0·940	1·0	9·0	83·35	6·25
Kudako,	0·860	12·72	33·67	39·6	10·6
Kertch,	0·887	..	29·0	70·5	..
Black Sea,	0·826	23·7	43·8	32·8	2·1
Anapa,	0·900	11·2	15·2	61·2	5·8
Suvorov,	0·914	9·5	8·8	71·0	5·7
Guri,	0·955	1·5	11·2	70·1	13·8
,,	0·968	..	..	87·33	9·9
Island of Sakhalin (Nutowo),	0·903	..	30·0	70·0	..
Galicia :—					
Sloboda-Rungurska,	0·845	12·5	37·5	40·7	8·3
,,	0·860	8·8	37·4	40·0	7·0
Lanczyn,	0·875	8·4	36·5	50·3	..
Ustrzyki,	0·846	9·6	38·4	44·3	3·13
,, (Lodyna),	0·840	17·0	30·0	45·5	4·0
Harklowa,	0·901	4·0	23·0	58·6	8·75
Rumania,	0·859	..	18·9	80·6	0·5
,,	0·845	28·85	26·3	42·5	1·6
,,	0·860	1·75	54·6	38·3	2·1
,,	0·839	..	57·25	41·2	1·3
,,	0·890	..	27·5	64·15	2·6

TABLE XXI.—*continued.*

a, Specific gravity ; *b*, Percentage of petroleum-spirit (benzine) ; *c*, Kerosene ; *d*, Intermediate and lubricating oils, with solid hydrocarbons ; *e*, Coke.

	a	*b*	*c*	*d*	*e*
Rumania, ...	0·896	2·0	25·1	67·6	3·1
,, ...	0·882	4·5	32·0	61·2	2·3
,, ...	0·846	21·26	33·86	40·28	2·97
,, ...	0·899	12·8	23·1	55·3	7·0
,, ...	0·829	26·2	19·4	48·7	2·7
,, ...	0·823	9·0	47·4	41·9	0·8
Alsace, ...	0·886	4·0	31·4	52·7	7·9
,, ...	0·873	10·0	26·1	57·1	5·7
Hanover, Horst, ...	0·872	1·94	35·1	59·0	2·0
Italy :—					
Neviano, ...	0·805	18·9	69·5	11·0	0·2
Ozzano, ...	0·807	37·3	40·4	19·9	0·3
,, ...	0·787	43·9	46·5	5·5	. .
Spain :—					
Huidobro, ...	0·921	. .	. .	78·0	10·0
Zante, ...	1·02	. .	. .	76·24	18·44
Algeria, ...	0·921	0·75	28·25	60·75	9·77
,, ...	0·879	3·8	32·4	51·8	7·1
,, (Ain Zeft), ...	0·888	6·2	20·4	61·9	8·0
,, ...	0·814	27·0	43·0	30·0	1·9
Gold Coast, Apollonia, . . .	. .	. .	. .	82·7	12·8
,, ...	0·972	. .	. .	80·9	11·9
Somaliland, ...	0·897	. .	34·0	66·0	. .
Persia, ...	0·846	. .	47·3	47·8	2·7
,, ...	0·900	. .	. .	97·0	2·0
,, (Tehiah Sourks, drilled well),	0·815	9·4	57·6	31·4	1·1
East Indies :—					
Upper Burma (Yenangyaung), .	0·869	1·35	25·78	67·98	. .
,, (at 2095 feet), .	0·827	33·0	41·5	21·5	. .
Lower Burma, ...	0·834	9·0	57·5	32·0	0·2
,, ...	0·825	9·25	69·25	21·25	0·1
Assam (Digboi), ...	0·857	8·8	37·8	49·4	3·8
,, (Budderpore), ...	0·980	. .	25·0	75·0	1·8
Khatan, ...	1·0	. .	. .	64·0	26·3
Eastern Archipelago—					
Java, ...	0·881	. .	46·8	46·1	7·1
,, ...	0·844	1·5	56·6	41·1	1·4
Sumatra, ...	0·771	37·2	52·0	5·9	0·5
,, ...	0·789	26·0	63·4	7·6	0·75
,, ...	0·857	17·53	32·8	47·0	2·0
,, ...	0·833	19·7	46·9	31·1	0·8
,, ...	0·812	23·3	42·8	28·1	1·9
. . . . . .	0·813	30·4	51·7	11·2	1·7
Borneo (Labuan), ...	0·965	. .	. .	97·1	2·6
,, (Sarawak), ...	0·924	. .	. .	94·3	3·3
,, (Kutei), ...	0·859	17·4	46·0	33·3	1·3
,, ,, ...	0·865	4·6	43·3	50·7	1·6
Timor, ...	0·825	. .	67·5	30·7	0·5
Philippine Islands (Cebu), . .	0·838	12·6	34·5	46·8	3·1
,, ,, . .	0·819	18·4	29·6	47·1	2·9
New Zealand (Taranaki, surface), .	0·971	. .	. .	90·0	9·75
,, (,, drilled well),	0·840	. .	48·25	51·25	0·4

Sainte-Claire-Deville has furnished the information contained in Table XXII (folding sheet) regarding petroleum from various parts of the world, and Ragozine[1] that given in Tables XXIII and XXIV. The first of these refers to the oil from particular groups of wells on the Apscheron peninsula.

[1] *Petroleum and the Petroleum-Industry* (*with Appendix of Investigations of Caucasian Petroleum, by Messrs. Markownikow and Ogloblin*). Petrograd, 1884. (In Russian.) Pp. 124–127.

Desc

50°	2
9	2
rogen	

TABLE XXII.—Composition, Physical Properties, etc., of various Descriptions of Petroleum.

No.	Description of Petroleum, etc.	Elementary Composition.			Percentage of Distillate at °C.																				Specific Gravity at °C.				Coefficient of Expansion.	Composition of Distillate.			Specific Gravity of Distillate at °C.		Specific Gravity of Residue at °C.		Calories per kilo.
		C.	H.	O.	100°	120°	130°	140°	150°	160°	170°	180°	190°	200	210°	220°	230°	240°	250°	260°	270°	280°	290°	300°						C.	H.	O.					
1	Heavy West Virginia petroleum, White Oak (135 m.)	83.5	13.3	3.2	1.0	..	..	1.3	..	..	..	12.	..	..	..	..	..	..	..	..	..	..	..	..	0°	0.873	50.1°	0.853	0.00072	85.3	13.9	0.8	13°	0.819	13.3°	0.864	10,180
2	Light " " Burning Springs (200 m.)	84.3	14.1	1.6	1.3	4.3	..	11	..	17.7	..	25.2	..	28.5	..	..	..	..	..	..	..	..	..	..	"	0.8412	..	0.808	0.000839	84	14.4	1.6	14.2°	0.762	14.8°	0.860	10,223
3	Light Pennsylvania petroleum (200 m.)	82	14.8	3.2	4.3	10.7	..	16	..	23.7	..	28.7	..	31	..	..	..	..	..	..	..	..	..	..	"	0.816	..	0.784	0.00084	85.1	14.3	0.6	13.6°	0.735	13.6°	0.845	9,963
4	Heavy Ohio. ..	84.2	13.1	2.7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	"	0.887	53°	0.853	0.000748	85.4 At 350° 86.7	14.4 12.2	0.6 1.1	.. 14°	.. 0.762	14.8°	0.860	10,399
5	" Pennsylvania " (200 m.)	84.9	13.7	1.4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	..	..	"	0.886	50.1°	0.853	0.000721	85.4	13.8	0.8	13.2°	0.802	13°	0.875	10,672
6	Petroleum obtained from Paris, probably Pennsylvanian	83.4	14.7	1.9	2.8	5.3	..	12	..	19.8	..	25.4	..	30.3	..	..	..	..	..	..	..	..	..	..	"	0.820	53.3°	0.784	0.000868	84.2	14.5	1.3	13.6°	0.736	13.6°	0.845	9,771
7	Heavy oil from gas coal	82	7.6	[1]10.4	..	..	..	..	..	..	..	..	..	12.5	..	..	..	..	..	..	..	..	..	..	"	1.044	51°	1.007	0.00743	..	..	..	..	..	..	..	8,916
8	Parma petroleum	84	13.4	1.8	1.1	9.3	..	33.3	..	39.5	..	60.5	..	69.3	..	..	..	..	..	..	..	..	..	..	"	0.786	51.1°	0.747	0.000706	85	13.7	1.3	13.2°	0.775	11.2°	0.850	10,121
9	Java .. (Rembang)	87.1	12	0.9	1.0	1.0	..	..	..	..	..	7.7	..	15	..	22.3	..	24.3	28.3	..	..	..	..	..	"	0.923	53°	0.888	0.000769	86.2	12.2	1.6	..	0.811	13.3°	0.930	10,831
10	" .. (Cheribon)	83.6	14	2.14	0.8	3.0	..	9.3	..	16.3	..	22	..	27.8	..	..	..	..	..	..	..	..	..	..	"	0.827	..	0.789	0.000923	83.9	14.1	2.0	13.1°	0.778	13.3°	0.914	9,593
11	" .. (Surabaya)	85	11.2	2.8	..	..	..	..	..	..	..	..	..	..	..	2.3	..	4.0	..	9	..	17.7	..	28.3	"	0.972	..	0.945	0.000652	85.1	12.2	1.7	13.2°	0.762	13.2°	0.942	10,183
12	Pechelbronn (Alsace)	86.9	11.8	1.3	..	..	..	..	..	..	..	..	..	4.1	..	8.3	..	13.3	..	..	25.0[4]	..	..	..	"	0.912	51°	0.879	0.00767	85.1	13	0.9	11.6°	0.825	14°	0.927	9,708
13	"	85.6	9.6	[2]4.75	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	"	0.908	50.6°	0.935	0.000697	..	..	..	..	..	..	..	..
14	" tar product	85.7	12	2.3	..	..	..	..	..	..	5.3	..	10.3	..	20.7	..	30.7	..	37.3	..	..	..	..	..	"	0.892	50°	0.857	0.000793	84.5	12.6	2.9	21.4°	0.816	21.2°	0.914	10,020
15	Schwabweiler	86.2	13.3	0.5	..	..	..	..	..	..	7.7	..	12	..	17.3	..	23	..	28.7	..	..	..	..	..	"	0.861	..	0.828	0.000858	84.3	13.6	2.1	22.2°	0.776	21.0°	0.882	10,458
16	" (French Petroleum Co.)	79.5	13.6	6.9	..	..	..	..	..	5.6	..	14.6	..	22	..	34.3	..	39.3	42.7	..	..	..	..	..	"	0.829	51.8°	0.795	0.000843	85.5	14.2	0.3	20°	0.776	21.8°	0.849	.
17	Gabian petroleum (Herault)	86.1	12.7	1.2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	At 292° 0.7	14	"	0.891	50°	0.731	0.000687	86.5	12.4	1.1	20.6°	0.860	20.4°	0.888	.
18	Hanover .. (Eddesse), taken from the surface	80.4	12.7	6.9	0.5	2.7	..	5	..	..	..	..	..	11.0	..	14	..	..	19	..	..	..	..	..	"	0.892	48.2°	0.860	0.000772	83.2	13.6	3.2	21°	0.775	22°	0.908	
19	.. .. from 50 m. (Wietze)	86.2	11.4	2.4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5.4	..	7.8	..	..	16.3	"	0.955	50.6°	0.925	0.000641	84.3	12.5	3.2	21°	0.842	21°	0.959	
20	.. .. .. 12 m. (Oberg)	84.4	11.5	4.1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8.6	..	..	..	..	..	"	0.944	48.2°	0.915	0.000662	84.1	13	2.9	21°	0.830	21°	0.944	..
21	East Galician petroleum	82.2	12.1	5.7	2.1	4.6	..	8.7	..	13.7	..	14.3	..	21.7	..	25.3	..	..	32.3	..	..	..	..	..	"	0.870	50°	0.836	0.000813	80.5	13.6	5.9	21°	0.778	21°	0.901	10,005
22	West "	85.3	12.6	2.1	1.0	4.0	..	9.8	..	14.3	..	23.3	..	27.0	..	30.7	..	..	36.7	..	..	..	..	..	"	0.885	..	0.852	0.000775	83.8	12.9	3.3	21°	0.786	21°	0.931	10,231
23	Caucasian thick black petroleum	85.3	11.6	3.1	..	..	..	..	..	1	..	1.3	..	2	..	2.7	..	..	10	..	..	21.3	..	..	20°	0.9405	58	0.904	0.000696	83.1	12.8	4.1	20°	0.857	22°	0.944	..
24	" black and viscid	84.2	12.4	3.4	3.3	8.7	..	15.7	..	19.3	..	24	..	27	..	32.7	..	..	34.7	..	..	..	..	..	0°	0.887	..	0.850	0.000750	83.5	13.5	3.0	20°	0.787	22°	0.936	..
25	Rumanian petroleum, black and viscid (Ploesti)	82.6	12.5	4.9	..	5.4	..	11.8	..	17.8	..	23.8	..	29.2	..	34.6	..	..	41.6	..	..	..	..	..	"	0.862	50.8°	0.828	0.000808	80.1	13.7	6.2	20°	0.778	22°	0.910	.
26	" "	83	12.2	4.8	..	0.7	..	3.3	..	6	..	10.7	..	15.3	..	19.3	..	..	26.7	..	..	..	..	..	"	0.901	50.8°	0.868	0.000748	83.5	13.2	3.3	20°	0.804	22°	0.924	.
27	Parma petroleum	84.9	11.4	3.7	..	..	..	..	..	..	..	..	..	7.7	..	..	..	..	17.9	..	..	..	..	..	"	0.938	50.8°	0.905	0.000716	83.8	12.6	3.6	21°	0.830	21°	0.944	.
28	Parma petroleum (Neviano de Rossi), 60 m.	81.9	12.5	5.6	1.8	16.2	..	39.9	..	54.9	..	65.6	..	75.4	..	79.8	..	..	88.6	..	..	..	..	..	"	0.809	52.6°	0.770	0.000963	83	13.1	3.9	20°	0.783	22°	0.874	
29	Lombardy (Retorbido), from 35 m.	86.4	12.2	1.4	..	..	..	..	..	..	..	..	..	7.5	..	9	..	..	29.7	..	52.3	..	..	..	"	0.919	52.6°	0.884	0.000752	84.7	12.3	3	21°	0.880	22°	0.936	
30	Zante petroleum, black and viscid	82.6	11.8	5.6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9.7	"	0.952	50	0.921	0.000673	82.7	12.8	4.5	21°	0.883	21°	0.942	
31	West Canada petroleum (Great Manitoulin Island)	83	14.6	2.4	..	..	..	..	..	6	..	14.7	..	19.7	..	28.1	..	35.8	..	..	..	..	..	..	"	0.828	51.8°	0.801	0.000883	83.3	16.1	0.6	19.4°	0.778	20°	0.846	
32	.. .. (Rothwell)	84.3	13.4	2.3	..	..	..	..	10.4	..	14	..	19.2	..	19.6	..	21.6	..	32	..	..	..	..	..	"	0.857	50°	0.838	0.000868	85.3	14.2	0.5	21.2°	0.773	20.4°	0.879	
33	.. .. (Petrolea)	84.5	13.5	2	..	At 125° 10.0	..	..	15	..	15.7	..	22.9	..	27.1	..	32.1	..	37.1	..	..	..	..	..	"	0.870	50°	0.851	0.000836	79.2 79.4	14.1	6.7 6.5	20.8°	0.781	20.4°	0.896	.
34	.. ..	82.7	13.5	3.8	..	..	..	..	..	..	3	..	9	..	14	..	20.2	..	28.2	..	..	..	..	..	..	0.844	51.8°	0.815	0.001	85.2	14.1	0.7	19.7°	0.782	20.1°	0.864	
35	West Virginia petroleum (Guthrie)	83.2	13.2	3.6	1.4	..	5.5	..	10.1	..	16.5	..	..	21.1	..	23.4	..	..	30.7	..	..	..	..	..	..	0.857	50.8°	0.824	0.000788	81.9	13.8	4.3	20°	0.781	21°	0.874	
36	" " (Mecook)	83.6	12.9	3.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8.9	..	..	..	..	..	..	0.897	50.8°	0.866	0.000704	84	12.3	3.7	21°	0.855	21°	0.893	.
37	Burmah oil (Rangoon)	83.8	12.7	3.5	..	..	4.3	..	5.3	..	..	..	6	..	..	..	8.7	..	13.3	..	..	..	..	..	28.2°	0.875	60°	0.855	0.000774	80.9	13.9	5.2	23°	0.795	28.2°	0.890	.
38	China petroleum	83.5	12.9	3.6	..	..	..	..	1.6	..	12.4	..	28	..	41.6	..	51.6	..	60.8	..	..	..	..	..	0°	0.860	55	0.822	0.000824	83.8	12.9	3.3	26.2°	0.884	30°	0.881	..
39	Crude oil (Ardèche)	80.3	11.5	[3]8.2	..	..	..	..	..	..	4	..	7.7	..	20.0	..	28.3	..	42	..	..	..	..	..	..	0.911	50°	0.874	0.000896	82.3	11.5	[6]6.2	22.2°	0.862	21.8°	0.912	9,046
40	Crude shale-oil (Autun)	79.7	11.8	8.5	4.0	6.7	..	12.7	..	17.3	..	24.7	..	31	..	38	..	44.7	..	..	..	..	..	..	..	0.870	60	0.829	0.000859	77.2	12.2	[5]10.6	22.6°	0.787	22.6°	0.921	..
41	Heavy oil from fir wood	87.7	10.4	2.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0.985	50.6°	0.952	0.000885	84.8	10.5	4.7	..	..	..	..	10,081

[1] This includes nitrogen and sulphur.
[2] This includes nitrogen.
[3] This includes nitrogen.
[4] At 264°.
[5] This includes nitrogen.
[6] This includes nitrogen.

TABLE XXIII.—Physical Properties, etc., of Petroleum from the Apscheron District.

Description of Petroleum.	Sp. gr. and Quantity.	Flashing-point.	Temperature of Distillation.	Quantity of Distillate.		Sp. gr. of Distillate at 12·5° C.	Flashing-point of Distillate.	Remarks.
		C.	C.	Grams.	Per cent.			
1. White Surakhani petroleum,	0·7852 200 grams.	Below 11·25°	Up to 100°	25·7	12·85	0·7572		Boiling commenced at 60° C.
			100° to 150°	81	40·50	0·7735		
			150° to 200°	75·6	37·8	0·7790		
			200° to 260°	11·7	5·85	0·8267		
Total,	..	..	260°	194	97	0·7843	Below 11·25°	
2. Balakhani petroleum from well of Group VIII, .	0·8661 250 grams.	21·25°	Up to 150°	34·7	13·88	0·7770		Boiling commenced at 120° C. Sp. gr. of residue 0·9058 at 15° C.
			150° to 200°	35·5	14·20	0·8266		
			200° to 250°	21	8·40	0·8489		
			250° to 305°	20·5	8·20	0·8588		
Total,	..	..	305°	111·7	44·78	0·8205	11·25°	
3. Balakhani petroleum from well of Group VIII, .	0·8660 250 grams.	21·25°	Up to 150°	17·8	7·12	0·7688		
			150° to 200°	32·7	13·08	0·8005		
			200° to 250°	20·9	8·36	0·8199		
			250° to 305°	32·4	12·96	0·8511		
Total,	..	..	305°	103·8	41·52	0·8175	11·25°	
4. Balakhani petroleum from well of Group III, . .	0·8756 250 grams.	25°	Up to 150°	17·5	7	0·7662		
			150° to 200°	34	13·60	0·8024		
			200° to 250°	18·2	7·28	0·8384		
			250° to 305°	30·7	12·28	0·8599		
Total,	..	..	305°	100·4	40·16	0·8206	11·25°	
5. Balakhani petroleum from well of Group X, . .	0·8710 250 grams.	25°	Up to 150°	22·7	9·08	0·7775		
			150° to 200°	23·1	9·24	0·8093		
			200° to 250°	21·5	8·60	0·8356		
			250° to 305°	32·7	13·08	0·8556		
Total,	..	..	305°	100	40	0·8224	11·25°	

TABLE XXIII.—*continued.*

Description of Petroleum.	Sp. gr. and Quantity.	Flashing-point.	Temperature of Distillation.	Quantity of Distillate.		Sp. gr. of Distillate at 12·5° C.	Flashing-point of Distillate.	Remarks.
		C.	C.	Grams.	Per Cent.			
6. Balakhani petroleum from well of Group XIV, .	0·8706 250 grams.	25°	Up to 150°	20·8	8·32	0·7750		Sp. gr. of residue 0·9097 at 12·5° C.
			150° to 200°	32·1	12·84	0·8103		
			200° to 250°	20·6	8·24	0·8400		
			250° to 305°	26·5	10·60	0·8552		
Total,	..	..	305°	100	40	0·8209	15°	
7. Balakhani petroleum from well of Group II, . .	0·8773 200 grams.	28·75°	Up to 150°	21·5	10·75	0·7718		Sp. gr. of residue 0·9170 at 15° C.
			150° to 200°	22	11	0·8187		
			200° to 250°	11·5	5·75	0·8462		
			250° to 305°	19·5	9·75	0·8618		
Total,	..	..	305°	74·5	37·25	0·8183	11·25°	
8. Balakhani petroleum from well of Group I, . .	0·8944 256 grams.	.. ..	Up to 150°	24	9·38	0·7884		
			150° to 200°	25·7	10	0·8319		
			200° to 250°	26	10·16	0·8643		
			250° to 305°	18	7·20	0·8784		
Total,	..	..	305°	93·7	36·74	0·8371	28·75°	
9. Balakhani petroleum from well of Group IV, . .	0·9061 250 grams.	.. ..	Up to 150°	12·5	5	0·8050		Sp. gr. of residue 0·9372 at 12·5° C.
			150° to 200°	16·3	6·52	0·8296		
			200° to 250°	21·7	8·68	0·8564		
			250° to 305°	21·3	8·52	0·8745		
Total,	..	..	305°	71·8	28·72	0·8470	46·25°	
10. Petroleum from the works of Karadjeff, Petrovsk, .	0·8824 250 grams.	42·25°	Up to 150°	9	3·60	0·7919		.
			150° to 200°	29	11·60	0·8128		
			200° to 250°	27·8	11·12	0·8421		
			250° to 305°	23·5	9·40	0·8161		
Total,	..	..	305°	89·3	35·72	0·8333	30°	

TABLE XXIV.—Physical Properties, etc., of Russian Petroleum.

Description of Petroleum.	Sp. gr. and Quantity.	Flashing-point.	Temperature of Distillation.	Quantity of Distillation.		Sp. gr. of Distillate at 12·5° C.	Flashing-point of Distillate.	Remarks.
		C.	C.	Grams.	Per Cent.			
11. Petroleum from Meyerson's Works in Astrakhan, .	0·8871 251 grams.	58·75°	Up to 150°	7·8	3·115	0·8021		
			150° to 200°	25	9·960	0·8216		
			200° to 250°	33	13·147	0·8440		
			250° to 305°	23·8	9·482	0·8614		
Total,	..	..	305°	89·6	35·704	0·8405	46·5°	
12. Bibi-Eibat petroleum from well of Group XIX, .	0·8746 250 grams.	15°	Up to 150°	32·7	13·08	0·7707		Specific gravity of residue at 12·25° C. =0·9405.
			150° to 200°	40·3	16·12	0·7990		
			200° to 250°	26·5	10·60	0·8427		
			250° to 305°	25·5	10·20	0·8747		
Total,	..	..	305°	125·0	50·00	0·8156	12·5°	
13. Binagadi petroleum from Prince Begtabegoff's well, .	0·9136 252 grams.	25°	Up to 150°	12·7	5·04	0·7590		
			150° to 200°	27·1	10·75	0·8069		
			200° to 250°	22	8·73	0·8686		
			250° to 305°	26·5	10·52	0·8925		
Total,	..	..	305°	88·3	35·04	0·8405	11·25°	
14. Binagadi petroleum from Prince Eristoff's well, .	0·9252 252 grams.	43·75°	Up to 150°	7·7	3·060	0·7914		
			150° to 200°	17·7	7·023	0·8206		
			200° to 250°	22	8·730	0·8664		
			250° to 305°	25·8	10·240	0·8921		
Total,	..	..	305°	73·2	29·053	0·8549	31·25°	
15. Kuban petroleum from a well in Kapustin, . .	0·8140 200 grams.	Below 11·25°	Up to 100°	26·5	13·25	0·7321		Specific gravity of residue at 15° C. =0·9390.
			100° to 150°	42·5	21·25	0·7583		
			150° to 200°	32·3	16·15	0·7845		
			200° to 250°	21·0	10·50	0·8248		
			250° to 305°	28·5	14·25	0·8713		
Total,	..	..	305°	150·8	75·40	0·7890	Below 11·25°	

TABLE XXIV.—*continued*

Description of Petroleum.	Sp. gr. and Quantity.	Flashing-point.	Temperature of Distillation.	Quantity of Distillate.		Sp. gr. of Distillate at 12·5° C.	Flashing-point of Distillate.	Remarks.
		C.	C.	Grams.	Per Cent.			
16. Kuban petroleum from a well on the River Tchekups, .	0·9449 250 grams.	65°	Up to 200° 200° to 250° 250° to 305°	21·7 15 32	8·68 6·00 12·90	0·8246 0·8645 0·8911		
Total,	..	..	305°	68·7	27·48	0·8665	43·75°	
17. Kuban petroleum from a well on the River Kudako,	0·8952 250 grams.	11·25°	Up to 110° 110° to 150° 150° to 200° 200° to 250° 250° to 305°	6·5 26·7 26·3 12·7 24·7	2·60 10·60 10·52 5·80 9·88	0·7304 0·7570 0·8085 0·8590 0·8806		
Total,	..	..	305°	96·7	38·68	0·8138	Under 11·25°	
18. Grozni petroleum (thin), .	0·8730 251 grams.	Under 11·25°	Up to 100° 100° to 150° 150° to 200° 200° to 250° 250° to 305°	10·1 30 29 18·2 19·8	4·30 11·95 11·55 7·25 7·91	0·6923 0·7303 0·7865 0·8401 0·8763		
Total.	..	..	305°	107·1	42·96	0·7865	Under 11·25°	
19. Grozni petroleum (thick), .	0·9250 250 grams.	..	Up to 150° 150° to 200° 200° to 250° 250° to 305°	3·7 20·3 21·7 22·2	1·48 } 8·12 } 8·68 8·88	0·8044 0·8471 0·8776		
Total,	..	..	305°	67·9	27·16	0·8424	31·25°	
20. Crimea petroleum—Messrs. Sokhan & Co. . .	0·9113 250 grams.	..	Up to 200° 200° to 250° 250° to 305°	6·7 20·5 34	2·68 8·20 13·60	0·8546 0·8692 0·8799		
Total,	..	..	305°	61·2	24·48	0·8742	..	

A sample of crude oil from a well at Zabola (Transylvania), examined at the laboratory of the Imperial Geological Institute of Vienna, gave results which indicate that 5 per cent. of benzine, 70 per cent of illuminating oil, 6 to 7 per cent. of lubricating oil, and 12 per cent. of vaseline and paraffin-like products could be obtained from it. Another sample, from a shaft 28 metres in depth, was considered capable of yielding about 15 per cent. of benzine, 60 per cent. of illuminating oil, 10 to 15 per cent. of lubricating oil, and 5 to 6 per cent. of a vaseline or paraffin-like product.

From Monsieur A. Pappel, the author has received the following results obtained in the examination, in the Khedival Laboratory, Cairo, of a specimen of Egyptian crude petroleum. The oil was of dark brownish-red colour, and had a specific gravity of 0·908 :—

	Parts per 1000.
Water,	4·5
Spirit,	11·0
Lighting oil,	187·6
Heavy oil,	744·9
Coke,	52·0
	1000·0

Mr. William Warren has furnished the author with the following particulars respecting samples of crude petroleum from Sumatra and Cebu, examined by him :—

TABLE XXV.—Products from the Crude Petroleum of Sumatra and Cebu.

Locality.	Specific Gravity of Crude Oil.	Spirit.	Kerosene.	Heavy Oil.
		Per cent.	Per cent.	Per cent.
Sumatra,	0·765	22·9	49·1	12·5
,,	0·769	30·0	45·0	16·1
,,	0·777	28·0	49·0	14·5
,,	0·800	27·5	52·5	14·0
,,	0·897	Nil.	40·0	55·4
Cebu,	0·842	13·5	37·5	31·5

VARIOUS CRUDE OILS.

Papua.[1]

Specific gravity,	0·802 15°
Bromine value,	3·27 per cent. by weight.
Flash-point,	lower than 20° C.
Paraffin wax,	2 per cent.
Boiling below 150°	32·5 per cent.; specific gravity, 0·758
,, ,, 150°–300°	58·7 per cent.; ,, ,, 0·822

In general it resembles Sumatra oil.

Alsatian oil was examined by E. Graefe.[2] The burning oil possessed the specific gravity, 0·798; viscosity, 1·07 (Engler); sulphur, 0·04 per cent; Wij's iodine value, 5·79; flash-point, 45° C.; calorific value, 10,662 gram calories; 32·5 per cent. boiled below 200° C.; and 96 per cent. was volatile below 300° C. The crude oil possessed the following characteristics:—specific gravity, 0·889; flash-point, 27° C.; sulphur, 0·67 per cent.; asphalt (Holde method), 11·5 per cent; paraffin wax content, 2·12 per cent.

[1] *Bull. Imp. Inst.*, xiii, 185 (1915). [2] *Petr.*, ii, 278 (1907).

Various Galician crude oils were examined by Wielzynski [1] with the following results :—

TABLE XXVI.

Source.	Sp. Gr.	Ignition Point.	Setting Point.	Viscosity.	Per Cent.			Calories per kilo.
					H.	C.	O, etc.	
				C.				
Boryslaw crude . .	0·925	..	35°	2·8/50°	14·73	83·47	1·80	11·064
Kosmacz, . . .	0·876	<10°	<–12°	2·6/15°	13·98	85·49	0·57	11·092
Polok . . .	0·831	<10°	<–12	1·2/15°	12·74	83·12	4·14	10·866
Urcyz, . . .	0·878	<10°	<–12°	1·87/15°	14·06	84·94	1·00	11·092
[For comparison] :—								
Texas, . . .	0·925	..	..	..	13·69	84·17	S=2·0, O=0·14	11·604
Romani (Apscheron), .	..	..	..	..	14·25	85·58	0·17	11·207

Katayame [2] gives the following details of Formosa crude oil :—

Fraction to	Per Cent.	Specific Gravity.
100° C.	1·5	..
100°–125°	15·8	0·779
125°–150°	21·8	0·798
150°–175°	12·2	0·8155
175°–200°	8·8	0·8205
200°–225°	7·8	0·8360
225°–250°	7·6	0·8385
250°–275°	7·5	0·8790
275°–300°	4·3	..

Solid residuum, 13·2 per cent.

The high values for the specific gravities of the fractions point to the presence of aromatic hydrocarbons.

Ohio (Mahone) oil is black, very viscous, with a specific gravity of 0·9036 at 20° C. It commences to distil at 230° C. and begins to decompose at 250° C. Paraffins, cycloparaffins, and asphalt are absent. The chief hydrocarbons appear to belong to the series C_nH_{2n-2} and C_nH_{2n-4}.[3] Mid-Continent oil (Oklahoma) was investigated by F. W. Bushing,[4] who gave the following details :—

Specific gravity, 0·8513 at 15° C.
Volatile to 150° C. ; 13·77 per cent. ; of sp. gr. 0·6296–0·7687.
Volatile between 150–300° ; 28·8 per cent. ; of sp. gr. 0·7715.

Bustenari crude oil [5] varied in specific gravity between the limits 0·820–0·926. Mean, 0·854.

Yield of benzine . .	4·1–29·5 per cent.		
Average yield, 125°–150° .	10 per cent.	Specific gravity,	0·760–0·765.
,, ,, 150°–200° .	15 ,, ,,	,, ,,	0·795–0·800.
,, ,, 200°–250° .	10 ,, ,,	,, ,,	0·835–0·840.
,, ,, 250°–270° .	4 ,, ,,	,, ,,	0·860–0·875.
,, ,, 270°–300° .	7 ,, ,,	,, ,,	0·885–0·890.

In practice the lamp-oil content is about 15 per cent., and that of solar oil 10 per cent. A residuum of 42 per cent. remains from which good lubricating

[1] *Petr.*, iii, 507 (1908).
[2] *J. Ind. and Eng. Chem.*, 469 (1914).
[3] *J. Ind. and Eng. Chem.*, iv, 101 (1914).
[4] *J. Ind. and Eng. Chem.*, vi, 888 (1914).
[5] S. Aisinmann, *Petr.*, iii, 565 (1908).

TABLE XXVII.—Particulars of Lubricating Oils (*Kunkler*).

Source and Stated Use of Oil.	Specific Gravity at 17½° C.	Colour by Transmitted Light.	Colour by Reflected Light.	Distillation commenced at ° C.	Flashing-point ° C.	Burning-point ° C.	Solidifying or Melting-point ° C.	Per cent. by Volume Volatile at 310° C.	Viscosity at ° C. (Water = 1) 20°	30°	50°	60°	70°	100°	150°
Russia.															
For spindles and the like,	0·895	Bright yellow	Greenish and blue	105	163	190	−10° liquid	1	11·82		3·40	..	.	1·53	
,, ,, ,,	0·895	..	..	110	165	194	−10° ..	1·5	10·96	.	3·15	..	.	1·40	
,, ,, ,,	0·893	..	.	105	167	193	−10° .	10·0	11·82	..	3·41	..	.	1·55	
,, ,, ,,	0·895	.	.	110	161	193	−10° ..	8·0	11·03	..	3·36	..		1·53	
For steam engines, and for replacing olive oil, rape oil, etc.,	0·909	Yellow	..	128	197	234	−10° ..	5·0	..		6·28	.	..	1·76	
,, ,, ,, ,,	0·905	..		120	195	234	−10° .	5·5	..	.	6·05	..	..	1·77	
,, ,, ,, ,,	0·906	..	..	120	180	220	−10° ..	4·0	.		5·86	.	..	1·71	
,, ,, ,, ,,	0·903	..	.	125	195	235	−10° .	6·0	.		8·34	..	.	1·86	
,, ,, ,, ,,	0·905	..	.	123	185	230	−10° ..	5·0	.	.	6·05	..	..	1·80	
For steam-engine cylinders,	0·916	Reddish yellow	..	130	215	265	−10° ..	36·0		..	11·65	8·55	5·09	2·21	1·42
,, ,, ,,	0·925	Dark brown	Greenish without blue	118	208	235	− 8° solid	16·0	.	..	..	12·01	8·26	2·88	1·53
,, ,, ,,	0·916	Dark red	Greenish with little blue	130	227	283	− 7° ..	38·0	..	.	16·19	9·34	6·73	2·50	1·48
,, ,, ,,	0·911	Reddish yellow	..	110	218	267	−10° .	27·0	..	..	10·44	7·13	5·67	2·15	1·38
,, ,, ,,	0·916	Dark red transparent	..	130	238	280	− 7°	27·5	.	..	..	10·92	6·76	2·85	1·48
,, ,, ,,	0·912	Dark brown	Greenish	110	188	225	−10° ..	4·0	.		12·40	8·51	5·78	2·30	1·44
,, ,, ,,	0·916	Reddish	Greenish with little blue	142	218	264	−10° liquid	10·5			10·23	7·00	4·44	2·07	1·36
For shafting and for general uses	0·916	Dark brown	Greenish	100	170	200	−10° ..	5·0		..	8·73	..	..	2·03	.
,, machinery, locomotives, etc..	0·920	,,	,,	120	185	212	− 6° solid	2·0			13·84	..	..	2·42	..
,, heaviest work.	0·909	Bright red	Greenish and blue	127	187	233	−10° liquid	14·0	.	.	7·94	..	..	1·88	.
,, shafting,	0·913	Dark brown	Greenish	97	170	196	−10° ..	5·0	.	..	10·38	..	..	2·21	.
,, general lubricating purposes,	0·908	..	,,	80	138	170	−10° ..	21·0	.	..	8·84	..	..	2·05	..
,, machinery, transmission-gear,	0·906	..	Greenish and blue	120	191	231	−10° ..	4·5	.		6·40	..	..	1·78	.
,, shafting,	0·909	,,	Greenish	82	142	180	−10° ..	13·0	.	.	7·30		..	2·09	
,, gas-motors and light work,	0·900	Yellow	Greenish and blue	115	175	207	−10° ..	5·0	..	.	1·50	..	.	1·63	
America.															
For spindles, etc., and to mix with animal oils,	0·911	Bright yellow	..	110	187	231	− 2° ..	0·0	9·23	4·80	3·13	..	..	1·40	
,, spindles,	0·908	,,	..	120	200	240	− 2° ..	0·5	10·96	6·46	3·32	..	..	1·61	.
,, machinery,	0·920	Reddish yellow	,,	125	206	245	0° ..	3·0	..	8·90	4·23	..	..	1·65	
,, steam-engine cylinders,	0·886	Reddish transparent	Greenish	185	283	330	+ 5° ..	35·0	..	..	..	..	11·73	4·17	1·78
,, ,, ,,	0·899	Dark brown	..	185	280	344	+ 4° ..	30·0	..	..	..	..	12·61	4·82	1·92
,, shafting,	0·884	,,	..	80	190	229	− 3° ..	1·0	..	14·73	..	..	6·09	..	2·00
Germany.															
Hanover.															
For machinery, transmission-gear, etc..	0·928	..	..	95	155	193	− 9° ..	5·0	..	..	15·48	..	..	2·69	.
,, shafting, transmission-gear,	0·916	..	..	100	164	193	−10° .	3·0	..	.	8·65	..	..	1·73	
,, general lubricating purposes,	0·910	..	..	95	162	193	−10° ..	3·0		.	3·84	..	..	1·63	
Alsace.															
For general lubricating purposes,	0·921	Brownish green	,,	105	152	195	− 2° ..	9·0	..	..	1·55	..	..	1·60	..
,, mixing purposes,	0·885	Bright yellow	Greenish and blue	80	115	142	−10° ..	80·0	..	.	1·92	..	..	1·25	.
Saxony.															
For general lubricating work,	0·994	Dark brown	Scarcely greenish	80	135	168	− 6° ,,	20·0	..	..	3·17	..	..	1·40	
,, mixing purposes,	0·897	Bright yellow	Strongly green	80	126	150	0° ,,	50·0	..	..	1·86	..	..	1·25	
,, ,, ,,	0·904	Dark brown	,,	80	126	150	0° ,,	17·0	..	..	2·36	..	..	1·28	
Vegetable and Animal Oils.															
Rape oil, crude,	0·920	..	..	170	260	..	−10° ,,	..	9·03	..	4·0	..	..	1·78	1·34
,, refined.	0·911	..	.	185	305	..	−10° ,,	..	11·88	..	4·96	..	..	2·05	1·40
Earth-nut oil,	0·917	..	..	195	300	..	− 6° solid	..	10·17	..	4·03	..	..	1·82	.
Sesame oil,	0·920	.		180	280	..	−10° liquid	..	9·89	..	4·03	..	..	1·82	..
Olive oil,	0·914	..	.	145	205	..	−10° ,,	..	1·30	..	3·78	..	..	1·80	.
Castor oil,	0·963	.		195	275	..	−10° ,,	..	..	..	16·46	..	..	3·01	.
Linseed oil.	0·930	..		185	285	..	−10° ,,	..	6·30	..	3·21	..	.	1·76	.
Seal oil,	0·922	..		162	240	..	−10° ,,	..	8·07	.	3·50	..	..	1·76	.
Neatsfoot oil,	0·916	..		215	305	..	−10° ,,	..	11·63	..	4·44	..	..	1·92	..
Tallow,	0·951	.	.	180	265	..	+42° solid	..	..	..	5·19	..	.	2·50	1·73

oil is manufactured. Unsaturation increases with rise in density, and in consequence the lamp-oil inclines to be smoky.

The fraction 102°–110° contains a considerable proportion of toluol.

The solar oil, of specific gravity 0·885–0·890, flashes at 100° C., and possesses a cold test of 20° C., a calorific value of 10,400, and a sulphur content of 0·3 per cent. From 100 kilograms there were obtained 85 cubic metres of gas, with a candle-power of 23–28.

Tschimion oil[1] from Fergana, Central Asiatic Russia, is characterised by :—

Specific gravity, 0·872. Flash-point, −5°·5 C.
Thick consistency and dark brown colour.

Wax content,	5·14 per cent.		
Asphalt ,,	3·23 ,, ,,		
Carbon ,,	85·79 ,, ,,		
Hydrogen ,,	13·65 ,, ,,		
Ash ,,	0·02 ,, ,,		
Volatile to 150° C.	17·75 per cent. ;	of specific gravity	0·739.
,, between 150°–200°	9·0 ,, ,,	,, ,,	0·790.
,, ,, 200°–250°	8·2 ,, ,,	,, ,,	0·826.
,, ,, 250°–300°	19·5 ,, ,,	,, ,,	0·842.
,, above 300°	40·4 ,, ,,	,, ,,	0·8986.

Residue, 3·0 per cent.

The fraction, 150–160, on ultimate analysis appeared to be composed of cycloparaffins.

Hanover crude petroleum has been investigated by F. B. Ahrens and J. Riemer,[2] with the following results :—

Sp. gr., 0·941 at 15° C. ; specific viscosity, 12–16 at 60° C., flash-point, 105° C. ; ignition temperature, 143° C. The oil is viscous, brown, and opaque ; it is chiefly composed of unsaturated and aromatic hydrocarbons. The wax content is 0·28 per cent. and asphalt insoluble in petroleum ether amounts to 1·03 per cent.

In Texas (Jefferson county) oil, C. F. Mabery[3] found 2·16 per cent. of sulphur and more than 1 per cent. of nitrogen.

Künkler[4] has published the result of the examination of various descriptions of **lubricating oil**, employed for the particular purposes specified (see Table XXVII).

Particulars of the lubricating oils made at the Bucharest refinery of the Steaua Romana are given in Table XXVIII (p. 294).

Capillary Power.—The specific gravity of Russian kerosene is higher than that of ordinary American kerosene, and still higher than that of American "water-white oil," but the Russian oil has greater power than the ordinary American oil of ascending a lamp-wick by capillary attraction, and affords in most lamps a better sustained, though smaller and less brilliant, flame than the latter oil. The relative capillary power of three descriptions of kerosene, as determined by noting the quantity of oil withdrawn by ordinary lamp-wicks in a given time, from vessels of the same size, is shown by the following results obtained in the author's laboratory :—

	Best Wick.	Inferior Wick.
American kerosene (water-white), specific gravity 0·790,	205·0	104·2
Russian kerosene (ordinary), specific gravity 0·822,	202·6	94·2
American kerosene (ordinary), specific gravity 0·800,	146·0	69·7

[1] P. Andrejeiv, *Petr.*, iv, 207 (1908).
[2] *Zeitschr. f. angew. Chem.*, xx, 1517 (1907)
[3] *Journ. Amer. Chem. Soc.*, xxiii, 264 (1901).
[4] *Dingler's polytechn. Journ.* cclxxiv, 280 (1889).

TABLE XXVIII.—Particulars of Lubricating Oils made at the Bucharest Refinery of the Steaua Romana.

Light-coloured Oils.

Name.	Purpose.	Specific Gravity.	Flashing-point (Open Test).	Cold Test.	Viscosity by Engler's Viscometer at 20° C.
			C.	C.	
"Misch Oel,"	For light machinery and for adulterating vegetable oils,	0·875	120°	Under −20°	2–2·5
"Spindle Oel,"	For heavier machinery,	0·902	130°	,, ,,	3·5–4
"Dresch Oel,"	For threshing-machines,	0·913	145°	−12°	7–8
"Prima Oel,"	For general purposes,	0·921	155°	−10°	13–14
"Extra Oel,"	For electric motors,	0·926	160°	−10°	23–24
"Regal Oel,"	For electric motors,	0·929	180°	− 3°	36–37
"Imperial Oel,"	For heavy machinery,	0·930	186°	+ 8°	43–45
Dark-coloured Oils.					
"Vulcan,"	.. .. ..	0·923	150°	Under −20°	40–45
"Maschinen - Bahn Oel (Valvoline),"	For railway axles, etc.,	0·921–0·928	155°	,, −10°	25–40
[1] "Cylinder Oel (Valvoline),"	.. .. ..	0·948	..	−5° to − 7°	40 at 50° C.

[1] For the production of this oil Tega crude petroleum is employed. This crude oil has a specific gravity of 0·900, and a flashing-point of 50°–55° C. (Pensky-Martens test). On distillation it yields a small quantity of solar oil, and the whole of the residue is treated with acid and soda for the purpose of making cylinder oil.

Viscosity.—The viscosity of petroleum products increases with the density, but oils of the same specific gravity from different localities frequently differ in viscosity. Very few physical properties are so markedly constitutive as is viscosity.[1] It is therefore eminently suitable as a discriminating test, as well as being valuable as a means of determining relative lubricating power.

Broadly an increase in viscosity of hydrocarbons is noted with decrease of hydrogen content, *e.g.* the paraffin hydrocarbons are more mobile than unsaturated hydrocarbons with a corresponding number of carbon atoms. Thus phenyl ethane ($C_6H_5.CH_2.CH_3$) at 25° C. has a viscosity of 0·00607, whilst the viscosity of phenyl ethylene ($C_6H_5.CH:CH_2$) is 0·0111. It is stated that hydrocarbons of the C_nH_{2n-4} series are as viscous and as efficient in lubricating power as sperm oil. Further, a molecule in which the grouping of the elements and radicles is symmetrical has a lower viscosity than one with markedly unsymmetrical grouping.[2]

In connection with lubricating oils, Künkler contends that whilst the vitally important factor is "adhesion," and viscosity *per se* is of minor importance,

TABLE XXIX.—Viscosity—Seconds for 50 c.c.

Results obtained with Redwood's Standard Viscometer.

Temperature, ° F.	Water.	Refined Rape Oil.	Sperm Oil.	Neatsfoot Oil.	Beef Tallow.	American Mineral Oil.			Russian Mineral Oil.		
						Sp. Gr. 0·885.	Sp. Gr. 0·913.	Sp. Gr. 0·923.	Sp. Gr. 0·909.	Sp. Gr. 0·915.	Sp. Gr. 0·884.[3]
50	..	712½	..	620	..	145	425	1030	2040	2520	..
60	25½	540	177	470	..	105	295½	680	1235	1980	..
70	..	405	136½	366	..	90	225	485	820	1320	..
80	..	326	113	280	..	73	171	375	580	900	..
90	..	260	96	219¼	..	63½	136	262	426	640	..
100	..	213½	80½	174¾	..	54	111	200	315	440	1015
110	..	169	70½	147⅖	..	50	89½	153	226	335	739½
120	..	147	60½	126	..	47	78	126	174	245	531
130	..	123½	57	112	..	44¾	63½	101	135½	185	398½
140	..	105½	50¾	88¾	..	41	58	82	116	145	317½
150	..	95½	49	75½	..	37½	52	70½	95	115	250
160	..	85	47½	70	..	..	46	63½	83½	93½	200
170	..	76	46	62	..	..	..	58	70½	77½	161
180	..	69	44½	56½	..	..	..	52½	61½	67½	134½
190	..	64½	43	53	..	..	..	47	56½	61	115½
200	..	58½	42	50⅖	54¾	..	..	42	48½	54	99¼
210	..	54	40¾	48½	..	..	..	40	..	..	85
220	..	50	39	47	..	..	..	38	..	..	77
230	..	47¼	36¾	45⅕	..	..	..	..	..	..	70½
240	..	45½	35¾	44⅗	..	..	..	..	..	..	64½
250	..	43¼	34¾	44	40	..	..	..	..	..	59¼
260	..	..	33¾	43½	..	..	..	..	..	..	54
270	..	..	32¾	43	..	..	..	..	..	..	48½
280	..	..	31 17/20	41½	..	..	..	..	..	..	46½
290	..	..	30¾	41	..	..	..	..	..	..	44¼
300	..	..	30	38	..	..	..	..	..	..	42⅖
310	..	..	..	35	..	..	..	..	..	..	..
320	..	..	..	33⅙	..	..	..	..	..	..	..

[1] *Viscosity of Liquids* (Longmans & Co., 1914).

[2] Dunstan and Thole, *Journ. Inst. Petr. Techs.*, iv, 191 (1918).

[3] Semi-solid at ordinary temperature.

yet the latter is of great service as indicating the quality of adhesion, a view borne out by general experience that the durability of an oil film is directly connected with the viscosity.

This is especially noticeable in comparing the Russian and American oils, which are so widely different in chemical composition. Table XXIX shows the relative viscosity of water and various oils, as determined by the author.

Table XXX records results yielded, in the author's laboratory, by lubricating oils manufactured by the Burmah Oil Company from the petroleum of Yenangyaung, in Upper Burma.

The colour of the first sample (3) by Lovibond's tintometer, in a 2-inch cell, series 500, was 130 ; and of the second sample (4) was 224.

TABLE XXX.—PROPERTIES OF BURMA LUBRICATING OILS.

Description of Oil.	Sp. Gr. at 60° F.	Flashing-point.		Viscosity.[1] Rape Oil at 60° F. = 100.		Cold Test.
		Close.	Open.	At 70° F.	At 140° F.	
Lubricating oil (3),	0·920	238	266	34·23	9·24	Ceases to flow at 30° F.
Lubricating oil (4),	0·930	330	354	73·76	12·47	Ceases to flow at 30° F.
Lubricating oil (5),	0·931	336	360	124·02	15·71	Ceases to flow at 42° F.
" Valvoline " (6),	0·949	400	422	..	25·95	Ceases to flow at 45° F.

Solidification Point of Petroleum Fractions.—Formanek, Knop, and Korber [2] give the following solidification points for petroleum distillates :—light benzine (sp. gr. 0·680 to 0·700), −135° to −170° C. ; medium benzine (sp. gr. 0·700 to 0·740), −125° to −150° ; heavy benzine (sp. gr. 0·740 to 0·760), −95° to −120° ; fraction, 24°–40° C., −203° ; crude petroleum, −58° ; refined petroleum, −85° to −90 ° ; fraction, 200°–220°, −93°.

Solubility of Water.—E. Groschuff [3] has determined the solubility of water in benzine, light petroleum, and paraffin oil to be :—

At 18° C. In benzine, 0·051 per cent. by weight.
In light petroleum (0·792 at 20° ; b.-p. 190°–250°) 0·005 per cent. by weight.
In paraffin oil (0·883 at 18° ; b.-p. 200°–300° at 10 mm.), 0·003 per cent. by weight.

The solubility and the temperature coefficient of solubility increase with rise of temperature.

Refractive Index.—Dr. C. Engler [4] has devoted much attention to the examination of the power of refracting light possessed by petroleum, and states that the most characteristic physical properties indicative of the locality from which an oil was obtained are the refractive index and the specific gravity. In proof of this statement he gives the following table (Table XXXI), in which it is seen that the refractive indices of the oils of Tegernsee and Pechelbronn

[1] By Redwood's Viscometer.
[2] *Chem. Zeit.*, xli, 713, 730 (1917). See *J.S.C.I.*, 329, A (1918).
[3] *Z. Elektrochem.*, xvii, 348 (1911).
[4] *Verh. Ver. Beförd. Gewerbfl. Preuss.*, 637 (1887).

are near to that of Pennsylvanian oil, while the Oelheim oil affords results not differing greatly from those given by the oil of Baku :—

TABLE XXXI.—Refractive Indices of Petroleum Distillates.

	Fraction 140°–160°.		Fraction 190°–210°.		Fraction 240°–260°.		Fraction 290°–310°.	
	Sp. Gr.	Ref. Ind.	Sp. Gr.	Ref. Ind.	Sp. Gr.	Ref. Ind.	Sp. Gr.	Ref. Ind.
Tegernsee, .	0·7465	1·427	0·7840	1·437	0·8130	1·451	0·8370	1·465
Pechelbronn (Alsace), .	0·7550	1·421	0·7900	1·440	0·8155	1·454	0·8320	1·462
Oelheim (Hanover), .	0·7830	1·435	0·8155	1·450	0·8420	1·468	0·8620	1·480
Pennsylvania	0·7550	1·422	0·7860	1·439	0·8120	1·454	0·8325	1·463
Baku, .	0·7820	1·436	0·8195	1·454	0·8445	1·467	0·8640	1·475

In determining the origin of a petroleum or its products, N. Chercheffsky [1] notes, *inter alia*, the refractive index. He gives the following illustrative results obtained with distillates below 300° C. :—

TABLE XXXII.—Refractive Indices of Petroleum-Distillates.

Origin.	Sp. Gr. at 15° C.	Refractive Index (at 15° C.).
American,	0·780	1·4345
American,	0·800	1·4453
American,	0·820	1·4564
Russian,	0·780	1·4300
Russian,	0·800	1·4419
Russian,	0·820	1·4533
Rumanian,	0·780	1·4334
Rumanian,	0·800	1·4458
Rumanian,	0·820	1·4572
Galician,	0·780	1·4356
Galician,	0·800	1·4466
Galician,	0·820	1·4586
Shale,	0·780	1·4373
Shale,	0·800	1·4469
Shale,	0·820	1·4568

The following results were obtained with lubricating oils and solid hydrocarbons :—

	Refractive Index (at 15° C.).
Russian spindle oil,	1·4888
American cylinder oil,	1·4954
Petroleum paraffin,	1·4185
Shale paraffin,	1·4161
Ceresin (ozokerite),	1·426

With the Zeiss-Abbé refractometer, at the temperature of 15° C., G. A. Le Roy [2] obtained the following values :—

	Refractive Index (at 15° C.).
American crude oil,	1·4540
American petroleum spirit (sp. gr. 0·720),	1·3995
American white burning oil,	1·4430
Russian crude oil,	1·4595
Russian petroleum spirit (sp. gr. 0·720),	1·4105
Russian white burning oil,	1·4530
Rumanian crude oil,	1·4639
Rumanian petroleum spirit (sp. gr. 0·720),	1·4055
Rumanian white burning oil,	1·4560

[1] *Comptes Rend.*, cl, 1338–1341 (1910); *J. Soc. Chem. Ind.*, xxix, 681 (1910).
[2] *Ann. Chim. Analyt.*, xvi, 12–13 (1911); *J. Soc. Chem. Ind.*, xxx, 122 (1911).

Seeing that refractive index is not eminently constitutive, the differences exhibited by various crude oils are not very striking. The variations in the proportions of the chief series of hydrocarbons which constitute these oils affect the numerical value of the index.

Optical Activity.—R. Zaloziecki and H. Klarfeld [1] examined a number of Galician oils and one from each of the following countries, viz. Pennsylvania, Russia, and Germany. They found that the last three named were inactive, and that of the Galician oils the light pale descriptions were generally inactive, whilst the dark heavy ones were usually active.

C. Engler [2] has expressed the opinion that the optical activity of petroleum is, in most cases, caused by the presence of an individual substance, probably the product of a destructive distillation of cholesterol or a cholesterol-like substance.

A. K. Koss [3] made a number of experiments with Ledok and Gogor (Java) petroleum, and expressed disagreement with Engler's view that the optical activity of petroleum is due to a product of the destructive distillation of cholesterol.

M. Rakusin [4] concludes that the crude oil is dextro-rotatory, the rotatory power being proportional to the depth of the oil-yielding strata, and that the rotatory power of the oil is due to the formation of the latter from compounds containing asymmetric carbon atoms.

Out of ten Japanese petroleums examined by M. A. Rakusin,[5] only one was polarimetrically inactive. It had a specific gravity of 0·7877 at 15° C., and was described as a remarkable example of an inactive oil obtained at a great depth (2100 feet). The oil was from the Amaze field.

The cylinder oil derived from the crude petroleum of Grozny, Baku, and America are dextrogyrate.[6] This behaviour, accompanied by the fact that such oils give Tschugaeff's cholesterol reaction with trichloracetic acid, appears to suggest an organic origin.

Lewkowitsch,[7] by means of the destructive distillation of glycerides with zinc dust, obtained an optically active hydrocarbon mixture which resembled petroleum. In the same year, A. O. Jones and Wooton [8] showed that the fraction 260°–340° of Borneo crude oil possessed $\alpha_D = -0{\cdot}18°$ in a 2-decimetre tube.

R. Zaloziecki and H. Klarfeld [9] showed that heavy dark oils were in general optically active, and that on distillation the fractions boiling above 200° C. at 12–15 mm. pressure showed the maximum gyration.

C. Engler [10] considered that the optical activity of petroleum was due to the decomposition of cholesterol derivatives, seeing that the maximum rotatory power of the oil coincided with that found in the products of the destructive distillation of cholesterol. Engler suggested that in all probability the majority of petroleums would be found to show in some fraction evidence of this phenomenon.

Raskusin [11] proposed a numerical method of measuring the opacity to

[1] *Chem.-Zeit.*, xxxi, 1155–1156, 1170–1172 (1907); *J. Soc. Chem. Ind.*, xxvii, 16 (1908).
[2] *Zeitschr. f. angew. Chem.*, xxi, 1585–1597 (1908); *J. Soc. Chem. Ind.*, xxvii, 932 (1908).
[3] *J. Russ. Phys.-Chem. Soc.*, xliii, 697–707 (1911); *J. Soc. Chem. Ind.*, xxx, 1104 (1911).
[4] *J. Russ. Phys.-Chem. Ges.*, xli, 483–500 (1909); *Chem. Zentr.*, 1909, 2, 859–860; *J. Soc. Chem. Ind.*, xxviii, 1028 (1909).
[5] *Petroleum Zeitschr.*, vi, 1068 (1911).
[6] Rakusin, *J. Russ. Phys.-Chem. Soc.*, xxxvi, 554 (1904).
[7] *Ber.*, xl, 461 (1907).
[8] *Trans. Chem. Soc.*, xci, 1146 (1907).
[9] *Chem. Zeit.*, xxxi, 1155, 1170 (1907); *J.S.C.I.*, 16 (1908).
[10] *Zeitschr. f. angew. Chem.*, xxi, 1585 (1908).
[11] *Ber.*, xlii, 1211 (1909).

polarised light. An oil which is polarimetrically transparent is said to possess the carbonisation constant [K]=100. When a 1 per cent. solution in benzol just permits the passage of the beam, K=1. Oils rich in paraffin show a high value of K, and apparently K is less as the geological age of petroleum is greater. The same author [1] stated that most crude oils yield dextro-gyratory fractions, but that lævorotation is exceptional. Opaque Bibi-Eibat oil (sp. gr. 0·880), on being decolorised by means of fuller's earth gave a filtrate which exhibited +1°·5 Sacch. in a 200-mm. tube.

J. Mercusson [2] obtained an optically active product from the destructive distillation, under pressure, of the unsaponifiable components of wool fat. The activity of the fractions is in inverse ratio to their volatility. Cholesterol on being repeatedly and slowly distilled gave dextrogyrate fractions, but rapid heating brought about the formation of lævorotatory material. The actual rotatory power of petroleum may be ascribed to (1) cholesterol products which have originated from animal sources and (2) terpene-like resinoid bodies of vegetable origin.

The subject of the optical activity of petroleum in relation to theories of origin is discussed in Section IV.

Radio-activity.—D. Hurmuzescu [3] found that the lightest varieties of the Rumanian oils examined were the most active, and that the activity decreased with time.

CHEMICAL COMPOSITION.

As regards its ultimate composition, petroleum consists essentially of carbon and hydrogen, together with oxygen, and usually with widely varying amounts of nitrogen and sulphur. From the results of a large number of analyses by Sainte-Claire-Deville [4] and others, the **carbon** appears to vary between 79·5, for an oil from Schwabweiler, in Alsace, having a specific gravity of 0·829, and containing 13·6 per cent. of hydrogen (*Sainte-Claire-Deville*); and 88·7, according to Boussingault, also for petroleum from Schwabweiler.[5] The **hydrogen** apparently varies between 9·6 for an oil from Pechelbronn, in Alsace, and 14·8 for an oil from Oil Creek, Pennsylvania (*Sainte-Claire-Deville*). Peckham gives the following as the composition of specimens from districts in the United States:—

TABLE XXXIII.—Composition of American Petroleum.

	Hydrogen.	Carbon.	Nitrogen.
Mecca (Ohio), ...	13·071	86·316	0·230
Cumberland (W. Virginia), ...	13·359	85·200	0·054
Hayward Petroleum Company (California), .	11·819	86·934	1·1095
Pico Spring (California), ...	..	..	1·0165
Canada Laga (California), ...	..	..	1·0855
Maltha, Ojai ranch (California), ...	..	..	0·5645

M. Delesse [6] found 0·154 per cent. of **nitrogen** in elaterite, and 0·256 per cent. in the asphalt of Trinidad. Mr. Beilby [7] states that he found in crude American

[1] *Ber.*, xlii, 1610 (1909).
[2] *Mitt. Königl. Materials*, xxviii, 143 (1910).
[3] *Petroleum Zeitschr.*, iii, 235–236 (1907); *J.S.C.I.*, xxvii, 16 (1908).
[4] *Comptes Rend.*, lxvi, 442; lxviii, 485; lxix, 1007. (See Table XXII, p. 286.)
[5] *Ann. Chim. Phys.*, 2, lxxiii, 442 (1840).
[6] *Ann. Mines*, 5, xviii, 151 (1860).
[7] *Journ. Soc. Chem. Ind.*, x, 120 (1891).

petroleum at least 0·008 per cent. of nitrogen, in crude Galician, 0·188 per cent., and in crude Baku petroleum, 0·05. He states that the nitrogen is present as bases which are removable by sulphuric acid, and that it tends to accumulate in the residues from the distillation. Mabery and Dunn [1] find that the proportion of nitrogen appears in most cases to increase with the depth of the petroleum well. Weller [2] has found alkaloid-like bases in the petroleum of Saxony, and Bandrowski [3] has ascertained the presence of similar bodies in Galician oil.

Griffiths and Bluman [4] observed that crude Rumanian oil, after extracting with dilute sulphuric acid, yielded a small proportion of a base which boiled at 117° C. and which can be reduced to piperidine.

In a paper on the nitrogen content of Californian bitumen, read at the Congress of Chemists at San Francisco, 9th June 1894,[5] Peckham considers it probable that "not only pyridine and quinoline are present, but that also a large number, if not all, of the methylated compounds of these bases are associated with them." Treatment of the distillates with dilute acid results in the removal of the acid and basic radicals of the compound ethers, and superior commercial products are obtained, the burning oil being of higher illuminating power, and the lubricating oils of increased viscosity in relation to the specific gravity. C. F. Mabery [6] has examined a considerable number of Californian oils, and finds that the nitrogen varies from 0·23 up to 0·88 per cent. by weight. A series of six bases were found, ranging as to formulæ from $C_{12}H_{17}N$ to $C_{17}H_{21}N$, and boiling between 130° and 275° C. They are quite unlike the members of the quinoline series as to properties.

Clifford Richardson's testimony is similar, and he has also examined Texas oils, in which he finds both resemblances to and differences from California oils; in some respects also the Texas oils stand alone.

According to this authority, those forms of bitumen which have been least exposed to the action of atmospheric oxygen contain the largest proportion of basic oils, analysis showing less nitrogen in the malthas, and still less in the asphaltums, than in the petroleums. It may be added that Beilby has found nitrogen, partly as bases and partly as salts of ammonia, in nearly all the specimens of American, Russian, and Galician oils which he has examined, and that Zaloziecki has also found pyridine bases in petroleum. Schestakoff [7] treated a Caucasian petroleum distillate with acid, neutralised the extract with alkali, and obtained 0·006 per cent. of a brown liquid smelling of pyridine, and distilling between 260° and 370° C. This was confirmed by Khlopin,[8] who, operating on Baku "masut" and Caucasian crude petroleum, found therein 0·005–0·006 per cent. of pyridine bases of the general formula $C_nH_{2n-5}N$.

In respect to the **sulphur** in crude petroleum much information has been published. The sulphur-containing compounds in petroleum may originate in two ways: firstly, from the decomposition of proteid matter in the original organic material whose decay has provided the mineral oil; and secondly, owing to secondary action between reducing agents generated by the putrefying mass and sulphates, such as gypsum. A possible inorganic synthesis could be imagined were the pre-existence of acetylene and sulphides predicated,

[1] *Amer. Chem. Journ.*, xviii, 215 (1896).
[2] *Berichte deutsch. chem. Ges.*, xx, 2098 (1887). [3] *Monatsh. Chem.*, viii, 224 (1887).
[4] *Bull. Soc.*, xxv, 723 (1901).
[5] *Amer. Journ. Sci.*, 3, xlviii, 250 (1894); also *J. Soc. Chem. Ind.*, 727 (1897).
[6] *Journ. Soc. Chem. Ind.*, 121, 123, and 505 (1900); see also Thiele, *Ibid.*, 138, and *Ibid.*, 795 (1901).
[7] *J. Russk. Phiz.-Khim. Obsch.*, xxx, 873; *J. Soc. Chem. Ind.*, 260 (1899).
[8] *Ber. deutsch. chem. Ges.*, xxxiii, 2837 (1900).

seeing that from these generators thiophene is derivable.[1] Krämer and Spilker [2] have put forward the suggestion that the sulphur in petroleum is due to the metabolism of bacteria contemporaneous with the algæ from which the mineral oil is supposed to have originated.

In this connection the work of W. Friedmann is of interest.[3] This author has investigated the action of sulphur on a variety of hydrocarbons. Cyclohexane yielded cyclohexadiëne, thiophenol, and phenyl sulphide. Hexylene gave $C_6H_{12}S$, $C_{12}H_{14}S$, $C_{18}H_{34}S_2$, and $C_{24}H_{20}S_2$. Normal octane produced dimethyl thiophene and diethyl thiophene, whilst from octylene there were obtained a thiophene $C_8H_{12}S$ and two products formulated as $C_{16}H_{28}S$ and $C_{24}H_{38}S_2$ (possibly a dicyclic derivative). Indene yielded $C_{36}H_{22}S$, $C_{36}H_{24}S_3$, and $C_{27}H_{20}S$, together with a compound $C_{18}H_{12}S$ which was characterised by the tenacity with which it resisted desulphurisation. This body did not react with ethyl iodide and absorbed bromine. Tentatively Friedmann regarded it as a thiophene.

Scheibler [4] also has obtained thiophene derivatives by means of the reaction between sulphur and petroleum.

Charitschkoff discovered thiophene in Grozni crude oil to the extent of one part in a million.[5]

Mabery and Smith [6] found an average of 0·5 per cent. of sulphur in a number of samples, and state that the oil of Ohio contains the sulphides of methyl, ethyl, normal propyl, normal and iso butyl, pentyl, ethyl-pentyl, butyl-pentyl and hexyl, but that neither mercaptans nor thiophenes were found. They add that in the Lima oil the sulphur is mainly concentrated in the 200°–300° distillate. Kast and Lagai [7] state that the petroleum of Tegernsee is the only crude oil in which they have found no sulphur, and that the sulphur in other oils varies between 0·064, found by Markownikoff and Ogloblin in an oil of Baku, and 1·87, found in an oil from the Kirghiz Steppe. The Bibi-Eibat oil is stated to contain " some " sulphur. They do not confirm Mabery and Smith's statement as to the nature of the sulphur compounds, and find that the Ohio oil loses only about 25 per cent. of its sulphur by treatment with sulphuric acid, followed by washing with an alkali, although its alliaceous odour is destroyed. The odour is attributed by them to unsaturated hydrocarbons rather than to sulphur compounds. Mabery and Smith, however, point out that the Ohio oil used by Kast and Lagai was obtained in Bremen, and contained 1 per cent. of sulphur ; they state that Ohio oil never contains more than 0·6 per cent., and quote, in support of their assertion, Professors Orton and Lord,[8] who found 0·553 per cent. of sulphur in crude Trenton Limestone oil ; other analysts, who report about 0·5 per cent. ; and the experience of commercial manufacture, which indicates on the average 0·55 per cent. Specimens of petroleum from the Texas oil-fields have been found by the author and others to contain from 2 to 2·4 per cent. of sulphur, in the form of sulphur compounds, and certain descriptions of Mexican crude petroleum contain an even larger percentage.

Canadian sulphur-petroleums contain more sulphur than do the Ohio petroleums. Mabery found 0·98 per cent. in a crude Canadian oil, in addition to a quantity present as hydrogen sulphide. Mabery and Quayle [9] have isolated the following sulphur compounds from Canadian oil :—$C_7H_{14}S$,

[1] W. Steinkopf, *Ann.*, cccciii, 11 (1914).
[2] *Ber.*, xxxv, 1212 (1902).
[3] *Ber.*, xlix, 683, 1344, 1551 (1916); *Petr.*, ix, 693, 978 (1916).
[4] *Ber.*, xlix, 2595 (1916).
[5] *J. Soc. Chem. Ind.*, 907 (1899).
[6] *Proc. Amer. Acad.*, xxv, 218, (1891).
[7] *Dingler's polytechn. Journ.*, cclxxxiv, 69.
[8] *Eighth Annual Report of the U.S. Geological Survey*, p. 624 (1889).
[9] *J. Soc. Chem. Ind.*, 505 (1900).

boiling-point 71°–73°; $C_8H_{16}S$, b.-p. 79°–81°; $C_8H_{16}S$, b.-p. 97°–98°; $C_9H_{18}S$, b.-p. 110°–112°; $C_{10}H_{20}S$, b.-p. 114°–116°; $C_{11}H_{22}S$, b.-p. 129°–131°; $C_{14}H_{28}S$, b.-p. 168°–170°; and $C_{18}H_{36}S$, b.-p. 198°–200° C. (all under 50 mm. pressure). These compounds, which Mabery has characterised as thiophenes or cyclic sulphides, would appear to have the same constitution as the bodies synthetically made by S. von Braun,[1] tetrahydrothiophene, for example, and pentamethylene sulphide are described as possessing a most unsufferable odour. Von Braun remarks on the difficulty of introducing one atom of sulphur as a member of a cyclic system, which may perhaps indicate that Mabery's formulation should be reviewed. Charitschkoff [2] finds that sulphur compounds are always present in that petroleum-spirit from Grozni petroleum which has a specific gravity of 0·685, whilst the naphtha (ligroïn) distillates of specific gravity 0·75 to 0·77 appear to be free from it. Kast and Künkler [3] state that the sulphur of the petroleum of Gemsah, on the shore of the Red Sea, is also not entirely removable by treatment with acid. Krämer [4] found 0·134 to 0·138 per cent. of sulphur in the oils of Alsace, and 0·077 to 0·085 in those of Peine (Hanover), and expresses the opinion that the sulphur exists as thiophenes.

Böttcher separated from the 55°–65° fraction, obtained from Pennsylvanian oil, a white body of the composition $C_5H_{10}SO_3$. Peckham reports the examination of a Californian oil, which contained enough sulphur to form a deposit in the neck of the retort, and Otto Hesse found in Syrian and American asphalt as much as 8·78 and 10·85 per cent. of sulphur. Peckham [5] also found that Californian petroleums on distillation decomposed even at 100° C., with evolution of sulphuretted hydrogen, more or less separation of carbon, and rise of boiling-point of the residue in the retort. Nawratil [6] found **sulphuretted hydrogen** in a sample of oil from Pagorzyn, in Galicia, while Hager [7] asserts the existence of **carbon bisulphide**, but this statement has never been confirmed. In a specimen of Algerian crude petroleum, obtained at a depth of 12 feet from the surface, the author found 2·19 per cent. of sulphur. In samples of the surface-oil from Gaspé, he found from 0·17 to 0·20 per cent., while in oil from a drilled well in this locality, there was only 0·09 per cent. Clifford Richardson and Wallace [8] find besides combined sulphur in the Beaumont petroleum (Jefferson county, Texas) also free sulphur (the limestone in which the petroleum occurs also contains crystallised sulphur). This presence of free sulphur in the oil seems to be the cause of its great instability. (See also Thiele, *J. Soc. Chem. Ind.*, 1271, 1902.)

The identification of the actual molecular structure of the thio derivatives in petroleum is a matter of some difficulty. Mercaptans are soluble in aqueous alkali and yield compounds with alcoholic mercuric chloride. They are oxidisable to sulphuric acids or to disulphides. Thio ethers and sulphides in general additively combine with alkyl iodides, react with halogens, and are oxidisable to sulphones and sulphonides. They also form compounds with mercuric, cuprous, aurous, and palladium chlorides, and with silver nitrate. The thiophenes are comparatively sluggish in reaction capacity, and are characterised by considerable stability. (See also Thole, *J. Inst. Petr. Techs.*. iii. 246, 1917).

[1] *Ber.*, xliii, 545 (1910).
[2] *Trudi Bak. Otd. Imp. Russk. Tekhn. Obsch.*, xii, 272; *J. Soc. Chem. Ind.*, 1009 (1897).
[3] *Dingler's polytechn. Journ.*, cclxxviii, 34 (1890).
[4] *Sitz. Ver. Beförd. Gewerbfl. Preuss.*, 296 (1885).
[5] *Proc. Amer. Phil. Soc.*, xxxvi, 10 (1897).
[6] *Dingler's polytechn. Journ.*, ccxlvi, 423 (1882).
[7] *Ibid.*, clxxxiii, 165, from *Pharm. Centralh.*, vii, 193 (1866).
[8] *J. Soc. Chem. Ind.*, xxi, 317 (1902).

Many other inorganic bodies appear to be present in traces in crude petroleum, though some of the substances found are doubtless wholly or partly due to the solvent action of the oil upon the containing vessels. Markownikoff and Ogloblin [1] obtained 0·09 per cent. of **ash** from the oil from the Benkendorff well at Baku. In the ash, **calcium, iron, aluminium,** and **copper oxides,** together with traces of **silver,** were found. Lidoff [2] obtained from another oil 0·11 per cent. of ash, containing 76·71 per cent. of iron oxide, 5·48 per cent. of lime, and 16·07 per cent. of "insoluble" matter. Norman Tate has shown the presence of **arsenic** and **phosphorus** in certain oils, and it has been stated that metallic arsenic condenses in the necks of retorts in which the bituminous limestones of Lobsann are distilled.[3]

HYDROCARBONS.

Some progress has been made in the determination of the actual constitution of the various **hydrocarbons** and **hydrocarbon derivatives** of which petroleum is made up. Höfer [4] states that members of each of the following groups have been identified :—

C_nH_{2n+2} C_nH_{2n-2} C_nH_{2n-6} C_nH_{2n-10}
C_nH_{2n} C_nH_{2n-4} C_nH_{2n-8} C_nH_{2n-12}

The chemical characteristics of the principal series of hydrocarbons of interest in connection with the chemistry of petroleum, together with tables of physical constants, etc., are described below.

OPEN CHAIN HYDROCARBONS.

Saturated Hydrocarbons. Paraffin.

General Formula C_nH_{2n+2}. Type of Normal Paraffin $R.(CH_3).R'$.

Paraffin Hydrocarbons, as the name implies, are very indifferent to the

TABLE XXXIVA.

PARAFFINS, C_nH_{2n+2}.

Name.	Formula.	Specific Gravity.	Boiling-point C°.
Propane, . . .	C_3H_8, . . .	0·613 (25°)	−37·0 at 760 mm.
Normal butane, . .	$CH_3.CH_2.CH_2.CH_3$	..	1·0 ,, ,,
Trimethyl methane, .	$CH_3.CH(CH_3)_2$, .	0·6 liq.	−17·0 ,, ,,
Normal pentane, . .	$CH_3[CH_2]_3.CH_3$, .	0·6263 (17°)	37·0 ,, ,,
Dimethyl ethyl methane,	$C_2H_5.CH(CH_3)_2$, .	0·6385 (14°)	30·0 ,, ,,
Tetramethyl methane, .	$C(CH_3)_4$, . .	..	9·5 ,, ,,
Normal hexane, . .	$CH_3(CH_2)_4CH_3$, .	0·633 (17°)	71·5 ,, ,,
Methyl diethyl methane, .	$CH_3CH(C_2H_5)_2$, .	..	64·0 ,, ,,
Dimethyl propyl methane,	$C_3H_7.CH(CH_3)_2$, .	0·7011 (0°)	62·0 ,, ,,
Di-isopropyl, . . .	$(CH_3)_2CH.CH.(CH_3)_2$	0·6700 (17°)	58·0 ,, ,,
Trimethyl ethyl methane,	$C_2H_5.C(CH_3)_3$, .	..	43·0–48·0 ,,
Heptane-n, . . .	$CH_3[CH_2]_5CH_3$, .	0·7120 (16°)	97·0–97·5 ,,
−2 Ethyl amyl, . .	$CH_3(CH_2)_3CH(CH_3)_2$	0·6833 (18°)	90·5 ,, ,,
β.δ dimethyl pentane, .	$(CH_3)_2C_5H_{11}$, . .	0·7022 (0°)	83–84,, ,,
Triethyl methane, . .	$CH(C_2H_5)_3$, . .	0·6890 (27°)	96 ,, ,,
Octane, ...	C_8H_{18}, . . .	0·7188 (0°)	125·5 ,, ,,
,,	..	0·7038 (12·5)	124·0 ,, ,,

[1] *Jurn. Russk. Ph.-Kh. Obsch.*, xiii, 1, 179 (1881). [2] *Ibid.*, xiv, 323 (1882).
[3] Daubrée, *Ann. Mines*, 4, xix, 669 (1851). [4] *Das Erdöl*, 1862.

TABLE XXXIVA.—*continued.*

PARAFFINS, C_nH_{2n+2}.

Name.	Formula.	Specific Gravity.	Boiling-point C°.
Nonane,	C_9H_{20},	0·7330 (0°)	149·0 at 760 mm.
Decane,	$C_{10}H_{22}$,	0·7456 (0°)	173·0 ,, ,,
Undecane,	$C_{11}H_{24}$,	0·7745 (M.P.)	214·0 ,, ,,
,,	..	0·7560 (0°)	..
Dodecane,	$C_{12}H_{26}$,	0·7730 (M.P.)	..
		0·7655 (0°)	214·0 ,, ,,
Tridecane,	$C_{13}H_{28}$,	0·7750 (M.P.)	234·0 ,, ,,
		0·7710	144 ,, 15 mm.
		0·7834 (20°)	221 ,, 760 mm.
Tetradecane,	$C_{14}H_{30}$,	0·7750 (M.P.)	252·5 ,, 15 mm.
		0·7750 (5°)	130·0 ,, 50 mm.
		0·7814 (20°)	142·0 ,, 760 mm.
Pentadecane,	$C_{15}H_{32}$,	0·7750 (M.P.)	270·5 ,, ,,
		0·7896 (20°)	..
Hexadecane,	$C_{16}H_{34}$,	0·7750 (M.P.)	287·5 ,, ,,
Heptadecane,	$C_{17}H_{36}$,	0·7760 (M.P.)	303·0 ,, ,,
Octadecane,	$C_{18}H_{38}$,	0·7760 (M.P.)	317·0 ,, ,,
		0·7668 (28°)	..
Nonadecane,	$C_{19}H_{40}$,	0·7770 (M.P.)	330·0 ,, ,,
		0·7770 (32)	..
Eicosane,	$C_{20}H_{42}$,	0·7770 (37)	205·0 ,, ,,
Heneicosane,	$C_{21}H_{44}$,	0·7780 (M.P.)	215·0 ,, 15 mm.
Docosane,	$C_{22}H_{46}$,	0·7780 (M.P.)	224·5 ,, ,,
Tricosane,	$C_{23}H_{48}$,	0·7780 (M.P.)	234·0 ,, ,,
Tetracosane,	$C_{24}H_{50}$,	0·7780 (M.P.)	243·0 ,, ,,
Heptacosane,	$C_{27}H_{56}$,	0·7790 (M.P.)	270·0 ,, ,,
Hentriacontane,	$C_{28}H_{58}$,	0·7800 (M.P.)	302·0 ,, ,,
Dotriacontane,	$C_{29}H_{60}$,	0·7810 (M.P.)	310·0 ,, ,,
Pentatriacontane,	$C_{30}H_{62}$,	0·7810 (M.P.)	331·0 ,, ,,

TABLE XXXIVB.—MELTING-POINTS OF THE ALIPHATIC HYDROCARBONS.

Synthetically prepared from the pure esters of fatty acids or by the action of magnesium on their alkyl iodide.

$C_{16}H_{34}$,	20° C.
$C_{18}H_{38}$,	38
$C_{22}H_{46}$	47
$C_{24}H_{50}$,	54
$C_{26}H_{54}$,	59–60
$C_{28}H_{58}$,	64–65
$C_{30}H_{62}$,	69–70
$C_{34}H_{70}$,	76–75
$C_{36}H_{74}$,	78

action of reagents. Being saturated, they do not form addition compounds with other elements ; bromine and iodine absorption are therefore negligible. Sulphuric and nitric acid are without appreciable action in the cold. Oxidising agents, like potassium permanganate and bichromate, likewise have no action. Liquid sulphur dioxide at low temperatures has but slight solvent action. Methyl sulphate has only a limited solvent action. The iso and tertiary paraffins appear to be more susceptible to attack, *e.g.* by a nitrating mixture, and, furthermore, the lower members are decidedly soluble in fuming sulphuric acid. Dilute nitric acid under pressure yields a nitro-derivative. Chlorine and bromine react readily with the paraffins, forming substitution compounds and evolving the halogen hydracid.

Unsaturated (Ethylenes).

1. **Olefines.**—General formula, C_nH_{2n}. Type $(R)_n.CH : CH_2$.

Characterised by direct combination with two univalent atoms (Br or I) or radicles, so becoming saturated. Hence these hydrocarbons have high bromine and iodine absorption values.

Generally the boiling-point is higher than that of the corresponding paraffin.

Absorbed by strong sulphuric acid with formation of ethereal salts; the higher members are chiefly polymerised by this reagent. This serves for their separation from paraffins. They yield chlorhydrins with hypochlorous acid,

Table XXXV.—Ethylenes, C_nH_{2n}.

Name.	Formula.	Boiling-points °C.
Propylene	$CH_3CH : CH_2$	−48 gaseous.
Ethyl ethylene,	$C_2H_5CH : CH_2$	−5 "
Plane-sym. Dimethyl ethylene,	$CH_3 . CH : CH . CH_3$	+1
Axial-sym. Dimethyl ethylene,		+2·5 "
Unsym. dimethyl ethylene	$(CH_3)_2C : CH_2$	−6 "
n-Propyl ethylene,	$C_3H_7 . CH : CH_2$	39 "
α-Amylene	..	..
Isopropyl ethylene,	$(CH_3)_2CH . CH : CH_2$	21 "
α-Isoamylene,	..	..
Sym. Methyl ethyl ethylene,	$C_2H_5 . CH : CH . CH_3$	36 "
β-Amylene, / Unsym.: methyl ethyl ethylene	$C_2H_5, CH_3 > C : CH_2$	31 "
γ-Amylene	..	..
Trimethylethylene,	$(CH_3)_2C : CH . CH_3$	36 "
β-Isoamylene,	..	..
Tetramethyl ethylene,	$(CH_3)_2C : C(CH_3)_2$	73 "

and are converted by mild oxidising agents like potassium permanganate to glycols.

With energetic oxidisers the characteristic double linkage is severed.

Ozone becomes added at the double bond, forming ozonides, decomposable by water, a reaction of great diagnostic possibilities.

Dilute sulphuric acid, certain metallic salts like $ZnCl_2$, Al_2Cl_6, cause polymerisation even at ordinary temperatures in some cases; yield additive compounds with certain salts, *e.g.* mercuric sulphate.

They are soluble in liquid sulphur dioxide.

The formolite test is made use of for quantitative estimation of the olefines in petroleum distillates.

Diolefines.—General formula, C_nH_{2n-2}. Type $CH_2 : CH\text{-}CH : CH_2$.

As the prefix "di" indicates, there are two olefine linkages, as indicated in the type formula, in the molecule. These hydrocarbons are also given the termination "diëne," to indicate their characteristic structure.

Precipitates are formed with aqueous solutions of mercuric sulphate and chloride, but the diolefines do not form silver and copper compounds as the acetylene hydrocarbons do. The diolefines are isomeric with the homologues of acetylene, thus 1, 3–butadiëne (divinyl, or erythrene, or pyrrolylene) $CH_2 : CH . CH : CH_2$ is isomeric with 3–Butine (ethyl acetylene) $C_2H_5 . C : CH$.

Diolefines absorb atmospheric oxygen more or less readily and may ultimately form gummy deposits. Ozone forms diozonides which are decomposed by water. Some spontaneously polymerise, thus isoprene (*β*-methyl butadiëne)

[$CH_2 : CH.C.CH_3 : CH_2$] becomes dipentene or cinene (a terpene hydrocarbon) [$C_{10}H_{16}$]. They combine with bromine, forming tetrabromides.

They are readily absorbed by aqueous sulphuric acid, yielding polymerisation products. It is doubtful to what extent they occur in petroleum, but it

TABLE XXXVI.—DIOLEFINES, C_nH_{2n-2}.

Name.	Formula.	Boiling-point °C.
Allene, sym. Allylene [Propadiëne], .	$CH_3 : C : CH_2$	Gas.
Dioinyl, Erythrene [1–3–Butadiëne] Pyrrolylene	$CH_2 : CH . CH : CH_2$	–5
$\alpha\gamma$-pentadiene, ...	$H_2C . HC : CH . CH : CH_2$	41
Piperylene, α-methyl butadiëne, . .	$CH_2 : CH . CH : CH_3$	42
Iso-prene. β-methyl butadiëne, . .	$CH_2 : CH . C(CH_3) . CH_2$	35
Di-isopropenyl, $\beta\gamma$-Dimethyl butadiëne, .	$CH_2 : C(CH_3) . C(CH_3) : CH_2$	71
1, 1, 3–trimethyl butadiëne, . . .	$(CH_3)_2C : CH . C(CH_3) : CH_2$	93
Diallyl [1, 5–Hexadiëne], . . .	$CH_2 : CH . CH_2 . CH_2 . CH : CH_2$	59
2, 5–Dimethyl–1, 5–Hexadiëne, . .	$CH_2C(CH_3)CH_2 . CH_2C(CH_3) : CH_2$	137
1, 1, 5–Trimethyl–1, 5–Hexadiëne, .	$(CH_3)_2C : CH.CH_2.CH_2C(CH_3):CH_2$	141
Conylene [1, 4–Octadiëne], . . .	$CH_2:CH.CH_2.CH:CH.CH_2CH_2CH_3$	126

appears to be generally admitted that the compounds that cause the black "sludge acid" are of this type, seeing that the olefines do not undergo energetic molecular change during the acid treatment.

These hydrocarbons, further, are of interest because of their occurrence in "cracked spirit." Erythrene in particular appears to be a product in all such cases. The objectionable smell and the gumming properties of "cracked spirit" are probably to be traced to the presence of diolefines.

Acetylenes or Alkines.—General formula C_nH_{2n-2}. Type $RC \vdots CR$. Are isomeric with the diolefines, but two adjacent carbon atoms of the molecule have the triple acetylenic linkage.

Characteristic metallic derivatives (acetylides) are formed with all hydrocarbons of the series where the hydrogen atoms are directly linked to carbon atoms, hydrogen being replaced by the metal. Thus acetylene forms copper

TABLE XXXVII.—ACETYLENES, C_nH_{2n-2}.

Name.	Formula.	Boiling-point °C.
Allylene, methyl acetylene [propine], . .	$CH_3 . C \vdots CH$	Gas
Crotonylene, dimethyl acetylene [2-butine], .	$CH_3C \vdots C . CH_3$	27
Ethyl acetylene [3-butine], ...	$C_2H_5 . C \vdots CH$	18
Methyl ethyl acetylene [3-pentine], . .	$C_2H_5 . C \vdots C . CH_3$	55
n-Propyl acetylene [4-pentine], . . .	$n\text{-}C_3H_7 . C \vdots CH$	48
Isopropyl acetylene [3-methyl-1-butine], .	$(CH_3)_2CH . C \vdots CH$	28
Methyl-propyl acetylene [4-hexine], . .	$n\text{-}C_3H_7 . C \vdots C.CH_3$	84

acetylide $CuC \vdots CCu$; methyl acetylene $HC \vdots C.CH_3$ similarly gives metallic derivatives, but dimethyl acetylene $CH_3.C \vdots C.CH_3$ does not do so. The formation of these characteristic metallic precipitates with mono-alkyl acetylenes and ammoniacal solutions of salts of copper, silver, etc., affords the most general method of separating and identifying these hydrocarbons, since the metallic salt may be decomposed by dilute acid with regeneration of the hydrocarbon.

The acetylides may also be regarded as carbides, thus calcium acetylide (CaC_2) and calcium carbide are identical.

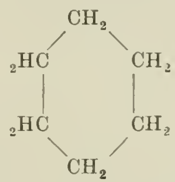
Some acetylenes polymerise readily and particularly when heated, forming aromatic (closed chain) hydrocarbons. In certain cases strong sulphuric acid causes such polymerisation, but in general the hydrocarbons are absorbed by the strong acid. Moderately dilute sulphuric acid often causes the addition of the elements of water with the formation of an aldehyde.

Being unsaturated, acetylenes form addition compounds readily with halogen elements, thus acetylene yields a dibromide, $C_2H_2Br_2$, and a tetrabromide, $C_2H_2Br_4$.

It is difficult to determine to what extent, if any, acetylenes are present in petroleum.

CLOSED CHAIN HYDROCARBONS (Ring or cyclic compounds).

Polymethylenes (Cycloparaffins, naphthenes).—General formula, C_nH_{2n} (or $C_nH_{2n-6} . 6H$, see later). Type—hexamethylene



The radicle group methylene (CH_2) is unknown as a separate molecular compound, but by association of groups forms closed chain hydrocarbons, *e.g.* tri, tetra, penta, and hexa methylenes. The isolation of compounds of this type from petroleums led to the name "naphthene" being given. Groupings

Table XXXVIII.—Polymethylenes, C_nH_{2n} (or $C_nH_{2n-6} . 6H$).

Name.	Formula.	Boiling-point °C.	Spec. Gravity at 0° C.
Trimethylene,	C_3H_6	–35	..
Tetramethylene,	C_4H_8	12	0·7090
Pentamethylene,	C_5H_{10}	49	0·7690
Hexamethylene,	C_6H_{12}	81	0·7990
1, 2, 3 trimethyl trimethylene	..	65–66	0·6921 (22°)
Methyl pentamethylene,	C_6H_{12}	72	0·7660
Heptamethylene,	C_7H_{14}	117	0·8300
Dimethyl pentamethylene,	C_7H_{14}	91	0·7780
Methyl hexamethylene,	C_7H_{14}	98–100·2	0·7780, 0·7859(0°)
Octomethylene,	C_8H_{16}	146	0·8560
Dimethyl hexamethylene,	C_8H_{16}	118	0·7810
Nonomethylene,	C_9H_{18}	171	..
Trimethyl hexamethylene,	C_9H_{18}	148	0·7870
Phenyl cyclo-hexane,	$C_6H_5.C_6H_{11}$	239	0·9441 (20°)
Hexa hydro p. cymene,	$C_{10}H_{20}$	170–172	0·7974 (20°)

of less than five methylene groups (pentamethylene) have not been identified in petroleum, and in the vast majority of cases only penta and hexa meythlene derivatives occur therein.

These hydrocarbons exhibit chemical stability similar to that of the paraffins.

With the exception of trimethylene, they do not form addition compounds with the halogen elements, that is, they are not unsaturated like the isomeric ethylene hydrocarbons. Again, they do not decolorise alkaline permanganate in the cold, not being readily susceptible to oxidation. Bromine and aluminium bromide yield poly-bromo derivatives of the corresponding aromatic compound.

Ordinary sulphuric acid has little or no action. The limited action of fuming sulphuric acid forms sulphonic acids of the normal benzene hydrocarbons and, further, may act as an oxidising agent. Nitric acid (cold) has only slight action. Fuming nitric acid, or warm nitrating acid (sulphuric and nitric acid), convert them partially at least into nitro-derivatives of the normal benzene hydrocarbons. Dilute nitric acid brings about rupture of the ring, and potassium permanganate behaves similarly. Chlorine substitutes as with a paraffin.

Their specific gravity is higher than that of the paraffin hydrocarbons of approximately corresponding boiling-point, which enables their presence to be detected in admixture with paraffins when hydrocarbons of other series have been removed.

They are somewhat insoluble in liquid sulphur dioxide, and do not form solid formolites by the action of sulphuric acid and formalin (Nastjukoff's test).

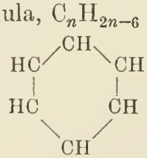
The cycloparaffins constitute a direct link between the straight chain hydrocarbons (aliphatic hydrocarbons) and the benzene hydrocarbons (aromatic hydrocarbons). Benzene, for example, can be reduced to a hexahydride, and this is identical with cyclo-hexane.

Unsaturated Cyclo-Hydrocarbons.—As with straight-chain hydrocarbons, cyclic hydrocarbons may be saturated (cycloparaffins) or unsaturated. The latter are soluble in liquid sulphur dioxide, and by the action of sulphuric acid and formalin (Nastjukoff's test) yield insoluble formolites. The reaction is said to be characteristic. They are soluble in strong sulphuric acid. Nastjukoff regards lubricating oils as consisting chiefly of saturated and unsaturated cyclic hydrocarbons.

The precise nature of the compounds of high molecular weight in petroleum is unknown except in the case of the readily identified wax. Many of the compounds yield on analysis figures which may be represented by the general formulæ, C_nH_{2n-2}; C_nH_{2n-1}; C_nH_{2n-6}, and so forth. Further, the stability of unsaturated hydrocarbons of high molecular weight is at least somewhat indeterminate, and it is not quite valid to regard insolubility in sulphuric acid as necessarily a sign of saturation in view of the recent work of Brooks and Bacon. These investigations showed that the polymerides of the higher olefines were produced by the action of strong sulphuric acid and remained undissolved by it. It is not likely, however, that such polymerides would be insoluble in excess of fuming sulphuric acid, and in this case it has been shown that the residual hydrocarbons may still be represented by similar formulæ to those just quoted.

AROMATIC HYDROCARBONS.

Benzene Series.—General formula, C_nH_{2n-6}; Type—Benzene, C_6H_6.



These have a characteristic "aromatic" odour. They do not form addition products, except in the presence of sunlight. Under suitable conditions halogen substitution products are formed, which are much less reactive than the halogen substitution products of the straight-chain hydrocarbons. They do not additively combine with halogen acids ; *e.g.* hydriodic acid.

Ordinary sulphuric acid attacks them slowly in the cold, but the higher members are most easily acted on. On warming, or by the action of the fuming acid, hydrogen is replaced with the formation of sulphonic acids. Nitric acid forms characteristic nitro-substitution derivatives, like nitro-benzene. Formalin in the presence of sulphuric acid yields formolites.

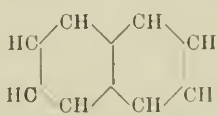
TABLE XXXIX.—AROMATIC HYDROCARBONS.

Name.	Formula.	Specific Gravity.	Boiling-point °C.
Benzene, ...	C_6H_6	0·87907 (20°)	80·36
Toluene, methyl benzene, . .	$C_6H_5 . CH_3$	0·8820 (0°)	111·0
Xylenes—			
Ortho-dimethyl benzene .	$C_6H_4(CH_3)_2$	0·7560 (14°)	142–143
Meta-dimethyl benzene, . .	$C_6H_4(CH_3)_2$	0·8780 (0°)	139·8
Para-dimethyl benzene, . .	$C_6H_4(CH_3)_2$	0·8620 (19·5)	138
Mesitylene (Trimethyl benzene) 1-3-5	$C_6H_3(CH_3)_3$	0·8558 (20°)	163
Pseudocumene (,, ,, 1-2-4	$C_6H_3(CH_3)_3$	0·8946 (4°)	169
Cumene, dimethyl toluene, . .	$C_6H_5 . CH(CH_3)_2$	0·8800 (0°)	152
Cymene 1 : 4	$CH_3.C_6H_4.CH(CH_3)_2$	0·8720	175
,, 1 : 2	$CH_3.C_6H_4.CH(CH_3)_2$	0·8580	157
,, 1 : 3	$CH_3.C_6H_4.CH(CH_3)_2$	0·8650	175
Pentamethyl benzene, . .	$C_6H(CH_3)_5$	..	231 [M.P. 51·5]
Isoamyl benzene, . . .	$C_6H_5 . C_5H_{11}$	..	193
Amyl benzene, ...	$C_6H_5 . C_5H_{11}$	..	201
Hexamethyl benzene, . . .	$C_6(CH_3)_6$	..	264 [M.P. 169]
Dipropyl benzene, . . .	$C_6H_4(C_3H_7)_2$ 1–4	..	219
Propyl-isopropyl benzene, . .	$C_6H_4(C_3H_7)C_3H_7$	..	212
Sym. triethyl benzene, . . .	$C_6H_3(C_2H_5)_3$ 1–3–5	..	218
v-Tetraethyl benzene 1-2-3-4, .	$C_6H_2(C_2H_5)_4$	..	251
N-Octyl benzene, . . .	C_6H_5, C_8H_{17}	..	262–264
Pentaethyl benzene, . . .	$C_6H(C_2H_5)$	..	277
Hexadecyl benzene, . . .	$C_6H_5C_{16}H_{31}$	..	230 at 15 mm. [M.P. 27]
Hexaethyl benzene, . . .	$C_6(C_2H_5)_6$	..	305 [M.P. 126]
Octodecyl benzene, . . .	$C_6H_5C_{18}H_{37}$	..	249 at 15 mm. [M.P. 36]

They are not oxidised by permanganate, but powerful oxidising agents like ammonium persulphate bring about oxidation with rupture of the ring-grouping and formation of straight-chain derivatives. Powerful reducing agents like hydriodic acid also result in rupture of the ring-grouping. Hydrogen in the presence of nickel reduces this aromatic series to the cycloparaffin.

The benzene hydrocarbons are soluble in liquid sulphur dioxide, and also dimethyl sulphate. Either may be employed in their separation from the paraffins, although the latter are only relatively insoluble.

Naphthalene Hydrocarbons.—More than one benzene ring may constitute a molecular unit, thus naphthalene, $C_{10}H_8$, is represented by two benzene rings having two carbon atoms in common, no hydrogen atom being associated with these atoms.



The aromatic hydrocarbons are widely distributed in petroleum. Most crude oils at least contain traces of benzene, toluene, and xylene, whilst mesitylene and its higher homologues have been isolated in certain cases when special search has been made. The striking assertion made by Brooks and I. W. Humphrey[1] that when petroleum is cracked at 420° C. and 100 lbs. pressure there is little evolution of gas, but a considerable production of aromatic hydrocarbons, leads to the view that complex phenylated hydrocarbons pre-exist in this crude oil. Support was given to this view by the synthesis of a "phenyl-paraffin" by means of a chlorinated paraffin, benzene, and aluminium chloride. The product being decomposed by heat yielded aromatic hydrocarbons and highly fluorescent distillate. Homologues of the naphthalenes have been discovered to exist in Borneo crude oil to the extent of about 6 per cent.; α and β methyl naphthalene, together with dimethyl naphthalene, were discovered.[2]

The characteristic fluorescence which is exhibited by many petroleum distillates is to be ascribed, according to Brooks and Bacon,[3] to naturally occurring aromatic derivatives. From the "acid-tar" these authors isolated such a compound which resembled chrysene or fluorene. The fluorescent material is slightly absorbed on fuller's earth.

The early and only partially successful attempts of Reichenbach and of Laurent[4] to separate petroleum into its constituent hydrocarbons by fractional distillation were followed by the important researches of Schorlemmer[5] and Pelouze and Cahours,[6] on American petroleum, and these again were followed by the work of Warren,[7] and of Warren and Storer.[8] The chemists last-named, as well as De la Rue and Müller,[9] also examined "Rangoon" petroleum. It has been found that Pennsylvanian petroleum (generally described as American oil) consists mainly of the **methane** or **paraffin** series of hydrocarbons, the composition of which is represented by the general formula C_nH_{2n+2}, while Caucasian petroleum consists mainly of naphthenes, which belong to the $C_nH_{2n-6}+H_6$ group, and are isomers of the ethylene (C_2H_{2n}) or olefine group. Stokes[10] investigated a specimen of crude oil from Cuba, and found that, like Russian oils, it consisted for the most part of naphthenes. Its specific gravity was 0·901 at 33° C., and it had an odour like cedarwood. Paraffin wax was absent, and not more than 1 per cent. of unsaturated fatty hydrocarbons were present. Mabery[11] has more recently, however, examined the hydrocarbons of Pennsylvanian oil with boiling-points above 216° C., and found that rising from $C_{13}H_{28}$ to $C_{26}H_{54}$, they all agreed in belonging to the C_nH_{2n+2} series, yet the two final hydrocarbons (boiling at 310° and above) which he obtained, belonged to the C_nH_{2n-2} series, members of which series also occur in the less volatile portions of Canadian, Californian, and Texas oils. This, Mabery thinks, reveals some relationship between all four of the oils just referred to. According to Markownikoff and Ogloblin, the naphthenes constitute at least 80 per cent. of the oil of Baku. Contrary to his previously published opinions that the fractions of Caucasian petroleum boiling below 60° C. consist exclusively of paraffins, Markownikoff[12] found in 1890 that in some of these the specific gravities

[1] *J. Amer. Chem. Soc.*, xxviii, 393 (1916); see also Jones and Wheeler, *J. Chem. Soc.*, cv, 2562 (1914).

[2] H. O. Jones and H. A. Wooton, *Trans. Chem. Soc.*, xci, 1146 (1907).

[3] *J. Ind. and Eng. Chem.*, vi, 623 (1914).

[4] *Comptes Rend.*, iv, 909 (1827).

[5] *Proc. Manch. Phil. Soc.*, iii, 81; *Phil. Trans.*, clxii, 111; clxix, 49; clxxi, 451; clxxiv, 269; *Proc. Roy. Soc.*, xiv, 164; xv, 131; xvi, 34, 367; xviii, 25, and xix, 20, 487; *J. Chem. Soc.*, xvi, 216; xxvi, 319 (1863, 1873).

[6] *Comptes Rend.*, lvi, 505 (1863).

[7] *Mem. Amer. Acad.*, 2, ix, 121, 135 (1867).

[8] *Mem. Amer. Acad.*, 2, ix, 177 (1867).

[9] *Proc. Roy. Soc.*, viii, 221 (1857).

[10] *Eng. and Min. Journ.*, lxiii, 347 (1902).

[11] *Proc. Amer. Acad.*, xxxvii, 565 (1902).

[12] *Jurn. Russk. Ph.-Kh. Obsch.*, xxii, 23 (1890).

are higher than is consistent with this assumption, and indicate the presence of cyclic hydrocarbons. Mendeléeff[1] considers that the Russian and American oils contain the same hydrocarbons, though in varying amounts. Beilstein and Kurbatoff[2] found *pentane*, *hexane*, and *heptane* in the lighter distillates from the oil of Tsarski Kolodtsi (Government of Tiflis), and state that this oil, unlike that of Baku, consists largely of members of the C_nH_{2n+2} group.

Krämer states that the distillate obtained below 150° C. from German oil consists also mainly of the *methane* group; and Engler has found the compounds C_5H_{12}, C_6H_{14}, and C_9H_{20} in the fraction boiling below 150° C. Bussenius and Eisenstuck[3] and Uelsmann[4] state that the oil of Sehnde (Hanover) has the general formula C_nH_{2n+2}. The Italian oil, according to Chandler, contains practically none of such compounds. In Galician oil, Lachowicz found *normal* and *iso-pentane* and *normal* and *secondary hexane, heptane, nonane*, and *decane*. O. Aschan[5] has found in petroleum-spirit from Baku *di-isopropyl* or *tetramethylethane*, and Charitschkoff[6] in Grozni spirit, large quantities of isoheptane, and in the portion boiling between 29° and 35° C. two isomeric pentanes.

The following members of the methane group have been isolated from Pennsylvanian petroleum:—

TABLE XL.—Paraffins from Pennsylvanian Petroleum.

Name.	Formula.	Boiling-point.	Specific Gravity.
Gaseous.		°C.	
Methane,	CH_4	..	..
Ethane,	C_2H_6	..	..
Propane,	C_3H_8	..	..
Butane,	C_4H_{10}	0	..
Liquid.			
Pentane (normal)	C_5H_{12}	38	0·628
,, (iso-),	,,	30	,,
Hexane (normal),	C_6H_{14}	69	0·664
,, (iso-),	,,	61	,,
Heptane (normal),	C_7H_{16}	97·5	0·699
,, (iso-),	,,	91	,,
Octane (normal),	C_8H_{18}	125	0·703
,, (iso-),	,,	118	,,
Nonane,	C_9H_{20}	136	0·741
Decane,	$C_{10}H_{22}$	158	0·757
Endecane,	$C_{11}H_{24}$	182	0·765
Dodecane,	$C_{12}H_{26}$	198	0·776
Tridecane,	$C_{13}H_{28}$	216	0·792
Tetradecane,	$C_{14}H_{30}$	238	..
Pentadecane,	$C_{15}H_{32}$	258	..
Hexadecane,	$C_{16}H_{34}$	280	..
Octodecane,	$C_{16}H_{38}$	..	..
?	$C_{26}H_{42}$	..	..
?	$C_{23}H_{48}$	..	..
?	$C_{25}H_{52}$	..	..
Solid.			
Paraffin (myricyl),	$C_{27}H_{56}$	..	..
,, (ceryl),	$C_{30}H_{62}$	370	..

[1] *Jurn. Russk. Ph.-Kh. Obsch.*, xv, 1, 189 (1883).
[2] *Ber. deutsch. chem. Ges.*, xiv, 1620 (1881). [3] *Ann. Chem. Pharm.*, cxiii, 151 (1860).
[4] *Ann. Chem. Pharm.*, cxiv, 279 (1860). [5] *Ber. deutsch. chem. Ges.*, xxxi, 1801 (1898).
[6] *Jurn. Russk. Ph.-Kh. Obsch.*, xxxi, 655 (1899).

By working on large quantities of crude Pennsylvanian petroleum, Warren separated both *normal* and *iso-butane*, *pentane*, *hexane*, *heptane*, and *octane* in quantities of some hundred cubic centimetres, and of boiling-points closely approaching to those given above, as is shown by the following *résumé* of his results :—

TABLE XLI.—Paraffins from Pennsylvanian Petroleum.

First Series.				Second Series.			
Formula.	Boiling-point. ° C.	Specific Gravity at 0° C.	Vapour-Density.	Formula.	Boiling-point. ° C.	Specific Gravity at 0° C.	Vapour-Density.
C_4H_{10}	?	0·600	2·110	C_4H_{10}	8 to 9	0·611	..
C_5H_{12}	30·2	0·640	2·538	C_5H_{12}	37·0	0·645	2·514
C_6H_{14}	61·3	0·676	3·053	C_6H_{14}	68·5	0·689	3·038
C_7H_{16}	90·4	0·718	3·547	C_7H_{16}	98·1	0·730	3·551
C_8H_{18}	119·5	0·737	3·992	C_8H_{18}	127·6	0·752	3·990
C_9H_{20}	150·8	0·756	4·600				

Warren also isolated the members $C_{10}H_{20}$ (boiling-point 174·9° C.), $C_{11}H_{22}$ 195·8°), and $C_{12}H_{24}$(216·2°) of the C_nH_{2n} group, but, according to Markownikoff, the compounds belong to the naphthene group already mentioned. Warren and Storer obtained the paraffins C_7H_{16} to C_9H_{20} from "Rangoon tar," presumably the crude petroleum of Yenangyaung in Upper Burma.

Referring to the constituents of Pennsylvanian, Ohio, and Canadian petroleum between 150° C. and 220° C., Mabery[1] finds that Pennsylvanian oil contains, besides paraffin hydrocarbons, smaller quantities of aromatic hydrocarbons (mesitylene, etc.). Ohio oil is represented by the same hydrocarbons of the C_nH_{2n+2} series, the higher specific gravity being due to a larger percentage of the aromatic series. Up to 173° C. the Canadian oil is the same as the others, but the fractions 196°–214° C. have the formula C_nH_{2n}, and Canadian oil contains more aromatic hydrocarbons than the other two. The results show a relation between the chemical composition of the hydrocarbons and the specific gravity of the crude oils, viz. Pennsylvania, 0·80–0·82 ; Ohio, 0·82–0·85 ; Canadian, 0·85–0·88 ; whilst South American oil, specific gravity 0·948, contains only the C_nH_{2n} ($C_nH_{2n-6} . H_6$?) series, which also forms the chief portion of Caucasian oil, specific gravity 0·88.

Mabery and Buck[2] also examined Texas petroleum. It was very thick and dark in colour, and had a specific gravity of 0·9500 at 20° C. It contained hydrocarbons from $C_{14}H_{26}$ to $C_{19}H_{35}$ of the series C_nH_{2n-2}, and higher hydrocarbons $C_{21}H_{38}$ to $C_{25}H_{46}$ of the series C_nH_{2n-4}, with boiling-points rising from 125° to 275° C., and specific gravities from 0·8711 to 0·9410.

In a paper on the hydrocarbons in Pennsylvania petroleum with boiling-points above 216°, Mabery[3] describes the separation and identification of the following :—

[1] *Proc. Amer. Acad.*, xxxii, 121 (1897).
[2] *Journ. Amer. Chem. Soc.*, xxii, 553 (1900).
[3] *Proc. Amer. Acad.*, xxxvii, 565 (1902).

TABLE XLII.—PENNSYLVANIAN HYDROCARBONS.

Name.	Symbol.	Boiling-point.	Melting-point.
Tridecane,	$C_{13}H_{28}$	226°	..
Tetradecane,	$C_{14}H_{30}$	236°–238°	..
Pentadecane,	$C_{15}H_{32}$	256°–257°	..
Hexadecane,	$C_{16}H_{34}$	274°–275°	..
Heptadecane,	$C_{17}H_{36}$	288°–289°	10°
Octodecane,	$C_{18}H_{38}$	300°–301°	20°
Nonodecane,	$C_{19}H_{40}$	210°–212°, 50 mm.	33°–34°
Heneicosane,	$C_{21}H_{44}$	230°–231°, ,,	40°–41°
Hydrocarbon, liquid at −10°,	$C_{22}H_{44}$	240°–242°, ,,	..
Docosane,	$C_{22}H_{46}$	..	44°
Hydrocarbon, liquid at −10°,	$C_{23}H_{46}$	258°–260°, ,,	..
Tricosane,	$C_{23}H_{48}$	..	45°
Hydrocarbon, liquid at −10°,	$C_{24}H_{48}$	272°–274°, ,,	..
Tetracosane,	$C_{24}H_{50}$	..	48°
Hydrocarbon, liquid at −10°,	$C_{26}H_{52}$	280°–282°, ,,	..
Pentacosane,	$C_{25}H_{52}$	..	53°–54°
Hydrocarbon, liquid at −10°,	$C_{27}H_{52}$	292°–294°, ,,	..
Hexacosane,	$C_{26}H_{54}$	..	58°
Hydrocarbon, liquid at −10°,	$C_{28}H_{54}$	310°–312°, ,,	..
Octocosane,	$C_{28}H_{58}$	..	60°

Mabery and Palm[1] have separated the following hydrocarbons from Ohio Trenton Limestone petroleum :—

TABLE XLIII.—OHIO (TRENTON LIMESTONE) HYDROCARBONS.

Series.	Formula.	Boiling-point.	Sp. Gr. at 20°.
C_nH_{2n},	$C_{12}H_{24}$	211°–213° atm. pressure	0·7970
,,	$C_{13}H_{26}$	223°–225° ,, ,,	0·8055
,,	$C_{14}H_{28}$	138°–140° 30 mm.	0·8129
,,	$C_{15}H_{30}$	152°–154° ,,	0·8204
,,	$C_{16}H_{32}$	164°–168° ,,	0·8254
,,	$C_{17}H_{34}$	177°–179° ,,	0·8335
C_nH_{2n-2},	$C_{19}H_{36}$	198°–202° ,,	0·8364
,,	$C_{21}H_{40}$	213°–217° ,,	0·8417
,,	$C_{22}H_{42}$	224°–227° ,,	0·8614
,,	$C_{24}H_{46}$	237°–240° ,,	0·8639
C_nH_{2n-4},	$C_{23}H_{42}$	253°–255° ,,	0·8842
,,	$C_{24}H_{44}$	263°–265° ,,	0·8864
,,	$C_{25}H_{46}$	275°–278° ,,	0·8912

In the next Table Mabery[2] gives the following hydrocarbons separated from Canadian petroleum, and the chlorides prepared from them :—

TABLE XLIV.—CANADIAN HYDROCARBONS.

	Formula.	Boiling-point.	Sp. Gr. at 20°.
Hydrocarbon,	$C_{12}H_{24}$	216°	..
Chloride,	$C_{12}H_{23}Cl$	160°, 15 mm.	0·9145
Hydrocarbon,	$C_{13}H_{26}$	228°–230°	0·8087
Chloride,	$C_{13}H_{25}Cl$	165°, ,, ,,	0·9221
Hydrocarbon,	$C_{14}H_{28}$	141°–143°, 50 ,,	0·8096
Chloride,	$C_{14}H_{27}Cl$	180°, 15 ,,	0·9288
Hydrocarbon,	$C_{15}H_{30}$	159°–169°, 50 ,,	0·8192
Chloride,	$C_{15}H_{29}Cl$	190°, 15 ,,	0·9358

[1] *Proc. Amer. Acad.*, xl, 323 (1904). [2] *Ibid.*, 334.

From Santa Barbara (California) petroleum Mabery[1] obtained the following:—

TABLE XLV.—CALIFORNIAN HYDROCARBONS.

	Formula.	Boiling-point.	Sp. Gr. at 20°.
Hydrocarbon, ...	$C_{13}H_{24}$	150°–155°, 60 mm.	0·8621
,, ...	$C_{16}H_{30}$	175°–180°, ,,	0·8808
,, ...	$C_{17}H_{30}$	190°–195°, ,,	0·8919
,, ...	$C_{18}H_{32}$	210°–215°, ,,	0·8996
,, ...	$C_{24}H_{44}$	250°–255°, ,,	0·9299
,, ...	$C_{27}H_{46}$	310°–315°, ,,	0·9451
,, ...	$C_{29}H_{50}$	340°–345°, ,,	0·9778

Balbiano[2] finds that Italian petroleum (from Velleia, near Piacenza) contains methylcyclopentane and cyclohexane, and is very rich in light oil boiling below 150° C.

Höfer[3] states that the American oil distillate known as "light oil" contains the C_5H_{12} to C_8H_{18} members of the methane group; while the illuminating oil consists mainly of the members C_7H_{16} to $C_{12}H_{23}$, according to *Muspratt's Encyclopädisches Handbuch der technischen Chemie* (Ed. iii., by Stohmann and Kerl, v. 986), or of the members $C_{14}H_{30}$ and $C_{16}H_{34}$, according to Biel.[4]

Mendeléeff[5] states that, from an examination of a large number of crude Baku oils obtained from varying depths, it is found that the specific gravity of the distillate obtained between 100° and 105°, after four or five fractionations, varies between 0·751 and 0·756, while that of the corresponding fraction of American petroleum lies between 0·703 and 0·710. According to Markownikoff and Ogloblin,[6] the fraction of Caucasian petroleum, boiling between 150° and 300° C., shows nearly the composition C_nH_{2n-2}, but after removal of hydrocarbons rich in carbon has the composition C_nH_{2n}. S. Young[7] finds the following in American petroleum:—Isopentane, normal pentane, pentamethylene, isohexane, normal hexane, methylpentamethylene, benzene, hezamethylene, isoheptane, normal heptane, methylhexamethylene and toluene. Comparison of the results obtained with American, Galician, and Russian petroleum shows that the same classes of hydrocarbons—paraffins, polymethylenes or naphthenes, and aromatic hydrocarbons—are present in the petroleum from all three sources, but that the relative amount of naphthenes and in all probability of aromatic hydrocarbons, is greatest in Russian and least in American petroleum. Charitschkoff[8] finds pentane and isopentane in Grozni (Caucasian) petroleum.

Varying proportions of the **ethylene** or **olefine** (C_nH_{2n}) group are found in most crude oils, but Lachowicz[9] and others state that many of the compounds belonging to this series, found in the refined products, merely result from the distillation, and do not exist as such in the crude oil. Lachowicz asserts that this group is absent from Galician oil, but Tuttschew[10] found it present in

[1] *Proc. Amer. Acad.*, xl, 340–346 (1904).
[2] *Gazz. chim. ital.*, xxxii (1), 437 (1902).
[3] *Das Erdöl*, p. 58 (1862).
[4] *Dingler's polytechn. Journ.*, ccxxxii, 354 (1882).
[5] *Jurn. Russk. Ph.-Kh. Obsch.*, xiii, 454 (1881).
[6] *Jurn. Russk. Ph.-Kh. Obsch.*, xiv, 36 (1882).
[7] *J. Chem. Soc.*, lxxiii, 905 (1898); also with E. C. Fortey, lxxv, 873 (1899).
[8] *Jurn. Russk. Ph.-Kh. Obsch.*, xxxi, 655; *J. Soc. Chem. Ind.*, 907 (1899).
[9] *Ann. Chem. Pharm.*, ccxx, 188 (1883).
[10] *Journ. f. prakt. Chem.*, xciii, 394 (1864),

small quantity. Beilstein and Kurbatoff identified these compounds in the oil of Tsarski-Kolodtsi (Tiflis). As already stated, the members of a C_nH_{2n} group, found in the Russian oil, are *naphthenes*, which are benzene derivatives, isomeric with the ethylene group. De la Rue and Müller ascertained the presence of preponderating quantities of the *ethylene* group in "Rangoon" petroleum, and Warren and Storer isolated from it the members of the group from C_9H_{18} to $C_{13}H_{26}$. Schorlemmer, Warren, and Chandler have found a lengthy series of members of the group in Pennsylvanian oil. Peckham and Chandler found them also in considerable quantity in Californian oil. C. F. Mabery and E. J. Hudson[1] find that the hydrocarbons of Californian petroleum chiefly consist of the C_nH_{2n} series. "If there be any C_nH_{2n+2} hydrocarbons present," they add, "they are contained in the portions boiling below 70° C.," *e.g.* in the light gasoline from this petroleum. The distillate at 68°–70° proved to be a mixture of hexane and hexamethylene. Large proportions of the benzene homologues were found, with benzene itself. Naphthalene was also present in the fractions boiling between 220°–222° C. The following higher C_nH_{2n} hydrocarbons were isolated:—$C_{13}H_{26}$ to $C_{19}H_{38}$, and $C_{21}H_{42}$. An essential characteristic of Californian oil is the relatively low proportion of distillates below 225° C. According to Höfer, the following olefines have been isolated from "North American" petroleum:—

Ethylene, .	. C_2H_4	Heptylene, .	. C_7H_{14}	Dodecatylene,	. $C_{12}H_{24}$
Propylene, .	. C_3H_6	Octylene, .	. C_8H_{16}	Decatrilene,	. $C_{13}H_{26}$
Butylene, .	. C_4H_8	Nonylene, .	. C_9H_{18}	Cetene, .	. $C_{16}H_{32}$
Amylene, .	. C_5H_{10}	Decatylene, .	. $C_{10}H_{20}$	Cerotene, .	. $C_{27}H_{54}$
Hexylene, .	. C_6H_{12}	Endecatylene,	. $C_{11}H_{22}$	Melene, .	. $C_{30}H_{60}$

O. Aschan[2] has discovered methylpentamethylene in Caucasian petroleum-spirit, and S. Takano's[3] investigations of Japanese petroleums show that seven such oils are composed of hydrocarbons belonging to the ethylene series (C_nH_{2n}). Two of the seven samples contained solid paraffin. The content of sulphur and nitrogen-compounds is high, and the calorific values exceed those of Russian or American oils. Aromatic hydrocarbons are plentiful.

Markownikoff and Ogloblin[4] and Mendeléeff have reported the presence of small quantities of the **acetylene** (C_nH_{2n-2}) group in Baku oil.

Members of the **benzene** (C_nH_{2n-6}) group and its derivatives appear to occur in all descriptions of crude petroleum. **Benzene,** C_6H_6, has been isolated from Pennsylvanian oil by Warren, Norman Tate, C. F. Chandler, Bolley, Schorlemmer, Schwarzenbach, and others; from Galician oil by Pawlewsky,[5] Pebal and Freund, and Lachowicz; from Baku oil by Markownikoff; from that of Tiflis (Tsarski-Kolodtsi) by Beilstein and Kurbatoff; and from Rangoon oil by De la Rue and Hugo Müller. **Toluene,** C_7H_8, appears also to be invariably present. **Xylene,** C_8H_{10}, was found in Rangoon oil by De la Rue and Müller, and in Pennsylvanian oil by Schorlemmer; **isoxylene** in Galician oil by Pawlewsky and Lachowicz, in Caucasian oil by Krämer, and in that of Baku especially, by Markownikoff. **Paraxylene** (boiling-point 137°) has been isolated from Galician oil by Pawlewsky.[6] **Cumene,** C_9H_{12}, has been found in Rangoon oil by De la Rue and Müller, and **pseudocumene** in Caucasian oil by Markownikoff and Ogloblin, and in the oil of America, Germany (Schwabweiler and Hanover), Galicia, and Italy (Terra di Lavoro) by Engler.[7] **Mesitylene,** an

[1] *Proc. Amer. Acad.*, xxxvi, 255 (1901).
[2] *Ber. deutsch. chem. Ges.*, xxxi, 1803 (1898).
[3] *J. Soc. Chem. Ind.*, 1003 (1900); also Mabery and Takano, *ibid.*, 503.
[4] *Jurn. Russk. Ph.-Kh. Obsch.*, xiii, 179; xv, 237 (1881, 1883).
[5] *Ber. deutsch. chem. Ges.*, xviii, 1915 (1884).
[6] *Ber. deutsch. chem. Ges.*, xviii, 1915 (1884).
[7] *Ibid.*, xviii, 2234 (1885).

isomer of cumene, was isolated by Lachowicz from Galician oil, by Engler from the oils of America, Hanover, Galicia, Italy, and Alsace (Schwabweiler), and by Markownikoff from the oil of Baku. Poni [1] found in Rumanian oil (Colibasi), besides trimethylmethane, in the portion boiling between 100° and 200° C., about 24 per cent. of aromatic hydrocarbons, viz. toluene, *m*-xylene, mesitylene and compounds of the formula $C_{10}H_{14}$. Kast and Künkler [2] found no mesitylene or pseudocumene in the petroleum from Gemsah on the Red Sea. Krämer and Böttcher found toluene, meta- and paraxylene, pseudocumene and mesitylene in German petroleum.

Hydrocarbons of the C_nH_{2n} series, which belong, not to the ethylene group, but to what is known as the **naphthene**, or $C_nH_{2n-6}+H_6$, group, are found in most oils, but especially in that of Baku, and have been examined by Beilstein and Kurbatoff,[3] Schützenberger and Jonine,[4] Markownikoff and Ogloblin,[5] and others. The naphthenes closely resemble the paraffins. Lachowicz ascertained their presence in Galician oil, which he states is about intermediate between the oils of Baku and Pennsylvania as regards the proportion of naphthenes contained. According to Le Bel, the oil of Tchongelek, in the Crimea, is largely composed of naphthenes, as are also those of Oelheim and Wietze.

Charitschkoff[6] has found that the fraction of Grozni petroleum boiling at 80°–82° C. contains a hexanaphthene isomeric with the synthetical substance. He also points out that the Grozni crude petroleum is distinguished from that of Baku by its higher specific gravity, and by containing a greater proportion of low-boiling constituents (benzine).

According to Markownikoff and Ogloblin,[7] the fraction of Caucasian petroleum boiling between 240° and 250° C. contains compounds of the formulæ $C_{11}H_{12}$, $C_{11}H_{14}$, $C_{12}H_{14}$, $C_{13}H_{14}$, and $C_{15}H_{30}$. They have also found bodies of the composition $C_{10}H_{14}$ and $C_{14}H_{28}$ in Caucasian petroleum. They consider that the aromatic hydrocarbons exist as such in the crude oils, and are not produced by the distillation, but Mendeléeff [8] believes that they are not present in the crude oil, and states that the large volumes of gas evolved on distilling such oil are produced by decomposition, and must not be regarded as gaseous hydrocarbons dissolved in the oil, because they cannot be redissolved. The compounds $C_{10}H_{10}$, $C_{11}H_{12}$, and $C_{12}H_{14}$, isolated by Markownikoff and Ogloblin from the 240° to 250° distillate, appear to be related to naphthalene, though they cannot be oxidised without complete decomposition. Markownikoff [9] has isolated octonaphthene from the petroleum of Balakhani and Bibi-Eibat.

Clifford Richardson and Wallace,[10] after investigation of petroleum of the Beaumont field (Jefferson county, Texas), conclude that the oil contains a large proportion of unsaturated hydrocarbons and their sulphur-derivatives, and that the saturated hydrocarbons are dicyclic polymethylenes, not satisfactory as illuminants. They agree with Mabery that the latter hydrocarbons belong to the C_nH_{2n-2} series.

Clifford Richardson has compared the characters of the petroleums of the older and newer fields of North America in papers contributed to the Franklin Institute in 1906,[11] from which the following extracts are taken :—

[1] *Ann. Sci. Univ. Jassy*, ii, 65 (1903).
[2] *Dingler's polytechn. Journ.*, cclxxviii, 34 (1890).
[3] *Ber. deutsch. chem. Ges.*, xiii, 1818, 2028 (1880).
[4] *Ibid.*, xiii, 2428.
[5] *Ann. Chim. Phys.*, 6, ii, 372 (1884).
[6] *Jurn. Russk. Ph.-Kh. Obsch.*, xxxi, 655 (1899) ; and *Viestn. Jirov. Vesch.*, iii, 133 (1902). See *Journ. Soc. Chem. Ind.*, 907 (1899), and 964 (1902).
[7] *Jurn. Russk. Ph.-Kh. Obsch.*, xiv, 36 (1882).
[8] *J. Soc. Chem. Ind.*, xiv, 54 (1882).
[9] *Jurn. Russk. Ph.-Kh. Obsch.*, xvi (2), 294, (1884).
[10] *J. Soc. Chem. Ind.*, 693 (1901).
[11] *Journ. Franklin Institute*, clxii, 57–70, 81–128.

Young has isolated from the lighter distillates of Pennsylvania petroleum in a very considerable degree of purity the naphthenes or monocyclic polymethylene hydrocarbons C_nH_{2n}, containing five, six, and seven atoms of carbon, pentamethylene, methylpentamethylene, hexamethylene, dimethylpentamethylene, and methylhexamethylene, corresponding to those found in Russian petroleum.

Both of the preceding investigators have found considerable amounts of aromatic hydrocarbons. Young finds benzene in the fraction boiling at about 65° and 66°, and toluene to a considerable extent in a higher fraction,[1] while other homologues have been detected by Mabery.

While unsaturated hydrocarbons are present in Pennsylvania petroleum, and are readily removed by strong sulphuric acid, there is, in the opinion of all modern investigators, no sufficient evidence that these hydrocarbons are members of the olefine series. Their actual structure has not yet been determined.

Sulphur and hydrogen derivatives of the hydrocarbons are present in but mere traces.

Table XLVI gives the characteristics of the various saturated hydrocarbons of the C_nH_{2n+2}, C_nH_{2n} and C_nH_{2n-2} series, as described by Mabery and Young—

TABLE XLVI.

C_nH_{2n+2} Hydrocarbons.

Composition.	Specific Gravity.	Ref. Index.	Boiling-point. °	Pressure.	Melting-point.	Authority.
C_4H_{12} Iso.			0	760 mm.		Mabery.
C_5H_{12} Nor.	0·6250 25/25°		36·3	,,		Young.
	0·6261 0/4°					..
	0·6454 ,,					..
,, Iso.	0·6392 ,,		27·95	711 mm.		Young.
C_6H_{14} Nor.	0·6771 ,,		68·95	,,		,,
,, Iso.	0·6730 ,,		61·00	,,		,,
C_7H_{16} Nor.			98·40	,,		,,
,, Iso.	0·6969 0/4°		90·30	,,		,,
C_8H_{18} Nor.	0·7188 20/20°		125·00	760 mm.		,,
,, Iso.	0·7190 ,,		119·50	,,		Mabery.
C_9H_{20} Nor.			151·00	,,		,,
$C_{10}H_{22}$ Nor.	0·7479 ,,		163·164	,,		,,
,, Iso.	0·7477 ,,		173–174	,,		,,
$C_{11}H_{24}$	0·7581 ,,		196–197	,,		..
$C_{12}H_{26}$ Nor.	0·7676 ,,		214–216	,,		,,
$C_{13}H_{28}$	0·7834 ,,	1·451	226	,,		,,
$C_{14}H_{30}$	0·7815 ,,	1·436	236–238	,,		,,
$C_{15}H_{32}$	0·7896 ,,	1·4413	256–257	,,		..
$C_{16}H_{34}$	0·7911	1·4413	274–275	,,		,,
$C_{17}H_{36}$	0·8000 ,,	1·4435	288–289	,,	10	,,
$C_{18}H_{38}$	0·8017 ,,	1·440	300–301	,,	20	,,
$C_{19}H_{40}$	0·8122 ,,	1·4522	210–212	50 mm.	33–34	,,
$C_{21}H_{44}$			230–231	,,	40–41	,,
$C_{22}H_{46}$	0·7796 15°		240–242	,,	44	,,
$C_{23}H_{48}$	0·7900 60°		258–261	,,	45	..
$C_{24}H_{50}$	0·7902 ,,		272–274	,,	48	,,
$C_{25}H_{52}$	0·7941 ,,		280–282	,,	53–54	..
$C_{26}H_{54}$	0·7977 ,,		292–294	,,	58	,,
$C_{28}H_{58}$	0·7945 70°		310–312	,,	60	,,
$C_{31}H_{64}$	0·7992 ,,		328–330	,,	66	,,
$C_{32}H_{66}$	0·8005 75°		342–345	,,	68	..
$C_{34}H_{70}$	0·8009 80°		366–368	,,	72	..
$C_{35}H_{72}$	0·80052 ,,		380–384	,,	76	..

[1] *J. Chem. Soc.*, 73, 914 and 918 (1898).

TABLE XLVI—*continued.*

Monocyclic Polymethylenes, C_nH_{2n}.

Composition.	Specific Gravity.	Boiling-point.	Pressure.	Authority.
C_5H_{10} Pentamethylene	0·7000 0/4°	50°	760 mm.	Young.
C_6H_{12} Methylpentamethylene	0·7660 ,,	72	,,	,,
C_6H_{12} Hexamethylene	0·7722 ,,	80·6	,,	,,
C_7H_{14} Dimethylpentamethylene	0·7543 20/4°	94	,,	,,
C_7H_{14} Methylhexamethylene	0·7964 ,,	102	,,	,,

Hydrocarbons, C_nH_{2n}.

Composition.	Specific Gravity.	Refractive Index.	Boiling-point.	Pressure.	
$C_{21}H_{42}$	0·8424 20/20°				
$C_{22}H_{44}$	0·8262 ,,	1·454	240–242°	50 mm.	Mabery.
$C_{23}H_{46}$	0·8569 ,,	1·4714	258–260	,,	,,
$C_{24}H_{48}$	0·8598 ,,	1·4726	272–274	,,	,,
$C_{26}H_{52}$	0·8580 ,,	1·4725	280–282	,,	,,

Hydrocarbons, C_nH_{2n-2}.

$C_{27}H_{52}$	0·8688 20/20°	1·4722	290–294°	50 mm.	Mabery.
$C_{28}H_{54}$	0·8694 ,,	1·4800	310–312	,,	,,

The lower polymethylenes or naphthenes, C_nH_{2n}, isolated by Young, are plainly monocyclic hydrocarbons. The higher distillates, like those which occur in Russian petroleum, corresponding in composition to the same general formulæ and containing twenty-one atoms of carbon and over, are associated with C_nH_{2n+2} hydrocarbons containing the same number of carbon atoms or one or two less. They do not solidify at very low temperatures and are separated from the paraffins by freezing and filtration. From our knowledge of the hydrocarbons in asphaltic oils it would appear that they differ from them essentially, as they are much more stable, have a lower density, and, for the same refractive index, nearly double the molecular weight and a much higher boiling-point:—

	Paraffin Petroleum.[1]	Trinidad Asphalt.[2]	California Petroleum.[1]	California Petroleum.[2]
Density, ...	0·8598	0·8690	0·8808	0·8654
Refractive index, . . .	1·4726	1·4721	1·470	1·474
Boiling-point, . . .	272–274°	170–180°	175–180°	178°
Pressure, ...	50 mm.	30 mm.	60 mm.	30 mm.
Formulæ, ...	$C_{24}H_{46}$	$C_{13}H_{24}$	$C_{16}H_{30}$	..

It appears from the preceding data that the paraffin petroleums of the Appalachian field consist of small amounts of monocyclic, aromatic, and polymethylene hydrocarbons, which have been separated in such a degree of purity as to be identified definitely; of minute traces of sulphur and nitrogen compounds and, predominatingly, of paraffin hydrocarbons from isobutane, C_4H_{12} to $C_{35}H_{72}$, the members above 14 being solids at ordinary temperatures. Polycyclic hydrocarbons of the C_nH_{2n} series are also present in very considerable amounts from C_{21} to C_{26}, the constitution of which is not understood, but which are quite different from the hydrocarbons of the same relation of carbon and hydrogen found in asphaltic oils, and have no relation to the ethylene or olefine series. Polycyclic hydrocarbons of the C_nH_{2n-2} series are also present in the fractions boiling above 290°, at 50 mm.

In the petroleum of the Ohio-Indiana field, the saturated C_nH_{2n} hydrocarbons of higher boiling-point, and the saturated hydrocarbons C_nH_{2n-2},

[1] Mabery. [2] Richardson.

both begin at a much lower number of carbon atoms than in the case of the Pennsylvania oil, while hydrocarbons of the series C_nH_{2n-4} are present which are not found in the Eastern oil.

Canadian oil, like that from Pennsylvania and Northwestern Ohio, may be classed as a paraffin petroleum, since it contains a predominating amount of hydrocarbons of the C_nH_{2n+2} series, especially in the solid form. It differs from these petroleums in that the amount of distillate below 150° is very much smaller, while the sulphur derivatives of the polymethylenes are present in very much larger amount, as are the aromatic and unsaturated hydrocarbons in the lower distillates, while the higher residues contain larger percentages of the solid paraffins and less unsaturated hydrocarbons. It resembles Ohio oil in having the lower liquid asphaltic hydrocarbons as components.

The petroleums of California are of the most varied character and all of them consist of more or less dense asphaltic hydrocarbons. Nitrogenous bases are often present in very large amounts and again in only small amounts. Phenols are a common constituent of the denser oils. Except in those constituents which boil at a comparatively low temperature, the components of California oils are unique in their density and viscosity.

None of the components is of the paraffin series, and the hydrocarbons being largely of the C_nH_{2n} and C_nH_{2n-2} series, among those of sufficient volatility to be used as illuminating oils the distillates below 150° do not make good burning oil. They burn with a smoky flame and must be mixed with a large proportion of Eastern kerosene before they can be used.

Beaumont (Texas) oil has a very high density for one beginning to distil at 110°, and the hydrocarbons of which it is composed, as shown by the ultimate composition of the original oil, and by a comparison of the specific gravity and refractive index of the 150°–300° distillates from the Engler flasks with similar distillates from Eastern oils, must belong largely or entirely to some series other than the paraffin, and probably to the same series as those found in the Sour Lake petroleum previously examined (*J. S. Chem. Ind.*, xix, 121 (1900)), rather than those of the Corsicana oil, which consists largely of paraffins. It is also plain that the oil contains a much larger proportion of unsaturated hydrocarbons removable by sulphuric acid than Pennsylvania petroleum. The Beaumont oil has a high sulphur content and carries, as it comes from the wells, a large amount of hydrogen sulphide in solution. This gas has previously been observed in solution in petroleum, but not in so large quantity as at Beaumont. The sulphuretted hydrogen is largely lost on standing and more completely on blowing air through it. After such treatment the oil contained 1·75 per cent. of sulphur in the form of sulphur derivatives of the hydrocarbons, and as free sulphur.

It is of interest to note that although naphthalene, acenaphthene, fluorene, anthracene, and phenanthrene are found in coal-tar, the only one which appears to be *undoubtedly* present in crude petroleum is naphthalene, although it is usually stated that anthracene, chrysene, pyrene, and fluorene are present in small quantity.[1] In this connection, it may be mentioned that Boussingault[2] mentions the deposition of naphthalene on cooling the fluid "bitumen" from the burning springs of Ho-Tsing, in the province of Szechuen in China, and that De la Rue and Müller found naphthalene in Rangoon oil. Krämer[3] states that naphthalene crystallises out from the distillate of 200° to 300° C. from the oil of Tegernsee and Oelheim, but mentions that this body was not necessarily present in the crude oil.

[1] See also Krämer and Böttcher, *Ber. deutsch. chem. Ges.*, xx, 595 (1887).
[2] *Comptes Rend.*, xcvi, 1452 (1883). [3] *Sitz. Ver. Beförd. Gewerbfl. Preuss.*, 299 (1885).

According to Engler,[1] the oil from the Tegernsee district is especially rich in aromatic compounds. Hydrocarbons of the general formula C_nH_{2n-4} have been found in the distillate from the asphalt of Pechelbronn,[2] and in that from the asphalt of the Val de Travers.[3]

Zaloziecki[4] identified benzene, toluene, xylene, and isohexane in Galician naphtha. Balbiano[5] raises the question of the occurrence of β-methyl Δ^{β} pentylene in American petroleum. Konowaloff[6] treated a Grozni fraction, 160°–165° C., with sulphuric acid and obtained sulpho-mesitylenic acid. Hence mesitylene is here present. Tichwinsky,[7] from three Russian crude oils, isolated hexahydrocymene—148°, $\cdot 7927/_{21}°$. Cumene and mesitylene were found by Engler[8] in oils from Germany (Hanover), Alsace, Galicia, Italy, Rumania, Russia, Java, Sumatra, and the United States, whilst ψ-cumene occurred in addition at Gemsah; p-cymene was found in oils from Canada, Ohio, Japan, and Russia; and Darene in oils from Baku and Canada. Diethyl toluene and isoamyl benzene were isolated from Baku oil; ψ-cumene[9] was isolated from the fraction 160°–161° as trinitro body, m.p. 184–185°.

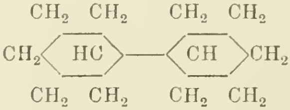
Coates[10] isolated the following:—

$C_{10}H_{18}$,	168°–170°	$8146/^{22}/_4$
$C_{11}H_{20}$,	198°–200°	$8378/^{26}/_4$
C_8H_{14},	120°	$7747/^{24}/_4$
$C_{12}H_{22}$,	215°–217°	$8511/^{28}/_4$
$C_{13}H_{24}$,	235°–238°	$8629/^{22}/_4$
C_9H_{18},	146°	$7992/^{24}/_4$

C. Mabery,[11] from Jefferson county oil which possessed a pronounced smell of hydrogen sulphide, isolated, after removing olefines and aromatic hydrocarbons:—

B.P. at 14 mm.		
130°–135°,	$C_{12}H_{22}$	$\cdot 8553/_{20}$
155°–160°,	$C_{14}H_{26}$	$\cdot 8746/_{20}$
190°–195°,	$C_{16}H_{30}$	$\cdot 8915/_{20}$

Mabery regards these bodies as being possibly homologues of hexahydrodiphenyl.



The same author,[12] from Pennsylvania crude oil, after treatment with fuming sulphuric acid, obtained:—

Tridecane,	221°	$\cdot 7834/_{20}$
Tetra ,,	236°	$\cdot 7814/_{20}$
Penta ,,	256°	$\cdot 7896/_{20}$
Hexa ,,	275°	$\cdot 7911/_{20}$
Hepta ,,	288°	$\cdot 8000/_{20}$
Octa ,,	M.P. 20°	$\cdot 7830/_{20}$

[1] *Verh. Ver. Beförd. Gewerbfl. Preuss.*, 637 (1887).
[2] Boussingault, *Ann. Chim. Phys.*, lxiv, 141, and lxxiii, 443 (1837, 1840).
[3] Völckel, *Ann. Chem. Pharm.*, lxxxvii, 143 (1853).
[4] *Bull. Soc. Cracow*, iv, 228 (1903).
[5] *Gazz.*, 36, i, 251 (1906).
[6] *Journ. Russ. Phys. Chem. Soc.*, xxxiii, 50 (1901).
[7] *Ibid.*, xli, 1136 (1909).
[8] *Das Erdöl.*
[9] P. Poni, *Ann. Sci. Univ. Jassy*, iii, 257 (1905).
[10] *Journ. Amer. Chem. Soc.*, xxviii, 384 (1906).
[11] *Journ. Amer. Chem. Soc.*, xxiii, 261 (1901).
[12] *Amer. Chem. Journ.*, xxviii, 165 (1902).

P. Poni,[1] in an investigation of Rumanian petroleum, showed that fraction 0–10° C. contained methyl propane. The 60°–100° fraction contained no secondary paraffins but yielded a nitration derivative of benzene and toluene. Twenty-three per cent. of the fractions 90°–110° was composed of toluene, *m*-xylene was found in the fraction 110°–144°, mesitylene in the fraction 146°–158°, and $C_{10}H_{11}(NO_2)_3$ from that boiling at 160°–162°, and methyl and ethyl cyclohexane were also present. The same author [2] obtained 20 per cent. of aromatic hydrocarbons from the fraction 35°/70° of Campina (Rumania) crude oil. The non-aromatic portion was in the main cycloparaffinoid.

A secondary heptane of boiling-point 91·5°–92·5° and specific gravity ·7116$^{15}/_{0}$° was isolated from Colibasi (Rumania) crude oil by N. Costachescu.[3]

J. Schmidt and A. Sigerart point out that dimethyl dicyclopentyl probably exists in Louisiana crude oil. This compound $(CH_3 . C_5H_8)_2$ may have been wrongly identified as dihexahydrodiphenyl.[4]

L. Edeleanu [5] discovered in Rumanian crude oil butane, pentane, hexane, and heptane, the *iso*-paraffins preponderating. There were also present pentamethylene, methylpentamethylene, dimethylpentamethylene, and ethylhexamethylene.

By the action of fuming sulphuric acid there were found in solution benzene, toluene, xylenes, mesitylene and ψ-cumene, together with unsaturated cyclic hydrocarbons and "terpene-like" bodies.

G. Chonin [6] obtained dimethyl 2·4 pentane from the fraction 80°–82° of Caucasian crude oil.

P. Poni,[7] by means of their nitro derivatives, identified β and γ methyl pentanes in the fraction 61°–62° of Rumanian oil.

N. Costachescu [8] obtained from the 90°–100° C. fraction of Colibasi petroleum the secondary heptane—2 methylhexane, having a boiling-point of 92° C. and a specific gravity of 0·7116 (0°/0° C.), together with small quantities of other isomeric secondary heptanes and dimethylpentamethylene (dimethylcyclopentane).

C. F. Mabery [9] has examined a sample of Mahone (Ohio) petroleum obtained from a depth of 115–150 feet, where the oil is associated with beds of bituminous coal. The crude oil had a specific gravity of 0·9036–0·9057 at 20° C., and by distillation under reduced pressure the following hydrocarbons were obtained in practically pure condition :—

C_nH_{2n-2}.	Boiling-point. °C.	Specific Gravity at 20° C.	C_nH_{2n-4}.	Boiling-point. °C.	Specific Gravity at 20° C.
$C_{11}H_{20}$	97°–98°	0·8549	$C_{15}H_{26}$	138°–139°	0·8662
$C_{12}H_{22}$	109°–110°	0·8576	$C_{16}H_{28}$	151°–152°	0·8692
$C_{13}H_{24}$	120°–121°	0·8614	$C_{17}H_{30}$	171°–172°	0·8716
$C_{14}H_{26}$	130°–131°	0·8654	$C_{19}H_{34}$	212°–214°	0·8790

Paraffins and cycloparaffins were absent.

[1] *Ann. Sci. Univ. Jassy*, ii, 65 (1903).
[2] *Monit. Petr. Roum.*, 20 (1907) ; *Petr.*, ii, 918 (1907).
[3] *Chem. Zentr.*, i, 682 (1911).
[4] *Ber.*, xlv, 1789 (1912).
[5] *Petr.*, iii, 689 (1908).
[6] *Journ. Russ. Phys. Chem. Soc.*, xli, 327 (1909).
[7] *Ann. Sci. Univ. Jassy*, iii, 95 (1904).
[8] *Chem. Zentr.*, i (682), 1911 ; *J.S.C.I.*, 348 (1911).
[9] *J. Ind. and Eng. Chem.*, 6, 101 (1914).

In Texas, Jefferson county, oil Mabery[1] identified, after removal of unsaturated compounds:

	B.P. at 14 mm.	Specific gravity.
$C_{12}H_{22}$, ...	130°–135°	$0{\cdot}8553/_{20}$
$C_{14}H_{26}$, ...	155°–160°	$0{\cdot}8746/_{20}$
$C_{16}H_{30}$, ...	190°–195°	$0{\cdot}8915/_{20}$

These hydrocarbons possibly are homologues of dihexahydrodiphenyl.

Hanover crude oil[2] contains the paraffins from C_{10} to C_{15}, decanaphthene and tridecanaphthene.

In Louisiana petroleum[3] there have been identified :—

Identified.	B.P.	Specific gravity.
$C_{10}H_{18}$, ...	160°–170°	$0{\cdot}8146/_{22^{\circ}}$
$C_{11}H_{20}$, ...	198°–200°	$0{\cdot}8576/_{26}$
$C_{12}H_{22}$, ...	215°–217°	$0{\cdot}8511/_{28}$
$C_{13}H_{24}$, ...	235°–238°	$0{\cdot}8629/_{22}$

and probably there are present :—

C_8H_{14}, ...	120°·5	$0{\cdot}7747/_{24^{\circ}}$
C_9H_{18}, ...	145°·7	$0{\cdot}7992/_{24}$

In reference to the **oxygen** shown by analysis to be contained by all petroleums, Höfer[4] states that some of it may be accounted for by absorption from the air. R. A. Ostrejko[5] has shown the effect of sunlight in facilitating the absorption of air by ordinary Baku oil of medium quality, opalescence or sediment, and strong acidity being produced. A penetrating odour is also developed, with deepening of colour. Several distillates variously refined showed that the amount of acidity increased concurrently with deepening of colour. The oxygen, both in the fresh oils and in those which have been exposed, appears to be almost entirely contained in acid and phenylated compounds. Hell and Medinger[6] first ascertained the presence of oxygen acids in petroleum, especially in that from Rumania. The Baku oil contains less oxygen acids than those of Galicia and Rumania. Pebal[7] found **phenol** in Galician petroleum. Markownikoff was the first to find phenol in crude Caucasian petroleum, and, in conjunction with Ogloblin, investigated the composition of the oxygen acids of petroleum. Markownikoff found as much as 5·25 per cent. of oxygen in the fraction of Caucasian petroleun boiling between 220° and 230° C. He considers the acids to be **carboxylic acids**, derived from the naphthenes of the petroleum, but Zaloziecki[8] states that they consist mainly of *acid lacto-alcohols*. Aschan[9] confirms Markownikoff's contention that they are naphthene derivatives, and has prepared octonaphthene from one of them. According to Krämer, however, these acids are ordinary *fatty acids*. C. J. Robinson[10] more recently gives great support to this statement by the discovery of acetaldehyde in both Pennsylvanian and Ohio petroleums. He found as much as 0·001 per cent. of acetaldehyde in the

[1] *Journ. Amer. Chem. Soc.*, xxiii, 264 (1901).

[2] F. B. Ahrens and J. Riemer, *Zeit. angew. Chem.*, xx, 1517 (1907).

[3] C. E. Coates, *Jour. Amer. Chem. Soc.*, xxviii, 384 (1906).

[4] *Das Erdöl*, 39 (1862).

[5] *Trudi Bak. Otd. Imp. Russk. Techn. Obsch.*, 1896, 10 [2], 21 ; [4], 19 ; [6], 1 ; *J. Soc. Chem. Ind.*, 26, 345, 645 (1896).

[6] *Ber. deutsch. chem. Ges.*, vii, 1216 ; x, 451 (1874, 1877).

[7] *Ann. Chem. Pharm.*, cxv, 19 (1860).

[8] *Zeitschr. f. angew. Chemie*, 416 (1891).

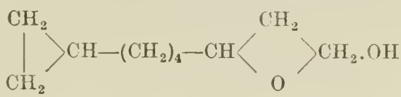
[9] *Ber. deutsch. chem. Ges.*, xxiii, 867 ; xxiv, 2710 (1890, 1891).

[10] *J. Soc. Chem. Ind.*, 232 (1899).

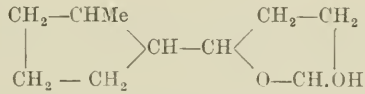
crude oil. Engler [1] has detected phenols and fatty acids in several German oils. Schidkoff [2] has detected the presence of acids soluble in water in various samples of Grozni oils (specific gravity 0·9242 and 0·9108); he found that the amount varies between 0·0443 and 0·1042, the proportion of free acids increasing with the specific gravity of the oil. But besides soluble acids (of which formic acid, oxalic acid, and petroleum acids are examples) Schidkoff also detected some organic acids insoluble in water acidified with hydrochloric acid.

K. W. Charitschkoff [3] has pointed out that the so-called naphthenic acids yield stable salts with basic oxides and displace mineral acids from their copper and silver salts. They give Rosenthaler's vanillin test, as do anhydrides and alcohols, and yield chloroanhydrides which are with difficulty decomposed by water.

Zalozetzky suggested the following type of formulation:—



whilst Brun proposed:—



Charitschkoff criticised these structural formulæ on the grounds that they did not exhibit the acidic function, and put forward the view that cyclohexane 3-acetic acid $C_6H_{11}CH_2.COOH$, for example, might tautomerically coexist with the keto alcohol $C_6H_{11}CO.CH_2.OH$.

From Baku oil S. Petroff [4] isolated as methyl esters the heptanaphthenic acid of Markownikoff; methyl pentamethylene 5 carboxylic acid, and isomeric heptanaphthenic acid $C_7H_{13}CO_2Me$.

The highly characteristic metallic derivatives of these acids are apparently confined to the cyclopentane series, according to Charitschkoff.[5] The naphthenates of copper, ferrous iron, cobalt, nickel, cadmium, tin, lead, mercury, and manganese are more or less soluble in petroleum, whilst those of ferric iron, aluminium, and chromium are only sparingly soluble in such oil.

C. L. Istrati and C. Teodorescu [6] distilled 25° fractions from Moreni crude oil and exposed them to the action of copper in the presence of sunlight. The copper lost from ·022 gram per 100 c.c. of fraction 100°–125° up to 3·499 grams per 100 c.c. of fraction 275°–300°. Direct determinations of the acidity of the fraction by means of alcoholic potash showed a steady increase with boiling-point. The same authors [7] showed that lactone alcohols with no action on copper coexisted with acids which formed copper salts in a fraction boiling between 250°–275°.

Amongst the many isolated cases of observations on naphthenic acids may be mentioned the discovery by M. A. Rakusin [8] of undecanaphthenic acid to the extent of 1·382 grams per litre in water struck at 177 feet on the Grozni field; further, the isolation of *m*-hexahydrotoluic acid by J. Pekoff [9] and the

[1] *Verh. Ver. Beförd. Gewerbfl. Preuss.*, 637 (1887).
[2] *Trudi Bak. Otd. Russk. Imper. Techn. Obsch.*, 1898 [4]; *J. Soc. Chem. Ind.*, 360 (1899).
[3] *Journ. Russ. Phys. Chem. Soc.*, xli, 1150 (1909).
[4] *Ibid.*, xliii, 1198 (1911).
[5] *Loc. cit.*, xliv, 348 (1912).
[6] *Bull. Acad. Sci. Rumania*, i, 19 (1912).
[7] *Chem. Zentr.*, i, 1596 (1912).
[8] *Petr.*, viii, 797 (1913).
[9] *Journ. Russ. Phys. Chem. Soc.*, xlvi, 178 (1914).

formulation by E. Pyhala[1] of two acids $C_{19}H_{37}.CO_2H$, $C_{21}H_{17}CO_2H$ which were derived from Baku machine oil.

Aschan[2] considered that naphthenes and their carboxylic acids are produced by the polymerisation of olefines which are derived from fossil fats.

For the utilisation of naphthenic acids reference should be made to section on Refining.

The conclusion that the oxygen is present in the form of carboxylic acids (forming the so-called naphthenic acids) has been confirmed by von Kozicki and von Pilat.[3] From a Galician petroleum naphthenic acids from $C_7H_{13}.COOH$ to $C_{14}H_{27}.COOH$ were isolated and characteristic compounds obtained which established their constitution.

Zelinsky,[4] by chlorinating certain fractions of Caucasian petroleum, treating the products with magnesium, subjecting the magnesium compounds to the action of carbon dioxide, and decomposing the complex substance formed with water and sulphuric acid, has obtained good yields (up to 60 per cent.) of organic acids. On heating one of these, the acid $C_8H_{14}O_2$, with glycerin, to 250° C., a tri-octin was obtained which had the properties of a fat.

SYNTHETIC ACIDS FROM PETROLEUM.

The attention of many investigators has been drawn to the question of synthetically preparing fatty acids from mineral oil. The solution of this problem on a commercial basis would open up a new source of a wide range of acid products of such varied uses as the bases for essences and perfumes, soaps, and possibly foodstuffs.

K. Charitschkoff[5] has shown that under the influence of heat, oxygen and alkali, non-crystallisable naphthenic acids are obtained. These compounds yield blue copper salts and appear to react also as ketones. The same author[6] pointed out that whilst the naphthenic acids, derived in the ordinary way from the alkali sludge in refining Russian oils, gave alkyl esters and copper salts, soluble in petroleum hydrocarbons to a dark green solution, and appeared further to possess a lactone-alcohol structure, the synthetic oxidation products, *e.g.* $C_{21}H_{27}O_5$, seem to be polybasic ketonic acids. In a later paper Charitschkoff prepared the acid $C_{24}H_{34}O_4$ from a fraction of Caucasian petroleum boiling between 164°–166° C. and having the specific gravity 0·7800, by means of the oxidation method outlined above. A similar product was made from dimethylcyclopentane.

W. F. Herr[7] used nitric acid as oxidising agent and from Baku crude oil obtained dibasic acids of the succinic, glutaric, and adipic series. The yields were :—

Fraction	80°–82°	. . . . .	16 per cent.	of acids.
,,	98°–102°	. . . . .	26 ,,	,,
,,	103°–106°	. . . . .	15 ,,	,,

B. Schryver and S. Kragen[8] modified Charitschkoff's procedure by adding mercury as a catalyst. They described oxidation products which were soluble in 80 per cent. alcohol and resembled tertiary unsaturated alcohols.

When mercuric oxide was used as a catalyst, A. Schmidt[9] was able to obtain

[1] *Zeit. angew. Chem.*, xxvii, 407 (1914).
[2] *Ann.*, i, 324 (1902). [3] *Petr.*, xi, 310 (1916).
[4] *Jurn. Russk. Ph.-Kh. Obsch.*, xxxiv, 968 (1902); *J. Soc. Chem. Ind.*, 194 (1903).
[5] *Journ. Russ. Phys. Chem. Soc.*, xl, 1757 (1908). [6] *Petr.*, ii, 480 (1907).
[7] *Petr.*, v, 692 (1910). [8] *Petr.*, xi, 521 (1916). [9] *E.P.*, 109, 386/17.

a 70 per cent. yield of acids from high-melting paraffin wax. From Galician wax melting at 52° C., M. Bergmann [1] obtained, after exposure at 130°–135° C., during fifteen days to a current of air, a brown mass of which the acid value was 132. In this product lignoceric acid was identified, together with $C_{11}H_{22}O_2$ and $C_{16}H_{32}O_2$ (isopalmitic acid ?).

Zelinski [2] showed that the Grignard reaction was incomplete except in the presence of iodine, aluminium chloride, or hydrogen chloride, as catalyst. From pentane he obtained isohexoic acid, from a naphthene boiling at 80°–82° he produced a cyclohexane carboxylic acid, and from a fraction boiling at 71°–79° C. he formed heptoic acid, methyl cyclopentane carboxylic acid, and cyclohexane carboxylic acid.

In a critical review of this subject R. J. Moore and G. Egloff [3] pointed out that the four sources of acid bodies from petroleum were :—

(1) Conversion of a chlorohydrocarbon to an acid.

(2) Utilisation of the Grignard reaction.

(3) Naphthenic acids.

(4) Direct oxidation. Vaseline, for example, treated with sodium peroxide formed a soap.

E. I. Orloff [4] found that when light petroleum (specific gravity 0·71) was passed with air over heated copper cyclic hydrocarbons and olefines were produced together with the aldehydes of aromatic hydrocarbons (presumably present in the petroleum). The author suggested that by means of this reaction formaldehyde may be obtained from natural gas.

The composition of the residues from petroleum distillation has received considerable attention, more especially as regards the Pennsylvanian oil. Morton, in 1873,[5] obtained by the distillation of petroleum-residue at a red heat a product which yielded needle-like crystals of a greenish-yellow colour and pearly lustre. This body, which he at first called **viridine**, and afterwards **thallene,** was found to be isomeric with anthracene, though unlike it in crystalline form, melting-point, and solubility. Hemilian [6] asserts that this compound, which he calls **petrocene**, has the formula $C_{32}H_{22}$. Tweddle, in 1876, stated that thallene is produced by the destructive distillation of a greenish substance, which he termed petrocene, obtained from petroleum-residues. According to Gräbe and Walter [7] thallene closely resembles the **picene** obtained by Burg from brown coal-tar. From the least volatile products of petroleum distillation, Divers and Nakamura have isolated a compound boiling between 280° and 285° C., and possessing the empirical formula C_4H_3, while Prunier [8] isolated from the green so-called *petrocene* (boiling-point 190°–240° C.), obtained by distillation of the residues after the ordinary paraffin had come over, hydrocarbons which he called **carbozene, carbopetrocene,** and **thallene.** These compounds were found to possess formulæ ranging from $(C_4H_2)_n$ to $(C_7H_2)_n$, where n is a variable higher than 4.

Klaudy and Fink [9] have obtained a new aromatic hydrocarbon from the "red pitch" condensing in the stills during the cracking of Austro-Hungarian petroleum. They have termed it "crackene," and the formula $C_{24}H_{18}$ is assigned to it. It forms yellow crystalline scales with green fluorescence, melting at 308° C., and decomposing on distillation at 500° C., though it may

[1] *Zeitr. angew. Chem.*, xxxi, 69 (1918).
[2] *D.R.P.*, 15, 1880.
[3] *Met. and Chem. Eng.*, xviii, 308 (1918).
[4] *J. Russ. Phys. Chem. Soc.*, xli, 652 (1908).
[5] *Am. Chemist*, iii. 106 and 162, and vii, 88 (1872, 1876).
[6] *Ber. deutsch. chem. Ges.*, ix, 1604 (1876).
[7] *Ber. deutsch. chem. Ges.*, xiv, 175 (1881).
[8] *Bull. Soc. Chim. Paris*, 2, xxxi, 293 (1879).
[9] *Monatsh. Chem.*, xxi, 118 (1900).

be sublimed with care. It is probably identical with the product obtained by Divers and Nakamura from Japanese petroleum, and very similar to the benzerythrene of Schmidt and Schultz.

The fact that the tarry residues obtained in the manufacture of gas from petroleum contain phenols and anthracene was first shown by Lietnii,[1] and the subject was soon afterwards investigated by Liebermann and Burg,[2] and by Salzmann and Wichelhaus.[3] Many years ago Nobel Brothers demonstrated the possibility of producing anthracene on a large scale by bringing Russian petroleum residuum (ostatki) into contact with highly-heated surfaces.

Vaseline.—The semi-solid mixture of hydrocarbons originally introduced under the proprietary name of vaseline, and now largely employed as a protective coating for metals, as well as in pharmacy, is obtained from American petroleum in the manner described in Section VI of this work. As met with in commerce, vaseline is usually colourless, or of pale yellow colour, translucent, fluorescent, amorphous, and devoid of taste and smell. It does not oxidise readily on exposure to the air, and is not readily acted on by chemical reagents. It is soluble in chloroform, benzene, carbon bisulphide, and oil of turpentine. It also dissolves in warm ether and in hot alcohol, separating from the latter solvent in flakes on cooling. Its melting-point is usually from 40° to 50° C., and its specific gravity 0·803 and upwards at 100° C. The *paraffinum molle* of the *British Pharmacopœia* is described as having a melting-point of 95° F., while the United States Pharmacopœia gives the melting-point of the corresponding product as between 104° and 125° F. Vaseline has been stated to consist principally of paraffins and iso-paraffins (probably $C_{16}H_{34}$ to $C_{20}H_{42}$), together with olefines, but its chemical composition has apparently not been fully determined. J. R. v. Wagner[4] and Miller[5] consider it to be a mixture of paraffin with volatile oils, but Moss[6] and others believe it to be merely a mixture of easily fusible paraffins. Much light has been thrown upon the composition of vaseline by the researches of Engler and Böhm.[7] By the distillation of the material, these chemists obtained an oil belonging to the C_nH_{2n} group, together with paraffin melting at 40°, and a so-called fluid vaseline solidifying at −10° C. Details of this investigation and further information as to the chemical nature of vaseline will be found in Section VI.

Mabery[8] examined commercial vaseline, and showed that this product is composed of heavy oils such as have been identified as forming the portions of Pennsylvania petroleum with high boiling-points, and Coraopolis heavy oil, viz. hydrocarbons of the series C_nH_{2n}, C_nH_{2n-2}, and C_nH_{2n-4}, with solid paraffin hydrocarbons. The quantity of solid compound present is sufficient to saturate the oil, and in slight excess to form an emulsion of the desired consistency. See Section VI (Refining) for further details on this subject.

Solid Hydrocarbons.—That solid hydrocarbons exist as such in crude oils which remain fluid at low temperatures, but from which paraffin is obtained on distillation, was at one time a matter of doubt, but the evidence which has now accumulated has finally proved their presence in most crude oils. Sadtler and McCarter[9] were among the earliest to point this out, but the fact that the boreholes of many wells become choked by the solidification of this substance

[1] *Dingler's polytechn. Journ.*, ccxxix, 353 (1878).
[2] *Ber. deutsch. chem. Ges.*, xi, 723 (1878).
[3] *Ibid.*, xi, 802, 1431 (1878).
[4] *Dingler's polytechn. Journ.*, ccxxiii, 515 (1877).
[5] *Amer. Journ. Pharm.*, iv, 1 (1874).
[6] *Jahresb. Fortschr. Chemie*, 471 (1876).
[7] *Dingler's polytechn. Journ.*, cclxii, 468 (1886).
[8] *Proc. Amer. Acad.*, xl, 361 (1904).
[9] *Amer. Chem. Journ.*, i, 30 (1880).

in them would alone be a sufficient proof. From the solid hydrocarbons that collect in certain oil-wells in Pennsylvania, Mabery [1] separated the following:—

TABLE XLVII.—Solid Hydrocarbons (Pennsylvanian).

	Formula.	Melting-point.	Specific Gravity.
Tetracosane,	$C_{24}H_{50}$	50°–51°	0·7900 at 60°
Hentricontane,	$C_{31}H_{64}$	66°	0·7997 at 70°
Dotricontane,	$C_{32}H_{66}$	67°–68°	0·8005 at 75°
Tetratricontane,	$C_{34}H_{70}$	71°–72°	0·8009 at 80°
Pentatricontane,	$C_{35}H_{72}$	76°	0·8052 at 80°

Hydrocarbons of the series C_nH_{2n+2} have now been identified in Pennsylvania petroleum in continuous series, with but few members wanting, from butane, C_4H_{10}, boiling-point −10°, to pentatricontane, $C_{35}H_{72}$, boiling-point 380°–384°, 50 mm.

Kast and Seidner [2] have found that the mud which collects on the bottoms of the storage-tanks of crude American petroleum contains much paraffin. Among others who have worked on the subject may be mentioned Goldstein,[3] Odling,[4] Partridge,[5] Schorlemmer,[6] Morgan,[7] and Engler.[8]

Höfer states that Galician oil from Eocene deposits is free from paraffin, which is only found in the Miocene and Cretaceous oils. Similarly, Schädler expresses the opinion that the geologically older petroleum of the Ropianka beds of Galicia contains more of the lighter hydrocarbons than the oils of the Eocene and Oligocene formations. In "American" oil, Norman Tate found 2 to 3 per cent. of paraffin. Engler states that the oils of Oelheim and Wietze are almost free from solid hydrocarbons, while that of Pechelbronn contains from 1 to 2 per cent. Much of the crude oil of Upper Burma contains from 10 to 12 per cent. of solid hydrocarbons, and in that of Digboi (Assam) the proportion appears to be almost, if not quite, as large. A general statement as to the comparative richness in paraffin of a number of typical specimens of crude petroleum, examined in the author's laboratory, will be found on page 284 *et seq.*

The oil from Bibi-Eibat, in the Baku district, is said to contain rather more paraffin than that from Balakhani-Sabuntchi, but the proportion present is very small. Shukoff and Pantjuchoff [9] show that the concurrent deposit of pitchy bodies largely prevents the isolation of what paraffin wax the Russian crude oils contain, so they worked upon distillates. They find, by a modification of the Zaloziecki method, that a white hard paraffin wax solidifying at 54° C. can be obtained. From various specimens of Caucasian crude oils they isolated percentages of wax varying from 0·2 to 0·76 per cent. and melting from 53° to 58° C.

Paraffin Wax.—The solid hydrocarbons, known collectively under the name of paraffin or paraffin wax, appear to belong chiefly to the paraffin series, C_nH_{2n+2}. They vary in specific gravity, melting-point, and boiling-point, with a somewhat wide range. By crystallisation from a solvent, or by fractional fusion, a partial separation of the hydrocarbons may be effected. Refined commercial paraffin is a white or bluish-white, translucent, waxy,

[1] *Proc. Amer. Acad.*, xl, 349–353 (1904).
[2] *Dingler's polytechn. Journ.*, cclxxxiv, 6 (1892).
[3] *Ber. deutsch. chem. Ges.*, xii, 689 (1879).
[4] *Proc. Roy. Inst.*, viii, 86 (1876).
[5] *Journ. Franklin Inst.*, xcvii, 479 (1889).
[6] *Journ. Chem. Soc.*, xxvi, 319 (1873).
[7] *Journ. Chem. Soc.*, xxviii, 301 (1875).
[8] *Verh. Ver. Beförd. Gewerbfl. Preuss.*, 637 (1887).
[9] *Chem. Rev. Fett- u. Harz-Ind.*, vii, 94 (1900).

solid substance, of lamino-crystalline structure, devoid of taste and smell, and characterised by chemical indifference. It consists of about 85 per cent. of carbon and 15 per cent. of hydrogen.

In an investigation into the composition of commercial paraffin undertaken in connection with the question whether paraffin is actually present in the crude oil or whether it is the result of change during the process of refining, Mabery[1] separated the following:—

TABLE XLVIII.—HYDROCARBONS IN COMMERCIAL PARAFFIN.

	Formula.	Melting-point.	Specific Gravity.
Tricosane,	$C_{23}H_{48}$	48°	0·7886 at 60°
Tetracosane,	$C_{24}H_{50}$	50°–51°	..
Pentacosane,	$C_{25}H_{52}$	53°–54°	0·7941 at 60°
Hexacosane,	$C_{26}H_{54}$	55°–56°	0·7968 at 60°
Octocosane,	$C_{28}H_{58}$	60°	..
Nonocosane,	$C_{29}H_{60}$	62°–63°	..

The specific gravity of paraffin obtained from United States crude petroleum is usually about 0·908 at 60° F., and about 0·750 at 212° F. The following determinations by Galletly indicate that the specific gravity of paraffin obtained from Boghead coal increases with the melting-point:—

TABLE XLIX.—SPECIFIC GRAVITY OF PARAFFINS FROM BOGHEAD COAL.

Specific Gravity.	Melting-point.
0·8236,	89·6° F.
0·8480,	102·2° F.
0·8520,	104·9° F.
0·9090,	128° F. [2]
0·9110,	128° F. [2]
0·9243,	136·4° F.
0·9248,	138·2° F.
0·9400,	176° F.

Beilby's experiments[3] with a sample of shale-oil paraffin, of a melting-point of 104·4° F., demonstrate that paraffin in solution and melted paraffin have practically the same specific gravity:—

	Specific Gravity.
In the solid state, at 21° C.,	0·8740
Dissolved in 0·885 paraffin oil, at 21° C.,	0·7950
In the melted state, calculated to 21° C.,	0·7956

The following table by Allen[4] indicates the relation between specific gravity and melting-point:—

TABLE L.—RELATION OF SPECIFIC GRAVITY TO MELTING-POINT OF PARAFFINS.

Origin of Sample.	Specific Gravity.		Solidifying-point.
	Solid, at 15·5° C.	Liquid, at 99° C.	
1. Shale-Oil,	0·8666	0·7481	44·0° C.
2. ,,	0·8961	0·7494	47·0° ,,
3. ,,	0·9000	0·7517	52·0° ,,
4. ,,	0·9111	0·7572	58·5° ,,
5. American Petroleum,	0·9083	0·7535	53·8° ,,
6. Ozokerite,	..	0·7531	61·5°
7. Rangoon Tar,	0·8831	0·7571	40·0° ,,

[1] *Proc. Amer. Acad.*, xl, 355–361 (1904).
[2] *Sic* in original, *Chem. News*, xxiv, 187, 188 (1871).
[3] *Journ. Chem. Soc.*, xliii, 388 (1883).
[4] *Commercial Organic Analysis*, Ed. 2, ii, 411 (1885).

At a temperature below its melting-point paraffin becomes plastic, and subjected for some time to slight pressure, it undergoes a molecular change, becoming transparent; but upon a change of temperature, or upon being struck, it resumes its normal translucent appearance, though by slow cooling it may be annealed. When two blocks of paraffin are struck together, a metallic sound is emitted, especially if the material be of high melting-point. Paraffin is freely soluble in mineral oils, in ether, in benzene, and in essential oils. It is sparingly soluble in hot absolute alcohol, but separates on cooling, and is insoluble in rectified spirit. When boiled with concentrated nitric acid, it is oxidised, the principal products being succinic acid, $C_4H_6O_4$, and cerotic acid, $C_{27}H_{54}O_2$, the formation of the latter indicating the presence of the hydrocarbon, $C_{27}H_{56}$, in the material. Paraffin is also oxidised when heated with potassium permanganate, and at a high temperature is attacked by concentrated sulphuric acid. The hydrocarbons of highest melting-point appear to be the most easily acted upon by nitric and sulphuric acids. Chlorine slowly attacks melted paraffin, and when heated with sulphur, paraffin is decomposed, sulphuretted hydrogen being evolved, and carbon deposited.

Asphaltic Bodies.—The solid forms of bitumen are represented by *ozokerite* and the various kinds of asphalt. An elastic description of bitumen, termed *elaterite* by Hausmann, and frequently referred to as "mineral indiarubber," occurs in the Odin lead mine near Castleton, Derbyshire.[1] A similar material, known as *coorongite*, has been found in the Coorong District, South Australia, but Professor Ralph Tate holds that this is a vegetable product. Among other forms of solid bitumen are the *albertite* of New Brunswick, the *grahamite* of West Virginia, and the *uintahite* or *uintaite* of Utah, also termed *gilsonite*, after Mr. S. H. Gilson of Salt Lake City. These forms are fully described by Dana.[2]

Ozokerite, which may be regarded as natural paraffin, varies from a very soft substance to a black material as hard as gypsum. Its specific gravity varies from 0·85 to 0·95, and its melting-point from 58° to 100° C. It dissolves in ether, petroleum, benzene, turpentine, chloroform, carbon bisulphide, etc. Boiling absolute alcohol dissolves about 3 per cent. of ozokerite. The colour of Galician ozokerite varies from a light yellow to a dark brown, with frequently a greenish shade due to dichroism. When rubbed, it becomes negatively electrified. It becomes plastic when heated, and usually melts at about 62° C.

The refined ozokerite of commerce is largely known as **ceresine** or **cerasin.** It is not crystalline, and some doubt has been expressed as to whether crystalline paraffins can be obtained from it except by distillation. Zaloziecki,[3] however, has obtained crystalline paraffin by crystallising ozokerite melting at 65° C. from excess of warm amyl-alcohol, and expresses the opinion that the absence of crystalline structure in the ordinary product is due to the presence of colloids, which prevent crystallisation. The question has been further discussed by Partridge.[4] Höfer [5] describes an almost white partly-transparent paraffin found in a fine-grained sandstone with the oil of Sosmezö (Transylvania). This paraffin, he says, is distinctly crystalline, as is shown by its behaviour towards polarised light.

The crude ozokerite found on Tcheleken Island on the Transcaspian coast is described by Beilstein and Wiegand [6] as brownish-black and sticky. The ozokerite of Utah has been examined by Newberry,[7] Wurtz,[8] and Seal.[9]

[1] Aikin's *Dict. of Chem. and Min.*, 1807, article "Bitumen."

[2] *Syst. of Min.*, 6th ed., 1017–1020.

[3] *Zeitschr. f. angew. Chemie*, 261 (1888).

[4] *Journ. Franklin Inst.*, xcvii, 479 (1889).

[5] *Das Erdöl*, 48 (1862).

[6] *Ber. deutsch. chem. Ges.*, xvi, 1547 (1883).

[7] *Amer. Journ.*, 3, xvii, 340 (1879).

[8] *Eng. and Min. Journ.*, xxvii, 108 (1879).

[9] *Journ. Franklin Inst.*, cxxx, 402 (1891).

According to Seal, it is dark brown, and contains crystals of gypsum. It melts at 53° to 55° C., and has a specific gravity of 0·928.

Ozokerite and other forms of paraffin do not dissolve aniline colours, but in candle-making the colouring-matter is introduced by previously dissolving it in a little melted stearin. It is worthy of note that the melting-point of a mixture of paraffin and stearin may be lower than that of the more readily fusible of the two ingredients, the mixture resembling, in this respect, many metallic alloys.

The following are some particulars of specimens of ozokerite from various sources:—

Baku—Specific gravity, 0·903; melting-point, 79° C. (Petersen).
Persia—Specific gravity, 0·925; dark green, rather hard.
England—(Morpeth, near Newcastle)—Specific gravity, 0·890; melting-point, 60° to 70° C.; soft and sticky, brownish (Wagner).
Boryslaw (Galicia)—Specific gravity, 0·930; dark yellow to dark brownish-black (Josef Merz).

Ozokerite consists of a mixture of hydrocarbons in various proportions. It contains 85·7 per cent. of carbon, and 14·3 per cent. of hydrogen. According to R. Heger,[1] the composition of ozokerite may be best represented by the formula C_nH_{2n}, and its formation may be attributed to the oxidation and decomposition of the hydrocarbons of petroleum, since the action of oxygen on these compounds simply eliminates hydrogen—thus, for example, naphthalene gives dinaphthyl and water:—

$$2C_{10}H_8 + O = C_{20}H_{14} + H_2O.$$

By further oxidation, there are obtained compounds of the formula C_nH_{2n}, which react with the hydrocarbons of the marsh-gas series, with formation of very complex carbon compounds of various melting-points, as, for example:—

$$2C_8H_{18} + O_2 = C_{16}H_{32} + 2H_2O \text{ and}$$
$$C_{16}H_{32} + C_8H_{18} + O = C_{24}H_{48} + H_2O.$$

Krämer and Spilker[2] believe, on the contrary, as regards formation, that ozokerite marks an intermediate stage between diatom-wax and petroleum, *i.e.* in the passage from the former to the latter, and they adduce evidence in support of their view.

N. Chercheffsky[3] gives the following solubilities of ceresin (pure Galician ozokerite), melting-point, 68·7° C.; and paraffin wax, melting-point, 52°–54° C.).

Table LI.—Solubility of Ceresin and Paraffin Wax.

	Solubility, grams per 100 c.c. at 15° C.	
	Ceresin.	Paraffin Wax.
Alcohol (96·5 per cent.),	0·056	0·108
Methyl alcohol (99·25 per cent.),	0·016	0·004
Amyl alcohol (b. pt. 129–131° C.),	0·100	0·496
Carbon bisulphide,	1·971	19·072
,, tetrachloride,	1·948	11·784
Chloroform,	1·276	5·332
Acetone (b. pt. 54–58° C.),	0·028	0·120
Ether,	0·592	1·920
Petroleum spirit (sp. gr. 0·710),	1·416	5·940

[1] *Seifensied.-Zeit.*, 321.
[2] *Ber. deutsch. chem. Ges.*, xxxv, 1212 (1902).
[3] *Les Matières Grasses*, iv, 2235 (1911).

Other physical data of value in differentiating these materials are the refractive index, critical temperature of solubility in alcohol, and turbidity temperature in petrol. The following data are given :—

	Paraffin Waxes.			Ceresin.
	American.	Shale.	Shale.	Galicia.
Melting-point,	53·7	42·1	46·5	68·7
Solubility in CS_2 at 15° C.,	19·07	38·68	34·65	1·97
Refractive index at 78° C.,	1·4280	1·4238	1·4246	1·4352
,, ,, at 100° C.,	1·4185	1·4152	1·4161	1·4268
Critical temperature of solution in 96·5 per cent. alcohol,	148°	136·5°	141°	172·5°
Turbidity temperature with petrol,	24·7°	..	..	47·4°

J. Marcusson [1] concludes from the examination of a low-grade Galician ceresin that it consisted mainly of iso-paraffins and not of naphthenes ; in addition all ceresins appear to contain small quantities of normal paraffins, which become concentrated in the more soluble portions. The generally accepted view that ceresin consists of higher homologues of the same series as paraffin wax hydrocarbons he regards as incorrect.

E. P. Schoch [2] obtained ozokerite of good quality from a dark brown waxy material occurring with crude petroleum at Thrall (Texas). The melting-point was 79·5° C., and from it ceresin of specific gravity 0·926–0·928 ; melting-point 75° C. ; and refractive index 1·4414–1·4420 at 90° C. was obtained. Its solubility in carbon tetrachloride was 308 grams per 100 c.c. of solvent. The material was regarded as free from paraffin.

J. Marcusson and H. Schuster [3] consider that in the upward filtration of petroleum, ozokerite and other amorphous hydrocarbons are retained in the adsorbent earth, whilst crystalline paraffins pass on in solution (see also Section VI, Refining).

Asphalt, or asphaltum, and **asphalt-rock** are found widely distributed, and occur in some localities in immense quantities. Although certain deposits, such as that forming the Pitch Lake of Trinidad, have been by some considered the primary product of the decomposition of vegetable or other matter, asphalt is usually regarded as having resulted from the combined action of evaporation and atmospheric oxidation upon liquid petroleum as it issues from outcropping strata. (Clifford Richardson gives an exhaustive report of the Nature and Origin of Asphalt in the *Journ. Soc. Chem. Ind.*, 13–32 (1898). See also Peckham, *Ibid.*, 1003 ; J. Endemann, 1005.)

The following table gives the comparative composition of Trinidad and Cuba asphalt on the basis of results obtained by distillation :—

TABLE LII.—Composition of Trinidad and Cuba Asphalt.

	1.	2.	3.
Water,	0·17	0·13	0·11
Volatile Bitumen,	51·81	64·03	8·34
Sulphur,	10·00	8·35	8·92
Ash (earthy matter),	28·30	19·51	16·60
Fixed Carbon,	9·72	7·98	66·03
	100·00	100·00	100·00

1. Refined Trinidad. . . . . Melting-point, 185° F.
2. Refined Cuba (soft), ... ,, 115° F.
3. ,, (hard), ... ,, 160° F.

[1] *Chem. Zeit.*, xxxix, 581, 613 (1915). See *J.S.C.I.*, 1002 (1915).
[2] *J. Ind. and Eng. Chem.*, viii, 1095 (1916).
[3] *Chem. Zeit.*, xxxviii, 73 (1914).

By solution in carbon bisulphide, the following comparative results were obtained :—

TABLE LIII.—COMPARISON OF TRINIDAD AND CUBA ASPHALT.

	Bitumen.	Fixed Carbon, etc.
Trinidad,	68·12 per cent.	31·88 per cent.
Cuba (soft),	87·84 ,,	12·16 ,,
,, (hard),	27·74 ,,	72·26 ,,

The chemical composition of Trinidad bitumen has been given as :—

Carbon,	80·32 per cent.
Hydrogen,	6·30 ,,
Nitrogen,	0·50 ,,
Oxygen,	1·40 ,,
Sulphur,	11·48 ,,
	100·00 ,,

In a report on "Asphalt Paving" to the Department of Public Works, Philadelphia, U.S.A., 1894, the following tabular comparison of Trinidad and Bermudez (Venezuela) asphalt is given :—

TABLE LIV.—COMPARISON OF TRINIDAD WITH BERMUDEZ ASPHALT.

	Refined Trinidad Asphalt.	Refined Bermudez Asphalt.
Specific gravity at 60° F.,	1·373	1·071
Bitumen soluble in carbon bisulphide,	61·507 per cent.	97·22 per cent.
Mineral matter (ash),	34·51 ,,	1·50 ,,
Non-bituminous organic matter,	3·983 ,,	1·28 ,,
Portion of total bitumen soluble in alcohol,	8·24 ,,	11·66 ,,
,, ,, ,, ether.	80·01 ,,	81·63 ,,
Loss at 212° F.,	0·65 ,,	1·37 ,,
,, 400° F. in ten hours,	7·98 ,,	17·80 ,,
,, ,, on total bitumen,	12·811 ,,	18·308 ,,
Evolution of sulphuretted hydrogen at,	410° F.	None at 437° F.
Softening-point,	160° F.	113° F.
Flowing-point,	192° F.	150° F.

Trinidad Asphalt.—According to C. Richardson[1] Trinidad crude asphalt consists of a suspension of relatively large size mineral particles in an extremely viscous medium, together with highly dispersed mineral matter in colloid form, intimately mixed with an emulsion of a thermal water with the bitumen present.

The asphalt is extremely homogeneous, giving on analysis the following figures :—

	Crude Per Cent.	Dry Per Cent.
Volatile at 100° (water and gas),	29·0	..
Bitumen soluble in cold CS_2	39·0	55·1
,, absorbed by mineral matter,	0·3	0·4
Mineral matter,	27·2	38·2
Water of hydration,	4·3	6·1
	99·8	100·0

[1] *J. Phys. Chem.*, xix, 241 (1915).

The bitumen is a black, glossy, brilliant, pitch-like solid with a semi-conchoidal fracture when broken. When exposed to gentle pressure it yields and flows. It softens at 76° C. and flows quickly at 83° C. Its ultimate composition is :—

Carbon	82·33	per cent.
Hydrogen	10·69	,,
Sulphur	6·16	,,
Nitrogen	0·81	,,
	99·99	

The bitumen is characterised by the absence of oxygen. The malthenes (soluble in light petroleum) of this bitumen are extremely sticky and not merely oily ; they possess great cementitious value. The asphaltenes (insoluble in light petroleum) impart cohesiveness and supply body and stability.

Most important is the content of colloidal clay in Trinidad asphalt. By means of the ultra microscope it has been revealed that the most carefully filtered solutions of Trinidad bitumens contain submicroscopic particles. This fact explains to a large extent the service peculiarities of the substance. The same author has investigated the formolite method for the determination of the unsaturated components of asphalts. For the preparation of hard asphalts from petroleum residues by means of the addition of sulphur and atmospheric oxidation the paper of B. T. Brooks and I. W. Humphrey [1] should be consulted.

A number of tabular statements of the results obtained in the examination of samples of asphalt from the Pitch Lake (Trinidad), and from deposits lying between the lake and the sea coast (" land pitch "), will be found in the *Sixth Annual Report of the Inspectors of Asphalt and Cements* (Washington, Government Printing Office, fiscal year, 1891–1892). From these results it appears that the lake-pitch is richer than the land-pitch in bituminous matter soluble in petroleum-spirit. The soluble portion is termed *petrolene*, and the insoluble *asphaltene*.

Mr. Henry G. Hanks, formerly mineralogist to the State of California, gives, in his *Fourth Annual Report* (1884), the following composition of two samples, and states that the results indicate the general character of Californian asphalt-rock :—

From Santa Cruz—Asphalt, ...	19·8
Sand, ...	80·2
	100·0
From Santa Barbara county—Bitumen, volatile portion, . .	35·0
,, fixed, ...	7·2
Quartz sand, ...	57·8
	100·0

The sand is angular, and consists almost entirely of transparent quartz. The bitumen is soluble in turpentine.

On the northeast coast of the island of Sakhalin, exudations of petroleum have saturated the peat of extensive morasses, producing by oxidation an impure asphalt. Samples tested in the laboratory of the Imperial Russian Technical Society were found to consist of bituminous matters soluble in ether 75 per cent. ; insoluble matter 24·6 per cent. ; ash 0·5 per cent. The sulphur

[1] *Jour. Ind. and Eng. Chem.*, ix, 746 (1917).

content is only 0·80 to 0·85 per cent. The melting-point is high, the mass beginning to soften only at 160° C.

Asphalt-rock (such as is used for paving) generally consists of limestone saturated with the bituminous material, which is usually almost free from solid paraffin. The grains forming the asphalt-rocks are almost invariably found to be totally uncemented, save by the bituminous matter, and the rocks fall to powder when the bitumen is removed by a solvent. This is the case with such widely different rocks as those of Seyssel, Forens, Lobsann, Limmer, Val de Travers, Kentucky, California, and Athabasca.

M. Durand-Claye has given the following particulars of several descriptions of natural asphalt-rock :—

TABLE LV.—Composition of Asphalt-Rocks.

	1.	2.	3.	4.	5.
Water and other matters volatilised at 100° C.,	0·35	3·40	0·40	0·40	0·80
Bituminous matter,	8·70	11·90	9·10	8·80	8·85
Sulphur in organic combination, or free state,	0·08	4·99	..	trace	..
Iron-pyrites,	0·21	4·44	..	..	..
Alumina and oxide of iron,	0·30	1·25	0·05	4·35	0·90
Magnesia,	0·10	0·15	0·05	3·85	0·45
Lime,	49·50	38·90	50·50	5·70	49·00
Carbonic acid,	40·16	31·92	39·80	8·15	39·40
Combined silica,	..	..	..	11·35	..
Sand,	0·60	3·05	0·10	57·40	0·60
	100·00	100·00	100·00	100·00	100·00

1. Val de Travers (Switzerland).
2. Lobsann (Alsace).
3. Seyssel (Ain, France).
4. Maëstu (Spain).
5. Ragusa (Sicily).

In his *Report to the Geological Survey of Kentucky on the Occurrence of Petroleum, etc., in Western Kentucky*, 1891, Dr. Orton furnishes a full account of the asphalt of California and Kentucky. The following table gives the results of four analyses, quoted by Orton, as showing the composition of the well-known French and German deposits :—

TABLE LVI.—Composition of French and German Asphalt-Rocks.

	Val de Travers.	Seyssel.	Forens.	Lobsann.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Water lost at 90° C.,	0·50	1·90	0·20	3·40
Portion soluble in carbon bisulphide,	10·10	8·00	2·25	11·90
Insoluble mineral matter,	0·45	0·10	0·05	1·25
Alumina and iron oxide,	0·25	0·15	0·15	..
Calcium carbonate,	87·95	89·55	97·00	69·00
Magnesium carbonate,	0·30	0·10	0·70	0·30
Sand,	..	..	..	3·05
Sulphur,	..	..	..	5·00
Iron (present as sulphide),	..	..	..	4·45

A single analysis of the Limmer rock, made at Columbia College, New York, showed the following composition of the "dried" material:—

Part soluble in carbon bisulphide,	8·26 per cent.
Clay,	4·98 ,,
Calcium carbonate,	56·50 ,,
Magnesium ,,	27·01 ,,
Iron oxide,	3·21 ,,

In three samples of asphalt from Western Kentucky, Dr. Peter found 9·4, 8·0, and 8·75 per cent. respectively of matters driven off by ignition.

According to Hilgard,[1] the asphalt-rock of Ventura county, California, contains:—

Water and volatile oil lost at 217° F.,	2·37 per cent.
Total asphaltum,	20·00 ,,
Ash,	77·65 ,,

The ash consisted of a fine clay containing a little sand and about 3 per cent. of calcium carbonate. S. F. and H. E. Peckham[2] examined a Texas asphalt-rock, "turrelite," a shelly mass cemented together by bitumen. The following results indicate its composition:—

Soluble in petroleum-ether,	9·415 per cent.
,, oil of turpentine,	4·121 ,,
,, chloroform,	trace ,,
,, dilute hydrochloric acid,	84·894 ,,
Sulphur in residue,	0·138 ,,
Silica and clay,	1·432 ,,
	100·000

The asphalt of the North-Western Territories of Canada, lying to the north of the land drained by the Peace and Athabasca rivers, has been examined by G. C. Hoffmann of the Canadian Geological Survey.[3] He reports that this asphalt is dark brownish-black, and becomes soft at 100° F., although quite hard at common temperatures. The material contains 12·42 per cent. of bitumen, 5·85 per cent. of mechanically included water, and 81·73 per cent. of sand. When treated with benzene or carbon bisulphide, the bituminous matter is dissolved out, and the residue consists only of colourless and transparent sand-particles which were merely held together by the bitumen.

Mr. W. H. Delano[4] considers that the term asphalt should be applied only to bituminous limestone, the composition of which he gives as varying from 7 per cent. of bitumen with 93 per cent. of carbonate of lime to 20 per cent. of bitumen with 80 per cent. of carbonate of lime. He states that the bitumen found in the Trinidad Pitch Lake is mixed with 33 per cent. of fine clay, sand, and vegetable matter, and 33 per cent. of water; and that refined Trinidad bitumen always contains from 20 to 25 per cent. of fine clay, but is nevertheless so tough, malleable, and stringy, that for asphalt "mastic" it is preferable to some other "short-fibred" bitumens chemically purer. Mr. Delano adds that, for use in asphalt-paving, bitumen should be free from "dross," perfectly black, not brilliant, of the consistency of bees-wax at 70° F., and free from oils that will evaporate at 480° F. "Mastic" is the name given to the material prepared for use in paving by mixing hot asphalt rock, ground to a fine powder,

[1] *Tenth Annual Report of the State Mineralogist*, California, 766 (1890).
[2] *J. Soc. Chem. Ind.*, 996 (1897).
[3] *Summary Rep. Geol. Surv. Canada*, n.s., iv, 14.
[4] *Twenty Years' Practical Experience of Natural Asphalt and Mineral Bitumen*, London and New York, 1893. See also *Proc. Inst. Civil Eng.*, clii, 3 (1902–1903).

with such proportion of hot bitumen, similar to that contained in the natural rock, that the product contains about 15 per cent. of bitumen and 85 per cent. of limestone. "Gritted asphalt-mastic" is composed of the mastic already described, remelted with 5 per cent. of bitumen, and from 30 to 40 per cent. of clean dry fragments of limestone or sand. For use in preparing mastic, the bitumen extracted from Seyssel asphalt is stated to possess the desired qualities in the highest degree. It is asserted that this bitumen may be heated to a temperature of 500° F., or cooled to many degrees below the freezing-point of water, without losing its tenacity and malleability. Its chemical composition is—carbon, 85 per cent.; hydrogen, 12 per cent.; oxygen, 3 per cent.

J. Marcusson [1] states that the oxygenated solid constituents of petroleum are "asphaltene" and "petroleum resin." The former may be precipitated by low-boiling petroleum spirit. If the residual oil is then mixed with fuller's earth, and the hydrocarbon oils extracted with petroleum spirit, chloroform extraction will remove the petroleum resins. These represent the first transformation product being produced by oxidation and polymerisation or by condensation. They are readily converted into asphaltenes by addition of oxygen or the intramolecular transference of oxygen. Both the asphaltenes and resins are polycyclic compounds, in some cases having a double bond structure, and containing variable quantities of oxygen and sulphur. These asphaltic bodies he regards as derived from the terpene-like constituents of the petroleum oil. For further details by the same author reference should be made to *Zeit. angew. Chem.*, xxix, 346 (1916).

The part played by sulphur in the material formation of asphalt is laid stress on by R. Zaloziecki and C. Zelinski.[2] Catalysis by mineral matter and subsequent oxidation appear to be the sequence of events.

TABLE LVII.—Analyses of Grahamite and Allied Materials. By C. Richardson.[3]

Name.	Specific Gravity.	M.P.	Coke.	Soluble in CS_2.	Soluble in Light Naphtha.
Paraffin base petroleum	·83	liquid	0	100	100
Asphaltic base,	·93	..	1·0	100	98
Maltha,	·97	Nil.	3	98	94
Asphaltum, medium,	1·03	60	12·5	96	70
,, hard,	1·04	80	14·5	..	63
Gilsonite,	1·04	130	15	99·4	53
Glance pitch,	1·10	130	15	99·7	23·5
Manjak,	1·10	200	24·7	98·3	22·2
Grahamite, Trinidad,	1·16	intumesces	35	98·8	14·5
,, Virginia,	1·14	,,	41	97·8	3·3
,, Oklahoma,	1·18	..	56·4	95·5	0·8
Albertite,*.	1·08	..	29·8	6·0	1·5

* Insoluble in heavy residuals.

Gilsonite.—A sample of gilsonite obtained from the west coast of the island of Leyte (Philippines) was of dull brownish-black colour; perfectly conchoidal fracture; specific gravity, 1·26; loss of weight at 163° C. during five hours, 3·28 per cent.; total bitumen (soluble in CS_2), 93·79 per cent.; insoluble

[1] *Chem. Zeit.*, xxxix, 581, 613 (1915). See *J.S.C.I.*, 1002 (1915).
[2] *Eighth Inter. Congr. Appl. Chem.*, x, 335.
[3] *J. Amer. Ch. Soc.*, xxxii, 1032 (1910).

organic matter, 1 per cent.; mineral matter, 5·21 per cent.; fixed carbon, 7·68 per cent.

Asphaltum in Petroleums.—According to Dr David T. Day, the proportion of asphaltum in various American oils is:—Coalinga (Cal.), 1·89 to 57·42 per cent.; Kern River, 16·2 to 38·7; Sunset-Midway-McKittrick, 11 to 51; Los Angeles (Cal.), 13·3 to 14·2; Santa Maria (Cal.), 12 to 12; Gulf Region, 0 to 20 per cent.

Large and increasing amounts of these asphaltums are being used for roofing and road-binding purposes, suitable oils being boiled down.

Asphaltum minerals of Utah have been examined by Bardwell, Berryman, Brighton, and Kuhre,[1] who give the following comparisons of solubility with Trinidad pitch and Bermudez asphaltum (grams of material in 100 grams cold solvent):—

TABLE LVIII.

Solvent.	Trinidad Pitch.	Bermudez Asphaltum	Gilsonite.	Ozokerite.	Rock Asphaltum.
Ether,	109	145	∞	13	14
Ethyl acetate,	30	24	3	1	4
Amyl acetate,	132	37	86	1	Insol.
Benzene,	48	36	71	18	12
Nitrobenzene,	39	24	9	Insol.	3
Chloroform,	10	23	54	∞	83
62° naphtha,	Very sol.	63	5	7	18

All were either insoluble or very slightly soluble in cold ethyl, propyl, and amyl alcohols, and in aniline.

Richardson [2] develops the view that the metamorphism of petroleum from gilsonite to grahamite is accompanied by gradually increasing specific gravity, coke yield, and melting-point, and by decreasing solubility in light petroleum:—

TABLE LIX.

	Flow.	Specific Gravity.	Per Cent. soluble in Naphtha.	Per Cent. Coke.
Texas residue,	° F.	·9524	88·0	6·5
Gilsonites:—				
1. Utah (softest),	285	1·011	55·5	10·0
2. ,, (hardest),	intumeses	1·057	24·5	16·7
Grahamites:—				
1. Cuba,	,,	1·157	38·8	40·0
2. Trinidad,	,,	1·156	14·8	40·0
3. Colorado,	,,	1·160	0·8	47·4
4. Oklahoma,	,,	1·184	0·4	51·4

The asphalts contain saturated hydrocarbons and are the less affected by strong sulphuric acid; gilsonite is chiefly unsaturated. Both have a common origin in petroleum but have been exposed to different environments.

[1] *J. Ind. and Eng. Chem.*, v, 973 (1913). See *J.S.C.I.*, 15 (1914).

[2] *J. Ind. and Eng. Chem.*, viii, 493 (1916).

Material.	Specific Gravity.	Per Cent. soluble in Naphtha.	Per Cent. Saturated Hydrocarbons.
Texas petroleum flux, ...	0·956	97·5	72·8
Residual pitch, ...	1·089	65·0	33·1
Bermudez asphalt, ...	1·082	62·0	24·4
Gilsonite (Utah), ...	1·044	47·7	5·5
,, (Okla.), ...	1·171	0·4	0·3

METHODS FOR THE EXAMINATION OF PETROLEUM FOR CHEMICAL CONSTITUENTS.

Successive and careful fractionation over such a column as the Young-Thomas separator still-head or a Raschig type of dephlegmator will give a series of fractions which may be graphically represented by plotting specific gravity or quantity against boiling-point. For the lower boiling part of a crude oil this procedure offers no difficulties, but for the less volatile portions a high vacuum is imperative since decomposition or "cracking" may take place with more or less ease. Seeing that most crude oils contain paraffins, naphthenes, aromatic and unsaturated hydrocarbons, it is desirable to investigate each series as far as practicable free from the others. It is at all events generally advisable to remove unsaturated compounds and submit them to a separate study. For this purpose advantage may be taken of the selective solvent action of liquid sulphur dioxide, in which case a reasonably good separation is effected. Strong sulphuric acid or even oleum may be used, or a nitrating mixture.

An inspection of the specific gravity-boiling-point and quantity-boiling-point curves will indicate the locale of the chief components. These may be often isolated by repeated fractionation, when it will be necessary (1) to establish an empirical formula by means of ultimate organic analysis; (2) to determine the molecular weight. A convenient method is to measure the depression of the freezing-point of naphthalene[1]; (3) to determine the chief physical constants: specific gravity, viscosity, refractive index, boiling-point, etc.; (4) to prepare some characteristic derivatives, *e.g.* the nitro-, chloro-, bromo-compounds.

The naphtha fraction is, in the main, largely composed of saturated hydrocarbons of the paraffinoid or naphthenic type. Aromatic hydrocarbons are almost universally present but to a less extent, benzene, toluene, the xylenes, mesitylene, and ψ-cumene being included in this boiling range. Unsaturated derivatives appear towards the beginning of the kerosene cut and thenceforward are found throughout the various distillates. Oils from different localities show variations in their content of unsaturated compounds. Thus:—

American lubricating oil, specific gravity, 0·875; iodine value, 22·8 (Wijs).
Russian ,, ,, ,, ,, 0·904; ,, ,, 16·8.

As to the precise nature of the components of the fractions which succeed the naphthas there is little information. It is known that the normal paraffins persist through a wide range and also that the naphthene series has been traced to so high an homologue as $C_{26}H_{52}$, but the nature of the accompanying compounds which appear to belong to such series as C_nH_{2n-2}, C_nH_{2n-4}, and so forth, is at present unknown. It may be hazarded that these bodies are not ordinary straight-chain olefines since they are particularly difficult to reduce

[1] Dunstan and Thole, *Journ. Inst. Petr. Techn.*, iv, 191–228 (1918).

catalytically and because they do not appear to polymerise under the influence of strong sulphuric acid.[1]

That unsaturation does exist is shown by the iodine values which, although apparently low, represent, for compounds of high molecular weight, a considerable percentage of unsaturated bodies. Further, an increasing solubility in strong sulphuric acid is found with rising boiling-point.[2]

PENNSYLVANIA CRUDE OIL.

	Fraction: 150° C.	150°–200° C.	Above 200° C.
Carbon per cent.,	85·3	85·3	86·8
Hydrogen ,,	14·9	14·65	13·2
Soluble in strong sulphuric acid (per cent.),	16	18	35
Volume of fraction (per cent.),	14	26	60

SUMATRA CRUDE OIL.

	Fraction: 150° C.	150°–200° C.	Above 200° C.
Carbon per cent.,	85	86·2	87·1
Hydrogen ,,	15	14·0	12·85
Soluble in strong sulphuric acid (per cent.),	16	28	36
Volume of fraction (per cent.),	54	..	..

The determination of iodine and bromine numbers has been used for many years as a discriminating test for unsaturation in oils, particularly those of animal and vegetable origin. In the case of petroleum, however, there are unknown factors such as the extent of substitution, the velocity of the addition, the influence of sulphur compounds and other impurities, which render the exact interpretation of the results a matter of some difficulty.

Bromine Absorption.—Mr. A. J. de Hailes has determined the amount of **bromine absorbed** by several specimens of crude petroleum in the author's collection, and has obtained the following results:—

TABLE LX.—BROMINE ABSORPTION OF CRUDE PETROLEUMS.

Description of Sample.	Bromine absorbed (after deducting Br converted into HBr).
United States (Bradford),	5·9141 per cent.
,, (Parker, Clarion),	2·7841 ,,
,, (Stoneham),	4·5752 ,,
Russia (Balakhani-Sabuntchi),	1·7730 ,,
Burma (Yenangyaung),	3·0392 ,,
Assam (Digboi),	4·2480 ,,
Italy (Montechino),	3·3947 ,,
,, (Neviano),	0·6140 ,,
,, (Ozzano),	0·8676 ,,
England (Derbyshire),	4·2330 ,,

C. F. Mabery[3] has determined the bromine absorption of Californian petroleums. Crude oil from Ventura county, specific gravity at 20° C., 0·8882, and bromine absorption 17·72 per cent., *i.e.* higher than Pennsylvania or Ohio oil, but nearly the same as the crude oil of Oil Springs, Canada. That from

[1] Brooks, B. T., and I. W. Humphrey, *Journ. Amer. Chem. Soc.*, xl, 822 (1918).
[2] Engler and Jezioranski, *Ber.*, xxviii, 250 (1895).
[3] *Amer. Chem. J.*, xix, 796 (1898).

Fresno county has a specific gravity at 20° C. of 0·8423, and a bromine absorption of 9·07 per cent.

A sample of Nova Scotia oil (crude) gave a bromine absorption value of 8·2 per cent., and the kerosene fraction, 11·7 per cent.

A sample of petroleum (specific gravity 0·760 at 15·5° C.) obtained from a shale-oil of Tasmania gave a bromine absorption of 113 per cent.

O. Rontala [1] recommends Frank's process [2] and gives a formula for the estimation of the percentage of olefines present.

Iodine Absorption.—R. Junkunz [3] states that the iodine absorption, by Hübl's method, in six hours, of American lamp oils was between 11·13 and 13·54, that of European oils being between 0·64 and 2·90.

Radcliffe and Polychronis [4] give the results shown in Table LXI for lubricating oils by both the Hübl and Wijs methods. These determinations were made in the course of an investigation in the three principal iodine absorption processes—Hübl, Hanus, and Wijs.

TABLE LXI.—Iodine Absorption of Lubricating Oils.

	Specific Gravity at 15·5° C.	Hübl.	Wijs.
American.			
Cylinder oil,	0·875	10·2	22·8
,, ,,	0·895	9·7	20·5
,, ,, (black),	0·900	13·9	30·9
Valve oil,	0·895	10·6	24·5
,, ,,	0·904	9·2	32·3
Spindle oil,	0·901	10·8	34·0
Lubricating oil,	0·901	9·9	30·5
Russian.			
Cylinder oil,	0·914	9·9	22·0
,, ,,	0·915	11·4	23·3
,, ,,	0·902	13·2	27·6
Engine oil,	0·904	6·4	16·8
,, ,,	0·909	6·5	17·1
Gas engine oil,	0·908	7·0	12·1
Spindle oil,	0·899	4·5	14·4
Scotch.			
Lubricating oil,	0·873	31·6	56·8
,, ,,	0·890	24·5	49·8
,, ,,	0·9025	19·5	43·6
Spindle oil,	0·901	25·2	48·8

The three Scotch lubricating oils were pure hydrocarbon oils from shale-oil.

THE ACTION OF VARIOUS REAGENTS ON PETROLEUM.

The Formolite Reaction.—A. M. Nastukoff has shown that petroleum and its distillates react with formalin in the presence of strong sulphuric acid, forming condensation products, both solid and liquid. The weight in grams of formolite from 100 c.c. of the oil is known as the formolite index. The reaction is said to be characteristic of unsaturated cyclic hydrocarbons, and the test shows that Russian and American lubricating oils consist chiefly of these. American cylinder oils rarely have formolite indices below 90; Russian oils

[1] *Chem. Zeit.*, ii, 638 (1912).
[2] *J. Soc. Chem. Ind.*, xxiv, 263 (1901).
[3] *Chem. Zeit.*, xxxix, 659 (1915).
[4] *J.S.C.I.*, 343 (1916).

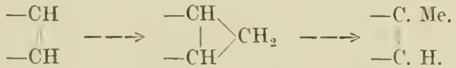
ranged from 58 to 87. Machine and spindle oils have lower values, and vaseline oils the lowest value of any examined.

J. Marcusson [1] states that the lubricating power of mineral machine oils is chiefly due to hydrocarbons which do not react with formalin and sulphuric acid. Russian machine oils yielded 10–24 per cent. by weight of formolite, whilst American oils yielded 30–33 per cent. American oils are also richer in unsaturated hydrocarbons which combine with iodine, eleven samples giving iodine values of 6·5 to 15·3 ; four Russian oils giving values from 3·3 to 5·6. The iodine absorption is due to both unsaturated alicyclic hydrocarbons and aliphatic olefines. Further examination of the unattacked portion indicate that condensed naphthenes (polynaphthenes) must be regarded as the main cause of the viscosity of heavy machine oils (especially Russian oils). Besides these hydrocarbons, all light-coloured machine oils contain viscous oxygenated compounds, of a resinous nature, which may be extracted by 70 per cent. alcohol.

V. F. Herr [2] has put forward the use of methylal as a more sensitive reagent than formalin.

A. M. Nastukoff [3] showed that benzene and formaldehyde in the presence of sulphuric acid gave high molecular weight condensation products which were stable and insoluble. Analysis yielded the following figures:—Carbon, 87·29 per cent. ; hydrogen, 6·78 per cent. ; oxygen, 5·23 per cent. ; sulphur, 0·70 per cent. On being distilled there was obtained a 12 per cent. yield of diphenylmethane together with a 7 per cent. yield of toluene. From petroleum naphtha the formolite gave the following analytical numbers:—carbon, 78·99 ; hydrogen, 7·39 ; oxygen, 10·95 ; sulphur, 2·67 per cent.

O. Fischer and H. Gross [4] from the condensation of formaldehyde and toluene, observed that ditolyl methane and polymeride thereof are produced. In the same year Nastukoff [5] discussed the mechanism of the reaction and suggested that the olefine reacts with the aldehyde in some such way as the following:—



forming an intermediate trimethylene derivative which opens up to an unsaturated cyclic system. There is therefore some considerable doubt as to whether the resulting oil after the application of this reaction really is that part of the original material unsusceptible to attack by the reagent. It appears possible that it should contain products of reaction other than those insoluble high molecular polymerides which are also formed. In view of this, Marcusson's views are untenable. Of very considerable interest is the paper on this subject by Nastukoff and Curin,[6] in which it is shown that, under the condensing influence of aluminium chloride, cyclohexane and trioxymethylene yield products of high molecular weight.

The action of Étard's reagent (chromium oxychloride, anhydrous) on petroleum has been studied by F. Schultz,[7] who reported that this, one of the most active bodies known to the chemist, combined with most energy in the case of the heavier distillates. For example:—

Boryslaw spirit (0·654 specific gravity) lost.	10·7 per cent.
,, lamp oil,	67·6 ,,
,, lubricating oil,	100·0 ,,
,, wax,	12·5 ,,

[1] *Chem. Zeit.*, xxxv, 729, 742 (1911).
[2] *Chem. Zeit.*, xxxiv, 897 (1910).
[3] *Journ. Russ. Phys. Chem. Soc.*, xxxv, 827 (1903) ; and xxxvi, 881 (1904).
[4] *Journ. Pract. Chem.*, lxxxii, 231 (1910).
[5] *Loc. cit.*, xlii, 1596 (1910).
[6] *Journ. Russ. Phys. Chem. Soc.*, xlvii, 46 (1915).
[7] *Petr.*, vi, 189 (1910).

Oxidation took place as well as addition to unsaturated linkages. The residues, after being treated with sodium bisulphite, afforded an oil possessing the odour of peppermint.

Ozone.—The pioneer in the investigation of the effect of ozone on unsaturated compound has been C. Harries.[1] In connection with petroleum E. M. Ainari and P. Feranoti[2] showed that Russian petroleum at 10° C. on being treated with ozonised air gave solid ozonides, *e.g.* $C_{17}H_{20}O_6$. Thus the fraction 135°–290° C. yielded 12 per cent. of this product, and that boiling between 295°–300° C. afforded 32 per cent. The ozonides were pale yellow or white powders, soluble in ether, chloroform, and benzene. They rapidly underwent decomposition at 20° C., and at 45° C. produced a red body which resinified at 150° C. Rumanian oil gave a similar ozonide, whilst an Italian fraction boiling between 140°–265° C. gave evidence of the ozonide derived from $C_{15}H_{16}$ and possessing the formula $C_{15}H_{16}O_6$. The unozonised portion was still optically active, hence the activity cannot be due to undecomposed cholesterol present in the crude oil.

F. W. Bushong, in an investigation of Oklahoma petroleum, used the Edeleanu method of extraction with liquid sulphur dioxide, and from the oil recovered from the 252°–254° C. fraction obtained a nearly white ozonide $C_{15}H_{16}O_3$. The reaction of unsaturated hydrocarbons, first extracted by liquid sulphur dioxide, with ozone is regarded as a valuable means of detecting new constituents of petroleum oils.

NATURAL GAS.

Natural gas, confining the term in this connection to the inflammable gases found in more or less close connection with petroleum, consists mainly of hydrocarbons of the paraffin series, methane, ethane, etc., together with other inert gases, such as nitrogen and carbon dioxide, the proportion of which may vary from very small amounts to almost half the volume. In addition traces of sulphuretted hydrogen, hydrogen and oxygen, may be present. Hydrocarbons of the olefine, or ethylene, series are recorded in most analyses of the gases of the Old World, but are seldom found in the New World gases. The occurrence of carbon monoxide has not been established in recent analyses.

A most interesting discovery has been the presence of helium in natural gas. H. P. Cady and D. F. McFarland[3] examined forty samples from Kansas and other States and found helium present from a mere trace to 1·84 per cent. E. Czako found a range in six samples of from mere traces up to 0·41 per cent.

It is of interest to note that many samples of gases collected from coal-measures are closely identical in composition with the petroleum gases which are high in methane content.

From the large number of recent analyses of American and Canadian samples the following maxima for component gases other than methane have been found: ethane, 27; propane, 6; nitrogen, 46; carbon dioxide, 6; sulphuretted hydrogen, 0·8; helium, 1·84 per cent.

Natural gas is broadly classified into "dry" gas, consisting almost entirely of methane and ethane, and containing no appreciable quantities of easily liquefied hydrocarbons; and "wet" gas, which on cooling to low temperatures, or on compression, yields appreciable liquid deposits. The utilisation of "wet" gas for the production of gasolene is dealt with later.

By the ordinary methods of gas analysis, involving combustion of the hydrocarbons with oxygen, fairly reliable results are obtained for "dry"

[1] See *Ber.*, xli, 3552 (1908). [2] *Ber.*, xli, 3704 (1908).
[3] *J. Amer. Chem. Soc.*, xxix, 1523 (1907).

gases, the hydrocarbons of which consist almost entirely of methane and ethane, but with natural gas containing more than traces of still higher hydrocarbons, especially the "wet" gas, such methods give entirely misleading results. Methods of analysis in which liquefaction by cooling with liquid air, the separation of definite fractions, and the combustion analysis of these fractions have been developed in the laboratories of the U.S. Bureau of Mines.[1] As indicating the extremely misleading results by the ordinary methods of analysis, the following analyses by each method of Pittsburgh gas may be quoted :—

	Methane.	Ethane.	Propane.	Higher hydrocarbons (butanes chiefly).
By slow combustion, ...	79·2	19·6	. .	. .
By fractionation, ...	84·7	9·4	3·0	1·3

Clearly all analyses of gases which contain a high proportion of ethane (which indicates the probable presence of still higher hydrocarbons) made by ordinary combustion methods can only be accepted with reserve.

By the fractionation method the following results for the hydrocarbons in a "wet" gas used for the production of gasolene have been obtained: methane, 36·8; ethane, 32·8; propane, 21·1; butane, 5·8; pentane and hexane, 3·5 per cent.

TABLE LXIIa.—Composition of the Natural Gas used in Twenty-five Cities (U.S.).[2]

State.	Town.	Total Paraffins.	Methane.	Ethane.	Nitrogen.	B.Th.U. per c. ft. at 60° F.
Arkansas and Texas, .	Texarkana, .	96·0	96·0	0·0	3·28	967
Indiana, .	Noblesville, .	93·0	86·8	6·2	6·2	984
Kansas, .	Iola, . .	97·7	96·4	1·3	1·4	994
,, .	Topeka, . .	95·5	88·8	6·7	3·7	1,013
,, .	Leavenworth, .	95·8	91·3	4·5	3·4	999
Kentucky, .	Louisville, .	98·2	77·8	20·4	1·8	1,143
Louisiana, .	Lewis, . .	96·5	96·5	0·0	2·1	972
,, .	Mansfield, .	97·3	97·3	0·0	2·3	1,009
Missouri, .	Joplin, . .	96·9	92·6	4·3	2·5	1,009
New York, .	Alma, . .	99·9	68·8	31·1	0·1	1,241
,, .	Buffalo, . .	95·1	79·9	15·2	4·9	1,073
Ohio, . .	Cincinnati, .	99·3	79·8	19·5	0·7	1,147
,, . .	Cleveland, .	98·7	80·5	18·2	1·3	1·131
,, . .	Marietta, .	98·8	73·2	25·6	1·2	1,188
,, . .	Springfield, .	95·0	80·3	14·7	5·0	1,068
,, . .	Columbus, .	98·5	80·4	18·1	1·5	1,129
Oklahoma, .	Bartlesville, .	95·5	92·4	3·1	3·1	986
,, .	Chelsea, . .	93·1	75·4	17·7	6·6	1,071
,, .	Guthrie, . .	90·0	69·4	20·6	9·9	1·062
,, .	Nurskogee, .	96·2	92·1	4·1	3·4	1,000
,, .	Nowata, . .	95·2	95·2	0·0	3·5	960
,, .	Pawhuska, .	94·2	88·6	5·6	4·4	991
,, .	,, .	87·2	66·5	20·7	12·5	1,034
,, .	,, .	93·9	85·1	8·8	5·1	1,012
Pennsylvania	Oil City, . .	98·9	67·6	31·3	1·1	1,232
Texas, .	Coricsanna, .	98·0	98·0	0·0	1·3	987
,, . .	Dallas, . .	61·5	50·6	10·9	38·4	702
,, . .	,, . .	61·7	51·3	10·4	38·2	700
,, . .	Fort Worth, .	61·7	51·5	10·2	38·3	698
,, . .	,, .	61·1	51·1	10·0	38·9	691
,, . .	,, .	61·5	50·6	10·9	38·4	702
,, . .	,, .	61·3	50·6	10·7	38·6	698

[1] "Analysis of Natural Gas and Illuminating Gas by Fractional Distillation at Low Temperatures and Pressures," G. A. Burrell, F. M. Seibert, and J. W. Robertson, *Tech. Paper* 104. [2] G. A. Burrell, G. G. Oberfell, U.S. Bureau of Mines, *Tech. Paper* 109, (1915).

Most samples were free or practically free from carbon dioxide, the maximum found was 1·4 per cent. in the sample from Lewis (Louisiana). Oxygen was absent. No olefine hydrocarbons were found in any samples.

TABLE LXIIB.—COMPOSITION OF NATURAL GASES OF ONTARIO.

County and Well.	Methane.	Ethane.	Propane.	Nitrogen.	B.Th.U. per c. ft. at 60° F.	Condensate.
Essex No. 1, . .	87·6	7·3	None	4·8	1,013	..
Kent No. 1, . .	76·1	18·0	,,	5·8	1,087	..
,, 2, . .	84·4	10·8	,,	4·5	1,043	10·6
,, 3, . .	86·0	8·5	,,	4·8	1,019	..
,, 4, . .	86·8	7·9	,,	4·8	1,017	..
,, 5, . .	83·4	10·6	,,	5·3	1,029	..
,, 6, . .	78·2	15·7	,,	6·1	1,068	..
,, 7, . .	84·1	8·5	,,	5·8	999	..
Kent "Surface," T. P. Howard .	83·0	0·0	,,	17·0	838	..
Kent "Surface," T. P. Raleigh, .	92·9	0·0	,,	6·7	948	..
Lambton No. 1, .	68·3	12·5	3·4	15·8	998	11·6
,, 2, .	69·0	15·7	1·8	13·5	1,021	9·1
,, 3, .	80·2	11·7	..	8·1	1,015	..
Haldimand No. 1, .	67·8	16·0	3·5	12·7	1,057	17·6
,, 2, .	79·7	11·4	..	8·9	1,007	10·8
,, 3, .	76·7	14·6	..	8·7	1,033	..
,, 4, .	81·4	11·8	..	6·9	1,027	..
,, 5, .	79·4	14·3	..	6·3	1,055	..
,, 6, .	81·8	11·8	..	6·4	1,035	..
,, 7, .	76·6	16·3	..	7·1	1,062	10·8
,, 8, .	76·3	15·4	..	8·3	1,043	..
,, 9, .	84·9	8·3	..	6·8	1,004	..
,, 10, .	77·6	15·4	..	7·0	1,056	..
,, 11, .	77·8	14·7	..	7·5	1,046	..
,, 12, .	80·0	11·4	..	8·6	1,010	..
Wentworth No. 1, .	80·2	13·1	..	6·7	1,042	..
Brant No. 1, . .	76·9	8·0	1·2	13·8	948	7·8
,, 2, . .	68·6	19·0	..	12·4	1,029	14·7
,, 3, . .	74·6	15·4	..	10·0	1,025	..
Welland No. 1, .	74·8	17·3	..	7·9	1,061	15·6
,, 2, .	80·0	12·9	..	7·1	1,036	..
,, 3, .	82·1	13·5	..	4·4	1,068	..
,, 4, .	83·6	12·0	..	4·3	1,056	..
,, 5, .	93·7	3·3	..	2·8	1,004	..
,, 6, .	75·6	15·5	..	8·9	1,038	..
,, 7, .	85·9	8·7	..	5·4	1,022	...
Elgin No. 1, . .	84·1	10·8	..	5·1	1,040	..
Norfolk No. 1, . .	84·4	6·8	..	8·8	972	..
,, 2, . .	83·8	7·7	..	8·5	983	..
,, 3, . .	75·8	14·2	..	10·0	1,017	..

The range of composition for forty samples of Ontario gas was :—methane, 68·3–93·7 ; ethane, 0–19 ; propane, 0–3·5 ; nitrogen, 2·8–17 ; carbon dioxide, 0–1·65 ; oxygen, 0–0·3 ; hydrogen sulphide, 0–0·8 per cent. Olefines, carbon monoxide, and hydrogen were absent in all cases.

Professor C. C. Howard of Columbus has published the following results of analyses of the natural gas from the Trenton Limestone in Ohio :—

TABLE LXIII.—COMPOSITION OF NATURAL GAS (OHIO).

	Findlay.	Fostoria.	Saint Mary's.
Hydrogen,	1·64	1·89	1·74
Marsh gas,	93·35	92·84	93·85
Olefiant gas,	0·35	0·20	0·20
Carbonic oxide,	0·41	0·55	0·44
Carbon dioxide,	0·25	0·20	0·23
Oxygen,	0·39	0·35	0·35
Nitrogen,	3·41	3·82	2·98
Sulphuretted hydrogen,	0·20	0·15	0·21
	100·00	100·00	100·00

Table LXIV gives, for comparison, the composition of several samples of Russian natural gas, and the results of two analyses of gas from deep borings at Middlesbrough. Charitschkoff [1] states that the natural gas of Bereke (Daghestan) issuing from the ground with the petroleum, contains 12·82 per cent. of carbon dioxide, 65·84 per cent. of methane, and 19·92 per cent. of ethane.

TABLE LXIV.—COMPOSITION OF NATURAL GAS (1 TO 6 RUSSIAN).

	1.	2.	3.	4.	5.	6.	7.	8.
Carbon monoxide,	0	0	0	0	0	0	0	0
Carbon dioxide,	0·95	2·18	3·50	0	2·47	4·44	0	0·3
Olefines,	4·11	3·26	4·26	0		0	0	..
Methane,	92·49	93·07	92·24	95·39	97·57	95·56	1·90	..
Hydrogen,	0·94	0·98	0	0	0	0	0	..
Nitrogen,	2·13	0·49	..	..	..	..	96·57	96·8
Oxygen,	..	..	..	..	..	..	1·53	2·9
	100·62	99·98	100·00	..	100·04	100·00	100·00	100·00

Nos. 1, 2, 3, 4, 5, and 6; natural gas from the Caspian region. Communicated to Mr. Phillips by M. Beliamin of Messrs. Nobel Bros., Petrograd. No. 4 is the result of a partial analysis.

Nos. 7 and 8: gas from deep borings at Middlesbrough, England (stated by Phillips to be given on the authority of Bedson).

Particulars of numerous other analyses of the natural gas of the Old World have been published. Abich [2] gives the following results of analyses by Schmidt and Bunsen of the gas of the Apscheron, Taman, and Kertch peninsulas:

TABLE LXV.—COMPOSITION OF NATURAL GAS (RUSSIA).

	Apscheron Peninsula (Schmidt).		Taman Peninsula (Bunsen).		Kertch Peninsula (Bunsen).	
			Titarovka.	Seleonnaia.	Jenikale.	Bulganak.
Methane,	92·49	93·09	92·24	95·56	95·39	97·51
Ethylene,	4·11	3·26	4·26	..	..	..
Hydrogen,	0·34	0·98	..	..	..	..
Carbon dioxide,	0·93	2·18	3·50	4·44	4·61	2·49
Nitrogen,	2·13	0·49	..	..	..	..

[1] *Jurn. Russk. Ph.-Kh. Obsch.*, xxxvi, 321 [1904]; *J. Soc. Chem. Ind.*, 1190 (1903).
[2] *Jahresberichte über die Fortschritte der Chemie*, 1003 (1855).

Engler gives the subjoined results of analyses of the gas evolved from the oil-wells of Pechelbronn:—

TABLE LXVI.—Composition of Natural Gas (Pechelbronn).

Marsh gas,	77·3	77·3
Olefiant gas and olefines,	4·8	4·8
Carbon dioxide,	3·6	3·6
Carbon monoxide,	3·5	3·4
Oxygen,	1·8	2·0
Nitrogen and loss,	8·9	9·0

About the year 1896, when searching for an underground water-supply, the London, Brighton, and South Coast Railway Company discovered the presence of natural gas at Heathfield, Sussex, about 46 miles from London. The gas had a strong smell of petroleum, and was reported to have an illuminating power of from twelve to fourteen candles. This gas was, in 1903, examined for the Royal Commission on Coal Supplies by H. B. Dixon and W. A. Bone, who found it to contain methane, 93·16 per cent.; ethane, 2·94 per cent; carbon monoxide, 1·00 per cent.; and nitrogen, 2·90 per cent.[1]

G. A. Burrell[2] examined ten samples of natural gas from South Carolina, and gives the following range of composition:—CO_2, 1·0–30·4; total paraffins, 67·2–96·7; methane, 54·2–88; ethane, 0–35·6; nitrogen, 0·9–5·2 per cent. Three samples contained traces of oxygen; no hydrogen, carbon monoxide, or olefine hydrocarbons were found.

The production of gasoline from natural gas is dealt with in a later Section.

[1] *J. Soc. Chem. Ind.*, 1225 (1902); 410 (1903); *Proc. Chem. Soc.*, xix, 63 (1903).
[2] *Bull.* 19, p. 47, U.S. Bureau of Mines.

SECTION IV.

THE ORIGIN OF PETROLEUM AND NATURAL GAS.

The question of the origin of petroleum and natural gas has received the attention of some of the most distinguished chemists and geologists, and has been experimentally investigated with instructive results. Whilst, however, it has been conclusively established by laboratory experiments, that products more or less closely resembling those which are met with in nature may be obtained by various processes, it cannot be said that any one theory of origin has yet found universal acceptance.

Humboldt, in 1804, expressed the opinion that the oil was distilled by volcanic action from strata at an immense depth, and Reichenbach, in 1834, advanced the theory that it was formed by the action of subterranean heat on the turpentine of pine trees. The earlier references to the origin relate only to the liquid and solid forms of bitumen, the connection between natural gas and petroleum having apparently not been recognised.

The various theories which have been formulated from time to time may be divided into three groups, the first consisting of those which attribute to petroleum an inorganic origin, the second of those which consider it as derived from the decomposition of terrestrial vegetation, and the third of those which regard it as a product of decay of marine vegetable or animal matter, or of both.

Orton, in his *Report on the Occurrence of Petroleum, Natural Gas, and Asphalt Rock in Western Kentucky* (1891), has given one of the most complete *résumés* yet published of the various views expressed. He classifies the theories dealing with the derivation from organic matter into two divisions.

The first division comprises those which are based upon the view that petroleum has been formed from organic bodies in the strata now yielding the oil, the decomposition having principally taken place *in situ*, and the oil being thus mainly indigenous to the yielding strata. This view has been supported by Sterry Hunt, Lesley, White, and Whitney, and to a greater or less extent by many other authorities.

The second division includes the theories dependent upon the conclusion that petroleum is a product of distillation, or of the *secondary decomposition* of organic matter. This general conclusion has been advocated by Newberry, Peckham, and a large number of other geologists. The assumption is that the original remains were partially transformed *in situ*, and that the conveyance to the rocks now yielding oil, of the petroleum produced by distillation, was aided by hydrostatic force, " the so-called bituminous shales " being " counted the chief sources of these products." In controversy on this point, some have assumed that water-pressure alone was implied by the term hydrostatic, instead of the wider signification, covering all fluids. Gas, whether free or suspended in petroleum, is a most potent agent in the distribution of the oil and of any associated water, whilst the concentrated salinity of the latter in many cases militates against any hypothetical connection with artesian water-passages.

Orton considers that petroleum is the parent product from which both gas and solid bitumens are derived, and, speaking of the common origin of these substances, says: "If a line were to be drawn anywhere in the series, it would be between gas and oil. The former, as we know, originates under many conditions in which petroleum does not occur; but, on the other side, petroleum is never found free from inflammable gas, and in a large way all the facts and occurrences of both so exactly correspond, that it is impossible to separate them in respect to their origin."

In referring to the wide dissemination of petroleum, Orton says: " . . . We need to bear in mind that the various members of the bituminous series are abundantly and almost universally distributed among the unaltered sedimentary rocks of the earth's crust. The valuable accumulations of these substances are rare, it is true, but one can scarcely go amiss of petroleum, asphalt, or gas, at least in small quantities, among the stratified rocks that retain their original structure. In particular, the rocks of the entire Ohio Valley can be said to be charged with petroleum. A well cannot be drilled at any point in the valley for even a few hundred feet, in which careful examination will not reveal the presence of some representative of this bituminous series. The aggregate of this disseminated petroleum is often found to be very large. A fifth of 1 per cent. of petroleum, if distributed through 1000 feet of rock, would make a total to the acre or square mile far beyond any production that has ever been realised from the richest oil-field, and percentages of this amount are not only not rare to find, but are even hard to miss.

"It is a popular impression that oil and gas are unusual substances in nature. The object of this paragraph is to show that this impression is entirely unfounded, and that we must free our minds from it if we would consider in proper light the question as to the origin of rock oil."

Inorganic Origin.—The theories which ascribe an inorganic origin to petroleum are considered inadmissible by geologists and others acquainted with the conditions under which the many widely different descriptions of the product are met with.

Prior to the formulation of the definite theory of an inorganic origin for petroleum, Brunet,[1] in a note to the Geological Society of France, suggested as a possible method of formation of asphalt, the action of nitrous and sulphurous volcanic gases on the terebinthine of conifers, which view he supported by experimental evidence. It may be mentioned that he was led to this conclusion during a study of mud-volcanos, which he, in common with other early observers, regarded as true volcanic phenomena. Twenty years later, Rivière,[2] finding that gas leaking from the mains condensed, in the surrounding soil and buried vegetation, into liquid hydrocarbons, suggested that in the same way gaseous hydrocarbons of igneous origin condensed in rocks and in deposits of ancient vegetation, forming the bitumen of both.

The first to advance a general theory was Berthelot, who, proceeding upon the hypothesis of Daubrée that the interior of the earth contains free alkali metals, ascertained by experiment that when carbonic acid or an earthy carbonate acts upon the alkali metals at a high temperature, acetylides are formed, and that under the conditions existing in the earth, these bodies when acted upon by water-vapour yield hydrocarbons resembling those of American petroleum, the exact composition of the hydrocarbons varying with the temperature. He therefore expressed the view, in 1866, that petroleum may have been produced by the infiltration of water containing carbonic acid gas into the interior of the earth, where it would be brought into contact with the

[1] *Bull. Soc. Geol. France*, ix, 252 (1838).
[2] *Comptes Rendus*, xlvii, 646–648 (1858).

alkali metals at an elevated temperature, and under great pressure, with the production of both liquid and gaseous petroleums.

In 1892 Maquenne [1] described a method of preparing barium carbide, and showed that this substance evolved acetylene on treatment with hydroxylated compounds. In 1893 Travers prepared calcium carbide by heating the chloride and charcoal with sodium, and from this he also produced acetylene. Meanwhile Willson [2] obtained calcium carbide from a mixture of lime and carbon in an electric furnace, and laid the foundation of the present acetylene industry. These results are of interest in connection with the question of the origin of petroleum, but further light has been thrown on the subject by the researches of Moissan, who has found that certain of the carbides yield liquid hydrocarbons on treatment with water. In a paper published in the *Journal of the American Chemical Society* in 1899, J. A. Mathews has given the following classification of the reactions of decomposition of the carbides :—

(1) The carbides of lithium, sodium, potassium, calcium, barium, and strontium are decomposed by water, giving mostly acetylene.

(2) Silver, copper, mercury, and gold (?) acetylides are acted on by hydrochloric acid, giving acetylene.

(3) Aluminium and beryllium carbides react with water, yielding methane.

(4) Manganese carbide with water gives methane and hydrogen.

(5) The carbides of yttrium, lanthanum, and thorium are decomposed by water, giving mixtures of acetylene, ethylene, methane, and hydrogen.

(6) Lanthanum, cerium, and uranium carbides give with water, besides the volatile products, a residue of liquid and solid hydrocarbons.

It will thus be seen that several of the carbides, including that of manganese, yield methane (CH_4), the lowest member of the paraffins present in Pennsylvania petroleum, and that some actually yield liquid and solid hydrocarbons.

In 1871 Byasson [3] suggested that petroleum might have resulted from the action on iron or sulphide of iron at a white heat, of steam and carbonic acid gas produced by the infiltration of salt water to great depths in the earth. His theory, like that of Berthelot, is based on laboratory experiments, which resulted in the production of hydrocarbons resembling petroleum.

In 1872 Anderson [4] objecting to the theory that oil was derived from coal, on the ground that even when oil-springs were found in proximity to such deposits there was no loss of bitumen in the coal itself, pointed to the known liability to polymerisation of the hydrocarbon gases, and the frequent occurrences of oil in fissures in the earth's crust, as evidence that petroleum had been formed by condensation of gaseous hydrocarbons from the interior of the earth.

In 1877 further evidence of the possibility of petroleum having had an inorganic origin was published. Cleoz [5] obtained petroleum-like hydrocarbons by the action of dilute sulphuric or hydrochloric acid, and even of boiling water, on a spiegeleisen (carbide of iron and manganese), and Mendeléeff published his notable paper on the inorganic origin of petroleum.[6] Mendeléeff refers to the great density of the earth, to the well-known presence of iron carbide in meteorites and of iron in the solar system, as shown by the spectroscope, and to the presence of iron in basalts and other eruptive rocks, as powerful arguments

[1] *Comptes Rendus*, cxiv, 677 (1892).
[2] *Journ. Soc. Chem. Ind.*, xiv, 135 (1895).
[3] *Comptes Rendus*, lxxiii, 609, and a brochure (22 pp.), 1876.
[4] *Trans. Geol. Soc. Glasgow*, iv, 174–177 (1872).
[5] *Comptes Rendus*, lxxxv, 1003 (1878).
[6] *Jurn. Russk. Ph.-Kh. Obsch.*, ix (1), 36 ; *Journ. Chem. Soc.*, xxxvi, 283 (1879).

in favour of the view that the interior of the earth contains large amounts of iron, whether combined with carbon or not. He states that he, like Cleoz, obtained olefines and other hydrocarbons, in the form of a liquid having properties exactly similar to those of natural petroleum, by the action of hydrochloric acid on spiegeleisen ; but the theory to which his name is usually applied ascribes the formation of petroleum to the action of carbide of iron at high temperatures in the interior of the earth upon water which has penetrated through fissures produced in the earth's crust by the elevation of mountain chains, or by other changes. He further alleges, as incidental arguments in favour of his theory, the absence of adequate organic deposits from the strata yielding petroleum, at least in Russia ; the occurrence of petroleum having no connection with the geological age of the oil-bearing strata ; and the relations between petroleum occurrence and volcanic manifestations noticed by so many observers. These statements have, however, been directly traversed by geological investigation.

At the meeting of the British Association in 1891, O. C. D. Ross advanced the theory that petroleum is a product of the action of volcanic gases upon limestones. He partly founds his theory on the observations of Bischof, that sulphur has been obtained in laboratory experiments by the action upon chalk of hot volcanic gases (sulphurous acid and sulphuretted hydrogen), and assumes that such action would further produce both olefines and paraffins, with a separation of sulphur and a conversion of the calcium carbonate of the chalk into gypsum.[1] No experimental evidence, however, in support of the views expressed has been adduced.[2]

The theory of the Russian geologist Sokoloff (1890) may be thus summarised :—Hydrogen and carbon enter very largely into the composition of the heavenly bodies, and hydrocarbons formed therefrom make their appearance at an early stage. In the earth, bitumen was in like manner produced, was absorbed by the glowing, viscid mass forming the core of our planet, and as cooling progressed was transferred to the outer layers, where it is now found. In 1889 Meunier had found ozokerite and its ally kabaite in a meteorite.

Peckham quotes the following authorities as considering it likely that petroleum is a condensation product of marsh gas :—Hitchcock[3] (1866), Coquand[4] (1868), and Grabowski[5] (1877). Coquand, like many others, connects the occurrence of petroleum with mud-volcanos, but he appears to be the only one who attributes the formation of petroleum to the condensation of marsh gas into liquid hydrocarbons under the influence of such pseudo-volcanic action.

In 1902 Sabatier and Senderens[6] produced by the action of acetylene and hydrogen on reduced nickel a mixture of liquid hydrocarbons bearing a resemblance to Pennsylvania petroleum, while acetylene alone with nickel gave a product resembling Russian petroleum.

In a survey of the various theories proposed, Mr. L. V. Dalton[7] thus summarises the arguments brought forward by the believers in the inorganic origin of petroleum :—

" 1. The absence of an adequate quantity of organised life in many petroliferous formations.

" 2. The differences between the oils produced by artificial distillation of coal, etc., and the natural petroleum oils.

[1] *Rep. Brit. Assoc.*, 639 (1891).
[2] *Chem. News*, xliv, 215 (1891).
[3] *Rep. Brit. Assoc.*, Sect. 57 (1866).
[4] *Bull. Soc. Géol. de France*, 2, xxv, 35.
[5] *Chem. Centr.*, 3, viii, 462.
[6] *Compt. Rend.*, cxxxiv, 1185–1188.
[7] *Economic Geology*, iv, 606 (1909).

"3. The very general distribution of petroleum in the earth's crust, regardless of the geological age of the rocks containing it.

"4. The connection between igneous rocks and other manifestations of volcanic activity and petroleum.

"The first of these objections to the organic theory has, it may be said, been altogether removed by further investigation, as even in the very oil-fields on the phenomena of which the argument was based evidence of abundant organic life has since been detected, and that of a character well qualified to give rise to petroleum. The second arises out of insufficient knowledge of the organic theories, for, as will be seen, so far from the supporters of these pointing to land-vegetation as the sole source of oil, the number of authors arguing for such an origin at all is now a small fraction of the whole. It should be remembered, however, that the earlier writers on both sides often failed to distinguish adequately between carbonaceous substances exhibiting traces of vegetable structure, such as coal and lignite, and those which are now, by general consent, considered as derivatives or allies of petroleum.

"Though petroleum does occur in greater or less quantity in rocks of all geological ages, it may be said that its quantity is far greater in rocks deposited under such conditions as would ensure the entombment of large quantities of organic material, and where the conditions of a particular period were throughout the world unfavourable to the existence of abundant life, that division of the geological record is nearly or entirely barren of petroleum.

"Finally, it is now known that the mud-volcanos so frequently accompanying petroleum are not of igneous origin, and that in fact true volcanic energy is seldom manifested in petroliferous regions, while the number of occurrences of petroleum in igneous rocks bears only a small proportion to the number of such occurrences in sedimentary deposits far from any known mass or outcrop of igneous rock.

"Against the theory as a whole may be urged the difficulty of understanding how the petroleum of such deposits as those of the United States and Baku (in fact the majority of geologically-known oil-fields of the world) could have reached its present position if derived in any way from the central magma of the earth, while it is also difficult to reconcile with the inorganic theory the fact of the extreme rarity of petroleum in the oldest solid rocks of the earth's crust and in any such igneous masses as are precluded by their mode of occurrence from containing oil derived from surrounding sedimentaries. It may be added that, as emphasised by Phillips, natural gas contains only a small proportion of hydrogen, whereas the synthesised gases of the igneous theorists contain very large proportions of that element, and no adequate hypothesis has yet been advanced to account for its elimination."

It must, however, be admitted that in some cases hydrocarbons are found in nature where only an inorganic origin will account for their presence, but these instances are in general of purely academic interest, and do not help to remove the difficulties in the way of those who would attribute an inorganic origin to petroleum generally.

Organic Origin from Terrestrial Vegetation.—The relation between petroleum and the oils obtained by distillation from peat, lignite, and coal, led, at an early date, to a belief that petroleum was produced from one or all of these materials. Although this theory was soon abandoned in its original form by the majority of observers, a few later writers have also considered that terrestrial vegetation has in some cases undergone a special mineralisation, being changed to liquid and gaseous hydrocarbons in place of the usual solid lignites and coal.

Hatchett noticed this (1798), as already mentioned in the section relating to the chemical and physical properties of petroleum. Binney[1] considered the bituminous matter which he found in a peat-bed on Down Holland Moss to be due to the decomposition of the peat, but Höfer[2] observes that this deposit, like many Continental peat formations, lies upon sand which may have supplied the bitumen.

Höfer[3] also remarks that the oil which trickles from the coal in Shropshire, especially at Coalport, near Broseley, is derived from a sandstone in the coal formation, and not from the coal itself.

By the distillation of wood with superheated steam, Daubrée obtained a carbonaceous residue and a distillate smelling like the oil of Alsace. Von Kobell and many others have considered anthracite to be the residue from the formation of petroleum from coal.

In 1860, Wall,[4] finding oil in Trinidad and Venezuela in a series of limestones, sandstones, and shales, associated with beds of lignite, was led to suggest that the latter had given rise to the oil, but in the same year Delesse[5] had found 0·256 per cent. of nitrogen in Trinidad pitch, which, though no clear proof of its animal origin, was evidence in its favour, and was explicable in the light of Prof. Rupert Jones's[6] discovery that the matrix of his samples of the asphalt was composed of Nummulinæ and *Orbitoddes*. In 1897 Peckham[7] studied the occurrence of plant remains associated with asphalt in Trinidad, on the basis of which Wall had built up his theory, and found that the lignite bed near the pitch-lake, and the pieces of lignite in the asphalt itself, were in exactly the same condition, that is, they were both still wood, and that the bitumen could certainly not have come from these, in his view. The author has in his possession specimens of soft woody fibre containing petroleum, which were found by the late George Scott in strata yielding small quantities of oil and gas, at depths of 40 to 50 feet and 60 to 70 feet, during the drilling of a well at Digboi, Assam, in 1893.

Griffiths,[8] in 1884, finding free phenol in pine cones, again suggested that petroleum was derived from the decomposition of conifers, on the ground of the occurrence in some mineral oils of a small proportion of the same compound. Sadtler[9] also suggested the participation of land-vegetation in the formation of petroleum, on the ground that vegetable fats such as linseed oil could be made to yield both kerosene and solid paraffin like those obtained from natural petroleum.

Watson Smith[10] has advanced a further argument in favour of the theory that petroleum is derived from coal, in connection with some experiments on a highly bituminous coal from Japan.

In connection with this matter, Höfer, who has been largely instrumental in placing the animal-origin theory upon a scientific basis, thinks that cannel coals, at least in many districts, derive their bituminous contents from the animal remains which are found in them. Newberry (1878)[11] points out that the cannel coal of Ohio contains large quantities of remains of mollusca, fish, amphibia, and crustacea.

The objections to the theory that petroleum has been produced from coal

[1] *Proc. Manchester Lit. Phil. Soc.*, iii. 136.
[2] *Das Erdöl*, 110.
[3] *Loc. cit.*, 113.
[4] *Quart. Journ. Geol. Soc.*, xvi, 467.
[5] *Ann. Mines*, 5, xviii, 151 (1860).
[6] *Quart. Journ. Geol. Soc.*, xxii, 592, 593 (1866).
[7] *Proc. Amer. Phil. Soc.*, xxxvi, 105 (1897).
[8] *Chem. News*, xlix, 95.
[9] *Amer. Journ. Pharm.*, lxviii, 465 (1895).
[10] *Journ. Soc. Chem. Ind.*, 979 (1891).
[11] *Report of the Geological Survey of Ohio*, part i, 125 and 174.

are at least strengthened by the fact that the largest deposits of the former are situated in strata of a period which was not coal-forming, and are usually far distant from coal-deposits.

In Pennsylvania, for instance, the coal- and oil-fields are totally distinct, and the former belong to newer rock-groups. Coal has nowhere been found below the oil strata of Pennsylvania and New York, and in the anthracitic and other coal-fields of North America no important deposits of petroleum have been found.

On the chemical side also, it may be objected that the tars distilled from wood or lignite present marked differences from, as well as some similarity to, natural petroleum, while in the course of distillation the compounds more characteristic of rock oils do not appear until a high temperature has been reached.

It seems possible, however, as suggested by Sadtler's linseed-oil experiments, that the parts of land-plants which are particularly rich in fats may have contributed in some small degree to the production of petroleum.

Organic Origin from Marine Organisms.—As regards the opinion that petroleum is indigenous to the strata in which it is found, geologists are very generally agreed that this is true of a large number of the deposits.

Sterry Hunt considers that limestones are almost invariably the source of petroleum, and that in the case of the Niagara Limestone, the Corniferous Limestone, and the Trenton Limestone, the oil was produced in those strata from animal and vegetable remains contained in them. Orton, however, points out that Sterry Hunt has sometimes described the oil of Pennsylvania and eastern Ohio as indigenous to the Devonian and Carboniferous sandstones which contain it.

Lesley argues that the conglomerates and sandstones of Kentucky are the primary source of the oil they contain. Orton holds the same opinion regarding the deposits of North-Western Ohio, and Andreae respecting those of Upper and Lower Alsace.

Höfer regards the oil of Shropshire and the bitumen of Seyssel as found in their parent strata, and Peckham decides that the oils of California, Texas, and Tennessee undoubtedly originated in the beds now containing them.

Sterry Hunt judiciously remarks that the fact of the alternation of similarly porous beds free from, and saturated with, petroleum, " shows that this material cannot have been derived from overlying or underlying beds, but has been generated by the transformation of organic matters in the strata in which it is met with."

He further states that in some cases petroleum is found filling cavities in the Lower Silurian limestone, as at Rivière à la Rose (Montmorency, Quebec), where it drops from the Birdseye Limestone, and at Pakenham, Ontario, where it fills cavities of large Orthoceratites in the Trenton Limestone. " From some specimens nearly a pint of petroleum has been obtained."

In the Marcellus Shales at the base of the Hamilton Group are found concretionary nodules containing petroleum, while at the summit of the same group similar concretions holding petroleum are again met with.

Even when found in sands and conglomerates, Sterry Hunt usually refers petroleum to limestone as the parent rock. He observes, with special reference to the Niagara Limestone, near Chicago, that " with such sources ready-formed in the earth's crust, it seems to me, to say the least, unphilosophical to search elsewhere for the origin of petroleum, and to suppose it to be derived, by some unexplained process, from rocks which are destitute of the substance." He adds :—" The forms in which it [petroleum] now occurs depend in great measure upon the presence or absence of atmospheric oxygen, since, by oxidation and volatilisation, the naphtha or petroleum becomes slowly changed into asphalt or mineral pitch, which is solid at ordinary temperatures. It would even appear that, by a continuance of the same action, the bitumen may lose its fusibility and solubility, and become converted into a coal-like matter. Thus, in the calciferous sand-rock in New York, a black substance, which has been called anthracite, occurs in cavities with crystals of bitter-spar and quartz. It sometimes coats these crystals or the walls of the cavities, and at other times appears in the form of buttons or drops, evidently, according to Vanuxem, having been introduced into these cavities in a liquid state, and subsequently hardened as a layer above the crystals which have conformed to it, showing that this coal-like matter was once in a plastic state. It is very pulverulent, brittle, of a shining black, and, according to Vanuxem, yielded but little ash, and 11·5 per cent. of volatile matter, which he regarded as water.[1]

"A similar material occurs in the Quebec group in Canada, the equivalent of the Calciferous Sand-rock, and fills cavities and fissures in the limestones, sandstones, and even in the accompanying trap rocks, as at Quebec, Orleans Island, Point Levis, and at Acton, presenting mammillary surfaces, as noticed by Vanuxem, which evidently show that it has once been semi-fluid. . . ."

The recurrence of similar phenomena in European rocks of various ages has been described in Section II of this work.

J. S. Newberry regards the oil and gas of the Allegheny field as having their source in the Devonian and Carboniferous shales underlying the reservoir rocks, and considers these shales, more especially the black shales, to have been subjected to a slow but continuous spontaneous distillation, "performed at a low temperature." In the *Geology of Ohio*, i, 158 (1873), he says:—"We have in the Huron Shale a vast repository of solid hydrocarbonaceous matter, which may be made to yield 10 to 20 gallons of oil to the ton by artificial distillation. Like all other organic matter, this is constantly undergoing *spontaneous distillation*, except where hermetically sealed deep under rock and water. This results in the formation of oil and gas closely resembling those which we make artificially from the same substance, the manufactured differing from the natural products only because we cannot imitate accurately the processes of nature.

"*Second.*—A line of oil- and gas-springs marks the outcrop of the Huron Shale from New York to Tennessee. The rock itself is frequently found saturated with petroleum, and the overlying strata, if porous, are sure to be more or less impregnated with it.

"*Third.*—The wells on Oil Creek penetrate the strata immediately overlying the Huron Shale, and the oil is obtained from the fissured and porous sheets of sandstone of the Portage and Chemung groups, which lie just above the Huron, and offer convenient reservoirs for the oil it furnishes."

Peckham has expressed the opinion that the different varieties of petroleum are the products of fractional distillation of carbonaceous matters at depths far below the rocks now yielding the oil, and cites the Bradford oil, whose large paraffin content he attributes to the great pressure under which it was formed. He considers that the distillation occurred slowly, and without violent heat, especially as regards the deposits of New York, Pennsylvania, West Virginia, and Ohio. He regards the distillation as caused by the metamorphic action and heat produced by the elevation of the Appalachian system, and adds that the chronic evaporation or distillation thus set up has converted the animal- and plant-remains into oils, the light oils into heavy oils, and these into asphalt

[1] *Geology of New York*, iii, 33.

and other solid bitumens, the process being associated throughout with the evolution of gas. Further, he is of opinion that the petroleums of California and Texas are indigenous to the shales from which they issue, and argues that the animal-remains in these shales, the large amount of nitrogen in the oil, and the fact that the fresh oils when exposed soon become the habitat of the larvæ of insects, show these descriptions of bitumen to be of animal origin. On the other hand, he regards the petroleums of New York, Pennsylvania, Ohio, and West Virginia as of vegetable origin.

In discussing Peckham's theory, Orton points out that evidence of metamorphic action is absolutely absent even at very great depths; drillings at Canal Dover, Ohio, brought up from a depth of 2700 feet, being perfectly normal, as is also the case with the Westinghouse well at Pittsburgh, the Cleveland rolling-mill well at 3200 feet, and wells at Springfield and Dayton, in Ohio. He states that the deep-lying shales show an absence of change, which precludes the idea that so high a temperature as 212° F., far below that at which distillation of oil would occur, has ever been reached in them. Orton concludes that the theory "does not harmonise with the facts of geology in the main oil-fields."

As regards the temperatures and pressures prevailing when the oils were produced, authorities are much divided in opinion. Some consider that high temperatures, approaching that employed for coal-distillation, have prevailed, while others argue that the composition of the oil precludes the possibility of such temperatures having been reached.

Krämer opines that petroleum cannot have been produced at as high a temperature as is employed for obtaining brown-coal tar, which again is obtained at a lower heat than ordinary coal tar.

Orton [1] holds that the production of the oil must have occurred at temperatures below 200° C., and calls distillation at such a heat "spontaneous" rather than "destructive."

Krämer and Böttcher [2] consider that petroleum has been produced under great pressure, and the former believes that variation in the character of petroleum found is due to changes occurring in the oil after its formation.

In confirmation of this latter opinion, Höfer contends that the absence of necessity for theories to account for the different varieties of petroleum is shown by the observation of Schultz (1882),[3] that the coals of different districts yield tars of different composition, Wigan coal, for instance, giving tar rich in phenols and benzene, while that from Newcastle yields a tar rich in naphthalene and anthracene.

Most of the previously named observers assume that petroleum is derived from both vegetable and animal remains. Lesley believes the Pennsylvania oil to have been formed from fossil fucoids and coral plasma, and Ashburner adopts a similar dual origin. Orton considers that the oil occurring in shale and sandstone is of vegetable, and that found in limestone of animal, origin. Peckham suggests that oil containing asphalt, but not paraffin, is of animal origin, while that containing paraffin is of vegetable origin. Strippelmann thinks that petroleum and natural gas were probably produced from vegetable and animal remains in Silurian, Devonian, and carboniferous formations, and Krämer maintains that they were formed by the dry distillation of organisms of the Carboniferous epoch.

As regards the general aspect of the theories dealing with the organic origin,

[1] *Preliminary Report on Petroleum and Inflammable Gas*, 11 (1886).
[2] *Berichte deutsch. chem. Gesellschaft*, 595 (1887).
[3] *Chemie des Steinkohlentheeres*, ii, 22.

Orton[1] thus expresses himself:—" Petroleum is undoubtedly indigenous to, and derived from, certain limestones, as Hunt has so strongly asserted. The Trenton Limestone is undoubtedly the most important source of oil and gas in the geological scale of the United States at the present time. On the other hand, Newberry's doctrine, that the great supplies of the Pennsylvania field are derived from Devonian shales, is becoming more firmly established and more generally accepted every year, though it seems likely that he has laid too much stress on *bituminous* shales. In other words, the theories are not exclusive of each other. Different fields have different sources. We can accept, without inconsistency, the adventitious origin of the oil in Pennsylvania sandstones, and its indigenous origin in the shales of California, or in the limestones of Canada, Kentucky, or Ohio.

" The double origin of petroleum, from both limestones and shales—and it is not necessary to exclude sandstones from the list of possible sources—deserves to be universally accepted. In confirmation of this double origin, it is coming to be recognised that the oil and gas derived from these two sources generally differ from each other in noticeable respects. The oil and gas derived from limestones contain a larger proportion of sulphur than is found in the oil and gas of the shales. Sulphur compounds impart to the oil a rank and persistent odour, from which it can be freed only with great difficulty. In the case of the oil-bearing shales of California, the petroleum is apparently derived from the animal remains with which the formation was originally filled. In composition, this oil agrees with the limestone oils already described. . . . Certain it is that the ' limestone oils ' differ in physical characteristics from the Pennsylvania oils ; for example, in a marked degree, they are dark in colour ; they are heavy oils, their gravity ranging generally from 34° to 36° B., though sometimes rising to 40° or even 42°. They have a rank odour, arising from the sulphurous compounds which they contain. The oils of Canada, Kentucky, and Tennessee, and of the new field in North-Western Ohio, all agree in these respects, and the oil and gas of the Utica shale and the Hudson River group of the slate fall into the same category."

The theories which regard some petroleums as produced by the decomposition or distillation of animal-remains are now largely accepted by chemists, and Höfer notes that the belief in an animal origin gains ground as our geological knowledge of the oil increases. Sterry Hunt, as already stated, regarded this theory as the most probable, and Peckham considers that, at any rate, the nitrogen-containing oils of California, Texas, and Tennessee are of animal origin.

Leopold von Buch traced the oil of the Upper Lias shales of Swabia to the animal-remains therein. Sir Roderick Murchison in 1829,[2] in an account of the bituminous shale of Seefeld in the Tyrol with its abundant fossils, remarked on " the probability of so many fish having materially co-operated in the bituminisation of the schist." Bertels considers that the Caucasian oil was produced by the decomposition of molluscs. Zincken holds that the bituminous shales, limestones, and marls which appear to have produced the oil, contained, in addition to the fish- and mollusc-remains, the unfossilisable fat of animal organisms.

The animal origin of the Carpathian oil is affirmed by Paul and Tietze, and Credner believes that the petroleum of North Germany originated in the strata of the Upper Jurassic formation, which contains animal- rather than plant-remains.

[1] *Report on the Occurrence of Petroleum, Natural Gas, and Asphalt Rock in Western Kentucky*, 43 (1891).

[2] *Proc. Geol. Soc.*, i, 139.

By fractionation of the distillate from a lime-soap of menhaden (fish) oil, Warren and Storer [1] obtained members of the methane, ethylene, and benzene groups, such as are found in petroleum.[2]

The most striking experimental evidence yet published in support of this theory is, however, that of Engler,[3] who distilled 490 kilos. of menhaden oil in a Krey apparatus at Riebeck's works in Webau, and obtained a distillate remarkably like petroleum. The distillation was commenced at a temperature of 320° C. under a pressure of 10 atmospheres, and was completed at 400° C. under a pressure of 4 atmospheres. He obtained about 60 per cent. of distillate of specific gravity 0·8105, about 8·9 per cent. of gas, and about 5 per cent. of unsaponifiable fat in the residue. The distillate was brown, and possessed a greenish fluorescence and a disagreeable, acroleïn-like smell. By fractionation, the distillate was found to contain pentane, hexane, normal and secondary heptane, and normal octane and nonane. From the chemical reactions of the distillate, the presence of olefines and of naphthenes and other aromatic hydrocarbons was inferred. Finally, from the distillate, a lighting oil was separated, which was described as indistinguishable from commercial kerosene, and this statement the author, having received a specimen of the product from Professor Engler, is in a position to confirm.

The temperatures and the pressures under which this experiment was conducted are not such as can be postulated in the natural formation of petroleum, the former being too high and the latter too low.

On repeating the experiments with trioleïn (commercial " oleïne "), similar results were obtained ; in fact, the menhaden oil used may be considered as a mixture of oleïn, stearin, and palmitin. The composition of the oil is such that, after combination of all the oxygen with part of the hydrogen to form water, the residue contains carbon and hydrogen in about the same proportions as are present in petroleum.

Engler considers that the glycerin or acroleïn formed during the reaction would be washed away from the petroleum, but Veith [4] has given a more elaborate explanation of their disappearance. He considers that the glycerin becomes converted by heat and pressure into acroleïn, which, by elimination of water and condensation, produces benzene. The fatty acids are converted into hydrocarbons and carbon dioxide, which becomes reduced to carbon monoxide, and ultimately into hydrocarbons, by the influence of dissociated hydrocarbons.

Although these experiments of Engler furnished such suggestive results, a further series, in which he attempted to obtain similar products from dried fish and other animal-remains, was totally unsuccessful, the distillate yielded being altogether different from petroleum.

Engler, therefore, considers that some change in the animal-remains must have taken place in the earth, whereby all nitrogenous and other matters, save fats, were removed, the petroleum being formed from the fat alone, by the combined action of pressure and heat, or by pressure only.

Zaloziecki (1894, 1895) [5] also believes in the animal origin of petroleum, but in a different manner. He considers that the first products of the decomposition of animal bodies would be nitrogenous matters and *adipocere*, which comprises the fatty matter of the remains, and that the adipocene would become

[1] *Mem. Amer. Acad.*, 2, ix, 177 (1865). [2] *Amer. Journ. Sci.* (2), xliii, 250.

[3] *Berichte deutsch. chem. Gesellschaft*, xxi, 1816 (1888) ; and xxii, 592 (1889). See also Engler and Seidner, *Dingler's polytechn. Journ.*, cclxxi, 515 (1889).

[4] *Das Erdöl*, etc., 95 ; and *Chemiker-Zeitung*, xiv, 1368.

[5] *Dingler's polytech. Journ.*, cclxxx, 69, 85, and 133 ; and *Chemiker-Zeitung*, xv, 1203.

covered with sediment and gradually converted into fatty acids, which finally decompose into hydrocarbons. He is of opinion that adipocere, ozokerite, and liquid petroleum are produced in the order named.

Ochsenius considers that the halogens in the water found with petroleum have had much to do with the production of the petroleum. He thinks that the fatty matters of decomposing animal bodies are converted into petroleum under the action of certain salts, notably alkaline bromides and aluminium chloride. Zaloziecki,[1] however, points out that the water found with petroleum is not always saline, and asserts that the action of salt is merely to arrest putrefaction. Sickenberger (1892)[2] believes that a connection can be traced between the abundant animal-remains in the Red Sea and the bituminous matter in the rocks on the coasts, whilst Barron and Hume (1902) largely support the suggestion, made by Fraas in 1868, that the coral-reef oil is still in process of formation, and refer that of the older rocks to the continuance of similar conditions throughout Tertiary times.

Höfer[3] mentions the following as arguments in favour of an animal origin for petroleum:—

1. Oil is found in strata containing animal but little or no plant remains. This is the case in the Carpathians and in the limestone examined in Canada and the United States by Sterry Hunt.

2. The shales from which oil and paraffin were obtained in the Liassic oil-shales of Swabia and of Steierdorf in the Banat, contained animal- but no vegetable-remains. Other shales, as, for instance, the copper shales of Mansfeld, where the bitumen amounts to 22 per cent., are rich in animal-remains, and practically free from vegetable-remains.

3. Rocks which are rich in vegetable-remains are generally not bituminous.

4. Substances resembling petroleum are produced by the decomposition of animal-remains.

5. Fraas observed exudations of petroleum from a coral reef on the shores of the Red Sea, where it could only be of animal origin.

In summing up the evidence as to origin, Höfer[4] expresses the belief that petroleum is of animal origin, and has been formed without the action of excessive heat, and observes that it is found in all strata in which animal-remains have been discovered. He considers that the oil is the primary, and gas a secondary, product.

Orton's opinions, which are somewhat different, are as follows:—[5]

1. Petroleum is derived from organic matter.

2. Petroleum of the Pennsylvania type is derived from the organic matter of bituminous shales, and is probably of vegetable origin.

3. Petroleum of the Canada type is derived from limestones, and is probably of animal origin.

4. Petroleum has been produced at normal rock temperatures (in American fields), and is not a product of destructive distillation of bituminous shales.

5. The stock of petroleum in the rocks is already practically complete.

F. C. Phillips (1894)[6] supports the view that petroleum has been formed by the slow decay of marine vegetable matter, under water, in the absence of air, on the ground that such a process is the only one known which yields a gas at all similar in composition to the natural gas of the petroleum fields. In reference

[1] *Loc. cit.* [2] *Chemiker-Zeitung*, xv, 1582.
[3] *Das Erdöl*, 118. [4] *Loc. cit.*, 131.
[5] *Report on the Occurrence of Petroleum, Natural Gas, and Asphalt Rock in Western Kentucky*, 60 (1891).
[6] *Am. Chem. Journ.*, xvi, 406–429.

to the theory of Mendeléeff he points out that, practically, no free hydrogen is found in natural gas, as would be the case if petroleum had been produced by the action of steam upon metallic carbides. Also, that whilst paraffins alone cannot be produced by such chemical reaction, the gaseous product resulting from the action of dilute sulphuric acid upon ferro-manganese contains 6 per cent. of olefines, and natural gas contains neither olefines [1] nor carbon monoxide. Similarly, in regard to the theory of animal origin, Phillips points out that the gaseous products obtained by Engler in the distillation of menhaden oil and oleïc acid contained from 25 to 38 per cent. of carbon monoxide, and a considerable proportion of olefines, while the amount of paraffins present was comparatively small; and he states that it is difficult to understand how such a gas could have been so changed in composition as to be rendered similar to natural gas. Phillips is of opinion that the process of decay of vegetable matter which has resulted in the formation of petroleum, is a secondary one of very slow progression, following the comparatively rapid changes which first occur, and that a gradual decay of this description is not possible in the case of animal-remains. Krämer and Spilker (1900–1902) support the view, first propounded by Witt in 1894, that the waxy matter secreted by diatoms may have contributed directly to the production of petroleum. The present formation of oil from the decomposition of seaweed on the Sardinian and Swedish coasts has been suggested in Section II in the accounts of Italy and Sweden, and oily matter seems to be formed in the Levant and the Red Sea, according to Natterer.[2] Lesquereux regards petroleum as due to marine vegetation, traces of which abound in the lower Palæozoic rocks, whilst coal is derived from fibrous terrestrial plants.

The theories which have been advanced in relation to the origin of petroleum have been critically examined by Aisinmann,[3] who summed up strongly in favour of the views expressed by Höfer and Engler.

The Engler-Höfer theory, as developed by its authors up to the present time, states that petroleum is derived from the natural decomposition *in situ* of the fatty remains of marine organisms, both animal and vegetable.

In regard to the manner in which the decomposition may have taken place, Mr. L. V. Dalton (*loc. cit.*) has thus summarised the opinions put forward by various observers:—

"The chemical evidence cited is fairly conclusive on this point, that if marine organisms are the source of petroleum, their nitrogenous parts are in some way eliminated prior to the formation of the oil; it has already been mentioned that the fats are known to persist after the disintegration of the other material, and Professor Engler (who first laid stress on the existence of two stages in the process of petroleum formation), and other authors, have suggested a very feasible manner in which the two processes are carried out in marine deposits. In the first instance, after the death of the animal or plant, bacterial action begins, attacking the cellulose of the latter and the nitrogenous tissues of the former, but leaving untouched the fatty matters of both at first. That this does actually take place in nature was shown by Engler, who found that while the decomposing organic remains in a zoögen-phytogen mud contained 20 per cent of fat, the living organisms contained only 15·7 per cent. The action of bacteria in the formation of petroleum was first suggested by Radziszewski,[4] and later researches have supported the view that these micro-organisms

[1] *Note.*—Some analyses of Russian gas show olefines to be present (see p. 345).
[2] *Scott. Geogr. Mag.*, xiv, 639, 642 (1898).
[3] *Zeitschr. angew. Chem.*, 738 (1893); and 122 (1894).
[4] *Archiv Pharm.*, 3, xiii, 455–459 (1878).

play an important part. Bertrand and Renault found their remains in boghead.[1] Dr. C. B. Morrey, Professor of Bacteriology in Ohio State University, found fossil bacteria in oil rocks,[2] while Meyer [3] found petroleum in a bacterial deposit from Altenberg. Some of these observers undoubtedly laid too much emphasis on bacterial action, which, as Lemière, who also contributed to the study of the subject, suggested,[4] would be arrested as soon as the central parts were rendered antiseptic by the hydrocarbons formed. We must therefore regard the action of bacteria as in the main limited to the first stage, *i.e.* the elimination of the nitrogenous matters, the action being automatically stopped almost as soon as the fats are attacked, whilst, as Engler objects,[5] soil (and sediment) acts as a bacterial filter, and so, when the action had extended to the fats, the progress of deposition would probably render these immune from further fermentation; on the other hand, he remarked that carbohydrates may be converted into fats by the agency of micro-organisms.

"Having, then, in this way accounted for the elimination of nitrogenous matters, which, as we have seen, give rise in distillation to compounds not found in petroleum, the process of transformation of fats into oil may be supposed to proceed slowly, as Phillips found did actually happen in the case of seaweeds, while Engler and others have emphasised the fact that not only does pressure tend to raise the temperature of bodies (as Scheithauer found to be the case to a remarkable extent with lignites), but that the actions which are normally carried out in the laboratory by the action for a short time of a high temperature are equally well performed by a comparatively low temperature acting for a very long period."

Considerable attention has been directed in recent years to the study of the optical activity of petroleums, as bearing upon their origin. It was suggested that the rotation of the polarised ray was due to the presence of small quantities of cholesterol, of which Dr. Lewkowitsch, in his *Chemical Technology of Oils, Fats, and Waxes* (ed. iii, 1904, vol. i, p. 138), remarks that "since all animal oil and fats contain small quantities of cholesterol, the presence of cholesterol in an oil or fat points to an animal origin."

Rakuzin [6] was the chief investigator of these optical properties, and he first announced the detection of cholesterol in petroleum; later observations have, however, tended to throw doubt upon his deductions, and it is still impossible to affirm that the presence of cholesterol or phytosterol (the similar substance found in vegetable oils) in petroleum has been established beyond doubt, though such a result would accord well with the Engler-Höfer dual theory of the origin of mineral oils.

Engler thus enumerates the various stages which in his opinion occur in the formation of petroleum from organic matter:—[7]

1. Putrefaction, or fermentation, by which albumen and cellulose, etc., are eliminated. Fatty matters (and waxes), with a small quantity of other durable material and possibly fatty acids from the albumen, remain.

2. Occurs partly during the first stage: saponification of the glycerides, and production of free fatty acids, either from action of water or ferments, possibly both. The waxy esters are either wholly or partly hydrolysed. The residues

[1] See Renault, *Bull. Soc. Ind. Min.*, 3, xiii, 865–1169 (1899); xiv, 5–157 (1900). Russian boghead contains *Micrococcus petrolei.*
[2] See *Bull. Geol. Surv. Ohio*, 4, i, 313 (1903).
[3] *Chem. Zeit.*, xxx, 814 (1906).
[4] *Compt. Rend. Congr. Geol. Internat.*, viii, 508 (1901).
[5] *Zeitschr. angew. Chem.*, xxi, 1590 (1908).
[6] *Jurn. Russk. Phiz.-Khim. Obsch.*, xxxv, 554, (1904), etc.
[7] *Zeitschr. angew. Chem.*, xxi, 1588 (1908).

from many crude oils are probably due to lack of completion of these actions.

3. CO_2 is eliminated from the acids and esters, water from the alcohols, oxy-acids, etc., leaving hydrocarbons of high molecular weight containing oxy-compounds, *cf.* the intermediate product like ozokerite of Krämer and of Zaloziecki, who also regarded that mineral as representing an early stage in the formation of oil.

4. Formation of liquid hydrocarbons and violent reaction with "cracking" into light or gaseous products=formation of proto-petroleum.

He adds, in regard to all these stages, that he is assuming that time and temperature compensate one another, though pressure has no action beyond raising the temperature slightly, and is in no way equivalent to it. He considers that with moderate temperatures and pressures oil of intermediate grade will be formed, while increase of either tends to form light oils. Polymerisation and addition-products are formed after the completion of stage 4.

He further suggests that the various hydrocarbons are formed as under :

Methanes—as direct products from the "bitumen," *i.e.* the fats of stage 1 and heavy hydrocarbons of stage 3.

Olefines—directly formed, by splitting up of saturated chain hydrocarbons of the paraffin series,

$$C_{2n}H_{4n+2}=C_nH_{2n+2}+C_nH_{2n} ;$$

they would afterwards polymerise to form simple methanes, etc., but they are probably partly reformed in distillation, especially at high temperatures, as in the "cracking" process.

Naphthenes—perhaps from the decomposition of aromatic acids or esters, or from isomeric olefines under the influence of heat and pressure.

Lubricants—formed directly from original fats, at low temperatures.

Benzenes, etc.—from the decomposition of fats at comparatively high temperatures.

Some of the results of more recent investigations are as follows :—

Aschan [1] considers that the naphthenes and their acids are secondary products and are formed by the polymerisation of olefines which result from the initial decomposition of fats. In support of this view he showed that amylene dissolved in carbon disulphide and allowed to react with aluminium chloride yielded (1) a product, C_5H_{10}, which resembled methylcyclobutane, boiling between 32°–40° C. ; (2) C_6H_{14}—possibly β-methylpentane ; (3) cyclohexane, C_6H_{12} ; and (4) paraffin, $C_{10}H_{22}$, $C_{11}H_{24}$, and $C_{12}H_{26}$.

In 1906 C. Neuberg,[2] developing the theory that petroleum originates from the optically active decomposition products of proteids, showed that the fatty acids derived from putrid cheese (acetic to hexoic) possessed $\alpha_D+1{\cdot}2$. Putrescent gelatine also gave active acids. Lipase reacting with the triglyceride of inactive dibromostearic acid formed a dextro-rotatory acid.

J. Lewkowitsch [3] distilled a mixture of zinc dust and chaulmoogra oil. He obtained a liquid possessing the characteristics of crude petroleum, the higher distillates of which were dextro-rotatory. Hence he concluded that active glycerides yielded active hydrocarbons.

A. Kunkler and H. Schwedhelm [4] remarked that the interaction of fats and calcium carbonate would yield intermediately ketonic products from which, by elimination of oxygen, hydrocarbons result. Stearin and chalk were heated together at 27° C. After 8 hours the action was completed, and the

[1] *Ann.*, 324, i. (1902).
[2] *Biochem. Zeit.*, 1, 368 (1906).
[3] *Ber.*, xliv, 4161 (1907).
[4] *Chem. Zeit.*, i, 1322 (1908).

temperature had risen to 320°. Wax, kerosene, and viscid oils were the primary products. From oleates the products were entirely liquid. The carbon in a mixed ketone may thereby become asymmetric. These authors point out that the possession of branched chains of considerable complexity will confer high viscosity on the hydrocarbon.

K. W. Charitschkoff[1] drew attention to the close resemblance between the product of the distillation of asphalt and petroleum, and considered that a genetic relationship was established. Asphalt, on being distilled, yielded naphthenes but no aromatic hydrocarbons.

The same author[2] has put forward the following reversible scheme of metamorphism :—

Unsaturated hydrocarbons ⟷ bitumen
↑↓ action of heat and time
petroleum.

Marcusson[3] synthesised an optically active "petroleum" by distilling the unsaponifiable components of wool fat under pressure. The optical activity of fractions from this material increased as the volatility decreased. Cholesterol on repeated slow distillation yielded dextro-rotatory distillates, whilst on being subjected to rapid heating, it afforded in part laevogyratory fractions. Marcusson considers that the optical activity of petroleum is partly due to cholesterol derivatives which are of an animal origin and partly to terpenes and resins of vegetable source.

As illustrating the remarkable tendency of olefines towards polymerisation, Ipatieff[4] heated ethylene under 70 atmospheres pressure to 380°–400° C. He obtained paraffins (C_5 to C_9), olefines (C_5, C_6), polymethylenes (C_9 to C_{15}), and hydrocarbons of lesser content of hydrogen.

The possible catalytic agency of earthy matter as the break-down of fats was investigated by H. C. Hviid,[5] who heated lard and oleic acid with silicious earth and obtained fluorescent hydrocarbons.

The more recent work of Engler[6] discusses the effect of fuller's earth and powdered quartz on the decomposition of olein and stearin. Apparently a greater yield of hydrocarbons is obtained than by merely heating the organic material alone. In this connection Gräfe[7] has shown that lycopodium spores when heated in the presence of fuller's earth gave a material which resembled Scottish shale-oil. Therefore in the conversion of organic remains to petroleum there must be considered not only the effects of time, pressure, and temperature, but also the influence of the mineral environment.

Engler's[8] final view up to the time of writing appears to regard the metamorphism of organic matter to petroleum in the following way :—

Waxes, resins, and fats (after the putrefaction and decay of proteins and cellulose, etc.)
↓
Ana-bitumens (soluble in benzene and carbon bisulphide)
↓
Poly-bitumens, kata-bitumens, ecgono-bitumens (crude petroleum), and oxybitumens.

[1] *Journ. Russ. Phys. Chem. Soc.*, xl, 1327 (1908).
[2] *Ibid.*, 44, 354 (1912).
[3] *Mitt. Konigl. Materielsprüfung*, 28.143 (1910).
[4] *Ber.*, 44, 298 (1911).
[5] *Petr.*, vi, 429 (1911).
[6] *Ber.*, 25, 153 (1912).
[7] *Petr.*, vi, 71 (1910)
[8] *Petr.*, vii, 399 (1912).

The differences between the oils of various localities and ages have been the subject of much discussion, and the exact cause of these variations is not clearly known. It may be mentioned, however, that Peckham's view, that asphaltic oils are mainly of animal origin, while paraffin is largely derived from vegetation, is worthy of acceptance on general chemical as well as geological grounds, since Krämer and Spilker, and others, have shown that vegetable fats produce paraffin either with or without artificial distillation, and the limestone oils, which on geological grounds are generally held to be mainly of animal origin, are notably asphaltic.

For other differences, Engler's view that variation in temperature and pressure accounts for the production of hydrocarbons of different densities, etc., may be considered with that of Krämer and Böttcher, that variation is due to changes after its formation, *i.e.* polymerisation, etc., both kinds of agencies being probably potent causes. Reference may also be made to the theory of Dr. Day,[1] based on experiments on the filtration of petroleum through fuller's earth, that filtration through clays may account for some of this variation, and he suggested that the oil of Pennsylvania may be the lighter and paraffin-containing parts of the Silurian limestone oil purified by filtration through the Devonian shales. The extent to which this theory can be applied may be considered as doubtful, but that such filtration of oil does occur in nature is known, and it may be that in some fields it has taken place on a fairly large scale, without being applicable to all.

Hypotheses as to the precise manner of production of the solid hydrocarbons are somewhat at variance. Kast and Siedner[2] have pointed out that the marked difference between petroleum-residues and ozokerite renders it unlikely that the latter was formed by evaporation of petroleum, and Zaloziecki, as already mentioned, believes that ozokerite is an intermediate product in the formation of petroleum from animal fats. Grabowski considers ozokerite to be an oxidation- and condensation-product of petroleum.

From the fact that a product resembling the petroleum of the Tegernsee district is obtained by the distillation of the asphalt from that place, von Gümbel has thought it possible that this oil has been produced by the spontaneous distillation of asphalt. It is, however, quite certain, as already pointed out in the section relating to the geology of petroleum, that the principal asphalt deposits are merely the result of the evaporation of petroleum along the outcrops of porous strata, and it may be added that Peckham has produced an asphalt-like substance by the spontaneous oxidation of Californian petroleum. Presumably the Bavarian asphalt, like all kindred masses, contains traces of still unoxidised petroleum, readily eliminated by distillation.

From the account given in this section, it will be seen that there has been abundance of speculation as to the origin of petroleum and that, in regard to some of the theories, a considerable amount of experimental proof has been forthcoming. Much experimental work, however, is still needed, and in such investigation it should be the aim to reproduce as closely as possible the conditions which obtain in nature. Probably, on the whole, the Engler-Höfer dual theory had at one time the largest number of adherents, but it has distinctly lost ground among geologists within recent years.

[1] *Proc. Amer. Phil. Soc.*, xxxvi, 112 (1897).
[2] *Polyt. Journ.*, cclxxxiv, 6 (1892).

PRINTED IN GREAT BRITAIN BY NEILL AND CO., LTD., EDINBURGH.