Oil-field development and petroleum mining

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Trained as a practical engineer, an aim has been made to put in unpretentious language and concise form the main principles of an industry bristling in unsolved problems and encompassed by far-reaching possibilities, presenting unbounded opportunities for enterprising engineers of education and initiative. The training is hard, and fraught with danger of injury to health when camping in tropical forests distant from civilisation, where distractions do not exist, and long hours are the rule.

Included in this volume is a brief account of the chief oil-fields of the world, accompanied by specially prepared maps, which, it is hoped, will prove valuable for reference. The main features attaching to the leasing of oil lands are reviewed, and oil-field legislation, customs, and usages are described in some detail, and freely commented upon. The principles of refining are briefly explained, and the chief characteristics of crude oil and petroleum distillates are alluded to. A lengthy discussion of the origin of oil has been included, and special efforts have been made to explain the factors governing the accumulation and geological distribution of petroleum.

Oil-well phenomena have been minutely described under numerous sections, and remedies for defective work liberally prescribed. Engineering problems involved in oil-field equipment and development are dealt with; and the relative merits of modern plant and drilling appliances are discussed without bias. Methods of extracting oil are detailed, and a chapter has been devoted to the important subject of recording, tabulating, and analysing data for statistical purposes. Included are many diagrams and charts, graphically representing features that are less obvious in columns of figures. Some of the charts, calculated throughout from recognised formulæ, may save much trouble and time to oil-field managers.

Particular attention has been paid to the prevention of waste, both culpable and that due to inefficient working.

exceptional value to me in the preparation of this volume.

To my delight, Mr Percy R. Clark, F.I.C.S., F.A.A., undertook the preparation of the chapter on oil-field organisation and accountancy, which cannot fail to prove of value to those initiating operations.

As a regular reader of British and American petroleum periodicals, I cannot fail to have drawn information from those channels that has found its way into the text, and I crave forgiveness from the editors of such journals for any material inadvertently unacknowledged.

America has at last realised the necessity of training students for an industry that is assuming such gigantic proportions, and special courses are now arranged in a number of the Universities of the country. Great Britain has not been behind hand, as besides Birmingham University, the Imperial College of Science (Royal School of Mines) has initiated a course of study. In this connection the engineering side should not be lost sight of, as oil-field development calls for engineering abilities of no mean order, if great waste of capital is to be avoided. Only an engineer can satisfactorily direct the operations of an oil company, especially where conducted in remote regions. The erection of dwellings and structures, making of roads, bridges, light railways, installation of machinery, electrical stations, telephones, the design of pipe lines, water services, etc., all call for engineering knowledge that only trained engineers can adequately supply.

It has been no simple matter to condense the contents to the limits of a single volume, but principles rather than lengthy descriptions have been kept in view. No student, who reads the book carefully, can fail to have a sound grasp of the principles underlying the vast industry of oil-field development.

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oil well was drilled in the Baku oil-fields of Russia, and the news of results which surpassed the most sanguine expectations or dreams was long regarded with suspicion.

Notwithstanding the abundance of petroleum found and its proved value, progress was hindered by lack of transport facilities to centres of consumption. In America and Russia the oil was conveyed in carts at great expense over bad roads to the nearest railway, and it was not until 1865 that the feasibility of piping petroleum was demonstrated in America, and ten years later before the first trunk line of any importance was constructed from near Butler to Brilliant Station on the Allegheny River, near Pittsburg. In 1879 the first great seaboard trunk line, 6 in. in diameter, was commenced from Colegrove, McKean Co., to Philadelphia, some 235 miles, with a branch 5-in. line, 66 miles long, from Millway to Baltimore.

In Russia the same transport difficulties were impeding the growth of the petroleum industry of the Caucasus, and one of the most enterprising Baku producers, following the example of America, constructed a pipe line between the Balakhany oil-fields and the Caspian seaboard at Blacktown. As in America, the carters, who had conducted a lucrative business in transporting oil, fiercely opposed the project, and for a long time it was necessary to guard the line from attacks by the disengaged carriers.

At that time the various oil products were barrelled, and exported or dispatched to their destination in that condition, but the increased trade led distributors to consider cheaper methods, as the barrels often cost far more than the contents. In 1879 Messrs Nobels, one of the largest oil producers in Russia, constructed a steamer provided with tanks for conveying oil in bulk across the Caspian Sea to the Volga where the great markets lay, and the success which rewarded their effort led to the general adoption of this means of transport on the Caspian Sea. About the same time some small ocean-going tankers were constructed, and a few years later tankships of considerable capacity were built for the conveyance of both refined and crude oil in bulk. In the year 1907 the unexpected developments in the oil industry led to many large tankers being built, the finest vessels having

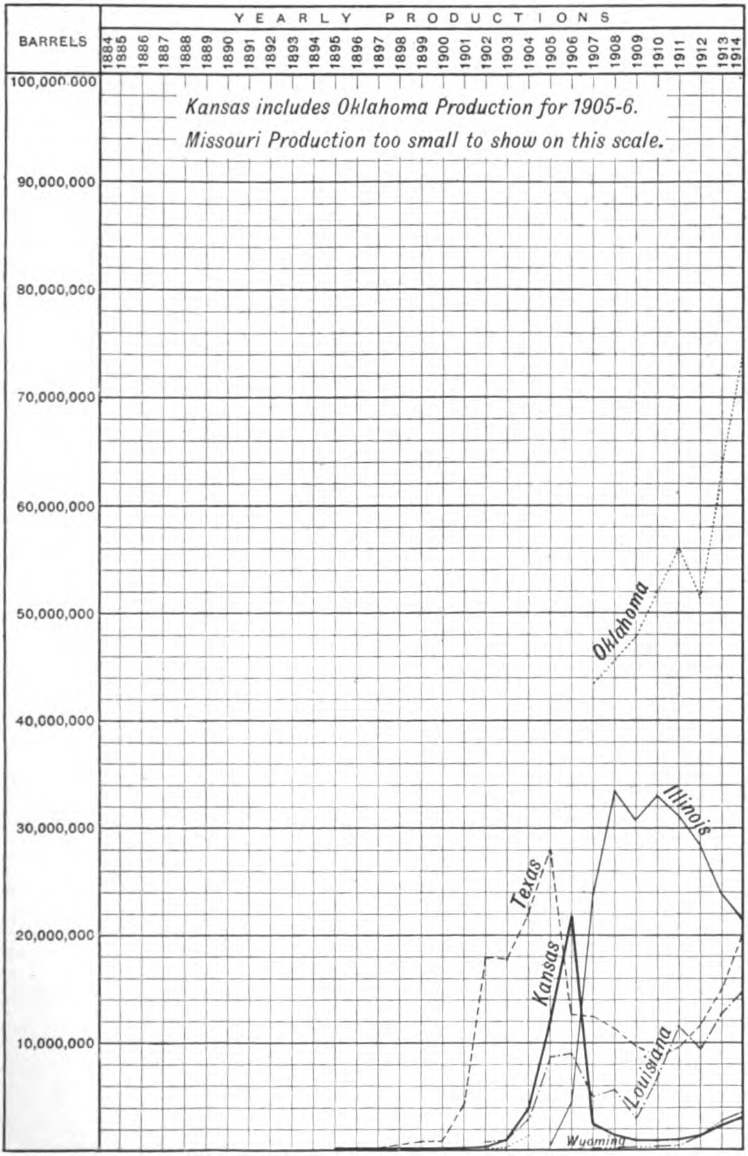

FIG. 1*a*.—CHART SHOWING PRODUCTION FROM OIL-FIELDS IN U.S.A.

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the Allegheny Mountains in a north-eastern direction, and is coincident with the geosyncline lying between these mountains and the big Cincinnati anticline. The nearly horizontal character of the strata throughout most of the area gives rise to steep and often very narrow and tortuous valleys, along which outcropping coal seams or other marked horizons may often be followed for considerable distances. It was in this country that in 1859 was born in Oil Creek, Venango Co., Pennsylvania, the modern industry of large scale oil production by means of drilled wells. The above quoted maximum production for the Appalachian field in 1900 was due to the help of West Virginia. The old Pennsylvania-New York area reached its maximum with 33,000,000 barrels (4,400,000 tons) in 1891.

Various attempts are made to group the oil districts of Pennsylvania and New York, which vary from time to time. The chief divisions are:—

(*a*) The *Bradford* district in the northern part of McKean Co., and which extends into Cattaraugus Co., New York. Development began in 1875; it reached its maximum in 1880. The productive sand is called by drillers the "third sand," although Carll showed it to be 1,000 ft. below the Oil Creek "third sand." The oil is amber, green, or black, and is usually heavier than that of the lower field.

The Allegany district of New York may be included with the Bradford.

(*b*) The *Warren Co.* area is situated in the east of Warren Co., and the north-east of Forest Co. It includes the Cherry Grove, Balltown and Cooper, Stoneham, Clarendon, Tiona, Kane, Grand Valley, and other pools. The oil sands are coarser than in the Bradford area, often containing pebbles, and belong to the Chemung group of the Devonian. The oil is usually amber in colour.

(*c*) The *Lower Field* includes Venango Co., where the oil industry of the United States started, some pools in south-west Warren Co., Clarion, Butler, Armstrong and Beaver counties. The Venango Co. oil is from the first, second, and third sands, white or yellowish conglomerates formed of pebbles loosely cemented with fine sand. The oils are green, sometimes black, On the southern border, in Wayne Co., is centred the main production of the state, whilst important pools are developed further west in Allen and Barren counties. The oil obtained from the Devonian corniferous limestone at Ragland, in Bath Co., is heavy, not unlike Lima oil, as is also the oil of Allen and Barren counties, whilst that of Wayne and adjacent counties approaches more to Pennsylvania grade, with sp. gr. .820-.840 (41°-37° B.), and is dark green in colour. In Ohio Co. high grade oil was struck in 1912, and is of interest as forming a link with the Illinois and Indiana field.

Lima-Indiana Oil-Field.—Lying to the north-west of the Appalachian field, the oil is derived from the Trenton limestone, which is occasionally dolomitised to afford a sufficiently porous rock. Beginning at Findlay in Hancock Co., in North-West Ohio, in the year 1884 development was rapid, and next year was marked by the great extension in use of natural gas in the United States, with which industry these fields were primarily associated, and in 1885 oil was struck at Lima, in Allen Co., and production increased rapidly, the sulphur oils here obtained being first successfully treated at the Toledo refinery in 1889, and excellent products are now obtained, including paraffin wax. In 1889 oil was first obtained in Indiana in Wells Co. The 1886 production of 1,000,000 barrels (140,000 tons) increased to 25,000,000 barrels (3,450,000 tons) in 1896. The subsequent decline was accentuated by the opening up of the Illinois fields, in 1907-8, which attracted operators from Lima-Indiana; nevertheless, the great rise in price of crude oil did not enable this decline to be entirely stemmed even in 1913, when a production of only 4,700,000 barrels (650,000 tons) was obtained. Three grades of oil are recognised, viz., North Lima, South Lima and Indiana, and Princeton; Indiana, the first-named, obtaining the best price.

The bulk of the North-West Ohio production comes from Wood Co., where development began in 1890 at Montgomery, and the oil is rather lighter than elsewhere, having a gravity of .814 (42° B.). Further east a second pool occurs. The Findlay district in Hancock Co., and Lima in Allen Co., are important producers, and also Sandusky Co. with the Gibsonsburg-Helena field, whilst lesser pools have been worked in Van Wert, Mercer, Seneca, Ottawa, By the end of 1913 these stocks had sunk to about 8,000,000 barrels (1,100,000 tons).

Mid-Continental Oil-Field.—This embraces a very large area. Kansas has developed twenty-five oil and gas pools in the following counties:—Franklin, Miami, Coffey, Anderson, Linn, Greenwood, Bourbon, Allen, Woodson, Wilson, Neosho, Sumner, Cowley, Chautauqua, Montgomery, and Labette. Although production on a small scale had proceeded for many years, it was in 1904 that Kansas first came into prominence with over 4,000,000 barrels (550,000 tons). Its output afterwards declined to about a million, but rose again during 1912-13 to 2,375,000 barrels (330,000 tons) in the latter year. This was due to increase of drilling coincident with the rise in price of crude oil, and the low cost of leases in Kansas, as compared with Oklahoma, caused much attention to be given to the former state.

Oklahoma contains the southern extension of the Kansas field, and its production, which came into prominence at the same time as Kansas, rapidly outstripped it in amount, and reaching 56,000,000 barrels (7,700,000 tons) in 1911, fell to 51,400,000 barrels (7,000,000 tons) the next year, to rise again sharply in 1913 to 63,579,000 barrels (8,800,000 tons), and in 1914 to 98,000,000 barrels (13,000,000 tons). This increase was partly due to the phenomenal Cushing pool, which was exposed in 1912. Towards the end of 1914 its capacity was estimated at about 250,000 barrels (34,000 tons) per day through the remarkable results attending the development of the Bartlesville sand. Many other districts contributed, including the Osage, the extension of the Hogshooter pool to the east, and of the shallow fields to the west; the developments between Bartlesville and the old Dewey pool; the developments in the immediate neighbourhood of Tulsa, and the new Wicey pool near Mounds. A new district in 1913, which became of importance in 1914, was the Healdton, Carter Co. The older fields are in the lands of the Cherokee, Osage, and Creek nations.

The development of Kansas and Oklahoma is an interesting study of rapid growth beyond the capacity of pipe lines and subsequent reaction in price of crude oil, over-production being accentuated by the inclusion of drilling obligations in Indian leases; a rapid rise in price always follows any symptom of the

Californian Oil-Fields.—Since 1909 California has yielded the largest production of any state in the Union, a position it formerly held from 1903 to 1906. In 1913 it reached nearly 100,000,000 (97,788,525) barrels (14,000,000 tons). Although essentially a region of asphaltic oils, used orginally as fuel, deeper drilling in the Coalinga district of late has resulted in the discovery of higher grade oil containing paraffin: and improvements in refining have led to the general introduction of topping and dehydrating plants, affording improved fuel in addition to other valuable products. The fields lie scattered in the coastal region north of Los Angeles.

After a small production, chiefly of heavy fuel oil, for many years in Ventura, Santa Barbara, Los Angeles, and Fresno counties, oil was discovered near Bakersfield in Kern Co. in 1899, and the Kern River field rapidly developed. This encouraged prospecting in many parts of the state, and rapidly increased the production of the Coalinga field in Fresno Co., and developed the Santa Maria field in Santa Barbara Co.

Before this time much prospecting had been carried on in the western side of the San Joaquin Valley, developing the Sunset, Midway, and McKittrick fields. Meanwhile the Sherman, Whittier, and other limited pools in and near Los Angeles had developed significant production. In 1910 and 1911 oil was discovered in the La Habra Valley and in the Lost Hills and Elk Hills. In 1912 large wells of unusual depth were developed in La Habra Valley field, with large gushers in the valley fields, but a decline in the old Santa Maria field was registered. Natural gas was piped from the valley fields to Los Angeles, and gasoline was largely extracted from natural gas. About this time the Standard Oil Company withdrew from the purchase of oils heavier than .946 (18° B.). 1913 saw no new pools discovered, but a number of large gushers within well-known oil pools, particularly in the Maricopa-Midway-Sunset and Fullerton fields. In this year no less than forty-eight wells were completed in California with initial yields exceeding 1,000 barrels (say 140 tons) per day, and at least five in the Maricopa-Midway-Sunset field came in at initial yields of 10,000 barrels (1,400 tons) and over.

Official returns give the number of producing wells in California

PLATE IV.

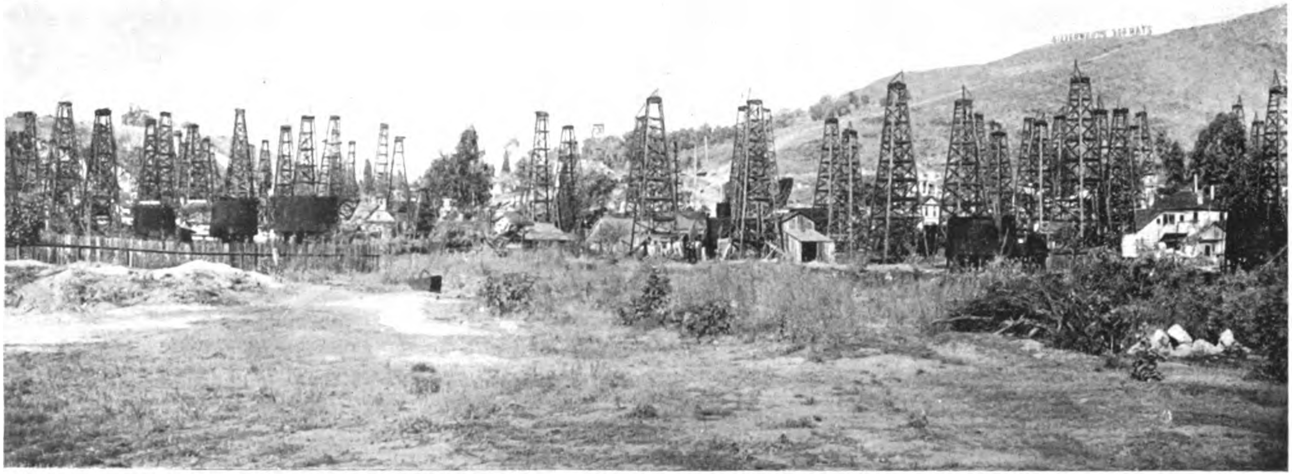

FIG. 2.—VIEW OF LOS ANGELES OIL-FIELD, CALIFORNIA.

A typical illustration of an oil-field located on a sharply inflected anticline where the width over which wells can be profitably drilled is confined to narrow limits.

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production of the State of Colorado declined to 150,000 barrels in 1914, the bulk of this coming from the Florence field.

Russia.—*Baku Oil-Fields.*—The oil-fields of Baku attained world-wide fame in consequence of the prodigious yields of individual wells at a time when such great outputs were unknown elsewhere. Single wells have for weeks yielded daily an output equal to the total annual production of many oil-fields elsewhere, where hundreds of wells were being regularly exploited.

Two of the world's greatest oil-fields lie within a few miles of the old Tartar city of Baku. The Balakhany-Saboontchy-Romany field occupies an area of about 2,640 acres on a plateau a few miles from the Caspian Sea; the Bibi-Eibat field is located in a secluded bay on the Caspian Sea coast, about 2 miles south of Baku, and covers an area of approximately 1,000 acres. Both these fields make a striking impression upon a visitor, as the large number of separate oil sources and the numerous small land holdings have led to an extraordinary congestion of derricks. About the year 1901, from these two fields of less than 4,000 acres was derived more than half the world's production of petroleum.

Very great difficulty has been found in drilling wells in the soft Tertiary clays and sands from which the oil is abstracted, and wells of 2,000-2,500 ft. cost £10,000 ($50,000) or more to complete, and require a starting diameter of 36-40 in. to ensure the requisite depth being attained with a workable size.

Since 1908 the Surakhany district, to the south-east of the Romany oil-field, has been methodically drilled with marked success. The field was first operated for gas which saturated the shallow sands, the product being led to the oil-fields for burning beneath boilers. At one time as much as 16,000,000 cub. ft. of gas was daily piped from Surakhany for this purpose. Sometimes quite large supplies of white oil, sp. gr. .785, were struck in association with the gas, but the limited demand for light spirit gave this wonderful oil no increased value. Deeper drilling, however, divulged the presence of the typical dark Baku oils, and work is now mainly confined to the exploitation of these sources, which have proved exceedingly prolific.

In the neighbourhood of Baku other small oil-fields have been developed to some extent, including Binagadi, where, in 1913, 1,300,000 tons (9,500,000 barrels) of oil from an area of approximately 8,000 acres. The first well was sunk in the early 'nineties, by an Englishman, Mr Alfred Suart, and the field has never falsified the hopes of its pioneers. Situated near to the main railway line to the Caucasus, and conveniently located for export facilities to both Novorossisk on the Black Sea and Petrovsk on the Caspian, it benefits from a choice of outlets which are capable of great development with the aid of pipe lines so far only projected.

The strata are much more compact and less liable to cave than those of Baku, enabling wells to be sunk much quicker and more cheaply. The structure also differs from that of Baku, and the oil-fields follow for many miles a narrow belt along the flanks of a ridge, rising from the valley of the Terek. In 1912 an extension of the Grosny oil belt was proved at Bellik, where exceedingly productive wells were struck near the crest of a nearly symmetrical anticline.

The refineries are erected along the railway near the town of Grosny, to which pipe lines from the field conduct the oil by gravity.

On the neighbouring parallel range of Sunja there are excellent indications of oil, which have, so far, been left unprospected, but which will one day certainly develop important fields.

Ural Caspian Oil-Field.—The existence of a field of no mean potentialities has been proved in an area north of the Caspian Sea, and inland from the port of Guriev. Fierce summer heat, intense winter cold, scarcity of potable water, and absence of transport facilities, have combined to delay the development of this area, which had been proved by small operators many years ago. Exceedingly prolific wells have been struck near Dossor, and the field is capable of great developments.

Two 6-in. pipe lines have been constructed to Bolshaya Rakushka where refineries have been built, and oil is conveyed from thence to the Russian markets *via* the Volga. Owing to shallow water, submarine pipe lines have had to be laid to where steamers can lie in safety.

The total concealment of the oil-bearing series beneath old Caspian Sea deposits over most of the area is a serious hindrance to geological study, rendering elucidation of the structure difficult and slow.

Cheleken Oil-Field.—South of the port of Krasnovodsk, in the Transcaspian provinces, lies the island of Cheleken, for centuries renowned for its wonderful display of asphaltic and ozokerite seepages and deposits. Involved structures and inconsistent results have dispirited many enterprising operators, but during the years 1911-14, in the region of Ali Tepe to the south-west of the island, exceedingly satisfactory results have been achieved, and wells of great yield have been struck at moderate depths. Endeavours to extend the limits of a somewhat confined area have hitherto failed, and the fate of the island as a great oil-field is still uncertain.

Cheleken petroleum is rich in paraffin wax. The crude is shipped to Baku for treatment in the Blacktown refineries. The production of the island reached a maximum in 1912, with 209,000 tons (1,500,000 barrels), and in 1913 it was 129,000 tons (950,000 barrels).

Maikop Oil-Field.—A belt fringing the northern flanks of the western extension of the Caucasus Mountains has, for years, been the centre of a peasant oil industry. In 1909 a field of considerable productivity was revealed near Shirvansky, where several initial wells, only 281 ft. deep, yielded up to 50,000 tons (375,000 barrels) of high grade oil. The limits of the rich pool proved to be restricted along the strike, and never justified the large capital that was spent upon the undeveloped portions of the field; and the mining regulations, framed on the basis of the Baku oil-fields, were such as to discourage prospectors to explore far afield along the belt of indications. On 23rd March 1915 a large gusher was brought in at a depth of 1,320 ft. on plot 457, which lies about a mile down the dip, in relation to the horizon of the original Shirvansky wells.[1] Up to 1915 the oil-field had given an output of about 500,000 tons (3,750,000 barrels) of oil. Pipe lines were constructed to Ekaterinodar and the port of Touapse on the Black Sea, and refineries were built at Ekaterinodar and Shirvansky.

Central Asiatic Oil-Fields.—Excellent prospects were exposed

[1] This well gave within nine months 70,000 tons (525,000 barrels) of high grade oil.

in developing an area in the Fergana district of Turkestan. Paraffin-bearing oils were struck at workable depths in some quantity, and in 1906 the output of the field reached 64,000 tons (450,000 barrels). No great energy appears to have been displayed in following up the initial success, although the oil was largely sought for by the Government railways for fuel and freight.

The area covered by the oil formations is very great, and oil seepages are known to exist on both sides of the Hissar Mountains. The Bokhara side is remote, but the deposits in many respects are similar to those of the Fergana fields.

Many areas in the Transcaspian province give favourable indications of oil, but difficulties of transport, inaccessibility, and doubts concerning disposal of output, have discouraged prospecting. Those adjoining the Caspian shore near Cheleken have received slight attention considering their interesting character.

Small Russian Oil-Fields.—On Holy Island, lying off the northern coast of the Apsheron peninsula, a regular development has been proceeding for many years. Oil is obtained in payable quantities, and either barged to the Blacktown refineries for treatment, or added direct to liquid fuel cargoes proceeding to the Volga. The last officially returned yield was 94,000 tons (680,000 barrels) in 1914.

Berekei, a district on the Caspian Sea shores, a few miles north-west of Derbent, attracted great attention in 1903, on account of the striking of several highly prolific wells that gave initial yields of 300-700 tons (2,000-5,000 barrels) daily. Water troubles arose that appeared insurmountable, and eventually most operators abandoned the field after it had produced from 50,000-75,000 tons (375,000-565,000 barrels) of oil.

At many spots in the Caucasus remarkable and unmistakable indications prove the existence of oil in large quantities, and in many cases trial wells have already demonstrated the fact. These areas are often held on insecure tenure, or located so unfortunately for transport of plant and materials and subsequent disposal of products that business men decline to proceed further at the moment. In the Taman peninsula, around Lake Baikal, in the Uchta district of Archangel, and on the Russian part of Sakhalin, oil has been discovered.

To the west of the Moreni (Stavropoleos) field is Gura Ocnitza, where satisfactory though not startling development has continued for many years, and to the east is Moreni (Bana), which has puzzled geologists and operators by the many peculiar features it presented. Here, in addition to the proving of oil on the southern flanks of the anticline as at Moreni (Stavropoleos), a shallow field of strictly limited proportions was opened up on the northern flanks, where wells gave often 5,000-10,000 tons (37,000 barrels to 75,000 barrels) of oil containing as much as 40 per cent. benzine. The discovery of this field at a time when benzine was in great request, created quite a sensation, as sales could be readily effected on the spot at £4 per ton ($2.50 per barrel), when initial yields of 100 tons (750 barrels) daily per well were not uncommon. Deeper drilling at Bana in 1914 disclosed the existence of paraffin-bearing oils in a different geological horizon, and large flowing wells were struck.

Filipeshti-Baicoi Oil-Fields.—Along the same anticline several other fields of commercial importance have been located. At Filipeshti de Padure, 5 miles east of Moreni, where a perfect symmetrical anticline is observable, paraffin oils are struck at a depth of 3,000 ft., but the high cost and lengthy process of drilling act naturally as a deterrent to producers of modest means, especially as wells have proved on the whole somewhat disappointing. At Baicoi and Tsintea, 4½ and 7½ miles east of Filipeshti, startling results have alternated with bitter disappointments, which in turn attract and repel operators from the field. The structure of both fields is so intricate, and the uncertainties so pronounced, especially at Baicoi, that only those endowed with the greatest optimism and ample resources have been induced to test their luck. Cheapened methods of drilling and a few good strikes are attracting renewed attention to the Baicoi field.

Baicoi oil is in demand on account of its richness in light products, but Tsintea oils are heavy, and usually realise 40-60 per cent. less in the market than the standard varieties.

Buzau and other small Oil-Fields.—The Beciu oil-field, in the province of Buzau, has attracted attention on account of the sustained though small yield of individual wells and the exceptional quality of kerosene the crude oil yields under distillation. The oil by a rapid decline, has drawn much attention to these most interesting fields.

Oil was known for a very long time, and appears to have had its uses recognised as early as the eighteenth century, towards the end of which a production of 7 tons per annum is recorded, obtained entirely from seepages or shallow excavations. Between 1810-17 burning oil was successfully distilled from the crude, but attempts to create an industry came to nothing, and the real founder was A. Schreiner, who, in 1853, with the aid of some Lemberg (Lwow) chemists, established small refineries at various centres.

Hand drilling was introduced at Boryslaw in 1862, and at Bobrka in 1863, and in 1867 A. Fauck began using the cable system at Kleczany. The difficulties due to disturbed geological conditions were not lessened by the scarcity of good casing, and it remained for the Canadian system, as brought by W. H. MacGarvey in 1882 to Kryg, to enable real progress in drilling to be chronicled. The old one metre square hand-dugs could attain a depth of 100 m. (328 ft.); the old cable drilling rarely achieved more than 200 m. (656 ft.), but the Canadian system has been modified and adapted, so that wells have now been drilled little short of 6,000 ft. Galician oil-fields require deep and expensive drilling. In 1913 there were in Boryslaw-Tustanowice 252 wells over 4,000 ft. deep.

The production, which in 1882 had grown steadily to 45,600 tons (330,000 barrels), reached 71,600 tons (515,000 barrels) in 1889, and then in 1902 a test well was drilled at Boryslaw to 3,000 ft., a district where the early activity in shallow oil had, during the 'sixties and 'seventies, given place to a feverish "fossicking" after ozokerite. The result of this well was a 3,000 barrel gusher, and Galician production progressed by leaps and bounds, passing the million tons in 1907, doubling this figure in 1909, and falling back to it again in 1913. This meant that Boryslaw and its extension, Tustanowice, absorbed all attention of Galician operators and in 1908 produced 95.3 per cent. of the total production; in 1913 the ratio was only 82.5 per cent.

The rapid progress in production referred to above subjected the industry to the problem of a large excess production above the as an oil centre. The Canadian system was introduced in 1896, early wells being drilled to 1,500 ft., and henceforward developments were rapid, leading to deep drilling in 1902, extension to Tustanowice in 1904, and growth of production as has already been seen. The Boryslaw anticline, an asymmetric fold much subjected to strike and also dip faulting, with older formations thrust over the productive Oligocene, pitches to the east under Tustanowice, Truskawiec, and Dobrohostow. In Tustanowice oil has been struck at 5,000 ft., whilst before the war wells were being drilled further east to 5,800 ft. and over.

The production nearly doubled itself in 1907, whilst the maximum was reached in 1909, with 1,700,000 tons (12,000,000 barrels) for Tustanowice, and 230,000 tons (1,700,000 barrels) for Boryslaw. In 1911 serious water trouble was met with in certain parts of Tustanowice, doubtless aided by the big strike faults, leading to rapid decline, so that in 1913 the Tustanowice production was only 691,000 tons (5,000,000 barrels), and Boryslaw 205,900 tons (1,500,000 barrels). Boryslaw oil is very rich in paraffin, is a good oil of .850-.860 gravity (34°-32° B.); it forms the standard market grade for Galicia, the price of other districts fluctuating accordingly.

South and south-west of Boryslaw-Tustanowice lie two parallel but less productive oil zones, *Mraznica-Orow*, 2 km. away, and *Opaka-Schodnica-Urycz*, 4.5 km. further on. Both are producing, Mraznica giving oil very like Boryslaw, but without as much paraffin, and of .873 (30° B.) gravity, whereas in Schodnica oil of variable gravity and colour is found, often with considerable paraffin contents. In 1914 deep drilling was proceeding along both zones. The production in 1913 was 29,550 tons (212,000 barrels) from Schodnica; whilst Urycz and Mraznica gave 8,000 tons (57,000 barrels) and 1,600 tons (11,000 barrels) respectively. Drilling was commenced at Schodnica in 1894, although for twenty years previous, production had been obtained. In 1900 the Schodnica-Urycz production reached 185,000 tons (1,330,000 barrels), since when it has gradually declined.

Bitkow.—Next in importance to Boryslaw-Tustanowice in 1913 was the production of *Bitkow*, situated west of Nadworna, in a very hilly district in south-eastern Galicia. Production has proceeded

Kroscienko-Nizne and *Wyzne*, which produced 5,600 tons (40,000 barrels) in 1913, and a fluctuating amount of like order for many years. A short distance north-east lie *Zmienica* and *Turzepole*, with an Eocene fold which gave 2,500 tons (18,000 barrels) in 1913; and still further north-east is a line of Cretaceous inliers in Eocene rocks. At one of these inliers, *Weglowka*, a production of 7,500 tons (53,000 barrels) was obtained in 1913, whilst in 1906 it was 11,860 tons (85,000 barrels). The inliers extend south-east in the direction of *Sanok*, as far as *Grabownica*, and have been worked in a small way at shallow depth, yielding very high grade oil. The only other locality giving any notable production in 1913 in this zone was *Humniska*, with 2,300 tons (17,000 barrels); in 1904 it gave 5,200 tons (37,000 barrels).

Midway between Sanok and Chyrow lies a field with production at *Wankowa*, *Brelikow*, *Leszczowate* and *Ropienka*, of 17,800 tons (128,000 barrels) in 1913. It had 36,000 tons (260,000 barrels) in 1901. There is here a compressed Eocene anticline between Oligocene folds.

South of Sanok lies the *Zagorz*, *Wielopole* and *Tarnawa* field, much faulted and with complex structure. Many but short-lived gushers have been obtained, usually from a depth of 1,600-2,300 ft., and are much subject to the influence of fissures. After being worked during the early 'nineties, the field was abandoned, but has since been restarted, the production in 1913 being 4,850 tons (35,000 barrels).

Gorlice District.—Between Jaslo and Gorlice are many fields, mostly lying east of the railway. Much of the early history of the Galician oil industry was here evolved, the first refinery being built, as we have already noticed, at Kleczany, in 1858, by Ignaz Lukasiewicz. *Kleczany*, the most westerly field in Galicia, was still producing 20 tons (150 barrels) in 1913. It yields an amber coloured oil with 15-20 per cent. of vaseline, a production of one barrel per month being profitable to work. The wells are long lived; its maximum production was 840 tons (6,000 barrels) in 1897.

The Canadian system of drilling was first employed in Galicia at *Kryg* in 1882, and for many years the Gorlice district remained the principal one in Galicia, the bulk of the Gorlice production

India.—*Burma.*—The oil-fields of Upper Burma have steadily acquired increasing importance, and achieved fame by the great profits earned in recent years by the leading operating company. For many years the restricted production was drawn from shallow wells at *Yenangyaung* and *Yenangyat*, some 300-350 miles north of Rangoon, on the Irrawaddy River. Deeper drilling in the Yenangyaung field, by an enterprising operator, disclosed the existence of much richer sands than had been hitherto suspected, and the industry quickly leapt into considerable prominence.

Yenangyaung is being actively exploited by a number of competing interests, which have acquired well sites of small area from hereditary native owners. Wells are sunk within a few feet of each other, and much competition is displayed in the race for deeper new sources. The upper sands are becoming commercially exhausted, and deeper drilling is annually undertaken in the search for new sands. Wells are now drilled to a depth of nearly 3,000 ft. The southern section of the field, known as Beme, has proved disappointing.

The *Singu* field is located on the southern section of a range of hills flanked by the Irrawaddy. Below 2,000 ft. rich oil sands have been penetrated and worked along a distance of 2 miles, near the crest of an anticline running nearly north and south.

An oil-field which will one day attract activity is the Yenangyat, which follows the western banks of the Irrawaddy for about 20 miles, and has then been proved at intervals for 12 miles further northward. Only a few plots have been methodically operated, but the light density of the oil will certainly eventually lead to its active development.

At *Minbu*, 20 miles south of Yenangyaung, an oil-field has been worked with some measure of success, and in the Chindwin, 150 miles north of Yenangyaung, a field has been proved, and steps are being taken to transport oil to a convenient point on the river.

Numerous districts in Burma show promise, and the delay in prospecting may be chiefly attributed to their distance from the river, the main artery and medium of transport of the country. The production of Burma in 1904 was 440,000 tons (3,300,000 barrels), and in 1914, 1,100,000 tons (8,250,000 barrels).

into existence, but gradually these were absorbed by the Nippon and the Hoden Oil Companies, the former taking over the International Oil Company, an offshoot of the Standard, in 1907. The oil-fields of Formosa became of importance in 1905, when drilling was performed in fifty-three districts, but wells were short-lived. Now the two big companies have entered that island, the Nippon Company at *Konaisha*, in the southern part of the island, the Hoden with good results at *Byoritsu*, in the north. Formosa now produces half the home consumption.[1]

Recently the Nippon Oil Company has introduced the rotary method of drilling with marked success at *Kurokawa*, in the prefecture of Akita, where, on 25th May 1914, at a depth of 1,368 ft., a well was brought in at 480,000 gals. per day, but was capped, and at the end of the year was giving 1,700 tons. Another well, drilled in on 1st September, gave 5,500 barrels. The company is laying a pipe line 9 miles to the port.

The production in the first half of 1914 was 130,000 tons.

The Nippon Oil Company has three refineries at Kashiwazaki, Naoyetsu (formerly the International), and Niitsu respectively, and owns nearly 100 miles of pipe lines.

The Hoden Oil Company has absorbed 140 different companies, and possesses 1,500 wells. It has six refineries, treating 17,000 barrels crude oil per month at its largest in Kashiwazaki, the crude coming from Nishiyama. Other refineries are at Nagaoka, Niitsu, Nuttari, Nagaoka (No. 5), and Sekiya.

Central America.—Mexico is the only Central American State in which important oil-fields have been developed. Honduras is reputed to afford numerous and extensive indications of petroleum on the Caribbean coast line. Oil is said to exist in the Republic of Panama near the Costa Rica frontier, and seepages have been reported from Nicaragua and Guatemala.

Mexico.—Mexico has rapidly risen in importance as an oil producer. Although this is mainly due to the development of two areas, each with a few phenomenal producers, viz., *Potrero del Llano* and *Juan Casiano*, many other areas are definitely proved

[1] *Petroleum*, 1st April 1914.

The handling of Mexican oil is being gradually simplified and cheapened by the construction of pipe lines, as is the development of the fields by railways. From Potrero del Llano an 8-in. line runs to Tuxpam Bar (33 miles), at which spot the Furbero oil is shipped by submarine pipe line to vessels at anchor. From Potrero also a 6-in. line passes through other fields and delivers to Tampico, *via* the Tamiahua Lagoon, across which the oil is shipped in barges. Eight-in. lines connect Tanhuijo with Tampico, and San Diego to Los Naranjos.

From Juan Casiano a treble 8-in. line connects with Tampico (65 miles), whilst a double 8-in. line is laid to Cerro Azul (22 miles), an 18-mile branch taking in Tres Hermanos. The Southern Pacific interests have an 8-in. line from Panuco-Topila to Tampico, and from the Chila-Salinas field an 8-in. line connects to the Panuco River. From Furbero a 6-in. line 53 miles long connects to Tuxpam, and from El Alamo (the Pennsylvanian Mexican Company) 28 miles of 8-in. line are constructed to the same port. Altogether in 1914 there were 425 miles of 8-in. line in operation in Mexico, and 50 more in construction. Pearson's have a narrow gauge (24 in.) railway from Cuesillos on the Tancochin River to Los Naranjos, 12 miles in length, with one from La Pena to Potrero del Llano of the same gauge, 25 miles long. The Huasteca Petroleum Company owns 30 miles of 36-in. gauge railway from San Geronima to Cerro Azul, which is to be extended another 23 miles. The Pennsylvanian Mexican Company has 14 miles of narrow gauge line from Zapatal on the Tuxpam River to El Alamo, and the Oil-Fields of Mexico Company have 45 miles of 24-in. line from Furbero to Cobos on the Tuxpam River.

The main refineries are at Tampico and Minatitlan, but much oil is exported without treatment.

West Indies.—Trinidad alone has so far given proof of the existence of payable oil-fields, but indications of oil occur in Barbados and Hayti, and there are somewhat important deposits of asphalt in Cuba, said to be associated with oil. Asphalt has been obtained off the coast of Tobago.

Trinidad.—This island is fulfilling the anticipations of those closely allied with its pioneer work. Detailed geological investigations and exploratory drilling have confirmed the early impressions

(62° B.) gravity, and a lamp oil which can be burnt in ordinary lamps without refining.

Barbados.—In the Scotland district of Barbados there are numerous and unmistakable indications of oil amidst the disturbed Tertiary strata that protrude from beneath the coral limestone in the district. A small production was at one time obtained near Turner's Hall by an operating company, and a refinery located on the seashore, 3 miles north of Bridgetown, produced distillates that found a local sale. The petroleum was of an asphaltic base, not rich in light oils, but very suitable for the production of lubricants.

The island has for a century exported a heavy oxidised oil under the designation of "Barbados tar," and a native bitumen, "Manjak," another product of oil, has been worked for many years. A considerable quantity of oil collects in the manjak workings.

Coral covers the island, with the exception of the central part which rises to an elevation of over 1,000 ft., but nowhere does the thickness of coral preclude the possibility of reaching the petroliferous sedimentary beds beneath, although drilling alone will divulge the structural features and degree of saturation with oil.

Dutch East Indies.—Oil-fields of immense value and great extent have been discovered and operated in the Dutch East Indian islands of Borneo, Sumatra, and Java, where extraordinary results have been achieved in a short space of time, whilst recently attention has been devoted to other islands, including Ceram, where a small production was recorded in 1913. The growth of the production for the whole Dutch East Indies may be gauged from the fact that in 1900 it amounted to 300,000 tons (2,200,000 barrels), whilst in 1914 it exceeded 1,600,000 tons (12,000,000 barrels). The oil is found in anticlinal folds with steeply dipping sides, and the axes are generally characterised by a wonderful display of the natural phenomena which are usually associated with petroleum. As in the other Eastern oil-fields, the oil-bearing strata are of Tertiary age, and are generally associated with coal and lignite. In Borneo there are both asphaltic and paraffin oils in the same oil-field at different depths. Some of the Sumatra oils are especially rich in light products, and these have been largely sought for the production of spirit for the European market.

The Perlak Oil Company started in 1901 and the South Perlak in 1905. Both companies, which own adjoining concessions in Atjeh, further north-west than the Langkat district, are now controlled by the Royal Dutch Company who pipe the oil to their refinery, a distance of 150 km. (94 miles). The production of the Perlak Company in 1909 was 286,000 tons (2,100,000 barrels), that of South Perlak Company 61,000 tons (460,000 barrels); but in 1914 the output had fallen to 135,000 tons (1,000,000 barrels) and 11,000 tons (82,000 barrels) respectively.

The south-eastern end of the Boeloe-Telang-Besitan anticline has been worked for many years by the Shanghai-Langkat Company (Maatschappij tot Mijn-Bosch- en Landbouwexploitatie in Langkat). This company came under the control of the Royal Dutch in 1909. Its production in 1914 was still about 300 tons (2,200 barrels) a day.

As long ago as 1897 in southern Sumatra, the Moeara Enim Company and the Sumatra-Palembang Company were formed, which developed with considerable success structures of a type similar to those known in the northern end of the island.

The principal areas producing are at *Kampong Minjak* and *Moeara Enim*, whilst Meliamoen, Babat, and Liaman Loeloei have all yielded considerable quantities in the past. In 1901 the Moesi Ilir Company was formed to exploit a large concession near Babat, but now all three companies are controlled by the Royal Dutch. The oil is high grade; that at Meliamoen has a specific gravity of .765-.775 (53°-51° B.), at Kampong Minjak .792 (46.5° B.), and at Babat .812-.889 (43°-27.5° B.). The fields are connected by pipe lines to the refineries at Pladjoe and Bagoes Koening, both near Palembang.

North-west of this district lies a most promising area known as *Djambi*, which was put up for auction by the Government in 1911-12. It is understood that the area will be divided between the Royal Dutch and the South Perlak Companies. In North Sumatra drilling was proceeding in 1914 at Peudawa.

Java.—The oil industry of Java is in the hands of the Dordtsche Company and its subsidiaries, which until 1911 had a marketing agreement with the Royal Dutch, but is now absorbed by that company. The company was formed in 1887 and possible source of petroleum if penetrated under suitable stratigraphical conditions that might be disclosed by careful study. Western Canada will doubtless receive more attention in the near future, as there are many districts on the eastern flanks of the Rockies presenting favourable indications and structures.

The output of the Ontario field has diminished since 1899, when it attained about 108,000 tons (808,000 barrels). Natural gas is still profitably worked and regularly supplied to a number of towns in Ontario.

Several serious efforts have been made to develop an oil-field in New Brunswick, where indications of petroleum are pronounced. Numerous wells have been sunk to depths of 2,000 ft., and high grade oil has been struck, but hitherto the quantities have not justified more extended operations. Natural gas has been struck in considerable volume and converted to useful employment, and the shales around the Alberta mine have been the object of repeated investigation with a view to their treatment.

Africa.—Except in Egypt, no oil-field of importance has been brought to light, and elsewhere Algiers alone has furnished real encouragement. Both the Ivory Coast and Gold Coast have been tested in the region of the Tano River with little success, and in Nigeria, where financial assistance was given to a prospecting company by the Government, no results were attained to justify the somewhat extravagant anticipations. In Angola and in Madagascar investigations have been conducted, and in the latter island drilling has been performed so far with insignificant, if not negative, results.

South Africa has been searched fairly well by prospectors, with little encouragement, although there are indications of oil and gas at many spots. In 1914 the British Government was induced to investigate certain indications of oil in Somaliland.

Egypt.—At two places on the coast of the Gulf of Suez commercial supplies of petroleum have been struck, and development on an important scale has been undertaken. The oil from the *Jemsa* and *Hurgada* fields is conveyed to Suez, where a large refinery has been erected for its treatment. Some wells gave large initial flows under high pressure, and there is every prospect of important inaccessibility, etc., have prevented *bona-fide* operators from attacking the problem.

The coastal belt of *Colombia*, from the River Magdalena to the Atrato, has been the scene of repeated geological studies and some serious drilling operations, but with indifferent and certainly indecisive results. Oil indications are very pronounced in some localities, and sufficiently encouraging yields of oil and gas have been obtained to stimulate further efforts.

Ecuador can boast of promising signs of oil in an exceedingly favourable geographical position at St Helena, near the delta of the Guayaquil River. A small local oil industry flourishes in the district through the extraction of oil from shallow pits, sunk into outcropping oil sands. The strata are evidently a continuation of the Peruvian belt, and are worthy of more attention than has hitherto been bestowed on them.

A strip of land along the eastern flanks of the Andes in *Bolivia*, from Yacuiba to Santa Cruz, presents frequent indications of oil, where beds of a certain known age reach or approach the surface under suitable structural conditions. Inaccessibility and labour difficulties have doubtless contributed to the little attention attracted by the deposits.

Even from *British Guiana* pitch deposits are reported, although in somewhat difficult and remote territory, and natural gas has been struck during drilling in the Essequibo delta.

Peru.—Peru can boast of one of the finest oil-fields in the world. Along a coastal belt of Tertiary rocks extending from near Tumbez on the northern frontier, to Payta a little south of Point Parinas, there are numerous manifestations of petroleum, and at least three important oil-fields have been exposed and are being actively exploited.

At *Negritos*, *Lobitos*, and *Zorritos* important oil-fields are being actively and profitably operated. The joint production in 1914 was about 300,000 tons (2,200,000 barrels), and extensive exports of benzine were being made.

Ten years previously the production of Peru did not exceed 50,000 tons (375,000 barrels) per annum. The wells of Peru vary in depth from 300-3,000 ft., and they have a long life, ultimate yields of from 3,000-5,000 tons (22,000-37,000 barrels) per well being common.

subscribed by the public for world-wide ventures, often with inflated capitalisations and insufficient working capital. Dead and forgotten properties were resuscitated and window-dressed with remarkable audacity, with the natural result that many concerns quickly came to grief, thereby throwing discredit upon an industry displaying exceptional potentialities. A competitive demand for proved or partially developed oil properties naturally led to excessive requests by vendors, and numerous subsequent reconstructions and liquidations bore testimony to the errors that those closely allied with the industry deplored.

Unprecedented excitement was, in 1914, aroused in Western Canada, where a small strike of light oil led to a quite unjustified speculation in lands for hundreds of miles around Calgary. Scores of companies with fanciful names and inflated capitals were promoted, and the shares were readily disposed of to credulous persons notwithstanding official warnings.

It would be well to dispel the fallacy which has been obtrusively circulated that oil-field development requires much more money than other commercial enterprises. The cost of equipping an average oil property bears no relationship to that required for a mine of the same tonnage; indeed, the development of an oil property that lies within the sphere of railways and roads is often well within the means of a private well-to-do citizen. The prospecting and opening up of unexplored tropical forests is a much bigger task, that should only be entertained under skilled and experienced guidance.

There are thousands of small operators in the American oil-fields who have started with little, and built up substantial and respected businesses, and wherever there is a free market for crude oil, there are excellent prospects for energetic, enterprising men with knowledge of the industry and of business capacity. The oil industry in most countries has been established and built up by numerous small operators, who have subsequently often been induced by tempting offers to sell their interests to financial groups, after amassing a good bank balance. It has, in fact, been the small man who has laid the foundation of oil enterprise in all but a few countries, where the conditions of living and disposal of products were prohibitive.

a certain amount on account for such oil as should be placed in storage pending sales at a fixed minimum. This agency eventually controlled an immense output, and to some extent assisted in arresting the declining tendency of prices, by restricting the operations of members. The agency exercised its power to make large sale contracts by an agreement with the Union Oil Company of California, and also built pipe lines.

At one time many Grosny producers united to fix a minimum selling price of 10 copecks per pood (12s. 6d. per ton, 42 cents per barrel). But a few who declined to join the combination caused much embarrassment by undercutting, and forced the combine to place large supplies of oil for a time in stock.

The great power possessed by the pipe line companies, upon whom the smaller operators often exclusively rely for the disposal of their products, has led to a general demand for the isolation and State control of such public utility concerns. They exercise a powerful influence over the areas they tap that could easily be interpreted as abuse of privileges at times. Oklahoma pipe line companies in 1914 decided to accept only 50 per cent. of the settled production of properties during the period of overproduction in that State, following the developments at Cushing.

Galicia afforded an interesting example of attempts to defeat depression in 1911, when the output of the famous Boryslaw-Tustanowice oil-field had quite outgrown its usual markets. As an example of the extent to which operators are willing to relinquish their position at moments of difficulty, the case is especially instructive. When crude oil prices were low, refiners made large profits at the expense of the producers, but when the price of crude oil rose the profits of refiners were seriously diminished. When struggling producers induced the authorities to erect large storage for surplus crude oil, and to make advances on oil put into storage, the price and output of crude oil rose rapidly, and refiners were working at a loss. Burdened by a tax of £6. 8s. per ton ($4.09 per barrel) on illuminating oil, home markets were restricted in view of the agreement of refiners to maintain a fixed price for home sales.

Surplus oils were thrown on the German market at any price they would fetch, thus rousing the antagonism of the Standard that placed a premium on tank cars about equal to the sum conceded.

Consideration for the peasants led the Roumanian Government in 1908 to pass legislation authorising the annual allotment to the various refineries of the country of a fixed proportion of the internal consumption of kerosene, the price of which was not to exceed a predetermined amount that afforded a reasonable profit to refiners. For the purpose of the Bill the refineries were divided into three classes thus:—

1. Large refineries with throughput capacity exceeding 40,000 tons per annum.
2. Medium refineries with throughput capacity between 40,000 and 10,000 tons per annum.
3. Small refineries with throughput capacity under 10,000 tons per annum.

The distribution was on the basis of annual throughput capacity, but the law differentiated in favour of the small refiner, who could not work so cheaply as the large refineries, by granting to the second class 200 per cent., and to the third class 400 per cent. more than the first. The ratio is therefore 1 : 3 : 5. In one year, when the home consumption was estimated to be 42,000 tons, or 1.6 per cent. of the throughput capacity, the distribution of the internal trade was as under, the refineries in practice only treating about half their throughput capacities.

	Throughput Capacity of Refineries.	Allotment.
1st category	1,886,000 tons × 1 × 1.6 per cent.	30,176 tons.
2nd category	115,800 tons × 3 × 1.6 per cent.	5,558 tons.
3rd category	78,000 tons × 5 × 1.6 per cent.	6,240 tons.

The internal consumption was taken at 42,000 tons = 1.6 per cent. of 1,886,000 + 347,400 + 390,000 = 1.6 per cent. of 2,623,400.

There were eight refineries in the first, five in the second, and forty-two in the third group.

The price was such that at normal times good profits were secured to refiners, but there have been times when this usually sought for right in reality imposed a burden, if not an actual loss, on refiners.

Germany in recent years was seriously considering the formation of a Government petroleum monopoly, which no doubt would have proved a very lucrative source of revenue. Russia imposes which controls its own mineral lands by the terms of its incorporation in the Union, has restricted sales of oil and gas lands to 640 acres, except in certain cases when 1,280 acres may be taken.

Several of the States have fixed the maximum area of oil and gas land to be acquired by a single person or corporation at 640 acres, and in the Indian (Choctaw, Chickasaw, Cherokee, Creek, and Seminole) reserves of Oklahoma a maximum of 4,800 acres has been wisely insisted upon. Osage lands are leased in blocks of between 320 and 5,120 acres, and all Indian leases are subject to the approval of the Federal Government, as protectors of the Indians.

An attempt was made in 1915 by powerful interests to force the hands of the authorities in the case of the 4,800 acres limit law of the Indian territory above referred to. Offers were made to construct pipe lines into new territory if larger grants of land were made to the promoters of the scheme, it being claimed that such small acreages did not justify the capitalists expending the large sums the projects involved. Even ordinary small producers were induced to support such demands in the hope of finding a quick outlet from lands held.

Land tenure in the United States is surrounded by some difficult problems, arising from the withdrawal of public lands from mineral location, settlement, selection, filing, and entry under mineral public land laws. The President has exercised his authority under the Act of 25th June 1910 to withdraw all known oil and gas lands in the States of California, Wyoming, and elsewhere from public location to form a petroleum reserve, and a number of cases awarded in favour of location owner in local courts are under appeal, and in partial abeyance pending reconsideration of the laws at Washington.

Litigation of great importance, involving enormous stakes, is pending between the Southern Pacific Railway Company and the U.S. Government. The Government endeavours to secure cancellation of certain patents, alleged to have been improperly obtained by the railway company in 1904-5 under the Act of 1866 — lands subsequently ascertained to have high values for oil. Other vast areas acquired under patents, particularly excepting all mineral lands except iron and coal, are the subject

The minimum unit of area permitted under Russian law for an oil property is one dessiatine (2.7 acres).

A curious and unique custom prevails in the Yenangyaung oil-field of Upper Burma, where certain native well owners, Twinzas, possess ancient and hereditary rights, recognised by the Government, over well sites inscribed by a circle 60 ft. in diameter (.065 of an acre). Hand-dug shafts were sunk into shallow oil sands, and a peasant industry long flourished, but the proved existence of rich deeper sands, which mechanical drilling alone could reach, led to keen competition for their acquisition by operating companies, and in consequence, much congestion of wells on the 200 acres composing the field.

Realising the value of an oil strike on an estate, it is not unusual for an enterprising proprietor to offer a bonus of free oil rights over a certain acreage to a prospector who will undertake to sink a few trial wells in likely territory.

Royalties and Consideration in Leases.—Royalties are payable in kind or in value, either as a fixed percentage or on a predetermined quantity or valuation per unit of volume or weight. It is curious that volume, which is a variable factor dependent upon temperature, should have become accepted in some countries as the unit of calculation.

Many interesting problems arise from the consideration of royalties. Payments in kind are obviously inconvenient in most cases, and are only acceptable by Governments, public bodies, or the few lessors requiring petroleum for some purpose. Its period of free storage and the losses sustained by such storage often entail disputes, but there is the advantage that, whatever the state of the market, the lessors obtain the full benefit. Percentage royalties payable in cash are open to the difficulty of amicably fixing a price of crude oil, no simple matter when there are no regular dealings or accredited oil exchanges. Operating companies naturally object to the contents of their books being disclosed, and if the lessee both produces and refines, and it is required that the value of the crude oil shall be calculated from the selling prices of a dozen products, in as many or more markets, confusion reigns supreme, especially under the skilful and mysterious work of book-keeping.

A fixed cash sum per unit of measurement involves no intricate annual rental of $16 per acre, and a royalty of 10 per cent. of gross production of oil. New Mexico imposes a minimum rental of $25 per quarter section (160 acres), and a minimum royalty of 5 per cent. on gross production for five years only.

Oklahoma grants oil and gas exploitation rights to the highest responsible bidder at public auctions. The period is five years, and no offer of less than 12½ per cent. is entertained. Indian reserve lands are leased for oil on a basis of a 15 cents to 70 cents per acre rental, merging into a royalty of not less than 12½ per cent. for a period of ten years. For gas wells an annual royalty of $100 is payable, or $50 if used only for private purposes.

Lands allotted to Indians outside the reserves may be leased for twenty years subject to permission of the Commissioner of Indian affairs. Royalties may be revised at five year intervals, and a bond of $1,000 is demanded. Osage tribal lands in Oklahoma are offered by auction, approved by the Secretary of the Interior. A rental of 15 cents, 30 cents, 50 cents, and $1.00 is demanded for the first four years, and $1 per acre per annum afterwards, merging into royalties of 16⅔ per cent. on gross production based on market value of the oil, on not less than a guaranteed minimum of 60 cents per barrel. Gas sold is subject to 16⅔ per cent. of actual value realised.

Unproven lands are frequently leased on a 10 per cent. basis, with no onerous obligation to drill unless oil is struck in the locality. Canadian farmers of Ontario have often derived a welcome supplementary income by a 10 per cent. royalty on oil or gas extracted without hindrance to agricultural pursuits. A fixed annual charge of from 25 cents to 50 cents per acre is charged on oil and gas lands in Manitoba, Saskatchewan, North-West Territory, and Yukon, the lease being for a period of twenty-one years subject to renewal on certain terms. British Columbia imposes a rental of 15 cents per acre for five years, with a royalty of 2½ cents per barrel on all oil extracted, but vigorous and continuous development work is specified. A bounty of 1½ cents per imperial gallon (17s. per ton) is paid by the Canadian Government on all crude oils produced or put in storage in Canada.

When the existence of oil has been virtually proved by neighbouring operations, royalties are often increased somewhat, and

The cost of developing an oil-field and the cost of extracting oil usually increase with the age of the field, in consequence of the diminished productions per well, and often necessary deeper drilling; consequently, other conditions remaining constant, the returns for a definite expenditure are reduced and the royalty constitutes the only factor that could be reduced to avoid all profit being eventually obliterated; but against the increased cost of operating there is often a rise in the price of oil that entirely or partially neutralises the reducing yield, at least for a time. If the cost of drilling wells and extracting oil remained fixed the equation

$$(\text{average production per well}) \times (\text{price of oil}) = \text{constant}$$

would represent a stationary state of affairs, but if working costs increase, the constant is displaced by a figure with an annual augmenting value. Applying the above formula to known oil-fields a value for the constant could be determined above or below which the local industry is in a flourishing or a depressed state.

Obligations in Leases.—Lessors of oil lands are rarely so careless or unbusinesslike as to lease their lands on a royalty basis without certain obligations, unless substantial bonuses or rentals are paid, which are regarded as ample compensation for inactivity. Both public authorities and private landowners have experienced the difficulties attending the fixing of definite obligations which impose no unfair burden on lessees. Private landowners may be divided into two classes—the cautious, thrifty ones, and those endowed with speculative instincts. The former prefer a definite rental, minimum annual royalty, or other fixed payment. The latter choose to throw in their lot with the lessees and rely upon production for their remuneration, consequently insisting upon drilling obligations within definite periods.

Public authorities have in view a dual purpose when drafting leases. They not only desire revenue, but they strive to create a local industry which in turn benefits the public exchequer in a variety of indirect ways, often more important than the revenue from royalties. Townships spring up, increasing the value of land, and attracting population to support the many trades which are automatically drawn by a thriving enterprise. The retained in shares and debentures or bonds that constitute a prior charge on the profits and sometimes assets of the company till redeemed. Shareholders of the original company thus receive a cash payment and a share distribution, the latter acquiring a marketable value that enables participants to realise their holdings and sever their connection with the concern if they so desire. An American practice is to amalgamate properties and make a bond issue to pay the cash purchase price and provide the working capital, this sum usually approximating to the reasonable valuation of the property. Ordinary shares are then distributed as a bonus to subscribers of bonds and retained by the promoters as their profits. This principle is open to grave objections, as (1) it gives to the promoters any high profits that may accrue from trading; (2) it makes the raising of subsequent capital difficult, and if so raised, depreciates the bonds or preference holdings; (3) it encourages extravagant development and unwise distributions of dividends to lift the market value of the ordinary or deferred shares.

Cash and share purchase considerations are given quite different values in sale negotiations, but the proportion must always be the subject of negotiation between vendors and purchasers, and be decided on the merits of the property or the projected transaction. Special attention should be directed to the question of royalties in valuations of oil properties or lands, as these comprise an increasingly heavy burden on producers as the age of the properties increases.

There has been some inclination in America to value properties by oil content, but for reasons given elsewhere (p. 159) the dangers attending this course are great. Many properties could be named where the extracted oil must exceed the original oil contents by several hundred per cent., assuming the almost prohibitive thicknesses and impregnation of sand. In certain oil-fields where the inclination of the strata is small, the density of the oil is such as to restrict lateral movement, and the sands are comparatively regular in thickness and consistency, some approximate figures may be arrived at by assuming a possible percentage extraction.

A practice that has acquired some popularity in the central

REVENUE EXPENDITURE STATEMENT.

Description of Property on which Expenditure Incurred.	1914. Production.		1915. Production.	
	Amount.	Per Barrel.	Amount.	Per Barrel.
Bailing and pumping charges - - -				
Repairs and renewals—				
Wells - - -				
Engines and boilers -				
Pumps and pipe line -				
Electrical installation				
Fuel or power - - -				
Rents and royalties -				
Administration and office expenditure - - -				
Taxes - - - -				
Sundries - - - -				
Cost of production - -				
Depreciation - - -				
Total cost of production -				

is the worked out cost per unit of production. Comparison of several years in this way discloses any extraordinary feature that might be missed in the analysis of accounts of a single year. The true actual cost of production is then the sum of revenue charges and the drilling charges, and if the depreciation allowances do not closely correspond with the capital outlay to maintain the plant whilst production has been practically stationary, it is clear that insufficient has been allowed in the accounts.

Attached are two forms for tabulating data when analysing the accounts of a company for valuation as a going concern. Items would be modified to suit local conditions and the methods of book-keeping adopted, but at least three years should be so treated to obtain average results. Depreciation is transferred from the capital account to the revenue account, where all figures are divided by the year's output to find the cost per unit of production.

Great variations occur in the cost of production, including the amount expended on drilling to maintain output. The most startling in low cost to come under the author's notice in his highly speculative nature of royalties, and the constantly fluctuating value arising from variation in production or prospects of the well or property dealt in, or even neighbouring properties, presents a field for speculative transactions equalled by few gambles.

The number of variables in calculating royalties gives endless scope for individual fancies. The value of a fixed percentage royalty in kind is dependent upon—

(*a*) Price of oil.

(*b*) Production of wells.

(*c*) Grade of oil.

(*d*) Dangers from fire, damage or intrusion of water.

(*e*) Activity or skill of lessees.

(*f*) Energy of neighbours.

Fixed sums per unit of volume or weight naturally eliminate some of the uncertainties of royalties.

The method of arriving at a valuation of royalties will be deduced from the above, and a cautious valuer will only admit of the use of average figures throughout, fortified or depressed for any other justifiable reason.

How dangerous yet seductive royalty anticipations become when submitted by plausible but dishonest brokers to the ignorant, although supported by a mass of quite correct data, the author has had opportunities to learn. On one occasion a large number of royalties in kind on important producing wells were offered at what appeared a most tempting price. An investigation, however, disclosed the fact that the royalties were on new wells giving a large initial or flush production, which would inevitably show a rapid fall in the near future. A further calculation showed that the production, although correct at the moment, would, if continued at the same rate for a year, exceed the entire annual output of the country in which the wells were located.

Oil-Field Waste and its Prevention.—In no commercial operations has there probably been greater unjustifiable waste of the resources of Nature than in oil-field development, some idea of which will be gleaned from occasional references in preceding chapters. In other mining operations, wasteful methods or processes do not entail permanent loss to mankind, as picked mines or discarded dumps may enable work to be repeated with extended employment of internal combustion engines, both gas and oil, and improved methods of extracting oil.

The wasteful methods on oil-fields were vividly illustrated in the Baku oil-field, where a contractor, only a few years ago, paid the authorities a substantial sum to recover the oil from the drainage of the oil-field. This contractor recovered 15,000 tons (112,500 barrels) of oil annually by simply passing the drainage of the oil-field through water traps. From a dam on the Kern River, California, as much as 250,000 barrels of oil have been collected in eight years.

Great advances have been made in preventing and restricting the spread of fires, which have often consumed many thousands of tons of oil within an incredibly short time. Improvements include more strict legislation about lights, fittings, and smoking, also the increasing use of iron derricks or wooden derricks protected by non-inflammable material.

Flowing wells are now better controlled, either by restricting the flow of oil, or diverting it in a way to ensure safety from fire, and diminution of losses. In some of the important oil-fields, indications of a possible flow are sufficient pretext for prohibiting further drilling operations until approved provision for the collection and disposal of the oil is made.

About the years 1890-1900 it was no uncommon occurrence for wells yielding 10,000-15,000 tons (75,000-112,500 barrels) daily to burn for days or weeks, and the author has himself seen three great eruptive wells burning contemporaneously in the Baku fields. Enormous losses have been sustained by Roumanian producers before stringent regulations were imposed on operators; and in Mexico the loss of oil from the famous Dos Bocas well was estimated at 1,000,000 tons (7,000,000 barrels).

Lighter products of the oil are saved by quick transfer of the crude oil to tanks or storage provided with protection from the sun's rays. Brief exposure to the atmosphere, especially if there is a wind, causes alarming losses of light density oils through evaporation. Large surfaces are avoided as much as possible when limited exposure cannot be prevented, to effect settlement of sand or water.

Oil is often pumped direct into storage tanks without exposure to the atmosphere, the tanks being provided with hermetically from 10,000,000-20,000,000 cub. ft. of gas daily allowed to escape. More natural gas is wasted in some of the American fields than would supply the whole of London, and even when directed to use it was the extravagant practice to leave flares burning night and day in the streets of towns within gas zones. In the early part of 1909 it was estimated that 70,000,000 cub. ft. of gas, equal in heating value to 1,500 tons of crude oil, were daily wasted in the Caddo oil-field of Louisiana, and wells in Ohio and Kansas were allowed to discharge into the atmosphere 25,000,000 cub. ft. of gas daily, equal in heating value to 550 tons of crude oil.

Much dissatisfaction was felt in America at the enormous waste of such an ideal fuel as natural gas, and in 1913 the Bureau of Mines of Washington was constrained to investigate the matter in Oklahoma, where, in the newly developed oil-field of Cushing, gas wells of 20,000,000-40,000,000 cub. ft. daily capacity were intentionally allowed to flow to waste before drilling into the deeper oil-yielding sands. In April and May 1913 it was said that five wells were daily discharging not less than 126,000,000 cub. ft. of gas into the atmosphere, and one well alone yielded 1,500,000,000 cub. ft. of gas before being shut in. Such stupendous figures cannot be realised until converted into oil or coal equivalents. From the latter mentioned well alone the heat value of the gas would be equal to about 34,000 tons (255,000 barrels) of oil or 50,000 tons of good coal. No wonder the Washington Government is concerned at the wanton waste of fuel, the main support of every industrial country, and ignorance alone will explain the attitude of landowners or lessors who quietly submit to their lands being depleted of products which one day will be appreciated at their proper value.

Investigations have shown all this waste of gas to be quite unnecessary, and that the strongest gas sources can be shut off and passed, and their flow controlled by suitable measures. These are explained on p. 392.

The suggestion has been made of storing surplus gas from oil or gas fields by its readmission to exhausted oil or gas sands on other areas through old wells. This procedure should be quite feasible if suitable measures are taken to seal wells piercing

CHAPTER III.

GEOLOGICAL STRUCTURE AND LITHOLOGICAL CHARACTER OF OIL-FIELDS, AND FACTORS GOVERNING THE DISTRIBUTION OF PETROLEUM.

Factors Governing the Formation, Accumulation, and Preservation of Petroleum—Character of Oil-Bearing Strata—Migration of Petroleum—Causes of Pressure—Subterranean Movements of Petroleum Occasioned by Development—Area Influenced by Producing Wells and their Spacing—Yield and Life of Oil Wells—Production and Life of Oil-Fields—Typical Well Logs.

Factors Governing the Formation, Accumulation, and Preservation of Petroleum.—Commercial supplies of petroleum are restricted exclusively to strata of sedimentary origin, thus differing essentially from metallic minerals, which are mainly derived from igneus intrusions, except where occurring as secondary deposits. Not only is petroleum confined to sedimentary strata, but it is beds of a comparatively recent geological age, the Tertiaries, which yield the bulk of the oil of the world to-day. With the possible exceptions of coal and iron, oil-fields are rarely coincident with mining areas.

It is quite certain that natural petroleum, whilst sometimes having an obviously adventitious origin, was more often formed in the series of beds in which it is now found when they were horizontally disposed; but as petroleum and gas are fluids, and obey the laws of fluids, their present distribution has been influenced by terrestrial disturbances which have from time to time thrust the containing strata into irregular contortions. Continuous or successive earth movements, especially in the neighbourhood of mountain ranges, have not only given the beds an inclination in certain directions, but have caused the strata to assume wave-like forms in adjusting themselves to crushing forces.

The ordinary anticlinal and synclinal structure is a normal consequence of such forces, and the axes of anticlines usually run approximately parallel with mountain ranges. The oil-fields of impermeability when dried. Its plastic nature may be increased by colloidal matter.

Oil-measures, as they have been appropriately termed, often attain a considerable thickness, in which clays, shales, sands, and sandstones alternate. Sometimes many hundreds of feet of barren clays or varied strata separate productive beds, but in other cases nearly every porous stratum within certain vertical limits yields oil. In some fields practically all the beds for thousands of feet are more or less petroliferous, but in other regions dry beds with no trace of oil are passed between successive productive seams. Some intermediate sands are saturated with water, and its exclusion is often a tedious and costly operation necessary for the protection of the oil sands amidst which they occur. These waters are discussed elsewhere. In certain oil districts structural features play a quite subordinate rôle to lithological character. This is especially noticeable in Kansas-Oklahoma, where almost horizontal beds continue over vast areas, and oil is exclusively confined to one or several sandy horizons traceable over long distances.

Remunerative yields of oil have been obtained through a vertical thickness of about 3,000 ft. on the Baku oil-fields of Russia. In the Yenangyaung oil-field of Burma, about 2,500 ft. of strata have yielded commercial supplies of oil.

The Carboniferous and Devonian oil-fields of America are characterised by commercial supplies of oil and gas being confined to lenticles or streaks in a few persistent strata, without which little or nothing is found, the oil-forming conditions only occurring during small periods of geological time at varying and long separated intervals.

Tertiary oil-measures often disclose a considerable vertical range, but an horizon of maximum productivity is observable in most oil-fields. Down to a certain depth sands increase in productivity, then follows an area of maximum saturation, after which production decreases or ceases, and water is found in increasing quantities. Many great oil-fields have exhibited the above phases, but in some cases two or more oil-bearing series of strata have been discovered separated by a thousand feet or more of barren beds.

which introduce so many mechanical difficulties, and impose such heavy expense in the hilly districts.

The limited area of oil-fields as compared with, say, coal-fields, points to a much greater restriction of the conditions favourable to the formation and accumulation of oil than coal. That oil-forming conditions disappear within short distances is illustrated by the fact that areas equally favourable from a geological point of view for the accumulation and preservation of oil are found barren, or almost so, a short distance along an anticline highly productive of oil. A second parallel anticline, differing little in general features, is often unproductive, and would have been expected to have yielded oil had there been a persistence of oil-forming conditions.

Lateral variation, which is so common a feature in Tertiary oil-field strata, is typical of the deltaic conditions under which petroleum is found. Exposures in most of the oil-fields give abundant evidence of the lenticularity of sands on a scale only commensurate with currents that would be unlikely under deep water conditions. On the larger scale a series of beds may be traced, gradually losing or acquiring an arenaceous character in certain directions, and consequently diminishing or improving opportunities are afforded for the accumulation of oil provided the conditions of formation are not varied.

Character of Oil-Bearing Strata.—Although sands and sandstones are the chief oil reservoirs in oil-fields, the intervening shales or clays are often impregnated with oil, and may have often been the media in which the oil was produced. Where much crushed into sharp folds, outcropping clays are sometimes seen to have innumerable slip or cleavage planes along which films of oil occur. Seams of sand, a mere fraction of an inch in thickness, and lenticular in shape, are often the receptacles for oil, and every fault plane with only a few inches of displacement is full of oil. Distributed in the clays will often be observed tiny lenticles of dry sand which have somehow escaped saturation like other sandy parts, thus disclosing some selective properties of the oil or water contents.

Some clays and shales within an oil zone have innumerable

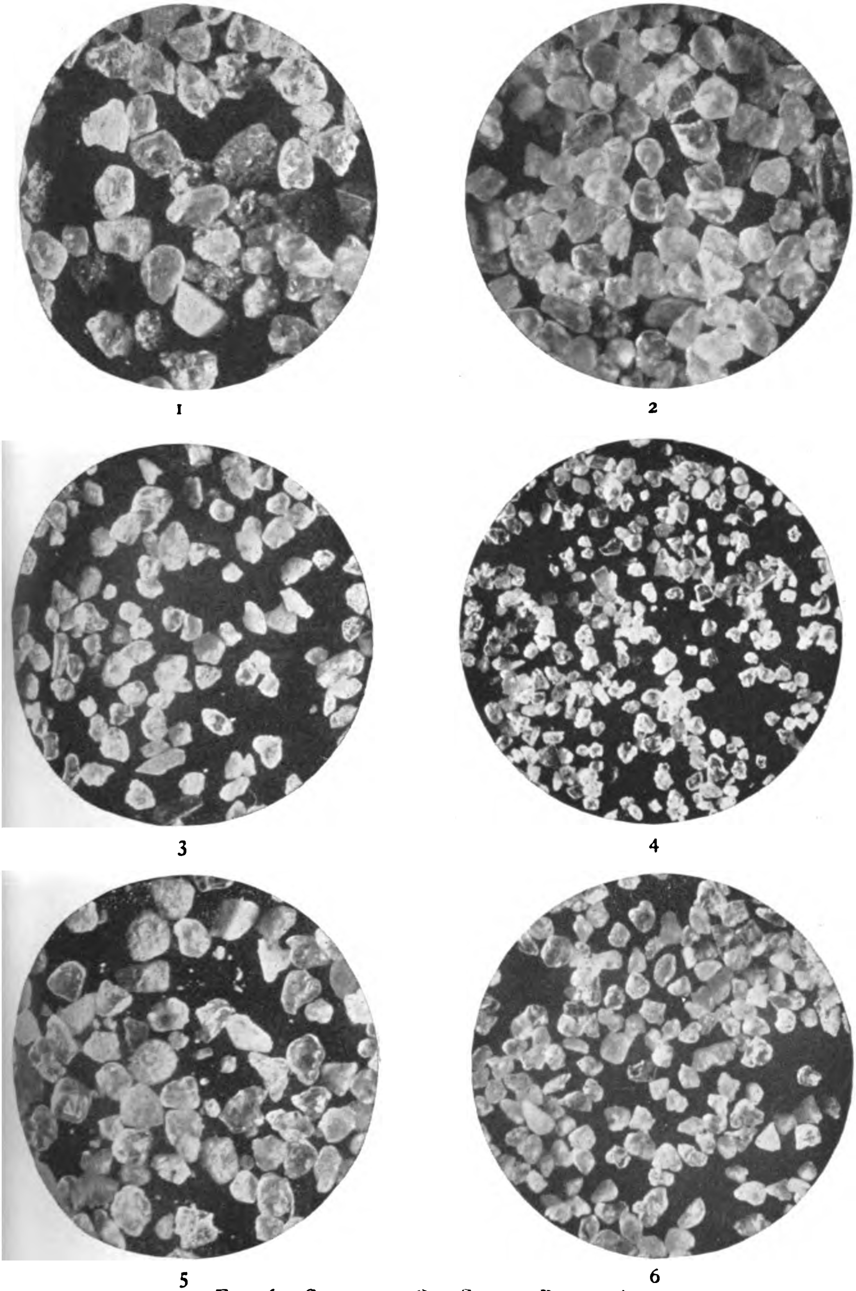


FIG. 6.—SCREENED OIL SANDS (RUSSIAN).

(Sample 1.)

1. Retained by 80-mesh screen.
2. Retained by 100-mesh screen.
3. Retained by 150-mesh screen.
4. Retained by 200-mesh screen.

(Sample 2.)

5. Retained by 100-mesh screen. (Note foraminifera.)
6. Retained by 150-mesh screen.

Magnification, 16½ diameters.

[To face page 106.

capacities approaching those reached by regular spheres. Some experiments were undertaken, at the instigation of the author, to determine the relative proportions of grains that would pass various sized screens up to 200 meshes per inch, beyond which the screens are unreliable. Much difficulty was experienced in cleansing the particles of oil to effect their absolute separation. The results suggest a direction for useful study, and particularly disclosed the wide variation in average size of particles within the same field. Appended are the results of a few Russian oil sands.

RESULTS OF SCREENING RUSSIAN OIL SANDS.

Size of Screen.	Percentage by Weight Detained by Screen.				
	Sample 1.	Sample 2.	Sample 3.	Sample 4.	Sample 5.
20 meshes to inch	...	...	...	...	...
40 " "	...	...	...	...	...
60 " "	...	...	...	...	...
80 " "	...	1.6	...	...	...
100 " "	...	4.9	...	5.2	...
150 " "	6.9	29.6	...	24.7	0.2
200 " "	19.7	38.1	...	31.4	19.1
Passed 200 meshes	73.4	25.8	100.0	38.7	80.7
	100.0	100.0	100.0	100.0	100.0

Provided oil sands can be cleansed of the last traces of oil without raising to high temperatures, there is little doubt that the elutriation process described and applied to metallurgy by H. Staddler[1] would prove useful for the separation of sand grains. By carefully adjusting the velocity of flow of water, fine grains of various grades can be isolated and collected in a way impossible by other methods. There is, however, the objection that density influences separation, and there might be cases where the particles varied sufficiently in specific gravity to diminish the value of this process.

The rich oil sands of medium grade have a very curious appearance when raised fresh from wells, and in Russia their

[1] "Grading Analysis by Elutriation," H. Staddler, *Trans. Inst. Mining Metallurgy*, 1913.

PLATE IX.

FIG. 7.—NODULE OF CALCAREOUS SANDSTONE WITH CARBONACEOUS NUCLEUS, FROM BAKU OIL-FIELDS OF RUSSIA.

FIG. 8. HOLLOW CONCRETIONARY NODULE FOUND IN PERUVIAN OIL-FIELDS.

[*To face page* 108.

Peru presents many fine examples of the influence of calcareous impregnation. The author traced, in a hillside section, an exposure where a thick, richly-saturated oil sand suddenly changed into an almost flint-like calcareous sandstone absolutely barren of oil. The erratic yields of wells penetrating the same source are largely accounted for by this variation in composition of the oil-bearing stratum.

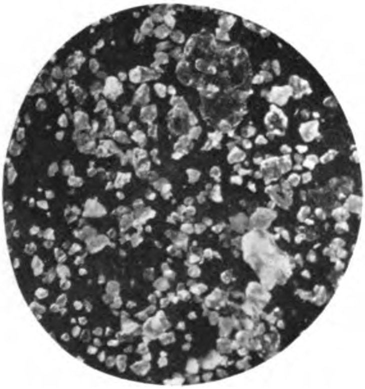
With the exception of California and parts of Texas, American oils of an arenaceous origin are mainly confined to consolidated or cemented sands, many of which only yield up their oil contents when subjected to considerable concussion by blasting with high power explosives. Enclosed petroleum lies stored either in irregular or discontinuous lenticles throughout the main mass, or in slip and joint planes which, until adequately disturbed, do not allow the contained fluids to issue. Sometimes little or no manifestations of oil are noted where the anticipated sand has been penetrated by drilling: at other times only insignificant yields are obtained till a powerful torpedo is fired to fracture the stratum. Wells are rejuvenated by repeating the process of blasting at intervals when the supply of oil decreases (see Chap. VII.).

Other fairly calcareous sands, like the "hundred foot" of the lower Carboniferous of the Appalachian oil-fields—a stratum which has been traced over thousands of square miles—only yield oil in certain localities, but even within those areas of concentration oil is confined to certain soft patches or pay streaks of extremely varying dimensions. The productive lenticles are often coarser sands, conglomeratic in nature, and far more porous than the surrounding sandstone, which is itself of medium coarse grain and porosity.[1]

When oil sands do not disintegrate with the extraction of oil, it is natural to anticipate a much lower rate of yield than from sands which break down, and so permit the expulsion of their contents.

Sands and sandstones displaying no calcareous cementation are often impregnated in an irregular manner which is difficult to explain. Sections of thick sands in the Guapo District of

[1] "Study on the Application of Anticlinal Theory of Oil and Gas Accumulation," Malcolm Munn, *Economic Geology*.



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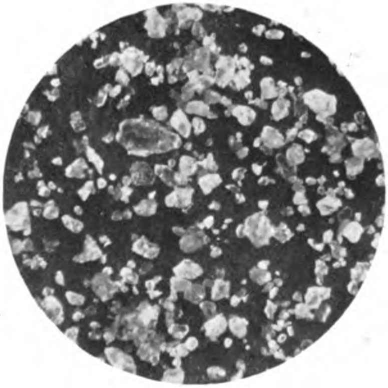

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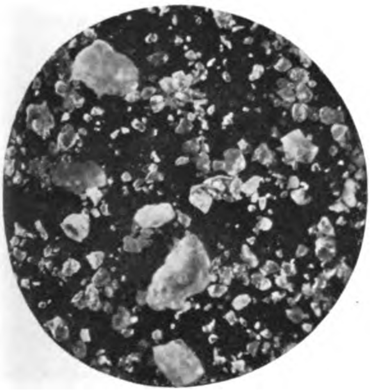

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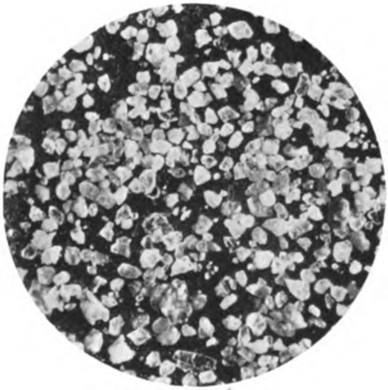

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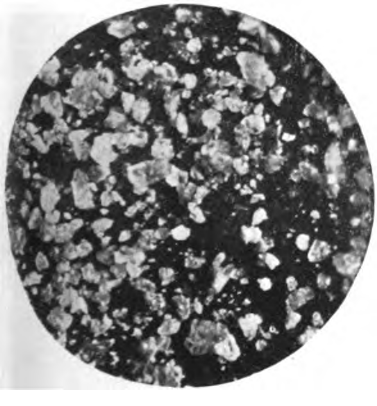

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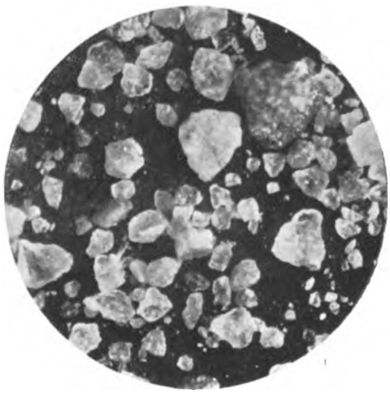

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FIG. 11.—ROUMANIAN OIL SANDS.

1. Moreni (Pana). 2. Moreni (Bana) Dry Sand. 3. Gropi.
4. Moreni (Stavropoleos). 5. Tsintea. 6. Chiciura.

Magnification, 17 diameters.

[To face page 114.

Roumania. Large flowing wells on this plateau led to the impregnation of the gravels with oil that was transported from point to point by water. For miles around the peasants extracted oil where formerly they drew water, and on the hill side where the plateau is cut into by the River Doftana, oil may be seen exuding from the gravels.

Faulting or damaged casing in an oil well will permit upper exhausted or barren oil sands, or even drained water sands, to be replenished when oil is flowing fiercely from a deeper source.

Acute flexuring in all but very plastic strata must be attended by considerable dislocation, and such faulting permits of a wider distribution of petroleum and gas than originally prevailed if the essential conditions exist. A suitable series of strata overlying an oil-bearing series, perhaps deposited upon the former after flexuring had proceeded for some time, and consequently less inflected and disturbed, might form a suitable medium for the escaping contents of the lower beds. The contents of oil-bearing strata of a resisting nature, that had suffered faulting after subjection to severe stresses, might be expelled into more plastic, porous, yielding beds which could absorb any fluids.

There is abundant evidence of migration in oil-fields where the oil is still confined to the oil series, although concentrated mainly within certain vertical limits where protection is afforded from loss due to distance from surface, and so permits remunerative drilling to be performed. Beyond certain depths the oil series either ceases or water-bearing sands are struck, sands which at one time were probably oil-bearing, but from which oil was subsequently expelled by water.

Gravity naturally plays an increasingly important part in the movement, interchange, separation, and concentration of water and oil as the declivity of the flanks of an anticline increase. Proof of the migration of oil is manifested in a variety of ways. Along the crests of denuded or faulted anticlines, issues of gas and seepages of petroleum, or a mixture of petroleum and water, are of great frequency. Even along protected anticlinal crests, oil, gas, or both often escape from points of weakness. When folds deviate slightly in their main direction, such issues are generally particularly pronounced owing to fracturing, and magnify the significance of this feature as evidence of subterranean movements, as prolonged escape of gas or oil from an area leads to the formation of definite channels along lines of weakness, which continue to afford outlet for gas that expands as it approaches the surface after release from a deep-seated source.

Time may possibly be able to achieve much that seems impossible when viewed from a commonplace scientific aspect. The rocks we regard as impervious are not so in reality, and time again may effect changes in their porosity and chemical composition. There seems little doubt that as slight elevations of level of sands in some of the American regions so frequently correspond with oil-productive areas, that with these movements must be associated the concentration of oil; but although elevated points are sought and often traced and tested, strata elsewhere productive of oil do not invariably disclose pools of oil. Sometimes the sands are dry, at other times only gas is found, and no adequate reason can be advanced for this difference.

Such slight departures from the horizontal lead one to cast doubts upon lateral movements of fluids being the sole cause of concentration at certain points. Any views regarding affinity of certain sands for oil may be dismissed in this connection, as distances introduce inadmissible frictional resistances, and one naturally leans towards theories in which vertical movements are involved. As these elevations are the results of earth movements, it is conceivable that under certain circumstances areas which yielded to these forces might fracture, and through such fractured regions fluids might be admitted to a porous sand within a certain range that elsewhere was dry or water-bearing.

The concentration of petroleum under the above-named geological conditions is rendered more difficult to imagine because the sands in which it occurs are often compact masses scarcely disintegrating at all when yielding oil, from which productions are usually only obtained by fracturing the rock by powerful explosives. It is also difficult to assert positively in all cases whether hydrocarbons saturate certain portions of these sands, or occur in fissures throughout their mass. The conditions are in any case such as to impose considerable opposition to migration. Gravity alone could do very little in assisting a lateral movement, Constant action of capillarity would, assuming the above action to continue, result in the displacement of oil from the pores of fine-grained beds, and its concentration in fissures, slip planes, etc., where sands were non-existent. Absence of water would prevent this movement, as any oil distributed amidst the beds would remain undisturbed. It is admitted that capillary force would be weakened by mixtures of oil and water (emulsions), and that bubbles of oil and gas would increase resistance considerably.

The small particles of oil, which would by this means be forced into the coarse sands or fissures, may then subsequently be collected to form larger accumulations by means of slowly moving currents of water, a very important rôle being played by the gas, a gas bubble always tending to pick up a pellicle of oil.[1]

The tenacity with which petroleum clings to some oil sands will be appreciated by anyone who attempts to free sands of oil for microscopic examination.

It is possible that the selective action is of water rather than oil in certain cases. If water of sedimentation, or otherwise, were in danger of displacement by intrusion of oil, certain patches of sand of, say, an acid character might display greater tenacity for water than others through the water adhering more firmly to the quartz grains. Other portions containing metallic sulphides might resist wetting by water, and would attract oil in preference. Such phenomena form the basis of the mineral separation flotation processes. Certain portions of sands possessing affinity for water would in this way retain water, whilst others became saturated with oil, the former eventually acquiring a pressure due to the sub-capillary pore water of surrounding shales. An upper layer of sand might, in this way, yield a negligible amount of water and oil, when the lower would prove prolific of oil.

Lenticles of more acid sandstones might, similarly, retain water in a mass of more neutral or basic sand, and resist tendencies to displacement by oil. Such sand might appear "dry" to the driller. Lenticles of this nature would form a convenient receptacle for the deposition of carbonate of lime, iron oxides, or sulphides that might arise from the action of oil or water, or both on surrounding country

[1] "The Accumulation of Oil and Gas in Sandstone," Roswell H. Johnson, *Science U.S.*, Vol. XXXV., 1912.

Opponents of orthodox theories sarcastically remark upon the kindness of Nature in withholding the escape of contained oil in outcropping inclined strata until suitable beds have been deposited along their exposed edges to receive their contents. This latter criticism is perhaps not quite justified, as there are numerous oil-fields operated to-day in proximity to, or in the midst of seepages where oil and gas have been escaping for unknown ages without exhausting their fluid contents. The only intelligent explanation of such phenomena as California presents, if geologists have correctly interpreted the intimacy above alluded to, is that water under hydraulic pressure has carried with it oil from the mother series in its efforts to find an outlet, the oil particles in its path being detained by surface friction whilst the water continued on its way. It might be argued that the oils now found are merely a residue of lighter products, in which case one would expect to find more frequent indications of the lighter varieties; nevertheless, the contention is reasonable.

Commendable criticism of the anticlinal theory of oil accumulation is submitted by Malcolm J. Munn[1] in discussing the structural features of certain oil pools in Pennsylvania. Careful levelling of some 2,000 wells, spread over an area of about 226 sq. miles, confirms the main occurrence of petroleum pools along the crests and near flanks of anticlinal folds. The sand selected was that known as the "hundred foot," near the base of the Carboniferous, as this was readily detected and sufficiently continuous to cover the whole area under study. Dips of from 1 in 26 to 1 in 175 were revealed within the area of concentration, and it was observed that mixed oil and water impregnated only certain detached lenticles throughout the sand. The proportion of oil, water, and gas, or level of liquid bore no relationship to the position of the pay streak or to each other, but it was remarked that exhaustion of water corresponded with exhaustion of oil.

Special attention is directed by Munn to the impossibility of accepting gravitation as the operative force where dips of such insignificance occur, and when the maximum difference of specific gravity between the contained oil and water was 0.2646.

[1] "Studies of the Application of the Anticlinal Theory of Oil and Gas Accumulation" (*Economic Geology*).

is no transition stage, and the disturbed condition of the Saliferous cores precludes recourse to explanations involving varying oil-forming conditions at various stages in the Salifère. It is difficult to conceive of any selective properties of certain oils for strata, or of strata for certain oils, and one is forced, therefore, to indulge in suspicions as to the common origin of the oil from the Salifère. Reference to p. 124, and Chapter V., will facilitate an understanding of the above.

Differences of density and varying percentages of contained hydrocarbons admit of explanations in numerous ways and, indeed, would rather be anticipated where migration had proceeded in numbers of distinct types of strata under profoundly different structural conditions, but differences in essential properties of oils, whose very origin is often attributed to a different cause, admit of no such simple explanation.

Problems of this nature are rendered more mysterious and inexplicable by the fact that in several of the Roumanian oil-fields beds of an identical age, within definite belts, present no agreement as regards their oil contents. At Moreni, Filipeshti, and Campina the Meotic beds yield true paraffin oils that are nearly solid at winter temperatures, although everywhere else in the country, even on the same anticline to the east, the Meotic series yield typical asphaltic oils when they recline against the Miocene Salifère.

This subject would be incomplete without reference to the Boryslav-Tustanowice oil-field of Galicia, which produces consistently to ascertained depths rich paraffin-bearing oils, besides considerable quantities of the solid ozokerite in the higher beds of certain parts of the field. Elsewhere in Galicia, oil-fields yield normal asphaltic oils, but areas are known, as also in Roumania, where seepages of paraffin oils or veins of ozokerite testify to the further existence of this grade of oil, although payable oil-fields have not been developed.

It is probably unwise to attach too much importance to the above inconsistencies, in view of the recognised ignorance of the true relationship of paraffin-base and asphaltic-base oils, but such conflicting results within narrow limits suggest caution in drawing sweeping deductions.

Causes of Pressure.—Petroleum does not flow from wells like hydrostatic head, and estimations based on levels of outcrops taken in the Appalachian oil-fields of the United States gave some basis for such assumptions. The hydrostatic theory is now discarded as untenable when applied to other oil-fields, and it is now known that pressures indicated by wells in the same field disclose such disparity, and occasionally such excessive pressures, that a hydrostatic origin is precluded from consideration.

Pressures as high as 1,500 lbs. per square inch have been recorded in West Virginia, where the wells are deep, but the more usual pressures vary from a few pounds to 500 lbs. per square inch. Closer investigation supports the view that pressures have often been overrated, and recent oil-field studies indicate that closed pressures are usually well within the limits of a hydrostatic pressure due to the depth of source measured from the level of water saturation. A depth of 1,000 ft. corresponds to a hydrostatic head of 432 lbs. per square inch, so that at 2,000 and 3,000 ft. respectively, pressures of 864 and 1,296 lbs. per square inch would result. If water were the controlling factor of pressure, consistency of pressures at constant depth below a certain datum would be anticipated, at least in the initial career of an oil-field, but no such constancy exists. If the static head of liquids in the well is taken as the indicator of pressure, some measure of comparison should be possible. Experience, however, shows that the levels of wells within the limits of a single field vary greatly, and no relationship can be established when presence or absence of water is allowed for. In the above figures fresh water has been taken as a basis of calculation.

The static heads of both water and oil, with due allowance for differences of density, do assume some regularity in some oil-fields within certain limits; and this head diminishes with the exhaustion of the field. Within circumscribed areas some fair consistency was noticeable in the steady lowering of static head in the Baku oil-fields as exhaustion proceeded, and it was especially observed that the water and oil acquired the same relative heads. Wells which turned from oil to water through imperfect exclusion or other causes indicated almost identical static heads.

Without the influence of gas, petroleum should obviously acquire a pressure equal to the hydrostatic head of capillary pore water, Oil pools in the Appalachian, Canadian, Roumanian (Bushtenari), Peruvian, and Russian (Balakhany and Maikop) oil-fields show declining, and in some cases almost total, exhaustion of petroleum without any influx of water such as would have followed its concentration under a hydrostatic pressure. In practically all the above cases referred to, depth of the oil sources assured a static head, if water existed, of sufficient moment to flood the areas involved.

The high pressures met with at the base of the syncline separating the eastside and westside oil-fields of Coalinga could not be accounted for by a hydrostatic head, nor would it explain the high pressures encountered in the syncline between certain folds in Trinidad.

Oil-field waters disclose chemical characteristics which often disclaim association with normal subterranean supplies. They present features which discourage migration ideas, and suggest their lifelong intimacy with the oil series from which the oil is still being extracted. Nevertheless, realising the extremely complicated structures and excessive faulting in many of the great oil-fields, it would be presumptuous to be too dogmatic about the influence of a hydrostatic head at some stage when internal circulation of fluids was not impeded by innumerable faults and involved flexures.

As explained more fully under migration, water has often been the medium of transportation and distribution of oil, and in some cases a hydraulic head has probably been partially responsible for the high pressures of oil isolated and held in position against impassable barriers, as in parts of Mexico.

The source of what might be termed the potential energy of petroleum is in reality hydrocarbons, some in a gaseous state, others in solution, but all capable of becoming kinetic and exerting great force when pressure is relieved. To methane must be mainly attributed the high pressures prevailing in oil-fields. Its close connection with oil through processes of migration, without separation, arouses the suspicion that its production continues, thus enhancing subterranean pressures within certain limits of pressure.

Assuming that the ideas put forward by the Engler school as to the process of conversion of fatty materials into petroleum conviction that their penetration at depth would lead to yields far beyond normal, and not in vain.

The development of the nearly horizontal, compact, and little faulted sands of many of the American oil-fields leads to no phenomena of note, as the maximum yield is at first, and production tails off as drainage ensues, until a shot is fired to break up the stratum further afield, and give the well renewed vigour. Not so with the more complicated, folded Tertiary oil-fields, especially where the sands are not compacted, and readily disintegrate, and travel with the petroleum they contain. The initial yield of oil is often small, and gas alone may be discharged for days, weeks, or even months before oil in quantity appears. The author has seen clean white sand violently expelled from Russian and Roumanian wells for many days before oil appeared, the whole country round being strewn with a covering whose weight caused the collapse of the roofs of buildings upon which it had fallen and accumulated. The sand becomes mingled with a gradually increasing spray of oil, until productions of several hundred tons, and sometimes several thousand tons daily are reached.

Expulsions of dry sand are not viewed with alarm, as they are frequently followed by oil, if struck within the limits of an oil-field. Provision is being naturally created for oil accumulation, by extending the influence of the well far beyond its immediate vicinity. The removal of much sand from wells, as generally occurs in the early stages of development of oil-fields where the oil is contained in loose sands, promotes the formation of an area of low density around the mouth of the lining tubes into which oil infiltrates and accumulates prior to its removal. For a long distance around the well the sand may, under the influence of agitation by gas, be impregnated to the extent of 50 per cent. of its volume, forming valuable receivers for the wells. From some of the richest areas in the Baku oil-fields as much as 20,000 tons of sand per acre have been ejected or raised with the oil.

The influence of early wells on an oil source extends much further than furnishing an area of high absorption and low

PLATE XV.

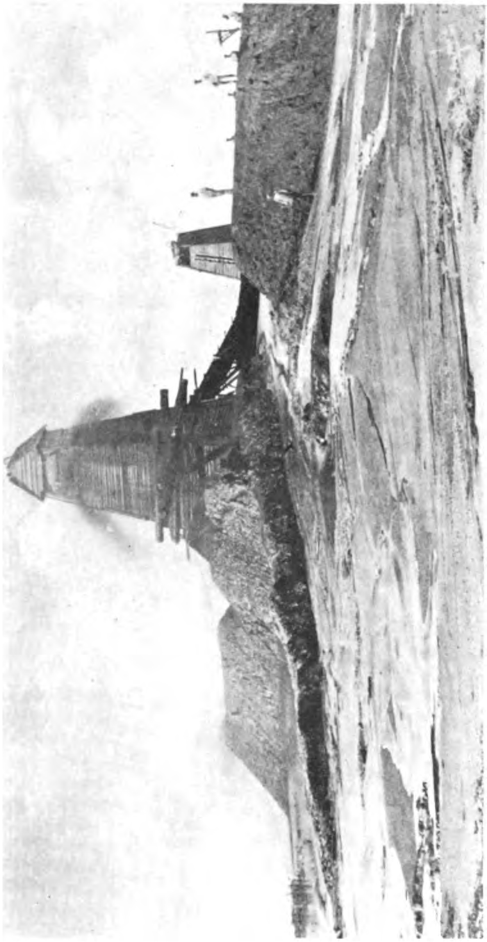

FIG. 14.—GREAT FLOWING OIL WELL IN BAKU OIL-FIELDS.
Showing streams of oil and accumulation of discharged sand, almost burying the derrick.

[To face page 138.

in time to share in the production, if not to deflect the flow entirely.

The world-famed "Oleum" property (Group XIX.) in Bibi-Eibat, Russia, owes its great productivity to the phenomena under discussion. It was the earliest property developed in the oil-field, and it was here that the greatest and most numerous gushers were brought in. From 27 acres between 8,000,000 and 9,000,000 tons (60,000,000 and 67,500,000 barrels) of oil were extracted in thirty years, and not less than 500,000 tons of sand have been ejected or raised with the oil. The sponge thus formed, aided by disintegrated fault planes, was continually replenished by inflowing oil from all around, as its contents were abstracted by bailing. The property thus acquired and retained a value never approached by any of the surrounding lands which, at a later date, entered development. In this case the water factor, to which reference is made later, largely entered.

The sensitiveness of petroleum wells is not generally appreciated. A sudden diminution or cessation of yield is not natural, and must be due to abnormal causes demanding careful investigation. Oil sands do not suddenly run dry, nor momentarily acquire greater saturation, and great fluctuations of yields are due to subterranean disturbances which should be studied. Influxes of oil are naturally attributable to subterranean landslides opening up a wider area, as the great inrush of sand which is often contemporaneous with the inrush of oil proves. Sudden diminutions of yield are due to checks and obstructions that in some cases clear themselves in time.

A very little change of conditions often has a remarkable effect upon the subterranean movements of oil, as the following selected examples which have come under the author's personal observation will show. A well which had yielded for years dried up, and was set aside for deepening. When prepared for drilling some months later, so much oil was found standing at a high level in the well that it was decided to bail it out. The level fell very little, and bailing was continued, with the result that the well yielded between 20 and 10 tons take advice upon such matters, and let each case be judged by circumstances.

Approach to a faulted zone of disturbed ground in some oil-fields is fraught with risk of failure, and sometimes absolute danger, but in other regions it is along the fault planes that the greatest producers are struck. The employment of high-power explosives in hard oil sandstones or dolomites to induce fractures is, in some fields, a recognised procedure, owing its origin to an appreciation of the benefits of fissured strata. Several leading operators in the Baku oil-fields, as far back as 1900, observed the influence exercised by faults of sufficient throw to locate their position, and measure their displacement and hade at the surface. A series of exceptionally large gushers were found to be so located that inclined faults were struck at considerable depth, and this information led to the location of wells to strike known faults at estimated depths.

Mrazec has long called attention to the importance of the junction planes between the Miocene Saliferous series and other newer strata reclining unconformably against them, and it is near them that great producers have been located in Roumania. This feature is particularly noticeable at Moreni and Baicoi, where extremely prolific gushers have resulted.

Attention should be called to the possible influence of wax in oil-fields yielding paraffin-base oils. That wax is deposited in wells is abundantly proved by large masses cleared or ejected from bore holes at intervals, and by the accumulations on the pump tubing and pump valves. Sir Thomas Holland has called attention to this feature in the Yenangyaung oil-field of Burma, and mentions *inter alia* that two opposing factors are at work. Temperature due to depth tends to keep liquid the wax, whilst loss of dissolved gases and lighter products with diminishing pressure reduces both the solvent properties and temperature of the oil, and favours the deposition of wax. Producers in the Boryslav-Tustanowice oil-field of Galicia have long appreciated the sealing effect of precipitated wax around the base of bore holes, and have evolved a process of swabbing (see p. 482) which draws in the accumulating wax, and assists and Ohio, most operators consider that a much greater proportion of the oil can be secured than where the salt water is absent, since the water acts as a rinsing fluid to flush the petroleum out of the sand, and bring it freely into the well. It is also claimed by the practical oil producers that the tendency of the rock to become clogged up with paraffin is much less when the petroleum is accompanied with salt water than when it is absent, so that for both of these reasons it is most probably true that the sand will yield up a greater portion of its oil when the latter is accompanied by salt water."

Malcolm Munn also refers to the contemporaneous exhaustion of water and oil in the Sewickley quadrangle of Pennsylvania in the same "hundred foot" sand, and the universal association of the two fluids in operated pools.

Some oil-fields in the final stages of exhaustion, like that of Petrolea, Ontario, Canada, owe their very existence to the presence of water which percolates into the nearly exhausted porous dolomites, rinsing out their remaining contents, which are pumped from numerous wells towards which the mixture flows. Advantage is taken of spring rains or a large freshet at Oil Springs, Lambton Co., Ontario, to pump oil washed from the Corniferous limestone, and raised to certain points on the anticline. Certain wells were pumped in progressive rotation as the water advanced or receded, carrying with it extracted oil.[1]

The present yield of the great Baku oil-field is mainly due to the prevalence of water, which, gaining admission to the exhausting oil sands, rinses them and carries their contained oil to hundreds of points of extraction. Many very payable wells give five volumes of water to one of oil, and a proportion of two of water to one of oil is exceedingly common. Few oil-fields, indeed, are entirely free from water, and in many the quantity of water diminishes as the field develops. Saturated water sands, at first demanding expensive methods for the exclusion of their contents, discharge slowly into the oil sands beneath as the latter become exhausted, each faulty or damaged well providing a passage for its descent, and each disturbed fault plane a possible channel for its wider distribution.

Descriptions of several interesting wells given below will illustrate the influence of the features just described. The pioneer

[1] Technical Paper 51, Petroleum Technology 11, L. G. Huntley, Bureau of Mines, Washington.

Such violent eruptions as those described could not fail to induce a movement of oil unattainable under quiet conditions.

It appears certain that isolated volumes of water trap and retain bodies of oil under pressure under certain conditions, and that the expulsion of the oil when relief is afforded by drilling is followed by an invasion of the water which caused its isolation and accumulation.

That the development of an oil-field might cause a certain redistribution of oil is an obvious deduction. Baku producers assert that such occurred in parts of the Russian oil-fields, areas originally unproductive yielding oil at a later period. The same is reported from the Appalachian oil-fields where the relief of gas under great pressure has been followed by admission of oil.

The beneficial influence of admitted water to oil strata in areas approaching exhaustion is discussed at some length by Huntley,[1] in a publication of the Bureau of Mines. Attempts to flood oil-bearing strata, with a view to concentrating oil, have met with indifferent success in Pennsylvania, mainly on account of insufficient data being available bearing on underground conditions, thereby rendering predictions uncertain. On monoclinal dips, water admitted at strategic points will travel down the dip and carry oil in its path to pumping wells, but in regions of low dips, variations of porosity and partial vacuum applied to wells may cause fluids to travel laterally or up the dip. It is agreed that admitted water could isolate and concentrate bodies of oil under some conditions, causing certain groups of wells in the affected area to give high yields for a time.

Conflicting interests with divergent opinions have proved an obstacle to the testing of large areas in this way under scientific direction. That the subject warrants investigation is obvious, and good results can be confidently predicted in certain areas where comparative regularity of sands in thickness, texture, and dip minimises uncertainties to a negligible quantity.

Exhaustion of oil can be traced and followed in certain unfaulted monoclines, where sand lenticles display fair regularity,

[1] "Decline of Oil Wells," L. G. Huntley, Bureau of Mines, Washington, 1913.

energetically developed properties can attract oil from surrounding territory.

Grosny affords an example of excessive enrichment in a less rich oil-field. The Akhverdoff property, still one of the best producers in the field, has yielded 42,000 tons of oil per acre, equal to a 40.5 ft.-acre volume. Assuming in this field an average 10 per cent. recoverable saturation, this would correspond to the contents with gas of about 500 ft. of strata; a very excessive figure for the field, and clear proof of lateral travel.

In some of the richest districts of the Baku oil-fields as much as 20,000 tons of sand per acre have been ejected with the oil from wells.

The above calculations serve to prove how illusory prophecies of prospective yields may prove in the Tertiary flexured type of oil-field, also the fair approximation possible in certain less disturbed areas. The area influenced by a productive well is often considerable. One well may flow unaided so long as another does not, but on the second developing a natural flow the first ceases. An influx of water in one well will often be transmitted within twenty-four hours to a whole series of wells. Cessation of pumping in one well leads to improved yield of another, and at times certain wells may be pumped for water alone, suspension of such pumping leading to the flooding or reduction of yield of other wells in the vicinity. Cement fluid used for excluding water has been traced far away in wells bailing from depths near that horizon. Occasionally in rich ground the activity of one well will excite others near by, causing them to flow also. Almost every oil-field attendant can recall numerous cases proving the sympathy of wells.

Where individual plots are of limited extent and surrounded or bounded by active competing neighbours, it is usual to drill hastily a large number of wells along the boundaries without any regard to economy. Custom and mutual goodwill, in some fields of medium richness, have reduced the evils of such competition, but generally in the rich fields the greatest efforts are made by conflicting interests to drill along boundaries, the earlier circumscribed circle requiring to be eliminated through extending beyond the area of enrichment.

The most effective distribution of wells to ensure equal drainage, so far as that is possible under oil-field conditions, is to locate the wells equidistant, *i.e.*, in equilateral triangles. Circles drawn round the three apices then give a minimum of overlap, or alternatively leave the minimum of area outside a radius equal to half the length of one of the sides of the triangle. Locations on steeply inclined flanks of anticlines or monoclines are sometimes spaced so that those down the dip are nearer than those along the strike, but in all cases wells on a second line along the strike are spaced to be between those on the first line.

Offsetting has become a recognised practice in American oil-fields where acquired customs often supplant law. Notwithstanding the absence of obligation to drill and even the provision for payments as compensation for delay in drilling, there is an implied covenant to drill offset wells if a productive well is drilled near the boundary on a neighbouring plot. It is claimed that failure to drill within a reasonable time seriously impoverishes the undeveloped land, and the owner is therefore entitled to relief.

Mutual goodwill and sound common sense have gradually established a custom in America of not drilling nearer than a fixed distance, often between 150 ft. and 300 ft. from the boundary of the property; consequently, a minimum of 300-600 ft. between wells is obtained, and this serves to avoid the wasteful competitive drilling that so often characterises the development of European oil-fields. As each well is drilled along the boundary of one property an offset is demanded and drilled in on the adjoining property to maintain a balance. The author has himself initiated and put into practice elsewhere this reciprocal arrangement without any recourse to law; and the custom is well worth cultivating in many fields where competitive drilling is now in vogue.

Yield and Life of Oil Wells.—Life and production of oil wells only occasionally bear a direct relationship to each other, and to the degree of exhaustion of the beds to which the wells are

Plate XVI.

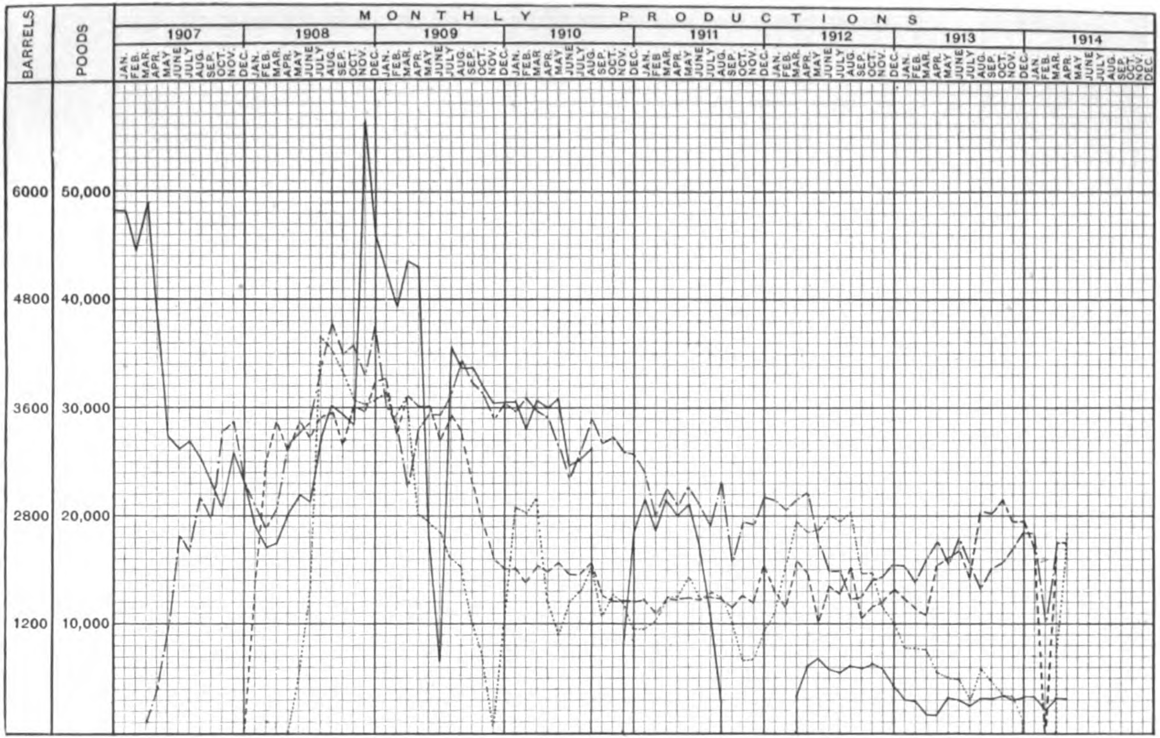

Fig. 15.—Monthly Production Chart of a Group of Four Wells in the Saboontchy District, Baku, showing Decline of Production.

[*To face page* 154.

Field.	Yield per Diem.	Approximate Conversion to Tons.
	Barrels.	
Appalachian oil-fields	1.73	.23
California	42.56	6.08
Lima-Indiana	2.74	.39
Colorado-Wyoming	8.35	1.11
Mid-Continent	8.81	1.20
Gulf	19.35	2.76
Illinois	8.37	1.14

Mechanical improvements in the methods of drilling oil wells and extracting petroleum are yearly enabling lower and lower grade properties to be profitably operated. So pronounced is this progress, that lands of little value a few years ago are acquiring considerable importance and realising high prices.

Production and Life of Oil-Fields.—Exhaustion, in oil-field phraseology, is a relative term only, and implies that the oil beds have been so far depleted that petroleum can no longer be extracted at a profit at the moment. An increased market value, a new invention, an improved system of drilling or extraction often invites renewed activity to abandoned areas, and leads to the recovery of thousands of tons of oil from so-called exhausted areas, much in the same way as modern mechanical or chemical methods enable abandoned mines to be reopened, or rejected "dumps" to be re-treated at a profit.

Supplies of petroleum in most oil-fields are derived from a succession of sands separated by unproductive strata, and in some cases the lower productive seams cannot be reached, except perhaps over a limited area, with the appliances in use, or at a cost that renders operations profitable.

Had the price of oil in Russia remained at the figure of 7s. 6d. per ton (24 cents per barrel), that it was in 1901-3, the great Baku oil-fields would long ago have been abandoned, and the deep sources left untouched. The old Appalachian oil-fields which have so long remained nearly derelict were in 1913-14 the centres of considerable activity, owing to the price of Pennsylvanian grade oil rising in value from 30s. to 75s. per ton ($1 to $2½ per barrel).

volume must be allowed for unextractable oil. Lenticularity of oil sands is a feature itself often imposing strict limitations to volumetric calculations, but irregular impregnation due to variable grades of sand, and partial or entire cementation of portions by carbonate of lime, silica, or other material, introduces uncertainties in most fields, nullifying the value of such estimations.

Other causes which modify estimations of oil contents are found in the location of the area with regard to degree of declivity and direction of dip. Initial wells near the crest of an anticline, where there has been concentration either of gas or oil, yield results that make all calculations appear absurd. Some such localities give only gas, others astounding quantities of oil. In many cases active development at low points on the dip of inclined strata causes so complete exhaustion of the sands at more elevated points that the latter yield merely a small percentage of the oil their position would have entitled them to under other circumstances.

Quite apart from geological features, which detract from the value of such figures, there is the question of the relative development activity on adjoining or surrounding leases. Impecunious, unskilled, or unenterprising leaseholders may have their lands largely drained by rich, skilful, and active neighbours.

Even approximate estimates of the oil contents of well-known oil-fields are difficult to prepare, as few famous fields have been exhausted or abandoned except through some catastrophe. Extensions of existing areas and penetration of deeper sources constantly modify calculations, nevertheless useful figures have been collected which aid one in forming rough approximations of capacity.

Selected parts of Pennsylvania have been estimated by State geologists to yield about 200 tons (1,500 barrels) of oil per acre, and the State geologist of West Virginia considered the oil beds of the State to be capable of giving a maximum of 650 tons (4,900 barrels) per acre.[1] In reviewing the subject in 1909,[2] it was estimated that the average yield on the Pennsylvanian oil-fields would not exceed 100 tons (750 barrels)

[1] "West Virginian Geological Survey," Vol. I., 1904.
[2] "Petroleum Resources of the United States, 1909," by Dr David Day.

extends to the south-east, has been obtained 150,000,000 tons (1,125,000,000 barrels) of oil; in round figures, 60,000 tons (450,000 barrels) per acre. In 1914 this area yielded 3,880,000 tons (29,000,000 barrels) of oil. The oil withdrawn from this rich field would fill a receptacle equal in area to that of the field to a depth of 57 ft.

Roumania furnishes examples of extremely rich oil-fields. An area of about 130 acres at Moreni has in ten years given 4,000,000 tons (30,000,000 barrels) of oil, or 30,000 tons (225,000 barrels) per acre. In 1913 the total output was 981,900 tons (7,350,000 barrels), or 7,000 tons (52,500 barrels) per acre. Galicia supplies one example of fame—the Boryslav-Tustanowice oil-field—where 12,000,000 tons (90,000,000 barrels) of oil have been abstracted from about 1,500 acres, or 8,000 tons (60,000 barrels) per acre. 897,000 tons (6,730,000 barrels) of oil were raised from this field in 1913, indicating its remoteness from exhaustion.

A single sand in the Maikop oil-field of Russia had produced 11,000 tons (82,500 barrels) per acre, about 314 tons (2,355 barrels) per acre-foot, or 30.4 per cent. by volume on the irregular area over which it has been located by drilling, and was in 1913 still producing 80,000 tons (600,000 barrels) per annum. Average Peruvian oil-fields appear to have a capacity of from 1,000-3,000 tons (7,500-23,500 barrels) per acre, but areas of increased enrichment have been struck.

Mr I. Streezhoff in 1910 placed the yield of Grosny (Russia) oil properties at 3,500,000 poods per dessiatine, or 21,000 tons (157,000 barrels) per acre, and stated that from the Akhverdoff property 7,000,000 poods a dessiatine had been extracted, equal to 41,700 tons (310,000 barrels) per acre. The total capacity of 1,600 dessiatines (4,300 acres) at Grosny was estimated at 11,200,000,000 poods (180,000,000 tons = 1,350,000,000 barrels), equal to 40,000 tons (300,000 barrels) per acre.

Oklahoma lands vary greatly in productivity, the yield probably lying between extremes of 200 and 2,000 tons (1,500 and 15,000 barrels) per acre. The yield per acre-foot of oil sand has probably been much greater in the deeper territory than in the shallow belts.

Typical Well Logs.—Attached are a few typical well logs from widely separated oil-fields :—

TYPICAL LOGS OF WELLS FROM VARIOUS OIL-FIELDS.

Well, Neosho County, Kansas, U.S.A.

(Yield, 4 to 5 barrels of oil a day. 5-in. casing to 623 ft.)

	Depth in Feet.
Surface soil	0-20
Brown gravel (fresh water)	20-30
Hard grey limestone	30-56
Sandstone	56-61
Hard grey limestone	61-65
Soft grey shale	65-70
Hard grey limestone	70-75
Soft grey sandstone	75-80
Soft grey limestone	80-115
Soft grey shale (limy)	115-125
Soft grey limestone (water at 128 ft.)	125-130
Hard grey limestone	130-142
Soft grey shale	142-320
Soft light grey limestone	320-335
Soft grey shale	335-370
Grey sandstone (salt water and gas ; hole filled up 200 ft.)	370-385
Soft grey shale	385-400
Soft grey limestone	400-420
Shale	420-428
Hard grey limestone	428-458
Soft grey shale (limy)	458-490
Hard grey limestone	490-513
Hard black shale (water, 40 barrels per hour)	513-521
Hard grey limestone	521-528
Soft grey shale (limy)	528-715
Soft grey shale (sandy, top of sand show of oil)	715-720
Soft grey sandstone and shale	720-728
Sandstone (oil sand, 22-ft. pay sand at bottom)	728-752

Well at Humble, Harris County, Texas, U.S.A.

(Gas at 215, 508, 645, 670, and 700 ft. Some oil and much gas between 790 and 950 ft. Pay oil between 951 and 990 ft. Yield, 100 barrels first twenty-four hours. Diameter of well, 11⅝ in. to 310 ft., 6 in. to 950 ft.)

	Depth in Feet.
Soft grey sand	30-40
Hard grey clay	40-60
Hard bluish sand	60-215
Hard grey sand and clay	215-310
Hard blue sand and clay	310-400
Loam grey sand	400-470
Fine grey sand	470-495
Hard blue clay	495-508
Hard blue sand and clay	508-572
Hard blue clay	572-645
Hard blue sand and clay in layers	645-710
Hard blue shale	710-950
Mixed rock and sand (limy)	950-990

	Thickness in Feet.	Depth. in Feet.
Sandy shale - -	64	982
Sandy shale (small streak of white sand with water) - -	40	1,022
Sandy shale (some clayey shale and sand) - - - -	29	1,051
Sandy shale (*with some oil at* 1,070 *and* 1,080 ft.) - - - -	49	1,100
Shale (much gas and oil entering) - -	10	1,110
Sand and shale (much oil) - - - - -	22	1,132
Shale (carrying oil) -	40	1,172
Shale and oil sand (much oil and gas) -	53	1,225
Broken shale (much oil)	5	1,230
Shale and oil sand (much oil) - -	20	1,250
Shale (gas increasing) -	18	1,268
Shale and sandy shale (with oil) - - -	28	1,296
Shale (much oil) - -	12	1,308
Pulverised shale (1,310-1,315 ft., light oil beneath) - - -	11	1,319
Shale (with oil) - -	19	1,338
Grey shale (strong gas)	4	1,342
Shale - - - - -	42	1,386
Sandy shale (gas flow heavy; well filled up 400 ft. with mud, water, and oil) - -	5	1,410
Light-coloured shale (no mud, no oil) -	88	1,498
Well filled with oil to 100 ft. of surface -	...	1,510
Well commenced flowing - - - - -	...	1,524
Oil sand (big flow of oil) - - - -	43	1,541

Well in Coalinga Oil-Field, California, U.S.A.

(Cable tools.)

	Thickness in Feet.	Depth in Feet.
Yellow sand, gravel, and boulders - - -	70	0-70
Yellow sandy clay - - - - - - - -	105	70-175
Water sand - - - - - - - -	30	175-205
Yellow clay - - - - - - - -	25	205-230
Water sand - - - - - - - -	54	230-284
Blue clay ($12\frac{1}{2}$-in. casing to 286 ft.) - -	11	284-295
Sand - - - - - - - - -	70	295-365
Blue clay - - - - - - - -	59	365-424
Blue sandy clay - - - - - - -	116	424-540
Blue clay - - - - - - - -	210	540-750
Blue sandy clay - - - - - - -	45	750-795
Blue clay - - - - - - - -	17	795-812
Hard sand - - - - - - - -	38	812-850
Blue clay - - - - - - - -	36	850-886
Sand (coarse) - - - - - - - -	71	886-957
Blue clay - - - - - - - -	203	957-1,160
Blue clay and shells - - - - - -	10	1,160-1,170
Blue clay - - - - - - - -	38	1,170-1,208
Shell - - - - - - - - -	4	1,208-1,212
Sand - - - - - - - - -	20	1,212-1,232
Blue clay - - - - - - - -	20	1,232-1,252
Shell - - - - - - - - -	5	1,252-1,257

	Thickness in Feet.	Depth in Feet.
Blue clay (30-in. casing to 782 ft.)	13	771-784
Yellow clay	101	784-885
Gas sand	50	885-935
Grey water sand	10	935-945
Water sand and rock	27	945-972
Grey sandy clay	51	972-1,023
Water sand and grey sand	13	1,023-1,036
Grey gas sand (28-in. casing to 1,050 ft.)	28	1,036-1,064
Oil sand	7	1,064-1,071
Water sand (26-in. casing to 1,085 ft.)	51	1,071-1,122
Gas sand and blue clay	51	1,122-1,173
Dry gas sand with some oil sand	45	1,173-1,218
Oil sand	15	1,218-1,233
Blue sandy clay (oil)	11	1,233-1,244
Dry gas sand	6	1,244-1,250
Gas sand and oil sand	48	1,250-1,298
Blue clay (24-in. casing to 1,323 ft.)	27	1,298-1,325
Water sand	22	1,337-1,359
Oil sand	14	1,359-1,373
Water sand	25	1,373-1,398
Sandy clay (gas)	51	1,398-1,449
Grey sand	37	1,449-1,486
Variegated clay	11	1,486-1,497
Grey sand	8	1,497-1,505
Water sand and rock	16	1,505-1,521
Water sand } 420 ft. of oil in well	7	1,521-1,528
Gas sand and blue clay } 420 ft. of oil in well	21	1,528-1,549
Gas sand and brown clay } 420 ft. of oil in well	16	1,549-1,565
Variegated clay (22-in. casing to 1,582 ft.)	22	1,565-1,587
Blue clay	15	1,587-1,602
Variegated clay	29	1,602-1,631
Clayey oil sand	14	1,631-1,645
Sandy clay	92	1,645-1,737
Oil sand (20-in. casing to 1,757 ft.)	25	1,737-1,762
Blue clay	23	1,762-1,785
Blue marly clay	8	1,785-1,793
Oil sand (18-in. casing)	27	...

Cemented between 34-in. and 24-in. casings and between 18-in. and 24-in. to exclude water. Production 100-150 tons daily.

Typical Well in the Grosny Oil-Field of Russia.

(American cable system or Russian pole tool.)

	Thickness in Feet.	Depth in Feet.
Surface sand	...	0-10
Yellow clay	37	10-47
Grey clay (24-in. pipe stopped at 50 ft.)	314	47-361
Limestone	3	361-364

	Thickness in Feet.	Depth in Feet.
Brown clay and sand	7	956-963
Grey clay and sand	15	963-978
Brown gassy clay	3	978-981
Green clay and stone	3	981-984
Brown clay	3	984-987
Clay and oil sand	7	987-994
Grey clay and sand	8	994-1,002
Brown clay	35	1,002-1,037
Grey clay	1	1,037-1,038
Grey clay and oil sandstone	21	1,038-1,059
Brown clay and sand	2	1,059-1,061
Brown clay	35	1,061-1,096
Brown clay and stone	6	1,096-1,102
Brown clay	18	1,102-1,120
Brown clay and stone	20	1,120-1,140
Grey gassy clay and sand	18	1,140-1,158
Brown clay	28	1,158-1,186
Grey clay, with exhausted oil sand	10	1,186-1,196
Grey gassy clay	12	1,196-1,208
Brown clay and oil	18	1,208-1,226
Brown clay and stone	2	1,226-1,228
Brown clay and sand	13	1,228-1,241
Brown clay and stone	2	1,241-1,243
Dark grey clay and stone	6	1,243-1,249
Dark grey clay	6	1,249-1,255
Dark grey clay and oil sand	3	1,255-1,258
Brown clay and sand	14	1,258-1,272
Grey gassy clay and exhausted oil sand	6	1,272-1,278
Brown clay and sand	5	1,278-1,283
Brown clay and sandstone	10	1,283-1,293
Brown clay	15	1,293-1,308
Brown clay and stone	13	1,308-1,321
Yellow stone	2	1,321-1,323
Brown clay and stone	8	1,323-1,331
Brown clay and exhausted oil sand	12	1,331-1,343
Brown clay and sand (14-in. pipe stopped at 1,344 ft.)	3	1,343-1,346
Grey clay and oil sand	2	1,346-1,348
Oil sand	25	1,348-1,373
Grey gassy clay and sand	1	1,373-1,374
Oil sand (not very productive)	6	1,374-1,380
Brown clay and stone	4	1,380-1,384
Oil sand	15	1,384-1,399
Grey clay	15	1,399-1,404
Brown clay	16	1,404-1,420
Brown clay and stone	12	1,420-1,432
Grey clay and green sand and stone	6	1,432-1,438
Brown clay	25	1,438-1,463
Grey sand and water	27	1,463-1,490

	Thickness in Feet.	Depth in Feet.
Brown sandy clay	13	1,490-1,503
Dark grey clay and sand	6	1,503-1,509
Brown clay and sand	11	1,509-1,520
Brown clay and stone	3	1,520-1,523
Brown clay and sand	7	1,523-1,530
Dark grey clay and sand	15	1,530-1,545
" " "	11	1,545-1,556
Brown clay	5	1,556-1,561
Brown clay, sand, and stone (10-in. pipe stopped at 1,592 ft.)	26	1,561-1,587
Brown clay	19	1,587-1,606
Green clay and sand	9	1,606-1,615
Grey gassy clay and oil sand	5	1,615-1,620
Oil sand (good production)	5	1,620-1,625
Brown clay	13	1,625-1,638
Brown clay and oil	12	1,638-1,650
Oil sand	53	1,650-1,703
Brown clay	37	1,703-1,740
Brown clay and stone	4	1,740-1,744
Oil sand	11	1,744-1,755
Grey clay and oil sand	45	1,755-1,800
Brown clay and oil	23	1,800-1,823
Brown clay and stone	25	1,823-1,848
Brown clay and sandstone	4	1,848-1,852
Brown clay and sand	12	1,852-1,864
Brown clay and oil	16	1,864-1,880
Brown clay, oil, and stone	9	1,880-1,889
Brown clay and oil sand	7	1,889-1,896
Brown clay and oil	34	1,896-1,930
Grey clay and stone	8	1,930-1,938
Grey clay and sand	4	1,938-1,942
Grey clay, green sand, and stone	3	1,942-1,945
Grey gassy clay and oil	14	1,945-1,959
Brown gassy clay and oil	5	1,959-1,964
Hard sandstone	5	1,964-1,969
Brown gassy clay	16	1,969-1,985
Brown gassy clay and oil sand	9	1,985-1,994
Brown gassy clay	5	1,994-1,999
Oil sand (big flow of oil; flowed for weeks unaided; depth of hole 2,037 ft., 8-in. pipes to 1,988 ft.)	3	1,999-2,002

Typical Well in the Tustanowice Oil-Field of Galicia.

(Production about 380 tons daily.)

	Thickness in Feet.	Depth in Feet.
Clay (17-in. casing to 87 ft.)	98	0-98
Shale (15-in. casing to 98 ft.)	33	98-131
Clay (13½-in. casing to 182 ft.)	460	131-591
Shale (12-in. casing to 246 ft.)	98	591-689

	Thickness in Feet.	Depth in Feet.
Shale	23	3,100-3,123
Sandstone	7	3,123-3,130
Clay (caving)	32	3,130-3,162
Sandstone	21	3,162-3,183
Clay	17	3,183-3,200
Shale	61	3,200-3,261
Sandstone	7	3,261-3,268
Shale	62	3,268-3,330
Sandstone	7	3,330-3,337
Shale	42	3,337-3,379
Laminated clay and shale	41	3,379-3,420
Sandstone	40	3,420-3,460
Shale	62	3,460-3,522
Sand (oil at 3,540 ft.)	38	3,522-3,560
Laminated shale and sand (caving; $7\frac{5}{8}$-in. casing to 3,640 ft.)	212	3,560-3,772
Shale	128	3,772-3,900
Laminated shale and sand (oil at 3,972 ft.)	68	3,900-3,968
Shale	32	3,968-4,000
Laminated shale and sand ($6\frac{5}{16}$-in. casing to 4,150 ft.)	160	4,000-4,160

Typical Wells in Negritos Oil-Fields of Peru.

(Casing perforated at various oil sources. Manila cable system of drilling.)

	Thickness in Feet.	Depth in Feet.
Grey shale (some oil at 220 ft.)	770	0-770
Oil sand (good oil source)	20	770-790
Grey shale	55	790-845
Oil sand (oil rose 600 ft. in well)	35	845-900
Grey shale	658	900-1,558
Oil sand (well flowing)	78	1,558-1,636

Grey shale	265	0-265
Oil sand with oil	10	265-275
Grey shale	275	275-550
Oil sand with oil	20	550-570
Grey shale	150	570-720
Oil sand (well flowing)	25	720-745

Initial productions, 20-30 tons daily.

characterise the oil-fields in the almost rainless regions of Upper Burma, Persia, Egypt, Algiers, and Peru, as well as many of the Russian oil districts, and some of the western fields of the United States.

The presence of petroleum in the rocks of a district is not always indicated by any outward signs which would give the least clue to a casual observer. Many of the oil-fields of the world owe their discovery to the casual striking of oil in wells sunk for water, or during searches for brine, which is commonly associated with oil. Drake's original well at Oil City was sunk amidst brine wells, and as recently as 1908 a rich find of oil resulted from the drilling of a water well in the Argentine Republic, at Comodore Rivadavia, by the Government of that country. In some regions there are seepages of crude oil which intimate the existence of supplies beneath the surface, and occasionally the issuing oil is allowed to accumulate in pools, from which it is periodically removed. On two occasions, in the years 1908-9, great quantities of petroleum suddenly issued from cracks in the ground along the Trans-Caucasian Railway, where oil-bearing strata occur; and in the later case, near Aliat railway station, it was said that the oil flowed in such quantities that large lakes of oil were formed on the surface, inundating the railway line for some distance. The varied phenomena attending the distribution of petroleum will be described and explained in detail in the following pages.

The predominance of unconsolidated plastic clays and clay-shales, that especially characterise oil-fields of Tertiary age, results in a form of weathering that is repeated in many far distant regions. Amidst such surroundings disintegration proceeds at a rapid rate, especially under the influence of rains and frequent landslides, and heavy mud greatly impedes normal operations during wet seasons. There is an extraordinary resemblance in such far-separated fields as Roumania, Galicia, Russia, Burma, Peru, and California.

In the neighbourhood of some oil-fields massive outcrops of sand, stained or even saturated with oil, bear eloquent testimony to their importance as possible sources of petroleum. Around the

FIG. 19.—LARGE MUD VOLCANO IN ERUPTION, TRINIDAD.

Many thousand tons of puddled clay were ejected in a few hours, accompanied by the evolution of hundreds of thousands of cubic feet of inflammable gas.

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evolution of immense volumes of gas. This central crater had a diameter of about 60-80 ft., and the discharged mud was so soft around that close approach was unsafe. At intervals of a few minutes violent eruptions occurred, accompanied by the evolution of enormous volumes of gas, causing the ejection of many tons of clay to a height of 20-30 ft. Before each explosion the ground for a radius of 50 ft. heaved and quivered, and the central portion rose slowly until it burst, causing the expulsion of masses of clay, the bulk of which fell back into the crater in great blocks.

Where water is present in large quantities mud volcanoes do not display the same violence, as the well-mixed mud is kept thin by constant agitation, allowing the gas to escape more freely through the fluid mass at any point. In another case the author made an estimate of material ejected in less than one hour, and found the quantity to exceed 35,000 cub. yds. spread over an area of several acres. Large cracks opened up in the ground over an area of many acres.

On the 21st December 1897 the disturbance occasioned by an earthquake led to the formation of a great mud volcano beneath the sea off the southern point of the Klias Peninsula of Borneo, when sufficient argillaceous material was ejected to form a new island 750 ft. long, 420 ft. wide, and 20 ft. above sea-level. The eruption occurred on the crest of a well-known anticline with steep sides, on which petroleum and gas exudations had frequently been observed in other localities where it crossed the land.[1]

Some renowned mud volcanoes exist on the Arakan Islands off the coast of Burma, and they often display unusual activity when an earthquake disturbs the inclined oil and gas bearing strata which occur in that region. Probably one of the greatest mud volcanoes on record was formed off the Burma coast on 15th December 1907, when sufficient material was ejected to form an island 1,200 ft. long, 600 ft. wide, and 20 ft. above sea-level, upon which a landing was effected by the

[1] J. A. Stigand gives the initial height as 50-60 ft., and states that the island eventually became joined to the mainland by accumulations of sand.

FIG. 20.—LARGE MUD VOLCANO IN DENSE JUNGLE.

FIG. 21.—TYPICAL MUD VOLCANOES OF ORDINARY DIMENSIONS.

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FIG. 22.—PITCH LAKE OF TRINIDAD.

Excavating pitch.

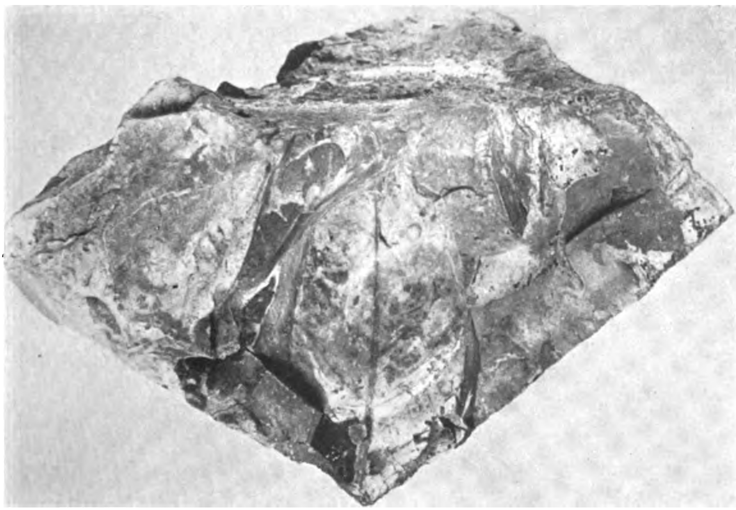

FIG. 23.—PORCELAINITE SHOWING LEAF IMPRESSION.

The rock is of a brick-red colour.

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roots, to which much soil was attached, it was apparent that the whole had been carried bodily from the edges of the lake, and had risen upwards with the pitch that filled the excavation after temporary abandonment.

Clifford Richardson gives the composition of the pitch as follows the sand, consisting of fine siliceous particles with salts of minerals which have separated from the water, and some oxide of iron which transmits a red colour to the powder :—

Water and gas	29 per cent.
Organic matter	7 "
Mineral matter	25 "
Bitumen	39 "
	100 per cent.

The ultimate composition of the bitumen is :—

Carbon	82.33 per cent.
Hydrogen	10.69 "
Sulphur	6.16 "
Nitrogen	0.81 "
	99.99 per cent.

At one side of the lake is a depression in the rough basin occupied by the pitch, and through this has been traced an overflow to the sea. The greater part of the distance is marked by numerous excavations, where pitch at some time or other has been extracted or is being extracted still. The width of this overflow probably does not exceed 100 yds., but as the land has been in the hands of numberless private owners, who, unless bought out by the Asphalt Company, worked the pitch themselves, or leased it to others, the stretch has been the scene of considerable activity.

This strip of pitch-bearing land was an object of prolonged litigation, and a generous source of revenue to Trinidad lawyers for many years. Pitch, being fluid in character, naturally swells into a pit soon after an excavation is depleted, the result being that the neighbours' lands are impoverished, and their ground level sinks or slips. Every proprietor, therefore, has a complaint against his neighbour, and work is usually suspended by an order of Court pending a judgment. A Government Commisof the stratum. In many cases the whole bed is stained and darkened with a bituminous substance in a solid state, although the fissures and cleavage planes sometimes contain thin films of solid or semifluid bituminous matter.

Bituminous sands and limestones are usually impregnated with 8-12 per cent. of bitumen, and where the latter occurs in a semifluid form with a low melting point its extraction is occasionally undertaken on a commercial scale by boiling water, steam, or direct heating in cupolas. The bitumen can also be extracted in a pure state by treating the rock with solvents, and this procedure is sometimes followed when a high grade bitumen permeates the beds.

The mining and treatment of bituminous sandstones has been extensively conducted in the United States, and especially in California where bituminous rocks abound, but few such enterprises have been successful, owing to the large deposits of the crude native material which can be worked at a greatly reduced cost, and the cheap production of pure products from some low grade petroleum residuum.[1]

Bituminous clays and shales are very frequently found, in all parts of the globe, but usually, whilst they yield a considerable volume of gas when heated, the liquid product rather partakes of the nature of a crude tar than an oil, and they are rarely treated on a commercial scale.

The European asphaltic limestones largely quarried in France, Switzerland, and elsewhere for paving purposes, owe their usefulness to their purity, character of grain, and, to some extent, their regular impregnation with bitumen of suitable melting points and quality for withstanding extremes of temperature. Some of the asphaltic limestones in the United States contain as much as 25 per cent. of bitumen, but the irregular size of the grains diminishes their value for paving purposes.

The asphaltic sandstones, unlike the limestones, are almost

[1] For full details of such operations, see the excellent publication of the United States Geological Survey, "Asphalt and Bituminous Deposits of the United States," by Eldridge.

innumerable, well-preserved impressions of leaves of plants with details beautifully delineated (see Fig. 23, Plate XXIII.). Shales which have suffered such treatment are sufficiently hard to resist weathering and sea action much longer than the surrounding less durable rocks, and they have formed bold cliffs in several places round the south-western coasts of Trinidad.

A locality in Barbados known as Burnt Hill is evidently another example of the same action, slow combustion having converted a hill of bituminous shale into a hard brick-like rock, which has also been used for road construction.

Burnt shales have also been removed from wells in California at a considerable depth, thus showing that the process of combustion can spontaneously proceed without the assistance of air, even at great depths. Eldridge and Arnold thus describe the burnt shales of the Santa Clara district of California: "The siliceous shale and 'chalk rock' forming the crest of the mountains south of the Santa Clara have at many points been burnt to a bright red colour. The fuel that supported such fires was perhaps the originally contained petroleum. Opposed to this view, however, is the very considerable depth to which the shale has been altered to a brilliant red lava-like rock, hence it may be inferred that spontaneous combustion alone has brought about the modification." Burnt shales have also been reported in Athabasca.

A somewhat similar phenomenon is not unknown in England on the Yorkshire and Dorsetshire coasts, where Lias or Kimmeridge clays of a bituminous character yield a slight exudation of oil which occasionally ignites spontaneously, causing the surface of the cliffs to burn for a considerable time.

Native Bitumens.—Quite distinct from hardened oxidised surface seepages of petroleum, popularly known as pitch, asphalt, etc., which are always contaminated with earthy and organic substances, are certain high grade native bitumens of great purity, which are the product of actions other than atmospheric on petroleum during its passage along subterranean fissures in which they are now found. The high grade native bitumens always appear as intrusions, and fill fissures and fault lines in

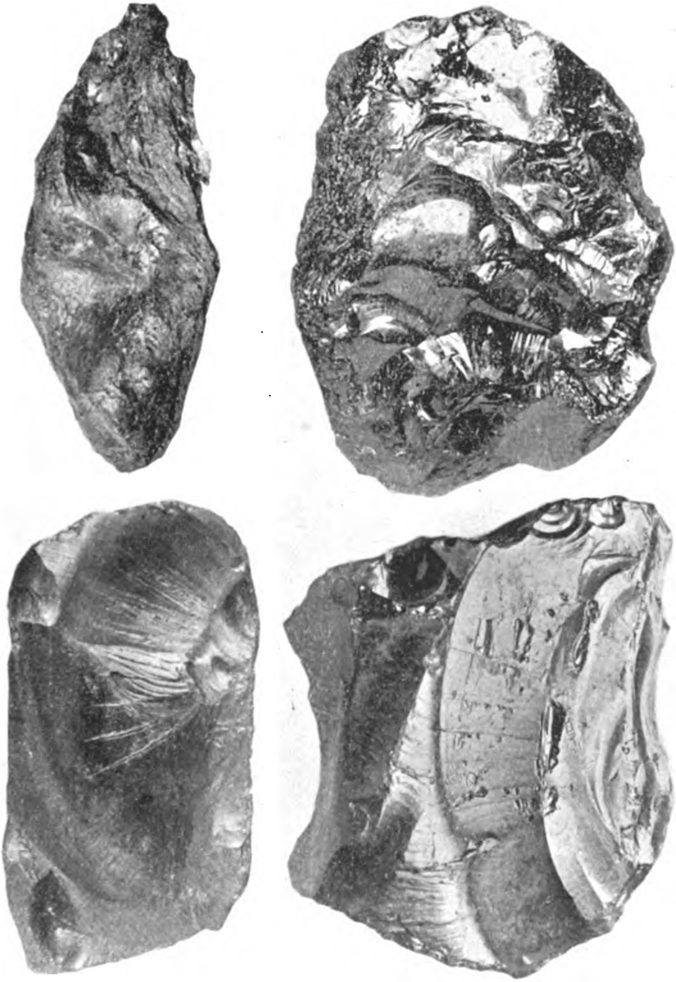

FIG. 24.—NATIVE BITUMENS.

1. Galician Ozokerite (mineral wax).
2. Russian Bitumen (high value).
3. Californian Petroleum Residue.
4. Barbados Manjak (high value).

Samples 2 and 4 show the conchoidal fracture characteristic of the higher grade bitumens.

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tion. The more valuable minerals, as Gilsonite and Manjak, melt and flow without decomposition at a moderate temperature, and when dissolved by solvents form products which, when applied to surfaces, are sufficiently elastic to prevent cracking under wide changes of temperature.

The veins of native bitumens have a width varying from an inch or less to several feet, and occasionally they open up into cavities many cubic feet in volume. The edges of the mineral vein often partake of a pencillated or columnar structure to a depth of several inches, and when the vein penetrates clays, the clays likewise to a depth of several inches are often characterised by a similar columnar form, evidently due to impregnation of material absorbed from the original bitumen-producing fluid. The veins often follow fault lines, whilst in other cases they penetrate fissures which deviate in several directions, rendering their development difficult. The original liquid character of native bitumens is proved by the occasional occurrence of pieces of unworn "country" embedded in the vein, as well as by the occasional penetration of liquid bitumen at points along the veins.

Much gas is evolved during the mining of native bitumens, and masses are often ejected with violence from the working face by gas which has collected under pressure in the mineral. Professor Cadman has also proved that native bitumens absorb oxygen from the air very readily, and as much care should be exercised in ventilating bitumen mines, and in adopting precautions against explosions, as in collieries.[1]

Solid native bitumens are distinguishable from coal, which some closely resemble in appearance, by becoming viscous or fluid on the application of heat, and by their solubility in solvents, such as carbon bisulphide, chloroform, petroleum spirit, etc. Most native bitumens are also soluble in crude petroleum or heavy natural oil, sometimes called Maltha. The superior quality bitumens mined in Syria, Barbados, and Utah never occur in wide veins, and it is the less valuable materials known

[1] See paper read before Institute of Mining Engineers' Annual Meeting, 1908, by Professor Cadman, "The Mineral Resources of Trinidad."

Galicia, but nowhere in such large quantities, although important unworked deposits exist on the island of Cheleken in the Caspian Sea.

Ozokerite has a specific gravity ranging from .850 to .950, whereas most other native bitumens have a density exceeding unity.

The ozokerite mines of Boryslav are now operated by modern hoisting machinery, and the mining is conducted by methods approved by the authorities. Ozokerite veins are found as yellow or dark yellowish-brown streaks or lenticles in dry compact clays. The clays show signs of considerable crushing, which has caused shiny slip planes to be prevalent. The wax follows these slip planes, and is especially concentrated beneath strata of rock, which clearly show the prevailing inclination of the strata as about 70°. Several working faces examined by the author, when he descended the mines in 1913, showed veins which did not exceed an inch to several inches in thickness. This material was yellow in colour, quite plastic, and could be kneaded into any shape by hand. The miners cast the purer wax into bags placed for its reception, whilst the surrounding clays are thrown into trucks and transported by a light tramway to the main shaft.

All the clay in the vicinity of ozokerite veins is impregnated with ozokerite, its extraction being effected by boiling the crushed material in water at the surface of the mine. The absorbed wax melts and floats on the surface of the water, from which it is periodically skimmed and run into moulds.

Very little water percolates into the mines, and there are fewer exudations of petroleum than would be anticipated within the confines of such a prolific oil-field. At a few points semi-solidified oils do issue from crevices and slip planes, proving the intimate association of the two minerals.

Petroleum gas of a distinctive odour is freely evolved at the working faces as the mining proceeds, but its percentage is kept to safe limits by artificial ventilation.

Crushed oak timbers, used as supports to the galleries, bear testimony to the crushing forces involved, and it is the need in two ways—first, by the greater solubility of chlorides than sulphates, and consequently the deposition of the latter in concentrated solutions; and secondly, by the reduction of sulphates to metallic sulphides as described by Hoefer. Iron pyrites is very prevalent in oil-bearing strata. In contradistinction to the saline type of oil-field waters there is the alkaline class met with in the Wyoming or some other oil-fields of the western states of America.

Such waters are rarely suitable for condensing purposes or boiler use on account of the flint-like incrustations that form even when boilers are liberally blown off. Heavy flows of such waters may occur when drilling in oil-fields, the ejection being sometimes due to artesian effect, and sometimes to association with natural gas, that lightens the column sufficiently to raise it to the surface. The temperature may be normal or high, and in the latter case may be due either to chemical action or ascent from great depths.

This intimate and usual association of petroleum with salt naturally suggests the occurrence of the missing product where the other is present. It was the search for brine that led to the discovery of petroleum in the United States, and induced Drake, in 1859, to sink a well for petroleum. Operations which led to the discovery of oil at Spindle Top, Texas, and so disclosed the possibilities of the Gulf district, were being conducted for salt, and in Russia, China, and other countries, brine was the object of search and not petroleum, which latter subsequently monopolised all attention.

Rock salt is the central core of the numerous domes of Texas, Louisiana, and Mexico, from which such vast supplies of oil have been obtained, and in Roumania it constitutes the central body of some of the great oil-fields of that country; whilst the Saliferous (Miocene) series, a group always charged with salt, is inextricably associated with all the oil-fields. In the Ural-Caspian area of Russia massive rock salt occurs in the oil belt, and scarcely an oil district could be named where saline waters have not been recorded.

Issues of water from the edges of domes and outcropping

PLATE XXVI.

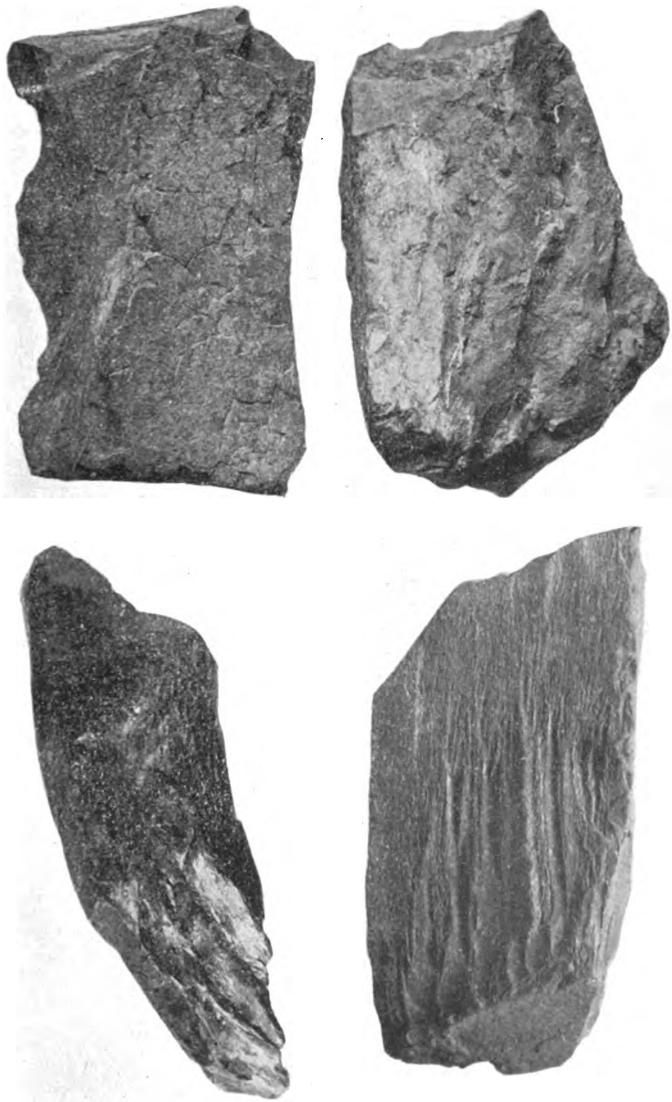

FIG. 26.—CHARACTERISTIC OIL SHALES.

1. Scotch Curly Shale.
2. Spanish Shale (Grenada).
3. New South Wales Shale.
4. Burnt Shale (deep red colour).

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line between them. Bituminous blaes, if fairly rich in ammonia and volatile hydrocarbons, may pass for shale if a practical test proves it to be workable for oil and ammonia on a profitable scale. As a general rule, good oil shale can be distinguished by its brown streak, toughness, and resistance to disintegration by the weather. Ordinary black blaes is more or less brittle and often gritty, and when exposed to the air it cracks and crumbles into fragments which ultimately revert to their original condition of clay or mud. Oil shale, on the other hand, resembles hard, dark wood or dry leather, and its quality in the field is measured by the degree of facility with which it can be cut and curled up with the edge of a sharp knife. It is free from grittiness, and is often flexible as well as tough. Some seams, such as those that crop out on the shore at Society, near Hopetoun House, instead of breaking up like blaes, form slabs sometimes a couple of feet in length, and are washed about and the edges rounded by the waves.

"Miners draw a distinction between 'plain' and 'curly' shale, the former variety being flat and smooth, and the latter contorted or 'curled' and polished or glossy on the squeezed faces. The same seam may be partly plain and partly curly; and curly beds are often richer in oil than the plain portions. Shale is probably curly because it is rich, as the higher percentage of hydrocarbon in some beds may have rendered them more easily crumpled than the stronger but poorer bands alongside of them.

"In internal structure oil shale is minutely laminated, which is apparent in the 'spent shale' after distillation, when it is thrown out in fragments composed of extremely thin sheets, like the leaves of a book or flakes in a piece of pastry.

"In thickness the shale seams vary greatly. At certain localities they disappear and pass into ordinary carbonaceous blaes, and at others they swell to 6, 10, or perhaps 15 ft. in thickness, with subdivisions of barren blaes or ribs of hard calcareous or quartzose 'kingle.'"

Some oil shales from the province of Castellon, Spain, Anticlinal flexures, yielding little but regular indications of oil and gas at intervals in their course, occasionally present unusual local displays of surface indications that require some explanation. It is generally found that such points correspond with deflections in the course of the anticline, and that the area of their occurrence is much fractured and broken up. Such occurrences lead one to treat these areas with suspicion, and there is a disposition to give them a wide berth, but it is not unlikely that in some cases increased saturation has resulted from a combination of doming and fissuring. Uncertain or erratic results are to be anticipated at such points, but this does not preclude the likelihood of good or even exceptional results being obtained.

Visible indications of oil should never be definitely discarded, however unsuitable the apparent structure. The great Bibi-Eibat oil-field of Russia was first operated amidst seepages, and that initial area always proved the richest; as this original area was receded from the productions were less. Grosny was opened up by a well sunk amidst surface indications, and the vicinity of the original well has always maintained its reputation as the richest in the entire field, corresponding, in fact, with the point of maximum elevation of the anticline. By far the most important oil-field of Burma originated amidst oil seepages, and the richest one coincides with the chief surface manifestations, and the highest point of the anticline. Development in California mainly followed petroleum seepages until geological investigations furnished the missing data. Most of the important Roumanian, and the famous Boryslaw field of Galicia were first decided upon entirely in consequence of surface indications, in some cases against geological advice.

Flattened crests or dome formations may bring to the surface considerable masses of almost horizontal oil sand presenting an extraordinary fine showing of seepages and asphalt deposits, which in no way detract from the value of the underlying beds, probably equally rich. Such a condition represents one of the rich areas in Trinidad that was quite neglected except by a few who appreciated its potentialities.

Exudations of oil bear direct and conclusive testimony to ditions for the preservation of commercial quantities of petroleum. A reason is thus furnished for the observed restricted extent, and yet on the other hand highly prolific character, of Tertiary oil-fields compared with those of Palæozoic or Mesozoic age.

Surface indications must be correctly interpreted before drawing deductions. Asphalt deposits are usually derived from seepages of oil, and it is often surprising what an imposing display is produced by an insignificant seepage of oil. Instances could be named of companies formed to exploit asphalt deposits that nowhere exceeded a few inches in thickness, and in the aggregate represented but small quantities. Superficial asphalt bodies usually constitute the oxidised residues of escaping films of oil that only indirectly communicate with the seat of their origin. Sometimes they arise from exudations of oil from outcropping oil sands, but much more frequently their extended occurrence is misleading to a novice. There are in some countries considerable thicknesses of sediments almost everywhere characterised by sweatings of petroleum, but nowhere yielding payable quantities of oil, in consequence of the absence of some essential lithological or other feature. The very prevalence of oil seepages will dictate caution to an experienced prospector until he has quite satisfied himself on the relative age and extent of the strata amidst which they occur.

Veins of native bitumen must be regarded with suspicion as indicators of payable oil. That they occur within the confines of oil-fields cannot be denied, but they much more frequently bear but a remote relationship to commercially productive oil sands. The Grahamite of Trinidad, the Albertite of New Brunswick, and the numerous other worked veins rarely directly communicate with oil-fields, although they are often in the region of such; but they do prove the occurrence of petroleum, and therefore must be regarded as a guide in its search. It is worthy of note that ozokerite fills fissures and impregnates clays overlying the main oil sources of Boryslaw, Galicia, and that at McKittrick, California, Grahamite veins may be observed in close proximity to productive oil wells. With a few exceptions only, the author is unaware of the of the region is a dead letter, early studies are often dispiriting, especially when large areas have to be covered where few, if any, outcrops occur.

Days and weeks might be spent in vain by a novice in seeking for indications of oil in some countries, where abundant supplies exist at depth. Outcropping sands impregnated with oil of medium density of the usual amber and light brown colour often exhibit no evidence of their oleaginous contents, and sometimes become bleached nearly white. Other sands have a natural brown colour, closely resembling an oil discoloration, but nevertheless yield no trace of oil on a cursory examination, nor emit the slightest odour. By digging some distance into the bed, their oil character becomes evident and the odour is pronounced.

Knowledge of a definite district enables an observer to discern quickly oil sands. They often assume some distinctive characteristic at their exposure which is at once recognisable, such as a certain tint, variegated appearance, efflorescences of certain salts drawn out by capillary attraction and deposited through evaporation of the water, or a special form of weathering.

Oil sands oozing petroleum can be at once recognised, often from a long distance, by their dark reddish-brown staining, but such discoloration must not be confused with water-bearing reddish-brown sands, to which they bear an extraordinary close resemblance at times. Heavy asphaltic oils produce a black stain which no weathering can remove, and often the outcrops are covered by a plaster of oxidised petroleum as asphalt, producing an effective antidote to weathering.

A curious phenomenon is reported by Mr G. E. Grimes in his geological report to the Indian Survey on the Yenangyang oil district of Burma, namely, that certain outcropping sandstone beds which show no signs of petroleum indicate a much higher temperature than the air and the surrounding strata, and these always prove to be oil-bearing at depth.

If the presence of petroleum is suspected in a sand displaying no visible evidence of impregnation, an excavation should be made, and the odour noted of a freshly broken fragment. Should this test fail to reveal evidence of oil a sample should be broken

CHAPTER V.

TYPICAL OIL-FIELD STRUCTURES.

Classification of Structures—Symmetrical Anticlines—Asymmetrical Anticlines—Diaper Structures—Monoclines—Saline Domes—Igneous Necks and Dykes—Relative Importance of Structure.

Classification of Structures.—Oil-field structures may for convenience be roughly classified into several general representative types that characterise commercially productive areas somewhat as follows:—

- Anticlines
  - Symmetrical
    - Simple folds—tending to form domes.
    - Folds with protruded cores (diaper structures).
    - Double monoclinal folds.
  - Asymmetrical
    - Simple folds—usually tending to domes.
    - Folds with protruded cores (diaper structures).
    - Overfolds.
    - Thrust faults.
- Monoclines
  - Simple inclination
    - Sealed by oxidation products.
    - ——— overlap.
  - Eroded anticlines
    - Sealed by asphalt.
    - ——— lateral variation.
    - ——— strike fault.
  - Terrace structure.
- Synclines
  - Normal.
  - Sagging anticline.
  - Ravine.
- Fractured rocks
  - Fault intersections, often with salt accumulations, sometimes with surface doming.
  - Igneous intrusions as dykes or necks.
  - Fissures or stockworks.

For comparison the classifications of Clapp and Hoefer are given:—

CLAPP.

I. Where anticlinal and synclinal structures exist—
   (*a*) Strong anticlines standing alone.
   (*b*) Well-defined alternating anticlines and synclines.
   (*c*) Monoclines with change in rate of dip.
   (*d*) Structural terraces.
   (*e*) Broad geo-anticlinal folds.

HOEFER.

I. Undisturbed country—
   1. Superficial, secondary accumulations.
   2. Regular and irregularly deposited lenses (Maikop).
   3. In sand bars, more or less regularly grouped (parallel) as at Pechelbronn—
      (*a*) At one horizon only (Zone).
      (*b*) Severa(l Series).

Classifications—continued.

CLAPP.

II. Quaquaversal structures—
   (*a*) Anticlinal-bulge type.
   (*b*) Saline-dome type.
   (*c*) Volcanic neck type.

III. Along sealed faults.

IV. Oil and gas sealed in asphaltic deposits.

V. Contact of sedimentary and crystalline rocks.

VI. In joint cracks of sedimentary rocks.

VII. In crystalline rocks.

HOEFER.

II. In disturbed country—

1. Normal anticlines (including geo-anticlines): symmetrical, asymmetrical, overfolded.
2. Diaper anticlines: symmetrical, asymmetrical, overfolded.
3. Domes: (*a*) independent; (*b*) on anticlines.
4. Sealed faults (Los Angeles).
5. Monoclines: (*a*) simple; (*b*) terrace structures.
6. Synclines and ravines (water free).
7. Fissures: (*a*) a single fault; (*b*) a fault series (Hannover); (*c*) a stockwork (Klenczany, Florence).

In discussing the various classes of structure attention will be drawn to subsidiary features of interest that have often perplexed geologists till the tectonic details of the field were understood. A casual glance at many of the sections will suffice to demonstrate the futility of attempting an elucidation of the structure without the aid of the drill, and usually a profound knowledge of local palæontology. Surface indications alone, with only discouragement from geologists, have led to the prospecting and discovery of some of the great oil-fields illustrated.

Many of the oil-fields of the world are located along well-developed folds which follow defined general directions parallel with mountain ranges. These flexures change in form and character from point to point, at times flattening out and disappearing as other regions have taken up the strain in parallel directions. Persistent flexures displaying an immense variety of forms, and presenting numerous interesting features, are illustrated in the following pages. Variations of level and pitching of the folds alternately bring interesting geological series to the surface, or throw them to great depths, sometimes beyond the reach of present-day mechanical contrivances, thus breaking continuous belts into a succession of exploitable areas.

When studied in a more general manner, it becomes noticeable that many of the productive oil-fields of the world are located along the great geo-synclines which formed a prelude to the building of the mountain ranges now in existence. A particularly pertinent example of this is the Appalachian oil-field, the geo-syncline being still the predominant feature in the structure, the subsequent folding which has led to the accumulation of the oil in workable pools being tectonically very subsidiary. Another very important geo-syncline known to oil-field workers is that embracing the Borneo, Sumatra, and Java oil districts.

Before proceeding with the description of the tectonics of oil accumulation it is well to impress upon the mind of the student two very important points. The first is the extreme irregularity in shape of the sand bodies in such sedimentary facies as are usually associated with the occurrence of oil, and the second, more or less related to the first, the indirect connection between the superficial phenomena of petroleum and the source of such phenomena. Dealing with the first point, it is a matter to be deplored that in illustrating a book by means of diagrams showing typical oil-field structures, it is necessary to employ very much smaller scales than would enable minute stratigraphical divisions to be marked; and also regarding many fields there is a real lack of data concerning such matters. A diagram depicting a regular sequence of "oil sands" and clays represents conditions never met with in Nature. A given horizon may be marked by sands over a wide area but never as a continuous sheet. All sand beds, on account of the conditions of their deposition, are lenticular: oil sands are usually markedly lenticular with one dimension predominant. A sand body may therefore represent an elongated lens isolated among surrounding shales (probably many of the prolific Mid-Continental oil pools of the United States approximate to this type), or where the coarser sediment tends to predominate we may have one body connecting with another, both laterally and normally to the planes of sedimentation, so that it becomes quite impossible to construct a true map of the complex resultant body from the data supplied from the well logs. With the complications introduced when the strata are subjected to fracture and displacement of varying amount along fault planes, it is no wonder that curious ideas may prevail as to the relations of different wells in some fields; and also a little reflection will suggest how, under favourable conditions, huge accumulations of oil may be tapped by one well.

When the superficial phenomena arising from oil accumulations in the earth's crust are studied, such as oil and gas seepages, mud volcanoes, sulphur springs, etc., it will be found that such phenomena are rarely traceable to a direct source. In the majority of cases they arise from faults. It is surprising how often seepages, apparently from sand, are found to be along the crest of an anticline, irrespective of any definite horizon, that is to say, are really from concealed beds, the actual rock yielding oil on the surface merely constituting a convenient exit. Bonarelli[1] has classified seepages as normal, longitudinal, and lateral. Normal seepages are crestal seepages as above described, longitudinal where pitching of an anticline causes an outcrop of an oil sand to occur across an anticline, and lateral where an eroded crest causes an oil sand to outcrop at its side, often an indicator of the oil prospects of a parallel non-eroded fold. To complete such a classification of seepages should be added others covering the various types associated with faulting, including cross-faulting (salt domes) and igneous dykes.

The prevalence of surface manifestations of oil is very variable. In undisturbed strata such as are found in the Appalachian field, mud volcanoes are unknown, and seepages are rare. In Mexico and along the Spanish Main, seepages on a tremendous scale are frequent, and of doubtful value as oil indicators. Elsewhere it is by no means uncommon for a petroliferous facies to give numerous seepages of high grade oil where no payable accumulations are ever found to exist. Thus the cautious prospector in a new region will refrain from placing too much reliance on such manifestations until he has tested their meaning with the drill.

Symmetrical Anticlines.—Terrestrial folds to which the term anticline is applied naturally partake of innumerable forms, and, according to the degree of flexure and the petrological character of the strata involved, vary considerably in the extent of faulting and subsidiary dislocation which, according to its magnitude, may or may not affect the petroleum contents. It is naturally along

[1] "La Formacion Petrolifera de Salta y Jujuy."

the crests that the oldest beds are exposed, and denudation may have proceeded sufficiently to expose along the crest and near flanks considerable outcrops of an oil-bearing series with its accompaniment of characteristic oil indications.

Sharp anticlines with highly inclined flanks, equal angular dips, and often faulted or eroded crests are common, and in some parts amidst mountains, such anticlines correspond with ravines that closely follow the anticlinal crest. Such flexures often expose moderate thicknesses of oil-bearing rocks and are invaluable for geological study, but they are rarely the seat of a thriving oil industry owing to their restricted dimensions, the ill effects of excessive faulting or erosion, and prolonged escape of hydrocarbon contents. Occasionally, however, where the grade of oil is high, or a local remunerative market exists, prosperous operations can be continued under such circumstances. In this connection students should be warned of the rarity with which anticlines correspond with topographical elevations; usually it is the reverse, for obvious physiographical reasons.

Rarely do anticlinal folds continue unbroken along level country for any considerable distance: nearly always the crest rises or plunges, causing certain interesting beds to approach, reach, or recede from the surface. Areas of maximum elevation may correspond with extensive exposures of oil-bearing strata, or they may represent points where the top of the oil beds only just outcrops, or they lie at considerable depth from the surface. It is these latter spots that are sought by petroleum geologists for especial study, as in the event of a good local development of oil sands and inconsiderable dips it is such localities that present the most obvious prospects.

Symmetrical anticlines with broad flat arches, and maximum development of the oil-bearing series of rocks which are mainly covered, are naturally rare in Nature, but when such conditions are closely approached oil-fields of great importance have been disclosed.

Fig. 27 illustrates the Yenangyaung oil-field of Burma, which has yielded about 5,000,000 tons (37,500,000 barrels) of high grade oil between 1888 and 1915. The oil-bearing Miocene (Pegu) beds just outcrop near the crest, where they lie nearly upper Pliocene. Oil occurs mainly in the middle Palembang, three sands being important.

Asymmetrical Anticlines.—Anticlines with unequally dipping flanks present innumerable types of structure. The asymmetry may be small or it may be great, one limb frequently being nearly vertical or even inverted, whilst the other is gently inclined and very favourable for oil development. When unconsolidated plastic clays predominate, and there is a general absence of hard rock, exceedingly sharp flexures and overfolds may be formed without the oil

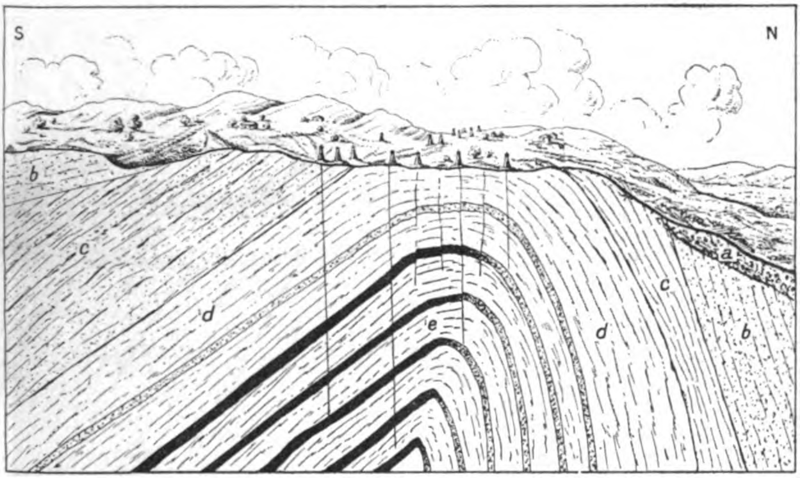


Fig. 31.—The Grosny Oil-Field of Russia.

a, Gravels. *b*, Meotic (Pliocene.) *c*, Middle Sarmatian. *d*, Lower Sarmatian. (Miocene.) *e*, Tchokrak. (Miocene.)

contents suffering escape, and a whole succession of creases, termed an anticlinorium, is sometimes produced, amidst which oil sands may be successfully operated. With a preponderance of yielding clays severely-contorted, enclosed oil-bearing sands will yield excellent productions of petroleum as fault planes are tightly sealed by the clays.

The structure of the majority of the oil-fields of the world is of the asymmetrical type. Russia affords a very typical example in the Grosny oil-field (Fig. 31), where oil-bearing beds of Sarmatian (Miocene) age form an uninterrupted belt for eight miles, along

The Moreni oil-field is typical of the delay and loss resulting from failure to appreciate the true geological structure, in this case partly unavoidable, for it is seen at a glance that the details of the structure must remain hidden from mere surface inspection; they are only gradually understood as data come to light from well logs. Old hand-dug wells had yielded oil for many years, but only since 1904 has successful drilling been accomplished at Stavropoleos. This has been repeated at Gura Ocnitsa to the west, and subsequently at Bana (see Fig. 40) to the east along the same Miocene inlier. More recently, at Bana, the northern side of the structure has been developed, at first in the shallow syncline (Fig. 40), and then in the underlying Sarmatian rocks near the salt contact; and in 1915 this latter development was extended westward toward the older Moreni area, whilst about the same time an important westerly extension of Gura Ocnitsa was made at Ochiura. Thus it is that with the gradual elucidation of the true underground structure, the gaps in the proven oil-bearing Neogene aureole embracing the Miocene salt formation tend to disappear.

Fanlike forms are imparted to the beds in contact with the Miocene in the process of protrusion, introducing features of uncertainty that the drill alone can determine; fortunately, however, an abundance of fossils simplifies the identification of the strata being pierced.

In the Carpathians the older Cretaceous rocks have been pushed over the later Tertiaries from the Miocene upwards, along the outer margin of the mountains. In the south-eastern corner, where the principal Roumanian fields are located, *i.e.*, in the sub-Carpathians, however, the action is already much less accentuated than further back in the mountains, and in Figs. 29 and 32 are shown diagrammatic sections at points along the outer zone of folding, visible before reaching the plains of the Danube. These sections are at points where actual oil development has taken place, but the folding has not been sufficiently severe to admit of fracture of the Pliocene beds and the development of the "diaper" structure. A piercing of the Pliocene beds, not unlike those at Gura-Ocnitsa-Moreni, accompanies the oil pools developed at Baicoi-Tsintea, whilst between these two areas, at Filipeshti, the overlying Pliocene beds were merely folded into an anticline

(Fig. 29), nevertheless affording a structure favourable to the accumulation of oil in the Meotic (lower Pliocene) beds.

Six miles north of Filipeshti and Baicoi occurs the next zone of fracture, along which are the oil-fields of Campina, Telega, and Bushtenari. Lying nearer to the mountains the movements have been proportionately more severe, and the upper Pliocene rocks here disappear, whilst through the Miocene rocks large masses of Oligocene have been thrust.

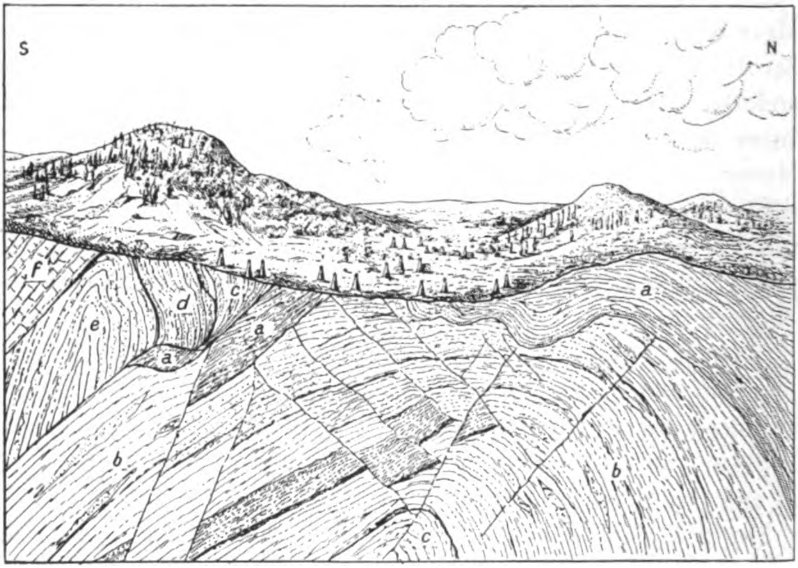


Fig. 35.—The Boryslaw-Tustanowice Oil-Field, Galicia.

a, Salifère. (Miocene.) *b*, Dobrotow. *c*, Menelite. (Oligocene.) *d*, Eocene. *e*, Hieroglyph Beds. (Eocene.) *f*, Cretaceous.

No structures like those last described have permitted commercially successful developments in Galicia, but nevertheless there is a distinct relationship between the fields. In Roumania oil is known in small quantities in the Flysch zone, but as we have seen, it is the later Tertiaries that yield the most abundant supplies.

In Galicia, the most important field, the Boryslaw-Tustanowice field (Fig. 35), has far exceeded all other localities in richness, yet excellent results on a smaller scale have been obtained from strata of Cretaceous, Eocene, Oligocene, and Miocene age elsewhere. The same outward thrust from the mountains has forced the older rocks over the Miocene, the section of the Boryslaw-Tustanowice fold showing a central core of faulted Dobrotow beds (middle Oligocene) which, with the underlying Menelitic shales, form the source of the oil here worked, and it is overlain by the Miocene salt formation over which have been thrust, in ascending order to the south-west, Oligocene, Eocene, and Cretaceous rocks.

Monoclines.—The term monocline is here retained as it has passed into general oil-field phraseology as equivalent to a series of uniformly dipping beds, irrespective of the relationship they may have to the general structure of the district. Important oil-fields have been opened up where strata show a gentle inclination in one direction for considerable distances. Many of the American oil-fields are characterised by dips of such insignificance that for all practical purposes the strata might be considered horizontal, the cause of concentration consequently being imperfectly understood. Kansas-Oklahoma oil-fields are located within the flat continental area, on what is known as the Prairie Plains monocline, lying west of the Ozark dome, and it is doubtful whether the small differences of elevation there recorded would enable gravity to effect the accumulations of oil in the many pools located over hundreds of square miles. The structure in the important pools of Cushing and the Glenn pool are distinctly anticlinal, usually developing a group of domes.

As it is quite impossible to indicate intelligently in diagrams suitable for reproduction such gentle dips, this important class of structure has regretfully escaped illustration. The official publications of the United States Geological Survey should be consulted.

In Fig. 36 is shown a section of the Westside oil-field of Coalinga, California, the oil-bearing Miocene overlying unconformably the Eocene shales, and outcropping in the hills to the west of the belt after a lengthy monoclinal dip.

The Peruvian oil-fields are located upon monoclinal formations that extend inland from the coast. Dips do not generally exceed 20°-25°, but upthrow strike faults repeat the sequence at intervals, greatly extending the area of possible exploitation. The sands are lenticular, displaying irregular impregnation, and speaking broadly the influence of faulting has not been very great. Secondary

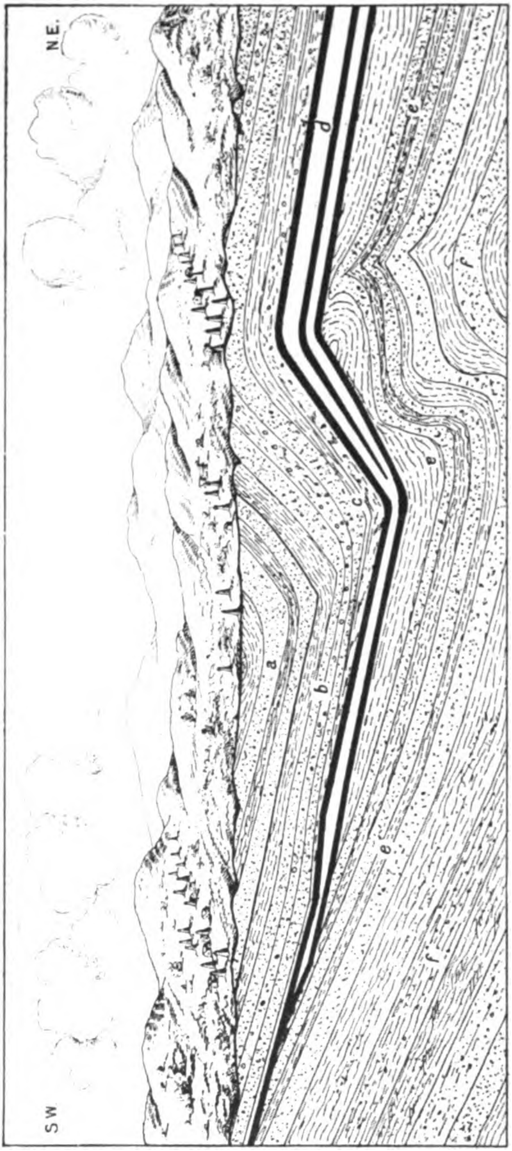


Fig. 36.—Coalinga Oil-Field, California.

a, Etchegoin. *b*, Jacalitos. (Upper Miocene.) *c*, S. Margarita. (Middle Miocene.) *d*, Vaqueros. (Lower Miocene.) *e*, Tejon. (Eocene.) *f*. Knoxville-Chico. (Cretaceous.)

faulting in a direction oblique to the strike has cut up and isolated large irregular blocks, amidst which are occasionally areas of complete saturation are found in the lowest, and therefore oldest sandstones. The area of saturation is less in each sand below the hundred-foot sand, and it is supposed that by some means the connate water has escaped, after perhaps aiding in the concentration of the oil in the first instance.

In proportion to the extent to which the water has disappeared, the oil has retreated down the slopes into the syncline, it being not improbable that this retirement of the level of water saturation has aided in the collection of scattered globules of oil. Roswell H. Johnson[1] has shown that when in motion the gravitational sorting of oil, gas, and water is readily accomplished where slight tendency to this would otherwise exist. The same author has shown[2] that gas bubbles tend to pick up a film or pellicle of oil, and in this way oil is transported in regions of low dip.

The descending pool of oil may reach the bottom of the syncline, or it may be arrested by a bar of closer-grained and finer-pored rock which would not hinder the water, or else fill up a hollow in the form of a ravine, subsidiary syncline, or even terrace. Griswold and Munn[3] call attention to the fact that in the Beaver quadrangle very small structural depressions seemed to hold accumulations of oil quite out of proportion to the area drained.

"In areas where the sand lies well above the water line, the oil occurs in very irregular pools, the shapes and dimensions of which are controlled by the porosity of the sand rather than by the direction of dip. The greater number of oil pools found at or near water line, lie in 'embayments' along the flanks of anticlines rather than on anticlinal 'noses' or promontory-like structures. This fact has an important bearing on prospecting, and is also of considerable interest as suggesting that the water line has in comparatively recent geologic time receded from a higher level."[3]

Saline Domes. — Some of the most extraordinary oil-field structures, whose origin is still in doubt, although the subject of considerable speculation, are the dome-shaped mounds of the

[1] "The Rôle and Fate of the Connate Water in Oil and Gas Sands," *Trans. Am. Inst. Min. Eng.*, 1915.

[2] "The Accumulation of Oil and Gas in Sandstone," *Science*, N.S., Vol. XXXV., No. 899, pp. 458, 459, 22nd March 1912.

[3] "Oil and Gas in the Cadiz Quadrangle, Ohio," United States Geological Survey, Bulletin 541.

Gulf field of North America. Along the low-lying coastal regions of Texas and Louisiana, where the strata over wide areas present exceptional regularity, with only gentle dips southwards, there are numbers of dome-shaped mounds rising abruptly from the plains to an increased elevation of from 10-50 ft. Around the domes, which do not usually exceed an area of a few hundred acres, there are often issues of salt or sulphurous waters, indicating some unusual local disturbance of the otherwise regular beds.

Attention was first directed to the mounds for salt, but the frequent association of gas and oil led to the drilling of a test well at Spindle Top, and a great outburst of oil was encountered, which immediately attracted considerable local interest to these structures. Prolonged investigation by C. W. Hayes and others of the United States Geological Survey, and by G. D. Harris and his staff on the Louisiana Geological Survey,[1] has practically established the fact that the core of all the Gulf mounds is rock salt, gypsum, and limestone, although in only a few cases has this been positively determined by drilling.

The partial elucidation of the structure of some of the mounds ndicates an area of local distortion, penetrating all the strata, even to those of Quaternary age, and conclusively assigning their origin to some vertically ascending body near their apices. The occurrence of sulphur and gaseous hydrocarbon emanations led to an early belief in the volcanic formation of the mounds, but so far there has been observed no evidence of intrusive rocks or metamorphic action.

An effort has been made to connect the mounds of Texas and Louisiana with certain fault lines running parallel to the chief faulting of that part of the country, and it has been ascertained that some of the domes are located at the intersection of these fault planes with others traversing a direction nearly at right angles. It is submitted that deep-seated hot waters supersaturated with saline matter have ascended along these points of weakness and deposited their dissolved salts when cooler beds were reached. To the force of crystallisation is ascribed the local upheaval of strata with the formation of the characteristic mounds.

[1] See "Rock Salt. Its origin, geological occurrence, and economic importance in the State of Louisiana," by G. D. Harris, assisted by C. I. Maury and L. Reinecke.

The oil and gas which have generally been found under high pressure in the strata above the salt, may either have originated from deep sources and risen with the ascending salt waters, or be the result of concentration to the apices of the domes from surrounding beds where oil was present in small quantities. The finding of oil deposits in the upturned edges of the sands penetrated by the salt mass, forming as it were an aureole around the salt, tends to strengthen the idea of an upward migration of the oil,

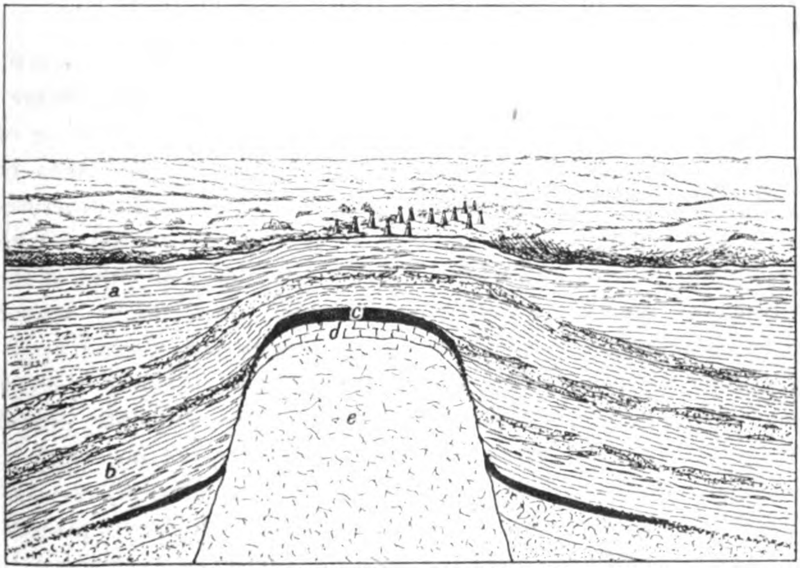


Fig. 41.—Hypothetical Section of Saline Dome.
a, Quaternary. *b*, Tertiary. *c*, Dolomite. *d*, Gypsum. *e*, Rock Salt.

and it is worthy of note that some of the deep drilling round Spindle Top, etc., has proved oil of a much higher grade than was met with at the apex.

Fig. 41 is a hypothetical section of a typical mound, and a structure of this type is supposed to characterise Spindle Top, Sour Lake, Saratoga, Batson, Dayton, Humble, Hoskin's Mound, Damon's Mound, Big Hill, etc., in Texas, and Hackbury, Sulphur, Vinton Welsh, Anse La Butte, Petit Anse, Cote Carline, Grand Cote, Belle Isle, etc., in Louisiana. The only other parts of the world where somewhat similar mounds have been reported are

CHAPTER VI.

ORIGIN, COMPOSITION, CHARACTERISTICS, AND TREATMENT OF PETROLEUM.

Origin of Petroleum and Natural Gas—Theories of Oil Formation from Organic Matter—Relationship of Paraffin and Asphaltic Oils—Relationship of Grade of Oil to Depth—Composition and Characteristics of Petroleum and Natural Gas—Uses of Petroleum Products—Distillation of Petroleum —Refining.

Origin of Petroleum and Natural Gas.—The problem of the origin of petroleum has been the subject of scientific controversy for many years, and numerous chemists and geologists of distinction have been led into an expression of opinion at some time or other. The problem is, however, still awaiting a theoretical solution that will give general satisfaction, although the more active development of oil-fields and an increased scientific interest in petroleum has led to a much clearer perception of the necessary antecedent phenomena resulting in the natural formation of liquid hydrocarbons. World-wide exploration has proved petroleum to be no curious fluid, produced, as was formerly thought, in a few isolated spots on the earth where peculiar conditions existed, but a common, widely-distributed product of Nature, which has been disseminated amidst sedimentary rocks of various kinds and ages.

In seeking the origin of petroleum, therefore, one must not introduce extraordinary theories for its production in certain localities, but must consider only such views as will account for its extensive production and wide distribution by common processes of Nature. In certain exceptional cases bituminous compounds which are closely allied to petroleum, may call for some unusual explanation, such as the occurrence of bitumen in meteoritic stones which have reached the earth, and the existence of similar products in volcanic rocks, but these isolated examples bear no intimate relationship to the enormous accumulations of petroleum which it is the aim of the oil prospector to locate and develop.

Modern discoveries have enabled the chemist to produce synthetically many of the constituents of petroleum by reactions in the laboratory, and even to reproduce some of the isomeric forms of the hydrocarbons which occur in crude petroleum. Many of the theories advocated or supported by leading chemists have been proved to be quite untenable, although no doubt ever existed that oil could be produced in the manner described, but geological considerations prevented the acceptance of these as natural methods of oil formation.

There are two general theories commonly presented to account for the origin of petroleum, which may be described as the Inorganic and the Organic respectively, of which latter both animal and vegetable sources of origin find distinguished advocates.

Inorganic Theories of Origin.—The inorganic theories attribute the origin of petroleum to chemical reactions in the interior of the earth, mostly involving the formation of gaseous hydrocarbons which rose in fissures from great depths and condensed and accumulated in upper cooler strata of a porous nature. This idea found many influential advocates at one time, and the ascertained action of water on the carbides of certain metals which results in the liberation of hydrocarbons was considered evidence in support. Some of these theories involved intricate chemical reactions and peculiar terrestrial conditions of temperature and pressure that made them extremely improbable, but they have never been generally accepted, chiefly because much more simple and probable reactions will account for the occurrence of petroleum, without introducing the many difficulties these theories make it necessary to concede.

In nearly all oil-fields petroleum is confined to strata within definite vertical limits. Above or below an area of enrichment lie unproductive sedimentary strata, often quite suitable for the storage of petroleum. Had the hydrocarbons emanated from great depths it is difficult to understand why the lower beds were not impregnated, or why no evidence remains of the exuding fluids in the crevices and fissures themselves. In nearly all cases where there are veins of bituminous material disseminated throughout strata, it is usual to find sedimentary beds impregnated with asphaltic matter beneath or in the vicinity of the impregnations, thus disclosing their origin.

The occasional occurrence of bitumen in vesicular volcanic rocks, where they are not in contact with petroliferous formations, may be due to the condensation of emanations of hydrocarbons (possibly derived from contemporary distillations of organic shales) at the time of the disturbances resulting in their upheaval, but in no case do such rocks yield more than a trace of petroleum. Igneous rocks are obviously unsuitable reservoirs for fluids were petroleum produced beneath and amidst them, and it appears more than a coincidence that so many of the world's most important oil-fields are developed in strata of a recent (Tertiary) geological age, which are generally underlain by an enormous thickness of older, unpetroliferous, sedimentary strata which would have arrested the upward movement of any deeper-seated products.

Theories involving intricate chemical reactions based only upon hypothetical considerations have found no acceptance with persons intimately acquainted with oil-field phenomena, although some of the suggested inorganic reactions are extremely ingenious, and show what persistent efforts to produce oil have followed a conviction that it has been derived from mineral matter.

Eugene Coste is the staunchest remaining advocate of an inorganic origin for petroleum, but his writings partake more of the nature of a general criticism of the acknowledged weak features of theories of organic origin than a presentation of convincing argument in favour of his own case. It is impossible to deny that petroleum, in anything but traces, is in no way associated with volcanic or even metamorphic rocks, nor is true vulcanism anywhere recorded within effective distances of oil-fields. Mendeleieff and other scientists were under the erroneous impression that mud vulcanoes were related to true volcanic phenomena mainly in consequence of the occurrence of oil-fields near mountain ranges.

does not relate to a single or several oil-fields in a cramped region, but applies to a number of oil-fields, spread over a wide area on the flanks of the Carpathian Mountains, which range sweeps round in a curve presenting changing strikes and innumerable phases of structure.

Unlike many oil-fields, the Tertiaries of Roumania and their continuation on into Galicia are particularly rich in fossils, and unusually good palæontological data are available for the recognition of geological horizons. Many fossils naturally persist through a considerable vertical range of strata, but there are certain species restricted in their range and development. So sound a basis for study could not fail to throw light on problems elsewhere very obscure.

The Salifère is characterised by prevalence of salt, and its local development often consists of massive rock salt, which has thrust its way upwards through softer, newer beds on many of the anticlinal folds. Petroleum is nowhere found in commercial quantities in the Salifère, although it everywhere contains oil, but wherever suitable beds of later age unconformably overlie, or recline against the Salifère, the former contain oil, often in enormous quantities.

Lewis Hamilton resolutely supports the contentions of local geologists, after years of study of Roumania, and confirms the fact that the yield of oil from Meotic, Levantine and other Pliocene strata bears a very definite relationship to the structure and angle of unconformity between these and the underlying or flanking Salifère. All the great oil-fields of the country display the relationship, and this knowledge is successfully applied in the search for new fields. Further confirmation of the relationship is afforded by the fact that the upper Pliocene beds do not contain oil when not thrown into suitable flexures and brought into contact, or in proximity to the Salifère.

The source of Roumanian oil is thus apparently demonstrated, but its origin is less obvious, though popularly and naturally attributed to organic matter in the shales of the Miocene saliferous beds. Some disconcerting features connected with this hypothesis are given on pp. 272-74, and are worth perusal.

is made to the diatomaceous and infusorial character of marls associated with Mexican domes by F. W. Moon.[1]

Further proof of the organic origin of natural petroleums is drawn from their optical activity shown when subjected to polarised light, a subject investigated by Rakosin. This latter property has been traced to the presence of cholesterol, which is essentially a constituent of animal fats, but in some cases phytosterol, the vegetable equivalent of cholesterol, and possessing the same optical properties, is found, thus indicating in such cases a vegetable origin. As cholesterol is said to be the more common optical product in oils, an animal origin[2] is generally preferred.

Vegetable Sources of Petroleum.—Accumulating evidence favours the opinion that vegetable matter may be the source of certain petroleums, although there is no justification for the uncompromising attitude of certain exponents of this theory. Two kinds of vegetable matter are possible, terrestrial and aquatic, and in the deltaic conditions that characterise so many oil-fields either could be equally well appealed to as a source of accumulation. The extensive coal and lignite deposits in many geological periods bear eloquent testimony to the presence of carbonaceous matter far in excess of that required to provide proved supplies of petroleum ; indeed, the very abundance of such deposits which have not been converted into petroleum furnishes a strong argument against accepting a carbonaceous origin for petroleum.

That vegetable matter can be partially converted into bituminous compounds or hydrocarbons by natural processes is demonstrated in every important coal-field. Marsh gas (methane) often occurs in great quantities in faulted zones amidst the coal measures, but the bituminous substances found in coal are not true bitumens that dissolve in the usual solvents and emit the characteristic odour on burning. Tars derived from the destructive distillation of coal in no way resemble natural petroleums or the product of oil shales, but contain such products as benzine, toluene, phenols, pyridines, naphthalene, anthracene, etc. In this

[1] *Transactions Inst. M.M.*, 1910-11, "The Relationship of Structure and Petrology to Petroleum."

[2] Lewkowitsch, "Chemical Technology of Oils, Fats, and Waxes."

he advocates. Certainly few of his deductions fit in with observations made in existing oil-fields, and exception can be taken to his conclusions in Trinidad, where, in one important oil-field of that island, petroleum is contained in lenticles of sand embedded in foraminiferal clays containing no traces of vegetable matter. The acknowledged lenticularity of oil sands is sufficient explanation for wide differences in the character of particular horizons within short distances.

It is an observed and constantly commented-on fact that coal-fields and oil-fields are nowhere coincident. In the chief region where they are remotely associated, namely, the Appalachian field of America, the two horizons are absolutely distinct, and the coal seams are used as a reliable index of depth in the search for oil and gas beneath. In Assam, coal occurs in the oil series, but as coal, and shows no relationship to oil, and in many oil-fields carbonaceous matter abounds, but always as such, and rarely in contact with oil seams.

The author has seen tons of lignite ejected by a flowing well sunk into the Dacian beds of Roumania, but it is well known that the contained oil was a product of migration, and not formed in the Dacian. Unchanged carbonaceous matter occurs in the Russian oil-fields; and in Peru and California large deposits of tree trunks displaying no trace of oil occur in the oil series.

Terrestrial vegetation in a finely divided state, deposited under certain conditions, might provide material, within limited areas, for the production of oil, but it is not lignite and coal that can be appealed to, as all investigations tend to indicate that lower forms of vegetable life, such as algæ, which are enormously abundant, very prolific, and which could flourish in saline waters under almost all climatic surroundings, are a more probable source. Under such conditions low forms of animal life could participate, thereby promoting a possible dual origin.

Experiments by Krämer and Spilker on mud from the Gulf of Stettin revealed the possibility of extracting from it paraffin bodies resembling ozokerite,[1] and muds collected from the Gulf of Suez and the Mediterranean have yielded traces of petroleum

[1] "Ber. deutsch Chem. Ges.," 1900, XXII.; 1902, XXXV.

in association with sulphur and ammonia. The oil is thought in part to be derived from algæ. Certain bitumens considered to be associated with petroleum, found on sandy plains near Inhambane, Portuguese East Africa, have been attributed to accumulations of certain species of algæ.

Messrs Wade and Illingworth[1] have studied some odorous muds collected amongst coral reefs in the Gulf of Suez, where the water often recorded a temperature of 40° C. These muds were found to consist mainly of such organisms as foraminifera, sponges, algæ, seaweeds, with other microscopic organisms. From this mud was extracted, at 60° F., measurable quantities of an oily substance of sp. gr. 1.013 emitting a true petroleum odour. The results confirm other data, but it is advisable to accept with caution any products collected within the region of known oil-fields, as exuding petroleum from outside sources may be absorbed by certain bodies, and confuse the issue.

In a salt marsh, in the Hundred of Malcolm, South Australia, there is a marginal deposit 30 in. thick of "Mudoil" and "Indurite" (?) which, according to G. A. Goyder, consists of decomposing diatoms in mud and sand. Hoefer thinks this an intermediate product between diatoms and oil, deserving study.

Animal Sources of Petroleum.—Nature provides quite as many examples of accumulations of animal life as of vegetable, but with both certain essentials must be fulfilled to prevent the total decomposition of the fatty or resinous parts. The larger forms of life are naturally too scarce to admit of inclusion in any theories, and even fish life could only rarely provide material for appreciable accumulations. Smaller forms of life are more readily preserved, and their highly prolific character would assist quick accumulations.

Exception is taken by one writer to an animal origin on the curious score that most dead animal matter is devoured, and refers to the prevalence of the death mark on the shells of molluscs he has collected, ignoring the fact that only

[1] "The Origin of Petroleum," by Arthur Wade and S. Roy Illingworth (*Mining Magazine*, August 1914).

a certain class of siphonated carnivorous univalves have the power of boring into other shells. Most univalves are vegetarians, and all bivalves live on infusoria or on microscopic plants brought to them by water currents which their own ciliary apparatus excites. Reference could be made to numerous fossil beds amidst oil zones where it would be difficult to collect amidst millions a dozen specimens showing evidence of attack in the way suggested.

Exception is often taken to the absence of phosphates if oil is derived from animal matter, and at first sight this appears a reasonable stricture. Phosphates are rarely found in fresh water, as calcium phosphate is insoluble, and other forms gaining admission would be quickly converted into that substance if calcium bicarbonate were also present in the water, as is almost invariably the case. Calcium phosphate is soluble to some extent in waters containing sodium chloride (or ammonium chloride or carbonate), consequently traces of phosphates might be expected in some oil-well waters if the oil were of animal origin. Unfortunately, there is little available evidence concerning the composition of oil-field waters beyond their salt contents, and examination might disclose the presence of phosphates. It is, however, in the strata from which the oil is derived that one would expect most indications of phosphates, and these have been studied even less than the waters. A further possible reason for the paucity or absence of phosphates in certain cases will appear in the section dealing with the absence of sulphates (see p. 269).

Phosphates have been found in the Baku oil sands to the extent of upwards of 2 per cent. of phosphoric acid, but if oil pools were the concentration of a considerable area of sparsely distributed oil, the quantity of phosphate at any definite point would be extremely small. In this connection it must not be overlooked that where oil is a migration product, as is generally the case to a greater or lesser extent, it is not in the beds in which oil is found that the search for phosphates should be made, but in the strata of their origin. It seems very unlikely that careful analysis would fail to disclose the presence of phosphates in such beds as, say, the Miocene of Roumania, or the Eocene of California, where and other sulphur compounds in the petroleum and gases, and of iron pyrites in the oil-bearing beds, must be accounted for.

7. A plausible reason for the high gas pressures usually encountered must be offered.

(1) No direct proof is available regarding an adequate supply of organic matter, as where petroleum has been formed all essential organic material has disappeared in the process of conversion. Coal and most terrestrial vegetation scarcely require consideration, as the former was produced from the latter under circumstances quite inapplicable to petroleum. The small quantities of vegetation washed from the land might add to other sources of supply.

Petroleum-producing conditions must have originated under water, and this water must generally have been more saline than ocean waters, consequently marine organisms appear a necessity for such large quantities of organic matter as it is necessary to assume.

Open oceans do not provide the essential conditions, although the aggregate quantity of organic matter would suffice. Freedom of dispersal of organic living forms would lead to no accumulations of their bodies; indeed, the beds of oceans far from land receive little deposit of any kind.

An inland sea, large gulf, or a lagoon, where all inorganic and organic washings from the land must accumulate, where wide margins of shallow warm water favour the growth of aquatic vegetation, where forms of animal life restricted in genera and species and prodigious in numbers flourish, and where, in comparatively stagnant water, microscopic forms of animal and vegetable life abound, would appear to furnish, after the lapse of long periods of time, adequate material for the production of the oil found in specific areas.

On the eastern shore of the Caspian is a large gulf, named Karaboghaz, separated from the open sea by a mere strip of land, and whose only communication with the open sea is by a narrow channel about 150 yds. wide and 5 ft. deep, through which a continuous but fluctuating stream of water flows, at a rate averaging 3 miles per hour, the current being entirely due to the great evaporation in a confined shallow area. The total

(3) It is well known that organic matter, even that most susceptible to decomposition, can be preserved indefinitely by sterilisation and total exclusion of air, which means protection from the attacks of bacteria; that is to say, dead organic matter has no inherent tendency to spontaneously break up.

Under normal sub-aerial conditions, such as exist in soil, organic matter will gradually be converted, by aerobic bacteria, into simple, oxidised, inorganic bodies, such as carbon dioxide, water, ammonia (passing into nitrates), and ash, the same materials from which it was originally formed directly or indirectly. But when free oxygen (ordinarily supplied by the air) is deficient, or absent, quite different products result; the action is still bacterial, but anaerobic bacteria take the oxygen they require for their life functions from compounds containing it; that is to say, they deoxidise them, and in doing so generate quite different bodies, hydrides being particularly in evidence, such as hydride of phosphorus (phosphoretted hydrogen), hydride of sulphur (sulphuretted hydrogen), and hydrides of carbon (the hydro-carbon marsh gas, the first member of the paraffin series, especially). It is highly probable that enzymes, products of bacterial action, are largely concerned in the chemical actions. In any case the result is a complete transformation of the original animal and vegetable substances, as is evidenced by every stagnant pond or septic tank.

(4) Supposing bacterial or enzyme action is admitted as a main factor in the production of petroleum from organic matter, all difficulty concerning the common or general absence of nitrogenous compounds in the oil or associated waters disappears; for whereas under aerobic conditions nitrogenous matter in decomposing tends to pass through the stages, ammonia, nitrites, and nitrates, under anaerobic conditions nitrites or nitrates are broken up, and nitrogen is set free as a gas. In this way much of the easily decomposable nitrogenous matter might disappear before burying up of the other organic matter, but evidently at times it did not, for nitrogen is often very largely in evidence in oil-well gases (see p. 261), indicating not only the presence of nitrogenous bodies in the original buried organic matter, but also a continuation of processes after covering up similar to those taking place before covering up took place.

At Starunia, near Stanislau, ozokerite is mined, but no very productive oil-field has been developed.

In Russia several examples of the same kind occur. The western extension of the Grosny field yields paraffin-bearing oils, although for an operated distance of many miles, where wells have been sunk to a considerable depth, nothing but true asphaltic oils have been found. The only apparent difference is that the anticline pitches to the west, rendering drilling deeper. Water in greater quantities is found, the same geological sequence of beds appear to persist, and the structure shows no pronounced change.

Cheleken, on the Caspian Sea, off Krasnovodsk, yields paraffin-bearing oils and ozokerite, although the beds are of Apsheron age, the same as overlie the oil-fields of Baku, where common asphaltic oils are universal. At Neftiania, in the Maikop oil-field, ozokerite occurs, although the region provides almost exclusively asphaltic oils, and in the neighbourhood of Tiflis, at Ildokani and Tsarsky Kolodsi, paraffin oils are obtained.

Petroleum of a typical asphaltic variety contains quite considerable quantities of wax in Mexico, the unusual association of the heaviest class of asphaltic oil with paraffin wax introducing many difficulties in refining.

In the Peruvian oil-fields the usual oil yields no appreciable solid paraffins, but in the higher oil series, oils containing a fair percentage of paraffin scale have been found at Lobitos and Negritos. California now provides a sensation by the discovery of paraffin-base oils beneath the ordinary variety in the Eastside oil-field of Coalinga. It is said that in Borneo paraffin-base oils were struck beneath the asphaltic type on one anticline. In the Minbu oil-field of Burma a dense viscous oil was struck containing no paraffin, although lumps of paraffin scale were raised with the detritus about the depth oil was struck.

The preceding facts indicate the close association of asphaltic and paraffin-base oils, and emphasise the advisability of hesitating to attach to the two classes a distinctively different origin. If the two varieties are derived from different material, the circumstances attending its deposition must bear a close resemblance.

percentage of hydrogen (25 per cent.) and smallest percentage of carbon (75 per cent.) by weight possible, and all higher members of the same homologous series contain a larger percentage of carbon and a lower percentage of hydrogen. Many of the finest oils in the world are composed largely of the normal paraffins (C_nH_{2n+2}), the higher members of the series being solid and known as paraffin scale after extraction.

The Russian oils of Baku appear to be largely built up of hydrocarbons known as naphthenes, being isomers of the olefine series, C_nH_{2n}, although there are many others, including the C_nH_{2n-6}, or benzine series, in the more volatile portion of some oils. Hurst has pointed out that the cause of the Russian oils having a lower flash point for a definite specific gravity than American oils is on account of the prevalence of naphthenes, which have a lower flash point compared with their specific gravities than either paraffins or normal olefines. So an approximate idea of the nature of the hydrocarbons composing an oil may be deduced from the relationship of specific gravity to distillation temperature and flash point.

Crude oils occasionally yield perceptible and sometimes appreciable quantities of aromatic hydrocarbons, benzine, C_nH_{2n-6} series, and their isolation can be effected for the preparation of nitrobenzine, the basis of many high explosives, and aniline, from which the aniline dyes are prepared. Selected oils from Borneo and Roumania are especially rich in the aromatic hydrocarbons, and their commercial extraction has been entertained from time to time.

Comparisons of specific gravity and the arbitrary designations of benzine, illuminating, and lubricating oils over a fixed range of temperatures of distillation give but an approximate idea of the actual constitution of the oil, although such divisions are useful for rough comparisons. It is usual, for general convenience, to adopt Engler's method of designating as benzine those products which distil up to 150° C. or 302° F., and as illuminating oils those distilling beween 150° and 300° C. (302°-572° F.). Such a rough separation is approximate only, but as a rule good lamp oils contain few fractions distilling

TABLE VI.—RELATIONSHIP OF FRACTIONS BETWEEN 140° C. AND 300° C.,[1] IN FIVE REPRESENTATIVE ILLUMINATING OILS.

Origin and Characteristics of Oil.	American (Water White). Specific Gravity, .7954. Boiling Point, 125° Cent. Flash Point, 42° Cent. Fire Point, 55° Cent.				Russia. Specific Gravity, .825. Boiling Point, 130° Cent. Flash Point, 31° Cent. Fire Point, 47° Cent.				Roumania. Specific Gravity, .811. Boiling Point, 112° Cent. Flash Point, 26° Cent. Fire Point, 38° Cent.				Texas. Specific Gravity, .819. Boiling Point, 120° Cent. Flash Point, 30° Cent Fire Point, 37° Cent.				Galicia. Specific Gravity, .812. Boiling Point, 110° Cent. Flash Point, 27° Cent. Fire Point, 39° Cent.			
Fractions up to	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.	Per cent. by Weight.	Specific Gravity.	Flash Point.	Fire Point.
Deg. Cent.			Deg.	Deg.			Deg.	Deg.			Deg.	Deg.			Deg.	Deg.			Deg.	Deg.
140	...	...	...	...	...	...	...	...	3.38	.766	...	...	...	...	...	...	1.65	.759	...	...
150	1.50	.756	...	...	2.77	.779	...	...	8.00	.733	...	...	3.33	.768	...	...	5.42	.764	...	...
160	2.49	.759	14	15	5.57	.784	...	...	13 60	.780	16	19	6.68	.777	...	...	6.16	.770	...	...
170	5.22	.766	22	23	9.39	.792	16	...	12.45	.7895	22.4	29	12.36	.790	17	18	9.70	.7775	21	24
180	7.29	.772	28	31	7.57	.802	24	30	10.48	.7975	33	39	13.73	.799	28	31	4.27	.785	26	30
190	8.55	.778	36	42	7.23	.809	33	40	7.08	.805	43	51	13.00	.810	38	42	4.96	.791	31	37
200	9.44	.784	45	53	6.98	.816	42	48	6.54	.813	52	59	11.48	.820	49	52	4.29	.796	37	42
210	8.22	.790	53	63	6.84	.823	51	58	6.24	.821	60	67	10.41	.830	59	63	4.24	.8015	44	50
220	7.89	.796	62	72	6.83	.829	59	67	5.67	.8285	67	75	9.52	.839	68	72	4.94	.808	51	57
230	7.74	.801	70	82	6.72	.8345	67	75	4.48	.836	73	80	8.50	.847	75	80	4.95	.813	59	67
240	7.02	.806	80	90	6.57	.839	75	84	4.28	.843	78	86	3.83	.855	82	87	4.96	.8185	67	77
250	6.37	.810	85	97	6.45	.843	83	92	3.62	.849	82	90	3.31	.863	88	94	5.16	.8235	75	84
260	4.50	.814	95	103	6.44	.848	91	101	2.91	.855	86	96	2.00	.870	94	100	5.30	.828	83	94
270	3.77	.818	103	109	6.20	.852	99	109	2.95	.861	90	104	0.82	.877	99	106	5.65	.833	92	102
280	2.77	.822	110	117	4.27	.857	107	117	2.55	.866	94	108	...	...	...	...	6.25	.8265	102	113
290	2.08	.826	117	124	4.12	.861	114	125	1.37	.870	97	114	...	...	...	...	5.10	.8405	113	124
300	1.63	.830	125	132	2.42	.8645	120	133	0.99	.873	99	119	...	...	...	...	4.70	.844	124	137
Above 300	3.52	.843	112	119	3.03	.878	143	158	2.90	.885	124	143	0.60	.892	...	...	12.20	.857	139	151

[1] From paper read before the Petroleum Congress in Liège, in 1902, by Dr Dvorkovitz.

TABLE VII.—Table of Baumé and Specific Gravity Equivalents.

Baumé.	Specific Gravity.	Baumé.	Specific Gravity.	Baumé.	Specific Gravity.
10	1.0000	37	0.8395	64	0.7243
11	0.9930	38	0.8346	65	0.7205
12	0.9860	39	0.8299	66	0.7168
13	0.9790	40	0.8251	67	0.7133
14	0.9722	41	0.8204	68	0.7097
15	0.9658	42	0.8157	69	0.7061
16	0.9594	43	0.8110	70	0.7025
17	0.9530	44	0.8063	71	0.6990
18	0.9466	45	0.8017	72	0.6956
19	0.9402	46	0.7971	73	0.6923
20	0.9339	47	0.7927	74	0.6889
21	0.9280	48	0.7883	75	0.6856
22	0.9222	49	0.7838	76	0.6823
23	0.9163	50	0.7794	77	0.6789
24	0.9105	51	0.7752	78	0.6756
25	0.9047	52	0.7711	79	0.6722
26	0.8989	53	0.7670	80	0.6689
27	0.8930	54	0.7628	81	0.6656
28	0.8872	55	0.7587	82	0.6619
29	0.8814	56	0.7546	83	0.6583
30	0.8755	57	0.7508	84	0.6547
31	0.8702	58	0.7470	85	0.6511
32	0.8650	59	0.7432	86	0.6481
33	0.8597	60	0.7394	87	0.6451
34	0.8544	61	0.7357	88	0.6422
35	0.8492	62	0.7319	89	0.6392
36	0.8443	63	0.7281	90	0.6363

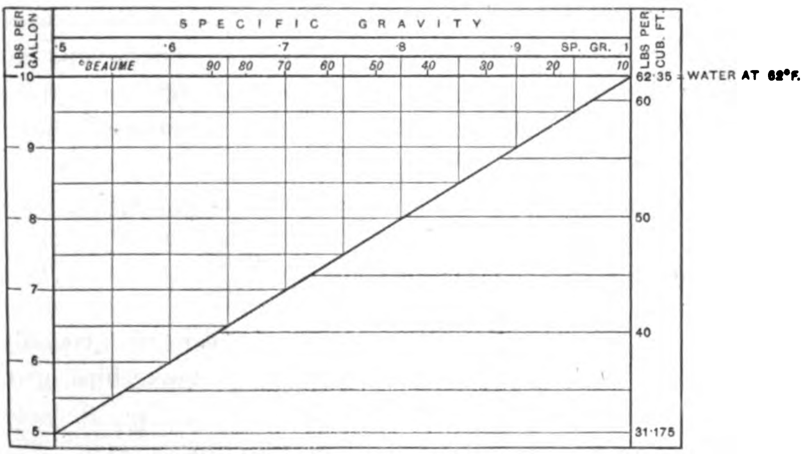


Fig. 43A.— Diagram illustrating Relationship of Baumé and Specific Gravity (compared with water) Equivalents, and giving Weights in Lbs. per Gallon and Cubic Feet.

Table VII. gives the Baumé and specific gravity equivalents.

A formula has been published by the American Bureau of Standards for converting Baumé into density compared with water, as under :—

$$°\text{ Baumé} = \frac{140}{\text{Sp. gr. of liquid at } 60° \text{ F.}} - 130.$$

$$\text{Sp. gr. at } 60° \text{ F.} = \frac{140}{130 + \text{deg. Baumé}}.$$

The coefficient of expansion of petroleum not only varies with different classes of oil of the same specific gravity, but also with alterations of temperature, and the expansion of heavy oils is less than that of light oils. Owing to the variation of expansion with different oils it is usual to prepare tables to apply to special oils with which one is constantly engaged, giving the amount to be added to or subtracted from the observed specific gravity for each degree fall or rise of temperature below or above normal temperature, to reduce the specific gravity to normal temperature. The coefficient of expansion of crude oils varies between extreme limits of about .00085 for light grade crude, and .00065 per degree C. for heavier crudes (equal to .00047 and .00036 per degree F.), and these values, when accurately determined by experiment, are added to or subtracted from the observed gravities to reduce to some normal basis for comparison. At increased temperatures the rate of expansion increases slightly, but it is usually neglected in crude oil estimations. Sir Boverton Redwood gives the following corrections that should be made for refined products :—

Products lighter than Kerosene	.00040 to .00048	per 1° F.
Kerosene	.00040	„
Gas oils	.00036	„
Lubricating oils	.00034	„

Davis, in his "Petroleum Tables," which are generally used by shipowners for calculating cargoes of tank ships, gives the following corrections :—

For Benzine	.00045	per 1° F.
„ Lamp oils (.795 to .825)	.00040	„
„ Solar and light lubricating oils	.00038	„
„ Heavy lubricating oils	.00035	„

Tables IV., V., VI., VIII., IX., give the specific gravities of a number of representative oils from different countries.

Ultimate Composition.—The ultimate composition of crude petroleum varies very little indeed, the percentage of carbon ranging from 84-86, and that of hydrogen from 11.5-14.5. Sulphur largely enters into the composition of some oils, and there are often appreciable proportions of oxygen and nitrogen. Table VIII. gives a few ultimate analyses of petroleum collected from various sources.

TABLE VIII.—ULTIMATE COMPOSITION OF REPRESENTATIVE PETROLEUMS.

Origin of Petroleum.	Specific Gravity.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.	Authority.
Pennsylvania - -	0.801	86.10	13.90	...	...	0.06	Engler.
Ohio - - -	0.827	85.42	14.59	0.064	...	...	Mabery and Dunn.
California (heavy) -	0.984	86.32	11.70	1.25	...	0.84	Mabery.
,, (light) -	0.846	86.24	13.08	...	...	...	,,
Texas (Beaumont) -	0.912	85.03	12.30	0.92		1.75	C. Richardson.
Roumania (Bushtenari) - -	...	86.30	13.32	...	...	0.18	Edeleanau.
Roumania (Campina) - - -	...	86.03	13.26	...	...	0.13	,,
Canada (Petrolia) -	...	83.94	13.37	...	...	0.99	Mabery.
Peru (Zorritos) -	0.850	86.08	13.06	0.071	0.748	0.041	...
Italy (Parma) -	0.786	84.00	13.40	...	1.80	...	Deville.
Russia (Baku) -	0.884	86.3	13.6	...	0.1	...	Redwood.
Galicia - - -	0.852	85.3	12.6	...	2.1	...	,,
Burma . - -	0.855	83.8	12.7	...	3.5	...	,,
East Indies (Java) -	0.880	87.1	12.0	...	0.9	...	,,

Calorific Value.—The calorific value of petroleum can be found by calculation from the ultimate composition, or it can be directly determined by combustion in a calorimeter. The results very closely coincide, and either is always sufficiently near for all commercial purposes for which comparisons are required. Petroleum cannot be readily burnt in ordinary calorimeters owing to the fierceness of the combustion, even when well mixed with absorptive substances to delay the action. The Mahler bomb type of calorimeter is the only safe and reliable instrument to use for liquid fuels, and a description oil, and by continuing the heat a point was reached when the oil took fire, and this was termed the "fire point." There is a considerable difference between the flash point and fire point of oils, amounting often to 25°-30° F. in the case of illuminating oil.

Investigations showed that to obtain consistent results a system of testing would have to be standardised, as the flash point differed with the manner in which the test was applied. When made in an open vessel a much higher flash point was recorded than when tested in a closed vessel, the difference reaching usually 25° - 28° F. Eventually the Abel-Pensky flashing test instrument was introduced and accepted as a standard by the British and some other Governments, and tests properly conducted show uniform results, as the instrument assures identical conditions in every test. Corrections have to be made for variations of atmospheric pressure, the flash point being lower with increased altitude or fall of barometer. For each one inch of variation in the mercurial column there is a reduction or elevation of 1.6° F. in the flashing point. Full directions for use are given with flash-testing instruments, as well as tables of corrections for barometric pressure.

The British standard flash point for lamp oil is 73° F. by the closed test, equal to about 100° F. open test.

Natural Gas.—Natural gas is extensively employed for both heating and illuminating purposes, especially in the United States, where it is often conveyed hundreds of miles in large mains under a high pressure. Natural gas has a calorific value far exceeding that of coal gas

The United States Geological Survey gives the analyses and particulars of average quality natural gas from different gas-fields, shown in Table X., where for the purpose of comparison the analyses of artificial gases are given also.

Very complete investigations of West Virginian natural gas have been made by Professor Phillips of the Western University of Pennsylvania on behalf of the United States Geological Survey.

TABLE X.—ANALYSES OF CHARACTERISTIC NATURAL GASES AND COMPARISON WITH MANUFACTURED GASES.

Constituent.	Average, Pennsylvania and West Virginia.	Average, Ohio and Indiana.	Average, Kansas.	Average of Coal Gas.	Average of Water Gas.	Average, Producer Gas from Bituminous Coal.
Marsh gas, CH_4	80.85	93.60	93.65	40.00	2.00	2.05
Other hydrocarbons	14.00	.30	.25	4.00	.00	.04
Nitrogen	4.60	3.60	4.80	2.05	2.00	56.26
Carbon dioxide	.05	.20	.30	.45	4.00	2.60
Carbon monoxide	.40	.50	1.00	6.00	45.50	27.00
Hydrogen	.10	1.50	.00	46.00	45.00	12.00
Hydrogen sulphide	.00	.15	.00	.00	.00	.00
Oxygen	Trace	.15	.00	1.50	1.50	.05
Total	100.00	100.00	100.00	100.00	100.00	100.00
Pounds in 1,000 cubic feet	47.50	48.50	49.00	33.00	45.60	75.00
Specific gravity, air being 1	0.624	0.637	0.645	0.435	0.600	0.985
B.T.U. per cubic foot	1,145	1,095	1,100	755	350	155

Table XI. is taken from this Report, and gives the analyses of nine representative samples of West Virginian natural gas.

An analysis of Pennsylvanian gas made by C. D. Howard, in which the hydrocarbons are distinguished, is given in Table XII.

TABLE XII.—ANALYSIS OF PENNSYLVANIAN NATURAL GAS (BIG INJUN SAND).

	Sample No. 1.		Sample No. 1.
Carbon dioxide (CO_2)	0.006	Ammonia (NH_3)	None.
Carbon monoxide (CO)	0.4	Carbon bisulphide (CS_2)	"
Oxygen (O)	0.2	Sulphuretted hydrogen (H_2S)	"
Hydrogen (H)	Trace.	Moisture (grains in 100 cub. ft.)	17.72
Heavy hydrocarbons	0.4	Total sulphur (grains in 100 cub. ft.)	0.182
Ethane (C_2H_6)	14.60	Total paraffins	95.54
Methane (CH_4)	80.94	B.T.U.'s per cub. ft.	1142.6
Nitrogen (N)	3.46		

From the great gas-fields of Surakhany, on the outskirts of the Romany oil-field of Baku, as much as 16,000,000 cub. ft.

TABLE XI.—ANALYSES OF REPRESENTATIVE WEST VIRGINIAN NATURAL GASES.

Constituents.	Fredonia.	Sheffield.	Kane.	Wilcox.	Speechley.	Murrysville, Lyon's Run, near.	Racoon Creek.	Baden.	Houston.
Nitrogen	9.54	9.06	9.79	9.41	4.51	2.02	9.91	12.32	15.30
Carbon dioxide	0.41	0.30	0.20	0.21	0.05	0.20	Trace	0.41	0.44
Hydrogen	0	0	0	0	0	0	0	0	0
Ammonia	0	0	0	0	0	0	0	0	Trace
Oxygen	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Sulphuretted hydrogen	0	0	0	0	0	0	Trace	0	0
Paraffins	90.05	90.64	90.01	90.38	95.42	97.70	90.09	87.27	84.26
	100.00	100.00	100.00	100.00	99.98	99.92	100.00	100.00	100.00
The paraffins contained in these gas samples have the following composition by weight:—									
Carbon	78.14	76.69	76.77	76.52	77.11	74.96	76.42	76.48	76.68
Hydrogen	21.86	23.31	23.23	23.48	22.89	25.04	23.58	23.52	23.32
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

be extracted from the gangue. The Elmore ore concentration process depends upon the mixture of well-crushed ore with an emulsion of oil and water by agitation in a vessel under a partial vacuum, when the well-known affinity of oil for metals leads to the particles of mineral matter becoming clothed with a film of oil, and rising to the surface of the liquid with the oil, whilst the unmineralised portion or gangue is precipitated.

Distillation of Petroleum.—The distillation and refining of petroleum can only be undertaken on a commercial scale after consultation with qualified chemical specialists, and the execution of many preliminary distillations of characteristic samples of the product to be treated. Only a brief outline of the usual methods adopted will be given, and readers needing information are referred to chemical works dealing with the subject, of which, however, there are very few. The engineering aspect has never yet been attempted.

Some high grade crude oils are simply exposed to heat from a steam coil, and "reduced" in open pans until the desired viscosity and freedom from moisture is reached to fulfil the duties for which the particular oil is being made, whilst a few natural oils are used direct in their crude state for lubricating purposes, after filtration to remove siliceous particles. Where crude petroleum is not employed direct for fuel or other purposes, it is subjected to a process of distillation whereby the various components of the oil are first expelled and then condensed, the condensates being grouped within certain ranges of density and flash point. The crude oil, sometimes previously warmed by waste heat, is introduced into steel cylindrical stills of varying design, heated by flues, and the expelled vapours are conducted from a dome above the still along pipes into a condenser. At first only light distillates pass over, but as the temperature of the still rises, denser distillates are expelled and are condensed. In the tail house leading from the condenser the condensed fluid discharges into a pipe from which there are a number of outlets, each controlled by a cock, and each leading to a separate storage tained in the stills to diminish the temperature of distillation, and avoid decomposition and burning.

The process of "cracking" is also made much use of in modern refineries, whereby a larger proportion of lighter products is obtained than would otherwise be the case. Cracking is brought about by raising the temperature of the oil in the still above the normal height for the distillate being collected, and leaving the upper exterior surface of the still exposed to the atmosphere, so that part of the products of distillation are thereby condensed and caused to fall back into the hot fluid. The result of the action is the reduction of hydrocarbons into products of lighter density and lower boiling point, accompanied, however, by the formation of a certain amount of permanent gas. The exact action of "cracking" seems little understood, and certainly "cracked" oils are inferior to uncracked, and they require more refining.

Increasing demand for petroleum spirits for use in internal combustion engines has acted as an incentive to inventors of cracking processes, especially as the price of suitable products has risen to a very high figure. Cracking processes mainly rely upon distillation under pressure or passage of vapours over hot surfaces in the presence of a catalyser, whereby heavy hydrocarbons are broken up into those of less complexity of the cyclic order. Solar oils and kerosene may be mainly converted into products with a boiling point suitable for internal combustion engines, but they need refining to remove objectionable odour and discoloration, and are often mixed with a proportion of light direct-distilled spirit to ensure quick ignition.

Distillation on a continuous principle has long been conducted in Russia, and since 1900 the process has been widely extended to other countries with highly beneficial results. For continuous distillation the stills are placed in batteries, each still being mounted slightly lower than the preceding one, so that oil admitted to the upper can flow by gravitation through the whole series, the rate of flow being regulated by cocks between each still. This pretty process is thus well described in the "Encyclopædia Britannica": "In the continuous process of distillation, instead of a single

Burma lamp oils prepared for the Indian market are usually solid at 60° F. They, the paraffins, however, concentrate mainly in the residuum from a certain point ascertained experimentally, and from thence onwards it is usual to distil under reduced pressure, and in the presence of superheated steam to minimise decomposition. Residues containing paraffin wax are naturally valueless for lubricants, and from such oils it is only certain paraffin-freed oils that can be converted into lubricants. When solid paraffins are absent, the residues yield under careful distillation, in partial vacuum, viscous products that, after refining, possess varying lubricating properties. This process was formerly conducted in circular cast-iron pot stills, but in modern refineries cylindrical stills on the continuous principle are being adopted.

Refining.—Most petroleum distillates require some process of purification before they can be placed on the market for domestic or commercial purposes. Illuminating oils, in particular, when unrefined, yield a smoky flame, and contained resinous matter clogs the wicks of lamps and hinders combustion. Small quantities of sulphur compounds also frequently exist that produce objectionable odours when the oil is burnt. The smoky flame is usually attributable to the presence of higher homologues of the unsaturated hydrocarbons, often mechanically carried over during the process of distillation, and frequently removed or much reduced in quantity by a second distillation.

Refining is almost universally accomplished with the aid of sulphuric acid, followed by a treatment with caustic soda. The action of sulphuric acid is not entirely understood, but the unsaturated and undesirable hydrocarbons are attacked by the acid, with the formation of a tar which is precipitated together with unaffected acid and can be drawn off as "sludge." Agitation with soda after a preliminary washing with water produces a certain amount of purification, but its main purpose is to neutralise acidity and remove acid products. Other oxidising agents, like permanganate of potash and ozone, cause some reaction, but sulphuric acid has rarely been improved upon in practice.

The distillates are agitated in cylindrical iron vessels with compressed air, or with mechanically-worked paddles, the latter, the purifying agent. Early mechanical difficulties that obstructed its practical employment have been overcome, and it is believed that an immense future lies before this clever invention.

Liquefied SO_2 is added to the distillate in a closed vessel with a glass side, where the operation can be observed. A dark cloud of hydrocarbons immediately forms, and at once settles with the SO_2 to the bottom, from whence it is allowed to discharge into a vessel, the purified distillate passing into another vessel. The temperature, often as low as $-10°$ C., and pressure at which the operation is conducted, depend on the character of the oil, naphthenes being dissolved at a much higher temperature than aromatic hydrocarbons. Under atmospheric pressure or a slight reduction of pressure and increase of temperature, the SO_2 is evolved, abstracted by a compressor, and recompressed into liquid for reuse. One precaution is essential to success, the distillates must be entirely freed from water, otherwise sulphuric acid is formed with disastrous consequences to the plant, therefore they are first passed through calcium chloride filters to remove the last traces of water.

Sulphur dioxide owes its efficacy largely to its violent attack on the heavier cyclic unsaturated and especially aromatic hydrocarbons, which are often the cause of the poor burning properties of lamp oils, but it also removes or reduces the quantity of sulphur compounds in a surprising way, producing good illuminants from oils that are usually in little request. The aromatic hydrocarbons abstracted are valuable for the production of turpentine substitutes, etc.

Some crude oils, like those of Ohio, Lima, Indiana, Texas, Mexico, Canada, Persia, Egypt, contain such persistent and obnoxious sulphur compounds that it is necessary to treat distillates prepared for domestic purposes with copper oxide or litharge (PbO) to secure their removal. These chemicals are recoverable for reuse by burning off the sulphur that has combined to form CuS or PbS.

Mineral earths have been used to some extent for refining oils. Distillates are agitated with fuller's earth or with bauxite, to the particles of which some of the heavier and discoloured and incautious attention to such details may lead to the enforced reduction in size of casing until the limit of practicable diminution is reached long before the required depth is attained.

Usually an escape of gas and a steady accumulation of oil in the well will indicate the proximity of an oil source, but drilling should only be suspended for a trial bailing or pumping after continuing some distance into an oil-bearing bed. A yellow emulsion is often the first indication of oil in a well with a high water level, the colour deepening, and being gradually followed by a separation of oil and its accumulation on the surface of the liquid. In several cases the author has personally given instructions for a trial bailing to be made when there was only water in the well and no indication of petroleum, being guided solely by the character of the sands raised and the knowledge that an oil-bearing horizon had been reached. In one such example, where water only was bailed for a week before being overcome, as much as 150 tons (1,125 barrels) of oil daily were obtained, and in another instance where water which filled the well was subsequently excluded by a cementation, a production of 500 tons (3,850 barrels) daily was obtained for a while, and in two years the well yielded 140,000 tons (1,050,000 barrels) of oil, although no indications of petroleum had been observed during drilling.

The rate of drilling varies greatly. In oil-fields where the strata do not "cave" and the wells are of small diameters, the average rate of drilling may reach 50-150 ft. daily with a cable rig, but where the strata are much disturbed or steeply inclined, and "caving" is constant, the rate often may not exceed 6-10 ft. daily. No definite relationship between speed and diameter can be predicted, nor do depth and speed bear any definite ratio to one another, but within the limits of an oil-field ratios can be established by plotting results.

Where the strata are compact and several oil sources of limited capacity have been passed, it is a common practice to insert the last column of casing with perforations at the depths where the oil shows occurred, the outer larger casings used for temporarily excluding the oil being then removed to permit these sources to supplement the main supply, if not required for the exclusion of water. Indications of petroleum during drilling are often described as "*oil shows*," and productive beds as "*pay streaks*."

Only rarely is a class of strata encountered that defeats the persistence and ingenuity of the engineer. In the absence of supplementary plant, operations may be temporarily or indefinitely suspended, or the cost of suitable materials may not be justified by events, but unqualified defeat is rare. One of the most rebellious substances to come upon in drilling is asphalt of a certain consistency that oozes from fissured clays, and creates a sticky mass through which any object can only with the greatest difficulty be moved. By attaching itself to the drill stem and tools, their motion is arrested and their recovery is seriously jeopardised: only constant, patiently administered pulls for long periods will effect their abstraction. Similarly the same substance, or something closely allied to it, will run into a well and form a base upon which the drill rebounds as from a rubber disc. Hours of steady pounding may fail to destroy the cohesion of such a substance which declines to mix with foreign matter.

Persistent drilling for days may destroy or dispel a small mass of such substances, but if they continue to ooze into the well it is only possible to continue drilling by excluding the source with casing slowly pressed past the troublesome zone. Admixture with benzine or other solvents after extraction of water might aid progress under some circumstances.

Clays of a certain consistency and plasticity resist the formation of a puddle or mud, but instead tend to squeeze up around the bit, forming a solid mass in the less confined space around the stem. Such result makes it necessary to drill upwards with the jars to secure the release of the bit. This quality of the strata can be neutralised by the occasional insertion of sand whilst drilling is cautiously prosecuted. Drilling in certain sands can likewise be aided by the addition of clay, the latter apparently hindering the rapid settlement of agitated sands such as is especially noticeable in highly saline waters.

Attention has recently been drawn by Dr W. Petraschek[1] to

[1] "Aids to Deep Boring in Clay."

district depends not only on the lithological character of the strata, but upon the physical conditions that prevail. Prevalence or scarcity of water, facilities of transport, character of available fuel, all bearing on the problem of power, are reflected in the rig. The non-existence of a suitable reversing clutch practically precludes the use of a combination of internal combustion engine and systems calling for reverse movements. Scarcity of water restricts the use of hydraulic processes, and absence of good water is a hindrance to the employment of steam without subsidiary condensing appliances or purifying processes.

A prevalence of hard, compact rocks can be negotiated successfully with a cable rig, but strata containing frequent recurrences of hard bands between non-caving softer strata can better be attacked by a Canadian rig, which permits the attachment and positive application of under-reamers that enlarge the hole to allow the descent of casing without frequent reduction of diameter. Although the speed of pole tools does not reach that of other systems in easy ground, they afford a means of penetrating almost all kinds of strata, and allow a wider range and combination of instruments and movements than any other system, whilst not precluding the use of a cable at will.

Soft, caving Tertiary strata and thick deposits of loose flowing sands can best be overcome by the modern hydraulic processes in which mud mixtures are employed. Their use was, till recently, restricted, through the absence of tools that would effectively pierce hard layers interspersed amidst the softer material, but recent inventions have removed this obstacle. Hydraulic processes are not favoured for prospecting, as they afford such little evidence of the nature of the strata being penetrated, and conceal indications of oil, but in proved fields, where depths are approximately known, the wet method of drilling may be changed over to the dry at any desired point. Unfortunately, drills that aim at the extraction of a core by the use of an annular cutter have found little favour with oil-field operators. Such processes impose restrictions that are unpopular, although in hard strata excellent cores can be cut and extracted by using diamond crowns, steel-cutting heads, or chilled shot.

is professionally associated, they have competed in speed with all other varieties of drills, and been retained for the eventual development of shallow fields. A third drum should be prescribed for manipulation of the casing line without the necessity of disengaging the drilling cable. Either a derrick or shear legs stayed by guy ropes should then be erected to support the casing blocks and sustain the weight of the column of casing.

Boring Records.—Whether prospecting in a new oil-field or exploiting an old one, complete, and as nearly as possible accurate, records of the borings should be kept. In some countries legislation enforces the compilation of drilling returns for official reference, but whether this is compulsory or not daily journals of all boring wells should be preserved. The geological information afforded by the early borings in a new district is of immense importance in deciding upon the direction in which future operations shall extend, and not only should the geological data be compiled, but a full history of the drilling should be given, in order that subsequent operators who have not had the early experience may realise the difficulties encountered in passing through the different beds.

A full boring journal should be divided into a drilling and a geological section. In the former should be stated the time worked, number of feet drilled, the length, duration, and cause of any delays or stoppages, and any special remark which would indicate the cause of slow drilling or loss or breakage of tools. Full particulars should also be given concerning the size, thickness, and kind of casing or lining tubes inserted or withdrawn, and notes should be made as to its freedom or tightness. In the geological return the depth should be given at which every change of stratum occurs, and as full a description of each stratum as possible; any observed change of level of liquid in the well should be recorded, and the presence and character of water, petroleum, or gas should be fully reported.

The importance of correct data can only be appreciated by those closely allied with oil-field development, as in cases where unexcluded surface water fills the well, an appearance of certain kinds of sand or the escape of a little gas is sufficient transcribed into a foolscap size book of printed forms kept for the purpose in the office. When companies send home drilling returns from abroad, it is usual to have forms of sufficient size to show either seven, fifteen, or thirty-one days' work according

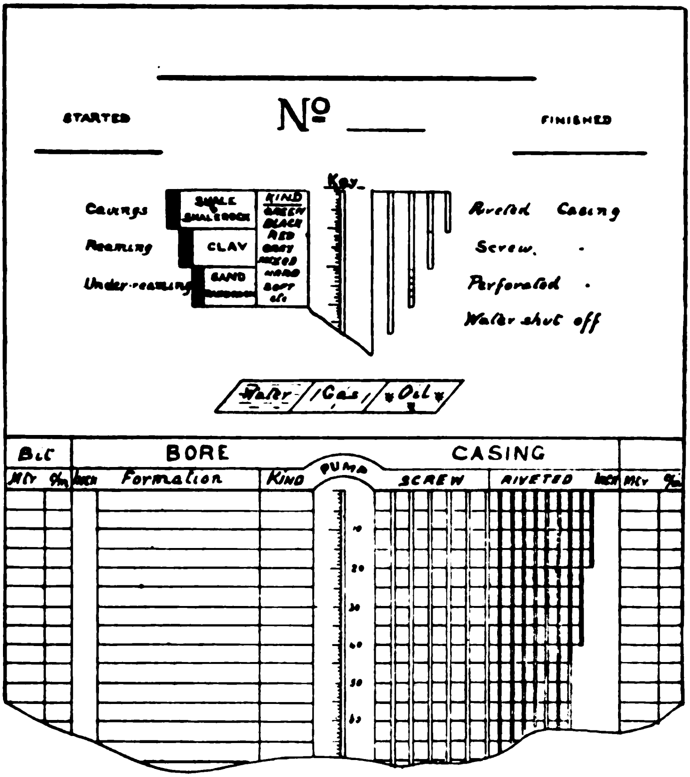


Fig. 45.—Form of Boring Return used in Galicia.

to the frequency with which the mails leave or the returns are required.

Fig. 45 illustrates a form of boring return, designed by Geo. von Kaufmann, and largely used in Galicia by the oil producers.

The United States Geological Survey issued some very excellent instructions for the preparation of well records in the "Record of Deep Well Boring for 1904," which should be read by those interested in the question.

COMMENCED 23RD JULY 1912.

Rig in use......................................

Contractor ....

At 550 ft. water rose to within 30 ft. of surface.

Much gas at 800 ft., and 20-in. casing got damaged and had to be repaired.

Trial bailed at 1,300 ft., but quantity of oil small. Sp. gr. .885; gas fairly strong and sweet.

Much trouble freeing casing afterwards.

At 1,450 ft. salt water rose to within 450 ft. of surface. Some gas present.

Thick oil sand at 1,700 ft., but no great indications of oil. Decided to deepen without trial bailing.

At 2,100 ft. rich oil sand struck; sand rushed up casing, and well flowed at intervals of a few hours.

Yield about 135 tons daily.

Drilled in 270 days; average 8 ft. daily.

Average per drilling day, $\frac{2140}{204} = 10.4$ ft.

" working day, $\frac{2140}{234} = 9.14$ ft.

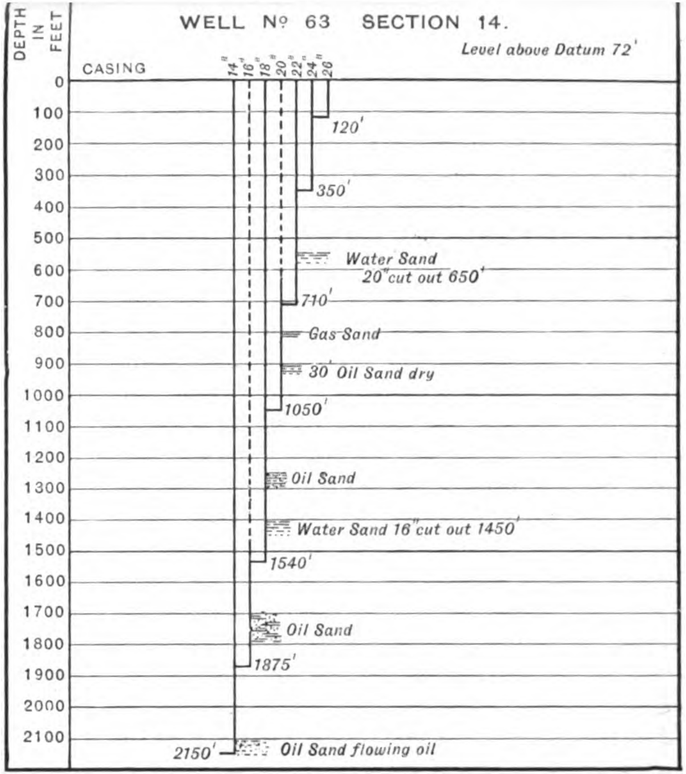


Fig. 46.—Useful Method of keeping Field Note-Book.

Books should be in squared paper, and two opposite pages allocated to each well. On one side are noted important details, and on the other a diagram of the well is shown.

suspended in the derrick and lowered into the well, a band brake on one side of the bull wheel shaft being applied to arrest the speed of descent to a safe amount. When the tools are near the bottom, the temper screw is attached to the cable, the weight thereby being thrown on to the walking beam, and the bull wheel shaft being released. A few feet of cable are uncoiled from the bull wheel shaft, and the engine then started, and speeded up till the oscillations synchronise with the natural vibrations of the rope. By feeding out the temper screw, the bit is lowered until a blow is delivered, and then periodically fed out as the material is pulverised and the bit fails to strike an effective blow.

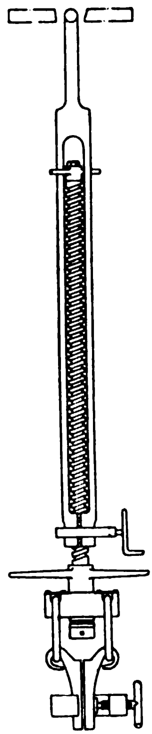


Fig. 48. Temper Screw.

As soon as the bit shows signs of not falling freely, the slack rope is taken up on the bull wheel shaft by attaching the driving ropes or throwing the chain into gear, and the temper screw thus relieved of weight, the connecting rod or "*pitman*" is disconnected from the crank-pin, and the beam then allowed to recline in an inclined position out of the way whilst the tools are raised to the surface and placed at one side of the derrick. The bailer is then lowered and the well cleaned out, sufficient water being run into the well previously to promote the formation of a mud capable of recovery by bailers.

Obviously, drilling from the beam could not be started with a 40-ft. string of tools, consequently the first hundred feet or more are drilled by a process known as "*spudding.*" For this operation the beam is disconnected from the crank-pin, and a grooved collar slipped on in its place. By means of a spudding shoe connected by a rope to the roller, a grip is taken of the drilling cable near the bull wheel shaft. By jambing the brake on the bull wheel shaft, and putting the main shaft in motion, the horizontal motion imparted to the connecting rope transmits to the cable from which the tools are suspended a vertical and reciprocating movement. Periodical release of the brake feeds

Specification of Cable Tool Outfit for 2,000 Feet.

Lining tube, 12⅜ in., 10 in., 8 in., 6½ in., and 5 in. internal diameter.

1 Steam boiler capable of evaporating with ease 1,500 lbs. of steam per hour at 100 lbs. pressure with fuel found in the district, fitted with feed pump, injector, and spares.
1 Horizontal 11 × 12-in. single cylinder reversing steam engine with pulley and flywheel, feed pump and feed water heater, with means for operating both throttle valve and reversing gear from the derrick, and ample spares and belting.
1 72 × 20-ft. wooden derrick and rig.
1 Set rig irons, 5-in. shaft.
1 No. 2 Barrett oilwell jack, complete with circle and bar.
1 1-ton Harrington chain hoist (T-beam) and swivel tool wrench, with 3¼ and 4 in. plates.
2 Sets 100-ft. telegraph cord wire and grooved wheels drilled.
6 No. 65 clothes line pulleys for use in elevating temper screw.
1 Set tool wrenches for 4-in. squares for 2¾ × 3¾-in. joint.
1 „ „ 3¼ „ 2 × 3 „
2 16-in. spudding bits 2¾ × 3¾-in. joint, 4-in. squares, 7 flat threads.
3 All steel California pattern drilling bits to work inside 12⅜-in. drive pipe, 2¾ × 3¾-in. joint, 7 flat threads 4-in. squares, 4 ft. 6 in. long.
3 All steel California pattern drilling bits to work inside 10-in. drive pipe, 2¾ × 3¾-in. joint, 7 flat threads 4-in. squares, 4 ft. 6 in. long.
3 All steel California pattern drilling bits to work inside 8-in. drive pipe, 2¾ × 3¾-in. joint, 7 flat threads 4-in. squares, 4 ft. 6 in. long.
3 All steel California pattern drilling bits to work inside 6⅝-in. casing, 2¾ × 3¾-in. joint, 7 flat threads 4-in. squares, 5 ft. long.
3 All steel California pattern drilling bits to work inside 5 3/16-in. casing, 2 × 3-in. joint, 8 sharp threads 3¼-in. squares, 5 ft. 6 in. long.
1 Tool gauge for each size bit.
1 Spudding shoe.
1 Box and pin template for 2¾ × 3¾-in. joint, 7 flat 4-in. squares.
1 „ „ „ 2 × 3-in. joint, 8 sharp 3¼-in. squares.
1 1¾-in. B.B. temper screw to let out 4 ft. 8 in., with 1¾-in. lower parts for 2⅛-in. dia. rope.
2 New era rope sockets for 2⅛-in. cable, 2¾ × 3¾-in. joint, 4-in. squares, 7 flat threads.
2 Sub-rope sockets for 2⅛-in. cable, 2 × 3-in. joint, 3¼-in. squares, 8 sharp threads.
1 Set jars 5¼ in. dia. × 8-in. stroke, 2¾ × 3¾-in. joint, 7 flat threads 4-in. squares.
1 Set jars 4⅝ in. dia. × 8-in. stroke, 2 × 3-in. joint, 8 sharp threads 3¼-in. squares.
2 25-ft. stems 4¼ in. dia., 2¾ × 3¾-in. joint, 7 flat threads 4-in. squares.
2 25-ft. stems 3½ in. dia., 2 × 3-in. joint, 8 sharp threads 3¼-in. squares.
1 Conductor bailer 11⅝ in. dia. × 10 ft. long.
1 Wrought-iron bailer 10 in. dia. × 19 ft. long.
1 „ „ 8 in. dia. × 19 ft. long.

shutting in oil and gas sources which could not be overcome by ordinary methods (see p. 392).

Cable drilling can be performed in thick muds, but steel wire lines must replace ordinary manilla cables. The well is kept filled by a pump, and when a certain amount of drilling has been performed the debris is cleared out in the ordinary way by sand pumps or bailers. The less the freedom with which the disintegrated material mixes with mud the more frequently it is necessary to clean out the hole.

Inexpensive additions are necessary to convert a cable rig into a circulating plant. Drilling is continued with a steel wire line through a casing head and oil saver, whilst a circulation is maintained down the inside of the casing and up around its exterior. This process has proved especially efficacious where caving difficulties combined to impede drilling and check the movement of the column of casing. The saving of a single column of casing in a deep well may itself represent several thousand dollars, but it is in time that the greatest advantages lie.

Fig. 51 shows the method adopted. A mud is prepared to suit the circumstances, and two suitably coupled-up pumps, capable of interchange at any moment, give the desired pressure to maintain a circulation.

A special feature of this process is the "*swinging spider*," which enables the casing to be raised and lowered without withdrawing the tools. As it is essential that the casing be kept within a few feet of the bottom of the hole during drilling, the advantage of this appliance is apparent.

Rope Sockets.—Connections between a manilla or wire cable and the string of tools is made by a rope socket. The lower part is internally screwed to fit the tools, whilst the upper is often in two parts, and internally bored with a taper hole into which the rope, increased in bulk by plaiting in additional strands, is firmly drawn. One popular type has a tapered side orifice into which the bunched-up cable end is tightly drawn and then trimmed.

Wire rope sockets are often constructed with conical recesses in the body of the tools corresponding with wedge-shape segments

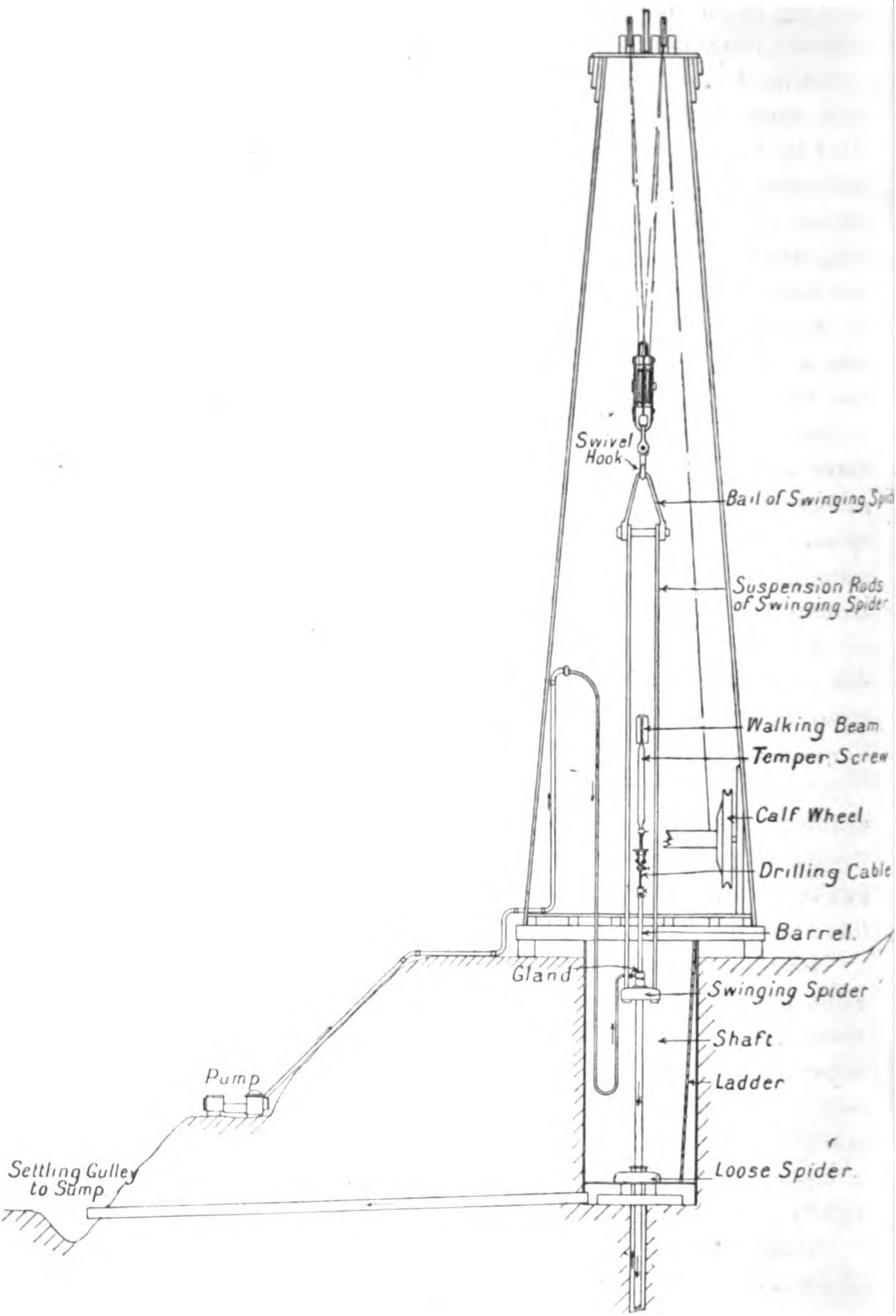


Fig. 51.—Diagrammatic Representation of Circulating (Cable) System of Drilling with Swinging Spider.

that firmly grasp the rope when weight is applied. One type of socket contains a simple conical recess, tapering downwards, into which the rope is thrust, the strands spread out, and the whole fixed in position with white metal or lead.

Wire rope sockets have been designed to take advantage of the spin transmitted to a wire rope. One such type has a ratchet which ensures the rotation of the tools in one direction. Another is provided with a ball-bearing that makes the rotation of the tools quite independent of the spin of the rope.

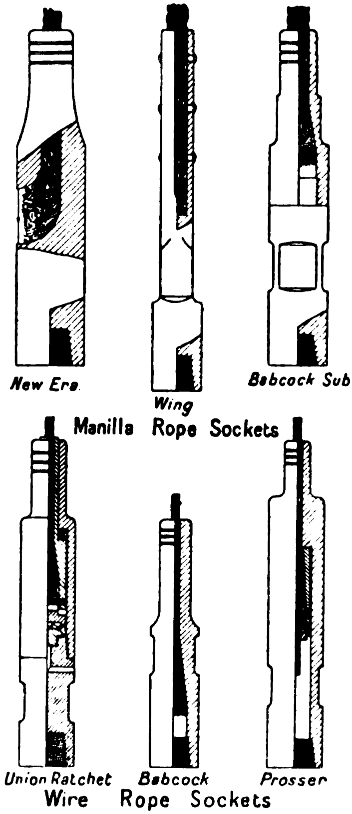


Fig. 52.—American Cable Tools.

Tool Joints and Tightening Apparatus. — Nearly all modern tool joints have taper threads of from six to eight threads per inch. Both pin and socket ends are carefully turned, screwed, and chased to gauge, so that they can be screwed up by hand wrenches to within the thickness of a sheet of tin plate. The joints of cable tools are screwed to butt, and loosened by massive tool wrenches, the ends of which are either levered from a half circle bolted to the derrick floor, or driven home by blows from a sledge hammer. Tool joints must be absolutely interchangeable, kept quite clean, and must always be preserved by thread protectors when not in use.

The best and most universally adopted apparatus for tightening up and loosening joints is the Barrett Oil-well "Jack" shown in Fig. 53.

Percussion Bits.—Several representative forms of percussion drills appear in Fig. 54. Cable drillers generally prefer the thicker type as shown in Fig. 54, *b*, and 54, *c*, whilst for pole tool systems the thinner, sharper variety illustrated in Fig. 54, *e*, is preferred.

There is a modern tendency to increase the length of drills, and in the smaller sizes they are often all steel, instead of having only a lower part of steel welded on to an iron shank.

Special shaped bits are sometimes used for particular duties. A "Star" bit (Fig. 54, *f*) is effective in rounding up a hole which for some reason is not quite circular, and bits with side wings are in general favour in Russia and Roumania.

Eccentric Bits.—It is possible in some kinds of strata to bore a hole several inches larger than the diameter of the bit by means

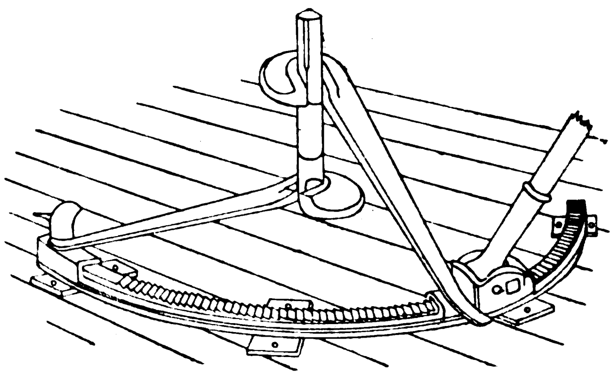


Fig. 53.—Method of Tightening up Joints of Drilling Tools with Barrett Oil-Well "Jack."

of eccentric bits. These drills, whilst passing freely through the casing, have an eccentric cutting edge whereby a hole larger than the diameter of the bit is made. Divergent views are held concerning the value of the many designs of eccentric bits in use. The objects aimed at will be self-evident from the features shown in Fig. 55. As a matter of fact, one form will give better results in certain ground than another, and only trial determines the advantage of any particular class in a certain locality. Eccentric bits should be nicely balanced by the judicious distribution of metal, although this feature is not often taken into account.

By their use in Galicia and Roumania, it has been possible without the aid of under-reamers to carry strings of casing behind the drill for many hundreds of feet, where formerly a reduction of

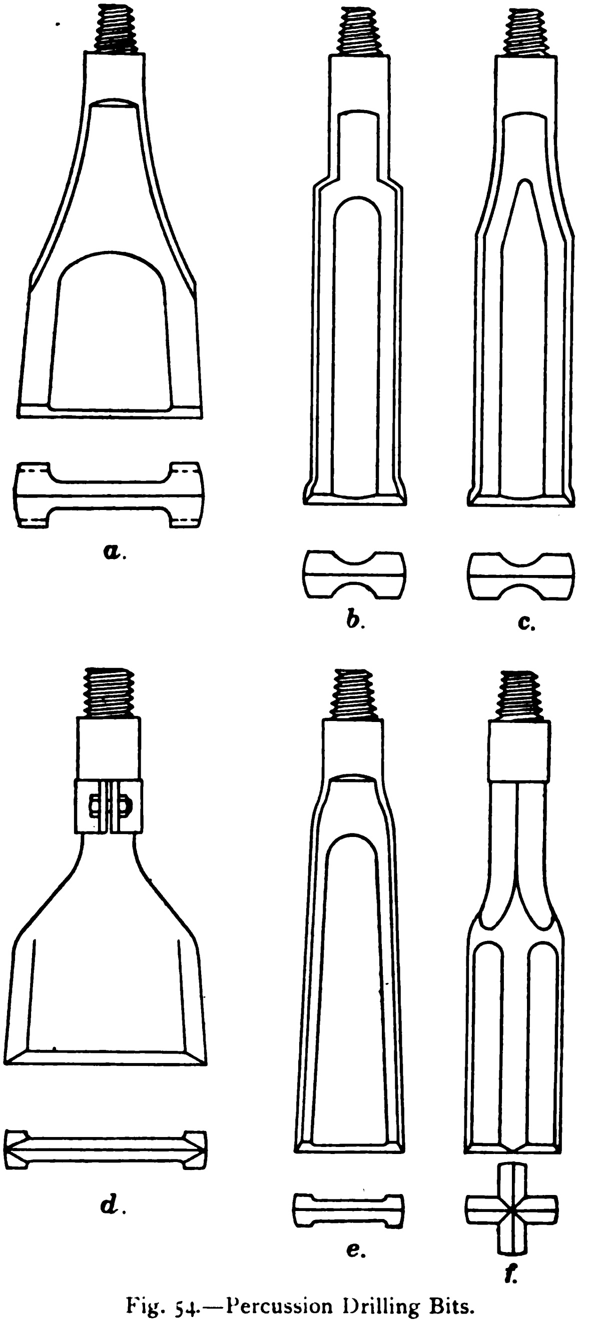


Fig. 54.—Percussion Drilling Bits.

a. "Spudding" Bit.
b. "Mother Hubbard" (American).
c. "Californian" (American).
d. "Russian."
e. "Canadian or Galician."
f. "Star."

(sharpening can scarcely be applied to the operation in most cases) and tempering of large-sized drills impose laborious duties on the attendants, and ingenious devices have been introduced to facilitate the work where neither a workshop nor extra men are often available. A small steam turbine-propelled blower for the forge is now

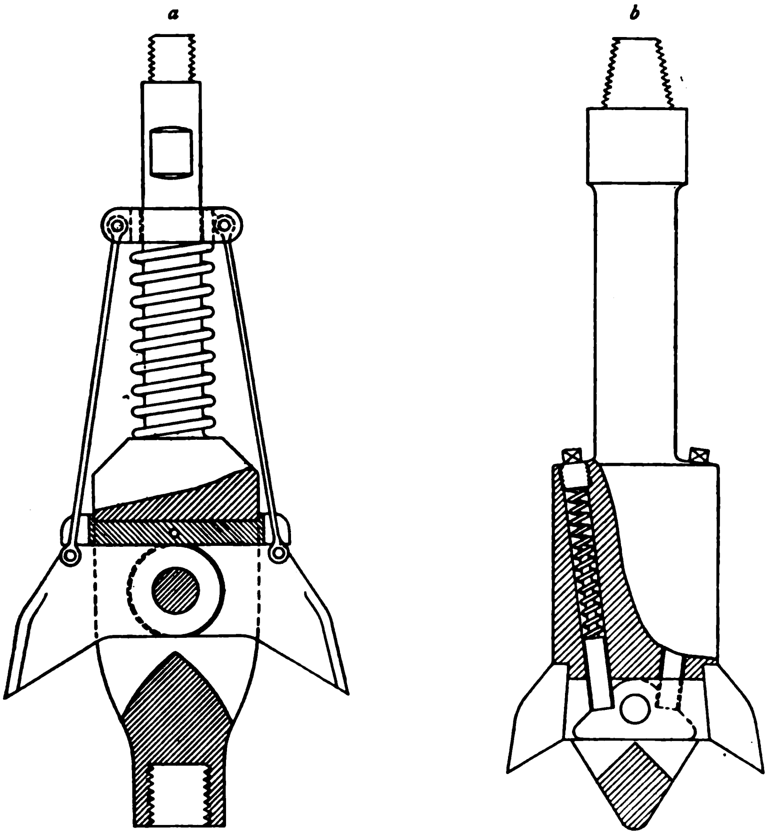


Fig. 56.—Under-reamers.
a. Russian. *b.* Austrian.

a common adjunct to a drilling equipment, but where bellows are retained, a rope is usually led from the handles of the bellows to some reciprocating part of the rig to perform the blowing. For the dressing of bits steam hammers are now procurable that can be cheaply erected at or near the well, and enable a blow to be delivered at almost any required angle.

base. In hard ground a cutting edge is given to the tool. Wear is mainly confined to the side edges, causing a gradual reduction of

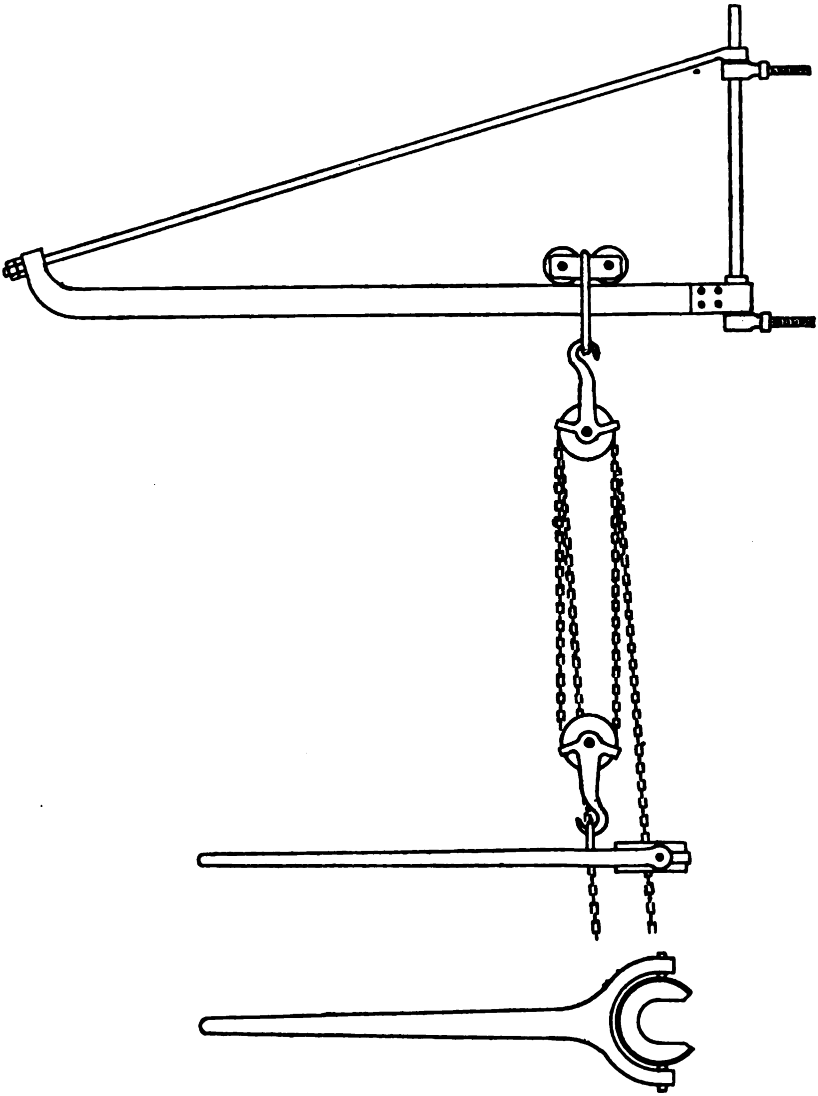


Fig. 59.—Derrick Crane with Swivel Wrench.

diameter that must be corrected by "jumping up." Drilling troubles will be constant if the diameter of drill is allowed to diminish too much by wear without dressing.

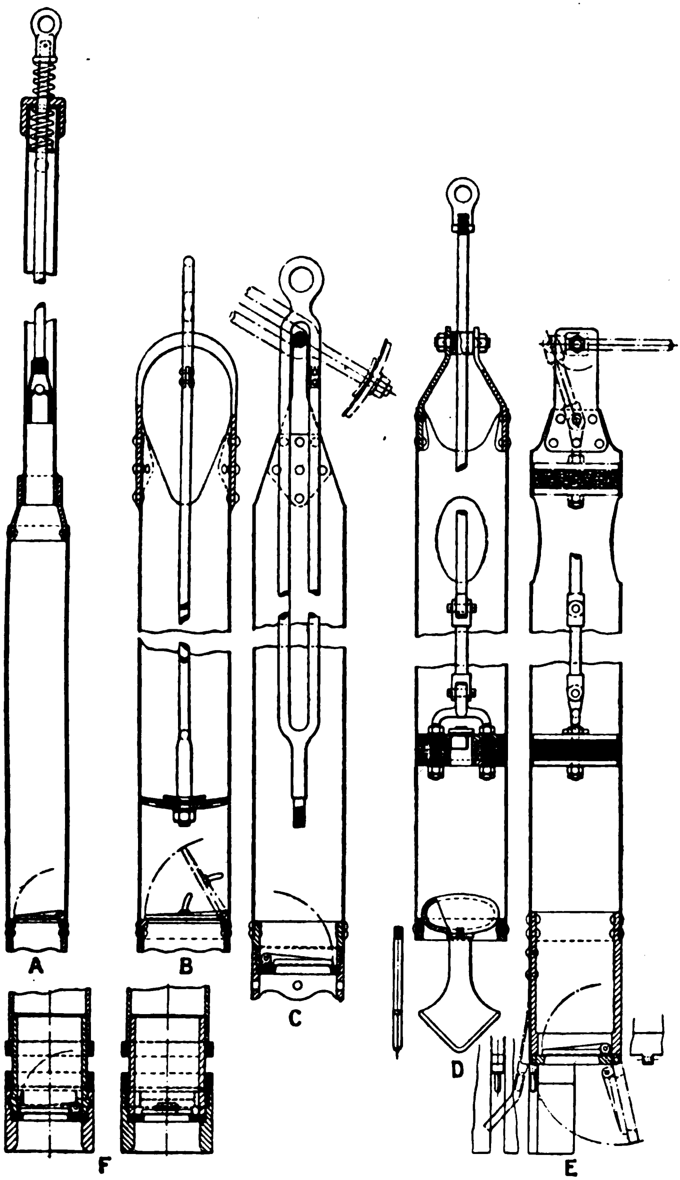


Fig. 62.—Types of Sand Pumps.

A. Russian type, with separate piston chamber.
B. Common type.
C. ,, ,, with extractable valve.
D. Knuckle joint type with pick valve.
E. ,, ,, with hinged valve seat.
F. Type of extractable valves.

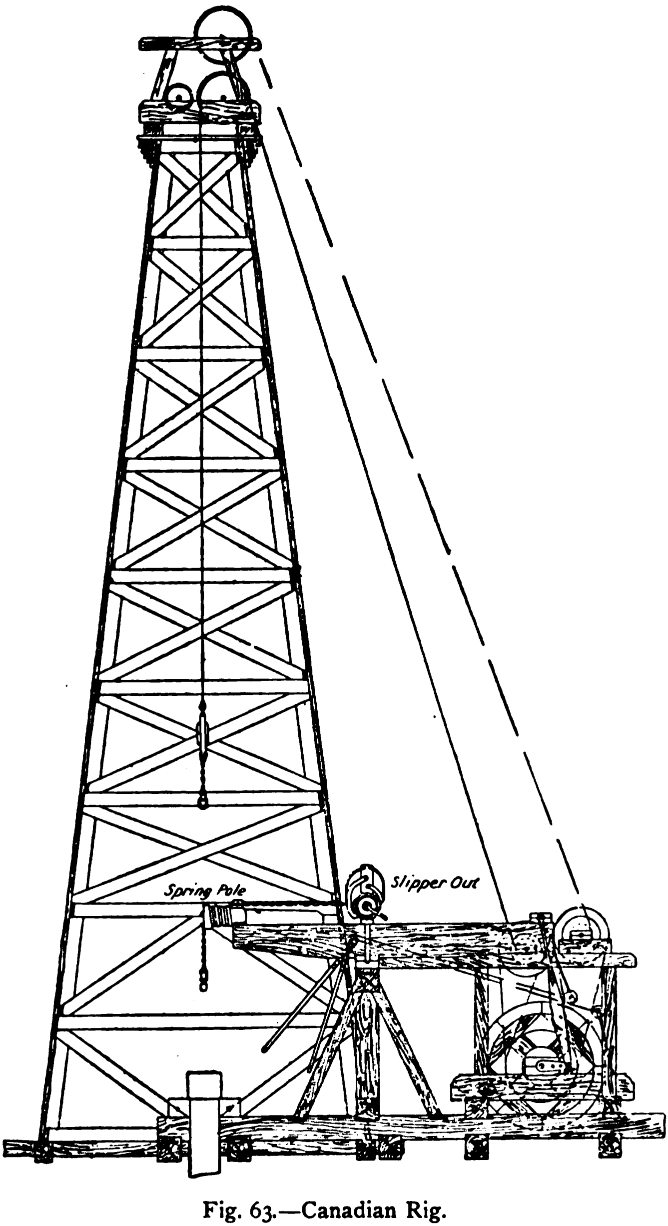


Fig. 63.—Canadian Rig.

hauling drum after disconnection of the hauling line, unless an extra spool is provided for the purpose separately controlled by jockey pulleys and levers. Variable lengths of stroke can be

3 Drilling bits to work inside 6½-in. I.D. drive pipe, 2½ × 3½-in. joint. 4-in. squares, 270 lbs. each.
3 " " " 5-in. I.D. drive pipe, 1¾ × 2¾-in. joint, 3-in. squares, 180 lbs. each.

Eccentric Bits.

3 Eccentric bits to work inside 12⅝-in. I.D. drive pipe, O.D. of shoe being 14⅛ in., 3 × 4-in. joint, 4½-in. squares, 450 lbs. each.
3 " " " 10-in. I.D. drive pipe, O.D. of shoe being 12 in., 3 × 4-in. joint, 4½-in. squares, 400 lbs. each.
3 " " " 8-in. I.D. drive pipe, O.D. of shoe being 9½ in., 2½ × 3½-in. joint, 4-in. squares, 300 lbs. each.
3 " " " 6½-in. I.D. drive pipe, O.D. of shoe being $7\frac{13}{16}$ in., 2½ × 3½-in. joint, 4-in. squares, 250 lbs. each.
3 " " " 5-in. I.D. drive pipe, O.D. of shoe being $6\frac{3}{16}$ in., 1¾ × 2¾-in. joint, 3-in. squares, 150 lbs. each.

Sinkers.

1 5-in. sinker, 25 ft. long, 3 × 4-in. joint, 4½-in. square.
1 5-in. " 15 " 3 × 4-in. " 4½-in. "
1 4½-in. " 25 " 2½ × 3½-in. " 4-in. "
1 3½-in. " 25 " 1¾ × 2⅜-in. " 3-in. "
1 3-in. " 20 " large pole joints for sand pump and fishing.

Jars.

1 6¼-in. drilling jar, 3 × 4-in. joint, 4½-in. squares.
1 5⅛-in. " 2½ × 3½-in. " 4-in. "
1 4⅛-in. " 1¾ × 2¾-in. " 3-in. "
1 5⅛-in. fishing jar, 2½ × 3½-in. " 4-in. "
1 4⅛-in. " 1¾ × 2¾-in. " 3-in. "

Substitutes.

1 Substitute 4 × 3-in. box, 2½ × 3½-in. pin.
1 " 4 × 3-in. pin, 2½ × 3½-in. box.
1 " 4 × 3-in. box, large pole pin.
1 " 2½ × 3½-in. box, 1¾ × 2¾-in. pin.
1 " 2½ × 3½-in. pin, 1¾ × 2¾-in. box.
1 " 2½ × 3½-in. box, large pole pin.
1 " 1¾ × 2¾-in. box, " "
1 " 1¾ × 2¾-in. pin, large pole box.
1 " large pole pin, small pole box.
1 " large pole box, small pole pin.

Drill Poles.

84 Special iron drill poles, each 36 ft. long by 1 in. dia. = 3,024 ft., small pole joint.
8 Tubular hand poles, 2 each 5 ft., 6 ft., 10 ft., and 15 ft., for each size joint.
20 Pairs small pole joints for welding.

Wrenches.

2 Heavy tool wrenches for 4½-in. squares.
2 .. .. .. 4-in. ..
2 .. .. .. 3-in. ..
2 Knock wrenches.
1 Catch wrench.
2 Chain levers (1 heavy and 1 light).
1 Key wrench for iron poles.

Swivels.

2 Pole swivels with chain for 1-in. poles.
2 Sand pump swivels.
1 Pole hook.
1 Sand pump hanger and chain.

Mud and Sand Pumps.

1 12-in. mud pump, 6 ft. long, with hinged bail and large pole pins.
2 10¾-in. sand pumps, 18 ft. long, with large pole pin.
2 8⅝-in. .. 18 .. .. ..
2 7-in. .. 18 .. with small ..
2 5½-in. .. 36 .. .. ..
2 4⅞-in. .. 36 .. .. ..
1 Spare valve for each of above.

Wedge Rings and Wedges.

(Heavy Pattern.)

1 Steel plate suitable for 13-in. and 10¾-in. O.D. drive pipe.
1 Set of wedges for 13-in. O.D. drive pipe.
1 .. .. 10¾-in. .. ..
1 Steel plate suitable for 8⅝-in. and 7-in. O.D. drive pipe.
1 Set of wedges for 8⅝-in. O.D. drive pipe.
1 .. .. 7-in. .. ..
1 Steel plate suitable for 5½-in. O.D. drive pipe.
1 Set of wedges for 5½-in. O.D. drive pipe.

Elevators.

1 Pair Scott's Mannington elevators for 13-in. O.D. drive pipe.
1 .. .. 10¾-in. ..
1 .. .. 8⅝-in. ..
1 .. .. 7-in. ..
1 .. .. 5½-in. ..

DRIVE CLAMPS.

1 Pair drive clamps and bolts to fit 4½-in. squares.
1 ,, ,, ,, 4-in. ,,
1 ,, ,, ,, 3-in. ,,
1 Set spanners.

Russian Freefall System.—The large diameter of wells in the Baku oil-fields, and the specially caving nature of the strata met with, have led to the adoption of a modified pole tool system which well suits the local conditions. The tools consist of a chisel or bit, under-reamer, sinker bar, and freefall, connected by 1½-in. square iron rods which extend to the surface. The tools are operated by a geared frame of heavy design driven by belting from an engine or motor in the derrick. The geared frames vary somewhat in design, but they are all provided with means of operating four distinct shafts or combinations which drive by gearing or otherwise three drums and a crankshaft. One slow geared shaft in the front of the frame is fitted with a drum and powerful side brake, and is used for raising and lowering the tools through a distance of about 50-60 ft. as the rods or tools are being connected or disjointed. Another larger drum geared for high speed is used for raising and lowering the bailer and sand pump, and a third drum shaft, also in combination with a brake, operates the heavy pulley blocks which are used for manipulating the casing. One of the above shafts, which can be disconnected from the drum, or a fourth shaft, is fitted with crank discs, which, by connecting rods, impart an oscillating motion to a walking beam pivoted on the upper part of the frame. The cranks are provided with holes at different radii to enable a varied stroke to be given to the beam by altering the position of the crank-pins, and means are arranged for throwing in and slipping out of gear the various drums as occasion demands.

The tools are screwed together singly and lowered into the mouth of the well by means of either a 1½-in. English welded chain, or a 1½-2½-in. steel wire cable attached to the front drum, a very heavy swivel hook with safety catch being attached to the chain or rope for the purpose. The 1½-in. square rods are generally 21 ft. long, screwed with taper threads, and are left coupled up in pairs to make 42-ft. lengths after the depth of

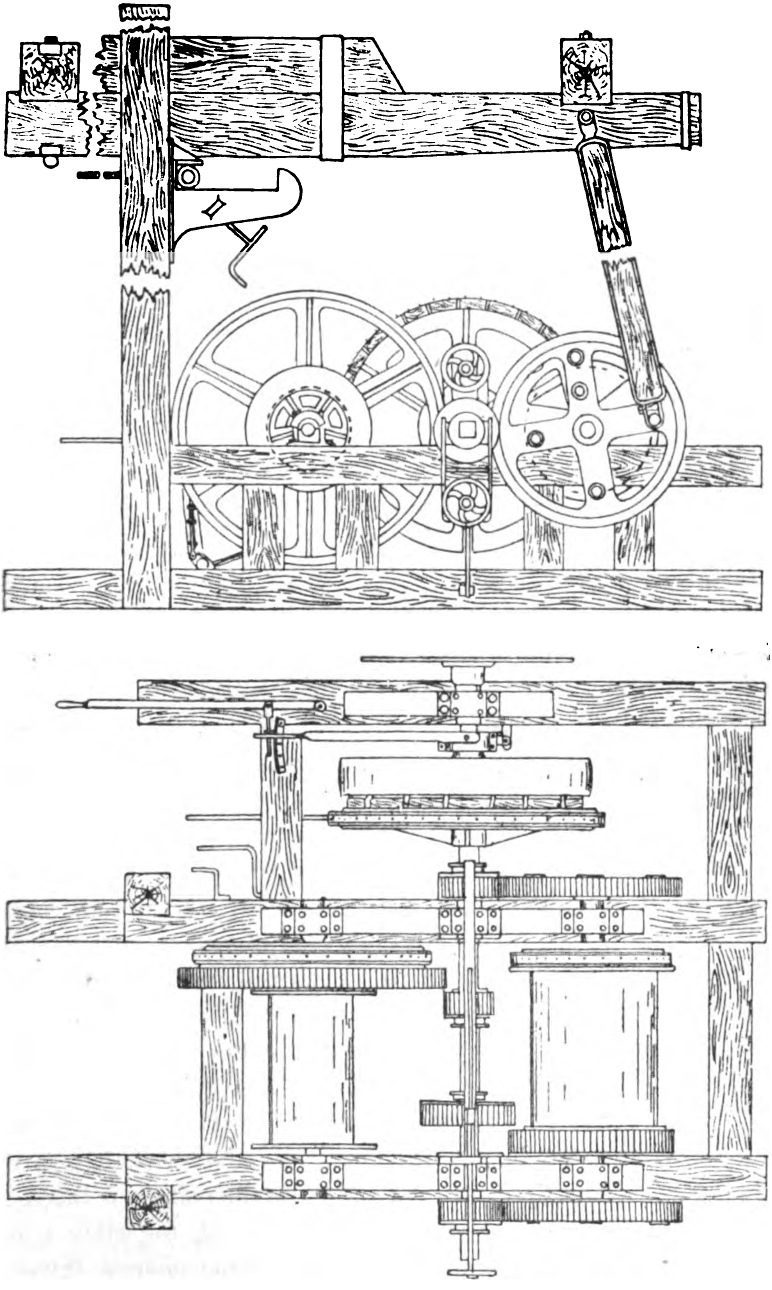


Fig. 66.—A Common Type of Russian Boring Frame.

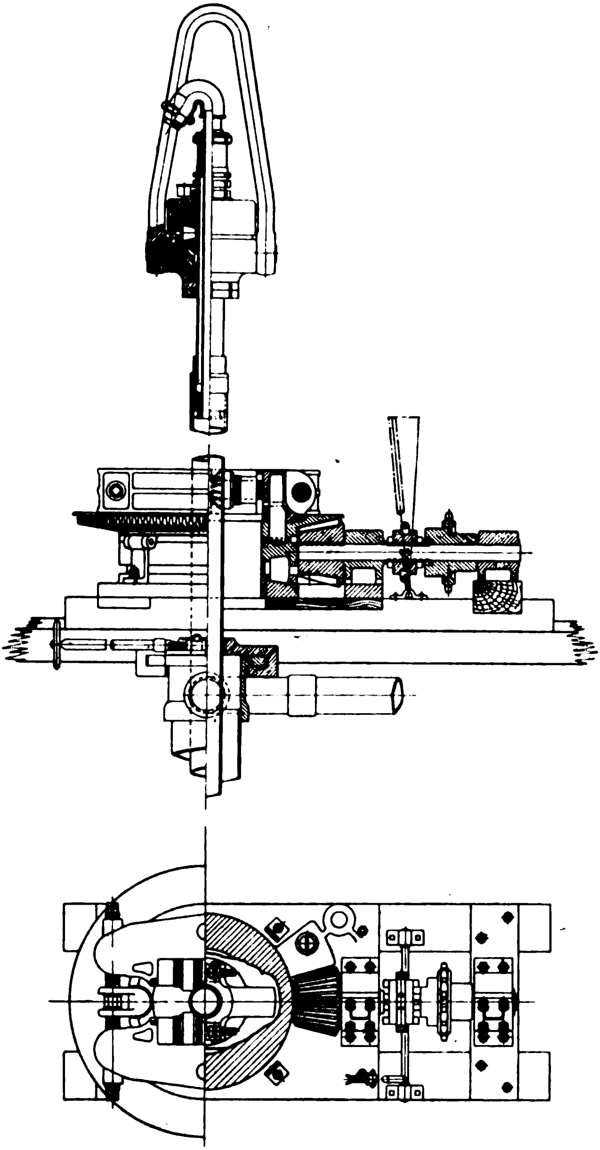


Fig. 67.— Hydraulic Rotary Table and Hydraulic Swivel, showing a Blow-out Preventer beneath Table.

then attached, after which the column is again picked up by the swivel and the collar lowered below the rotary table. The grip rings are then set up to the drill rod, the pump started, and as is now commonly used. Besides imparting greater torsional strength for transmission of power they reduce the annular space between the well sides and drill rods, thus increasing the velocity of the circulating fluid. Friction naturally fixes limitations to the reduction of area, but it is obvious that the higher the velocity of the liquid the sooner will particles of dislodged material reach the surface.

Two important but little appreciated factors in flush drilling, bearing on successful work, are worthy of attention.[1] Firstly, it is a mistake to continue circulation of mud when not rotating, and the bit is off the bottom, for there is a tendency in soft strata to form a flat hole through the jets impinging at two spots on opposite sides of the drill. Secondly, the drill stem, when left stationary, certainly leans against the wall of the well at places, thereby deflecting the circulating mud to the opposite side, and tending to enlarge the hole at those points.

Porous sand and gravel saturated with water can often be pierced with the rotary when all other methods have failed. A thick mud is prepared by puddling clay, and continuous pumping gradually "muds up" the stratum, and usually enables the troublesome bed to be passed. Sometimes the whole of the circulating fluid is absorbed for days before the sand or gravel is rendered impermeable and circulation established.

Puddling machines are sometimes employed for preparing a thick clay mixture where drilling furnishes insufficient clay to produce a satisfactory one. A clay free from sand must be selected, when a mixture will be introduced that will scarcely settle if left quite undisturbed.

The universal use of the rotary is not imminent yet, notwithstanding its extended use. The process as at present evolved does not readily admit of under-reaming, and sharp sandy seams only a few feet thick wear away the drill in a short time, necessitating its removal for dressing.

Under-reaming can be effected by a newly invented bit known as the Donald Excentric Flush Bit, which is merely an adaptation of the eccentric drill to rotary work. If this proves applicable to

[1] See Discussion on "The Use of Mud-laden Water in Drilling Wells." I. N. Knappe, Amer. Inst. Min. Eng., February 1915.

Rotary fishing spears may be of a very simple design if the drill rods are quite free, but if they are gripped by accumulated detritus, spears of the ordinary type used for casing are employed, with internal hollow spindle through which the flushing can be continued during the process of lowering on drill pipes and setting.

Another useful type of fishing tool is the die and tap, which can be lowered with guides to screw a thread either internally or externally on stripped rod ends or sockets, or even fractured ends of tubing.

Tool joints for rotary drill pipe are often internally screwed on the female end, especially when used in holes where there is a narrow margin between the outside diameter of drill pipe collars and the casing or bore hole. This enables the simple, rapid, and firm attachment of flush pipes if a drill rod breaks, and the re-establishment of a circulation of mud if necessary.

The loss of a steel bit of the short type is often a matter of concern, as its position prevents its capture by fishing tools. In soft ground bits can be driven aside by percussion drills or even other strong flat bits, but if this is impossible cement should be inserted after washing the well clean, and the lost bit can then be cut out by a chilled shot rotary cutter. Rotary drillers are now favouring bits several feet long, or bits with long drill collars, so that in case of loss they stand up vertically and can be more easily recovered. The disadvantage of a long fish-tail bit is that the jets of fluid are too far from the cutting edges of the bit.

An apparatus which is largely employed with rotaries is what is called a "*Blow-out Preventer.*" These are massive cast-iron fittings, attached to the last column of casing inserted, which enable adjustable iron slips that encircle the casing to be closed tightly around the drill stem, in case the well commences to flow whilst drilling is in progress. When closed the oil, gas, and circulating water discharge from a side orifice that can be controlled by a valve, and can be led through piping to a point distant from the well whilst the oil sand is being drilled into. The full specification of a rotary outfit is as follows:—

then be driven over the casing by blows ... the taper top ... driven well inside the ta... and the enlarged part of the mandrel ... itself and the taper piece.

Specially difficult cases of lost tool... occasionally overcome by lowering c... cutters, or drills, and rotating from the ... cut an end, or drill a hole which could ... a firm hold taken on which to apply p...

A special screw jack, with ball-be... delicately feed... rotated by a ... this purpose.

Fig. 78. Impression Block.

Many of t... when the to... of soft strat... is rarely le... the fracture ... affected par... the detach... damage, o... brought t... as to the ... an impr... to ascer...

Impression blocks (Fig. 78) c... a body suitable for lowering o... lower flat or circular face, as ... thick layer of some plastic ... an impression, the ... wiring.

An e... was inv... hermeti... prearr... hood ... then ... shutt...

threading at one end
acting as coupling. A
ed end fits into a cor-

String of Wash Tubes Expelled by Eruption of Oil, Gas, and Sand during Cleaning Operations of a Plugged Oil Well.

slot cut in the collared end, thus enabling the rods when to be rotated in either direction without unscrewing. ure a maximum of torsional strength with a mini well as to furnish means for flushing the well if a

2-4 in. diameter iron rods with parallel threading at one end and a collar at the other, a loose socket acting as coupling. A machined rib on the extremity of the screwed end fits into a cor-

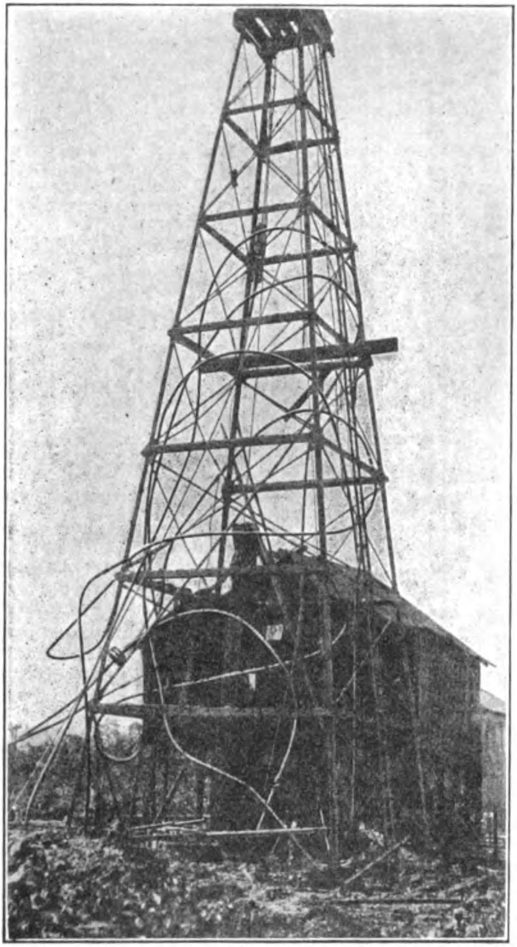


Fig. 81.—String of Wash Tubes Expelled by Eruption of Oil, Gas, and Sand during Cleaning Operations of a Plugged Oil Well.

responding slot cut in the collared end, thus enabling the rods when connected to be rotated in either direction without unscrewing.

To secure a maximum of torsional strength with a minimum of weight as well as to furnish means for flushing the well if advisable, heavy solid drawn tubing is now being used for fishing rods, joints similar to those described above being used.

For positive acting fishing tools the above rods cannot be surpassed, and they constitute part of the customary equipment of modern drilling contractors and large drilling companies. In America, for the more difficult fishing operations, special tools are lowered on a string of casing or drive pipe, but the advantages of rods over this latter practice are obvious.

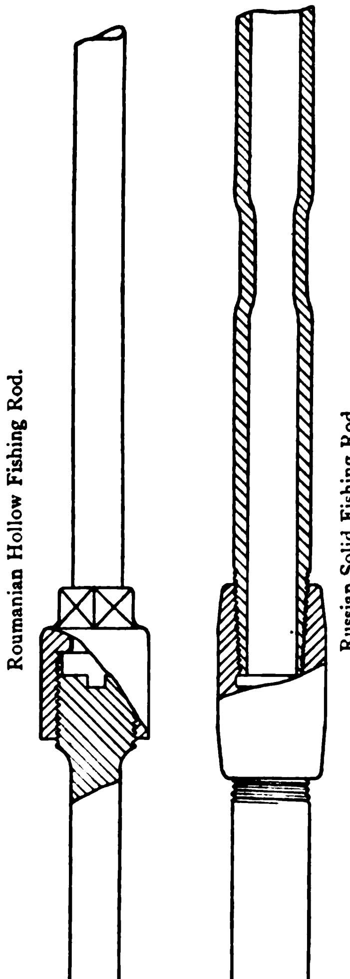


Fig. 82.—Fishing Rods or Poles.

Heavy solid drawn tubes with long left-handed threads are used for fishing in the Roumanian oil-fields. The resistance of a long thread is sufficient to ensure a grip being taken on lost objects, but the left-hand threads allow the tools to be released without the danger of unscrewing if the tool cannot be moved.

Portable Drills.—The expense of dismantling and re-erecting a derrick and rig at each well site has long been a source of concern amongst operators where wells can be completed in a week or two, and more time is occupied in transportation and re-erection of rig than in the drilling. When drilling occupies one or two years, as in Russia, Galicia, and parts of Roumania, the derrick is converted into a workshop, windows being fitted, heating appliances installed for winter, and everything comfortably arranged.

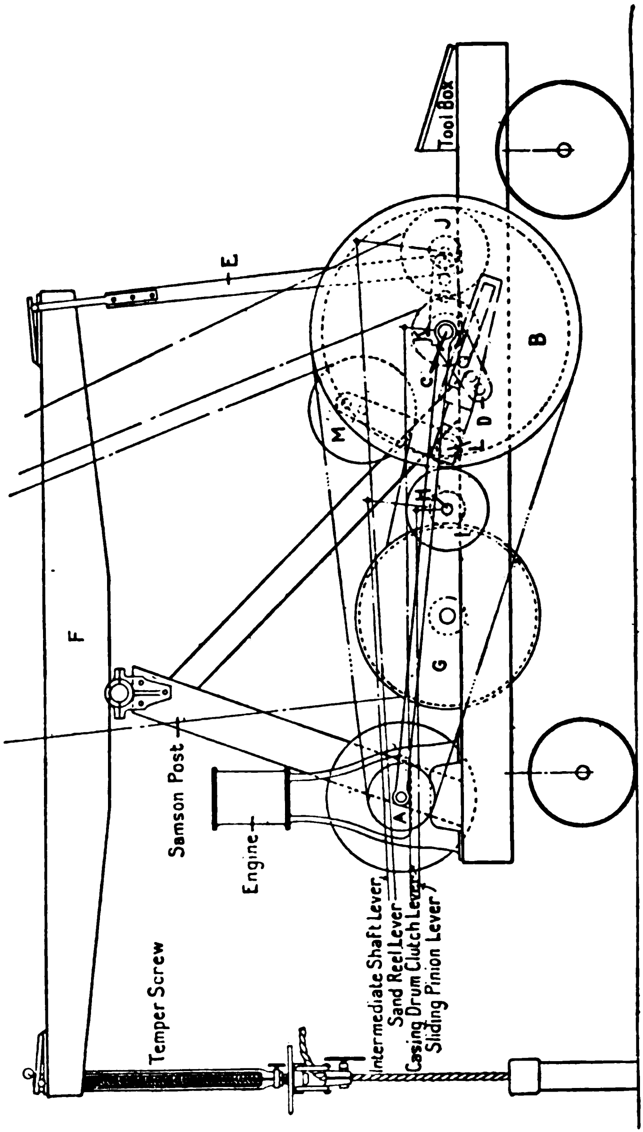


Fig. 83.—"Star" Portable Drill (Diagrammatic Sketch).

The casing drum I is mounted on the engine shaft H, and is operated by clutch gearing. The framework is of timber.

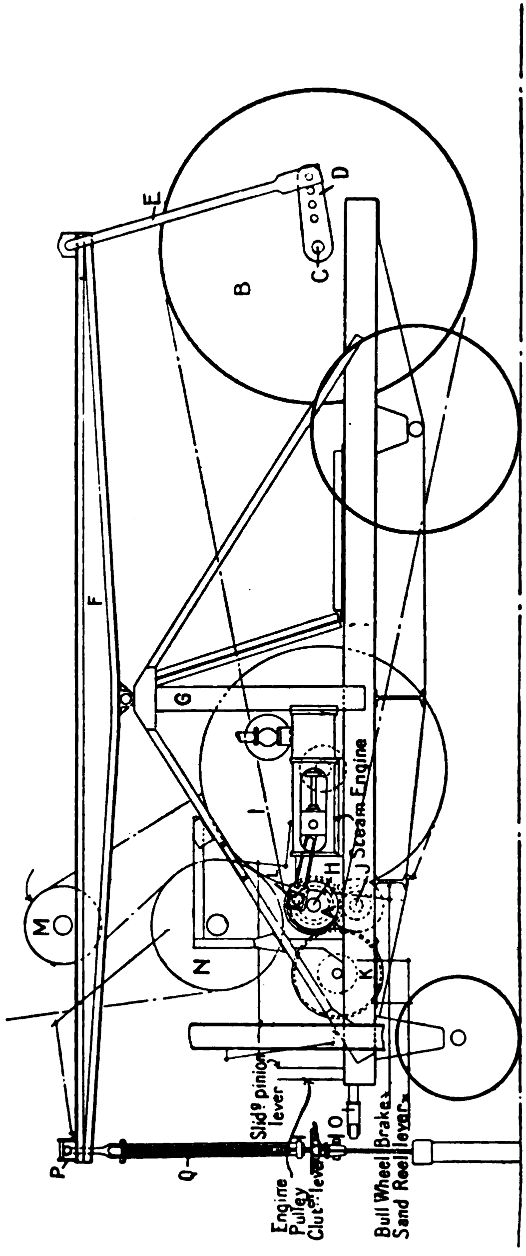


Fig. 84.—"Columbia" Portable Drill (Diagrammatic Sketch).

An all steel framework rig that has achieved a reputation.

by using electrical energy is only 8.5 kw. per hour, 11.4 H.P., with maximum requirements of 75 H.P. In Roumania the average cost of electric power for drilling wells is about 20 fr. ($4) a day, representing a charge of about 2.50 fr. (50 cents) per foot in average wells of moderate depth. Some indicator tests of a steam engine drilling in the Coalinga oil-fields of California gave the following results:—[1]

Lifting tools - - -	20 H.P.
Bailing - - - -	10 H.P.
Raising sand pump - -	22 H.P.
Drilling - - - -	10-14 H.P.

The actual cost of power can be calculated from the above figures, as well as the cost per foot of hole. If gas is used, 45,000 cub. ft. may be taken to equal 1 ton of oil, or 6,000 cub. ft. 1 barrel.

Casing requirements in wells differ widely, and are dependent upon the following factors:—

a. Class of casing needed to support walls.
b. Freights and transport from works to sites.
c. Price of metal.
d. Number of water sources to be excluded.

In table on p. 592, the proportionate cost of casing may be noted. The average cost of casing used per foot of drilling can be calculated for circumscribed areas, and used as a basis of calculations. Baku wells, 2,000 ft. in depth, with initial diameters of 36-42 in., often necessitate the employment of 300 tons of steel.

Analysis of 133 Coalinga wells showed the cost of casing per foot to average:—[2]

$2.70	in wells to	1,500 ft.,	averaging	1,305 ft. deep.
$4.00	„	2,000 „	„	1,844 „
$4.44	„	3,000 „	„	2,450 „
$4.58	„	above 3,000 ft.	„	3,332 „

Roumanian wells of about 1,500 ft. in depth use casing to the value of about $8 per foot, and in Burma the cost fluctuates around $3 per foot.

[1] [2] "Petroleum Industry of California." *Loc. cit.*

Labour may fluctuate in cost between \$5 to \$30 (£1 to £6 per diem, and the total cost of wells may be between extremes of \$1.50 and \$30 (6s. and £6) per foot.

Suppression of Wild Oil and Gas Sources.—There are sometimes reasons for drilling through several oil sources, either to tap a known deep source or to prospect for deeper horizons. Prolific oil or gas sands may be passed by cautiously working with a hole full of water, and avoiding anything that might induce a flow, but at other times the water is expelled and more or less violent eruptions of gas or oil prevent further progress until the gas or oil is sufficiently exhausted to allow casing to be manipulated or drilling continued. In the Mid-Continental oil-fields of America, sands containing gas under pressures of from 300-800 lbs. per square inch have often to be passed to reach the oil sands, and the practice of allowing this gas to escape has led the American Government to undertake investigations with a view to effecting its conservation. The experiments conducted with mud have proved exceedingly successful, and demonstrated that powerful sources may be drowned, extinguished, and passed with little loss of gas and at no great expense.

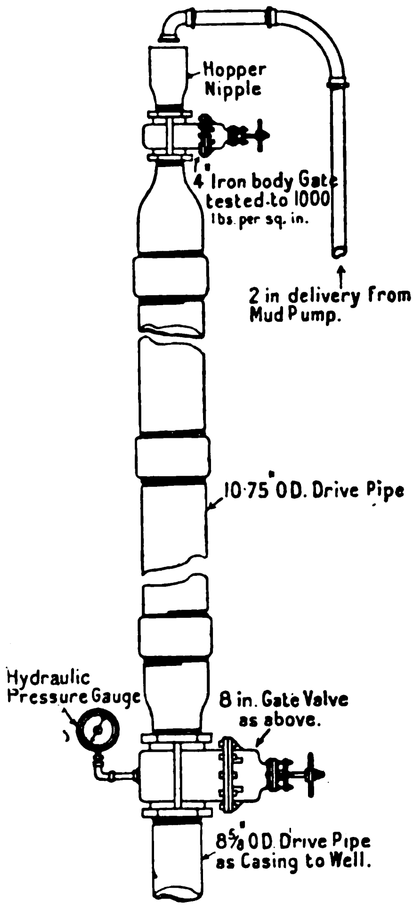


Fig. 86.—Arrangement for Filling with Mud Wells under High Gas Pressure.

When a powerful gas source has been reached, a thick puddle of clay, quite free from sand, is pumped into the well. If the pressure is too high, or the volume of gas too great to allow the mud fluid to enter the well, a valve is screwed to the casing head, several lengths of 10-in. or 12-in. casing are attached by means of a reducer, and another valve placed either at the top or at a point where a pipe leading from the pump enters the casing. An air valve is required to allow the escape of air and gas from the receiver, and the casing should be securely anchored. The lower valve is closed and mud is pumped into the receiver till full, the air valve being opened to allow the escape of contained air or gas. On closing the upper valve and opening the lower the fluid enters the well by gravity, the lower valve is then closed and the operation repeated till the well is filled. By this means gas sources yielding up to 40,000,000 cub. ft. daily have been rendered inert and passed until the casing has been set securely in suitable material below the gas source. Drilling can then be continued in a dry hole if desired.

Sometimes the above procedure cannot be carried out on account of the high pressure of gas, and the insecurity of the casing already inserted. This has been overcome by attaching to the top of the casing a T-piece with the single outlet leading horizontally. On the upper part of the T is fitted a gland and stuffing box, through which 3-in. tubing can be lowered to the bottom of the well. By tightening the gland and slowly restricting the side flow of gas by a valve whilst mud is being pumped into the 3-in. tubing the gas pressure can be ultimately suppressed, and the well left in a state to complete or deepen.

Mud introduced into wells in the manner described is instrumental in excluding water sources by plugging the porous stratum from which the water issued.

Shooting or Torpedoing Wells.—Where petroleum is disseminated amidst hard dolomitic limestones or calcareous sandstones, or where lateral variation of texture in hard rocks leads to the irregular distribution of petroleum throughout a bed, considerable benefits are often derived by blasting the oil-bearing rock with powerful explosives. The effect of explosions on hard rock not only leads to the destructive shattering of a productive bed, thereby enabling freer movements of the oil, but it sets up a subterranean disturbance in the oil and gas enclosed under high pressure in the pores of the rock, which continues for a

"The beneficial or harmful effects of a shot must depend largely upon the texture of the stratum yielding the oil, for it seems to be true that some shales are compacted rather than shattered by the explosion. For this reason, shooting is not practised in the Florence field, which, of all the older oil districts, the Boulder field most resembles. Owing to the difference in texture of the various beds yielding oil in the Boulder field, it is but reasonable to expect that the same shot which would prove beneficial to one well would be ruinous to another. On this account, if on no other, the texture and composition of the oil strata should be carefully studied by methods far more discriminating than the superficial ones now used.

"A second reason for injurious effects from shooting lies in uncertainty about the exact depth of the sand which it is intended to shatter. Measurements of depths by steel tape are indeed becoming more common, but in a considerable number of wells the depths of all formations are known only by cable measurement. Even in wells but recently sunk it is not uncommon that the stated depths of important sands are thus liable to errors of 25-50 ft.

"The possible injuries from a shot at the wrong place may be readily seen from the following considerations: Given a porous rock saturated with oil which is under a certain pressure. This rock is now, for the sole reason that it has no outlet in any other direction, being surrounded (as in this field) by impervious rocks. This well is now shot in such a way as to rupture the impervious rocks which have surrounded the oil sand. The oil may now leave the sand by other openings besides the well, and may thus be dissipated in other porous beds and the well may be ruined. Such an effect may be produced even by shooting at the proper depth if the charge employed be too heavy. In one instance a well was shot at 740 ft. with 500 lbs. of dynamite, 60 per cent. nitro-glycerine. The formation above the sand was a uniform dense shale. A good quality of sandstone was blown from the hole in chunks reaching a maximum of 14 lbs. The shale was ruptured to the surface. Open cracks of an inch or more extended for some rods from the well. Presumably, also, cracks reached a considerable depth below the sand which was to be shattered.

the bottom by attaching to the lower end of the first shell the required length of 'anchor,' which consists of a length, or several connected lengths, of tubing made of tinned sheet iron.

"The shells are lowered by means of a manilla line about ⅜ in. diameter to the bottom end of which a hook is fastened, which automatically detaches itself from the bale of the shell when this comes to rest. The empty shell is supported in the top of the hole, while the explosive is poured in from the tins in which it is transported to the well. Each shell takes two tins of explosive to fill it. Any drops of nitro-glycerine which may run down the outside of the shell are carefully wiped off to prevent premature firing of the shell due to friction against the casing. The tins, when emptied, are replaced in the wagon.

"The line is paid out by hand, the shooter keeping a careful watch to ensure the shell from sticking in the bore before it reaches the bottom of the hole. When the first shell with the anchor reaches the bottom of the hole, the line is marked as a guide to make certain the remaining shells are lowered to the right position. The line is then withdrawn, and the steel measuring line again run to make certain of the correct position of the first shell. This being ascertained the other shells are lowered, the mark previously placed on the manilla line being sufficient guide to ascertain the correctness of their position.

"When all the shells are placed in position, it may be necessary to pull the inner string of casing should the lower end of this be seated too near the shot. Every shot to be fully effective should have as tamping a head of fluid (water or oil) of from 100 ft. to 400 or 500 ft. in depth. It is important that this fluid tamping should not stand up into the inner string of casing. The result of firing a shot with the fluid standing up into the casing would be the splitting of the casing. Hence this is always removed first, unless there is sufficient room between the top of the shot and the bottom of the casing for an ample head of fluid. In that case, before shooting, the excess fluid is swabbed out until it is certain the level is below the bottom of the casing.

"If there is any danger of caving taking place on the removal of this casing, an electric detonator is lowered with the last shell and the casing is pulled over the insulated cable from the detonator to the surface. Otherwise the shot is generally fired by means of a squib, which is a tin tube containing a small stick of dynamite, in which is buried a detonating cap connected to a length of fuse which is lighted before the squib is dropped into the well. Where this fails to explode the shot a small tin tube containing a charge of glycerine and a firing head is lowered into the well on a copper wire, and when it is in position the firing head is struck by means of a short length of 1 in. diameter pipe threaded on to the wire and dropped into the well.

"The firing of the shot is generally followed by the ejection of the fluid contents of the bore hole, unless the hole is a deep one and the fluid head large compared to the size of the charge, in which case the shot does not always 'come out.'

"A good well will generally make several strong flows after shooting. After this first flush production has ceased, the well will require a good cleaning out, as for some time the disrupted sand continues to fill up the bottom of the hole, and until this sand ceases to come in cleaning out must be continued, otherwise it would be impossible to pump the well continuously. This cleaning out may take from one or two days to as long as three weeks before the loose sand is got rid of.

"The effect of the shot is to increase the production of the well to a considerable extent. Hard, compact sands are in general most benefited by shooting, but it is impossible to gauge the benefit beforehand. Certain sands give very little 'natural' production, *i.e.*, production without the aid of a shot. A notable sand in this respect is the 'Booch' sand found in the neighbourhood of Morris in the county of Okmulgee. This sand is found at a depth of 1,000-1,200 ft., and was entirely neglected until the effect of a shot was tried on it. Many Booch-sand wells on being drilled in will only produce about half a barrel or so of oil per day, but on being shot will start off at a daily production of one or two hundred barrels or even more. The remarkable effect of a shot in the Booch sand has not been satisfactorily explained.

"The work of shooting wells is naturally very dangerous, and every year a number of shooters lose their lives from accidents. Shooters receive a salary of about $150 per month which cannot be considered high considering the responsible and hazardous nature tractor for any delays for which the Company can be properly held responsible under the terms of this Agreement, provided always that such delays be not due to the Contractor's default in giving reasonable notice to the Company of his requirements and provided also that such delays be not due to circumstances over which the Company has no control. In the event of the Company compensating the Contractor for any delays as aforesaid the Company shall be entitled, upon its making application for such purpose to the Contractor, to utilise temporarily the services of the Contractor's employees, for which services the Company may have paid compensation to the Contractor.

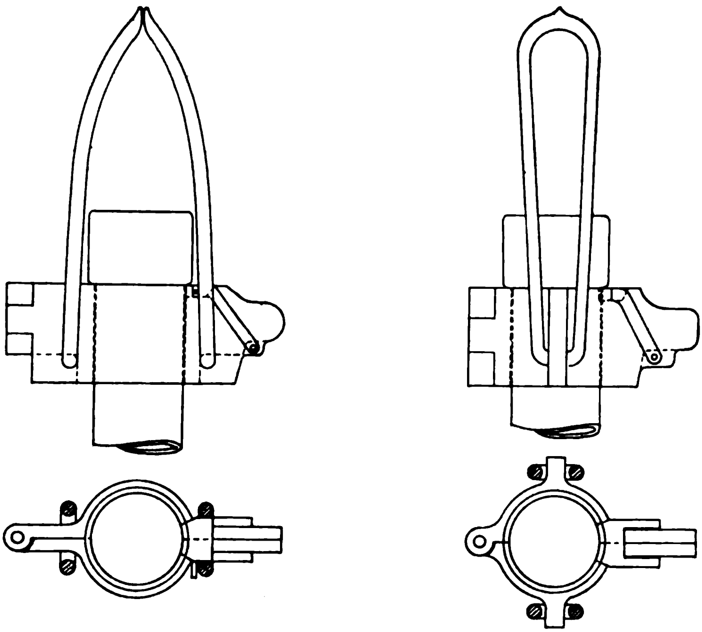
34. To pay to the Contractor daily for any period exceeding five days occupied by the Company in transferring the plant (after the same shall have been dismantled by the Contractor, and prepared by him for removal) from a finished well to a new site. The Contractor giving every assistance in the removal when so compensated.

Settlement of Accounts.—35. To adjust and pay all accounts between itself and the Contractor monthly, but it is mutually agreed that the Contractor shall not receive a larger sum than 75 per cent. of the amount due to him on account of uncompleted wells, the balance of 25 per cent. being retained by the Company as a guarantee of the completion of this contract by the Contractor. Should the Contractor become liable or indebted to the Company in any sum or sums of money under the terms of this contract, the Contractor shall pay to the Company or satisfy the amount of his liability of indebtedness before he shall be entitled to draw or receive any further moneys from the Company.

36. Each well shall be considered a separate account for the purposes of payment.

TABLE XIV.—Dimensions and Weights of Assorted American Casing and Drive Pipe.

Nominal Internal Diameter.	Diameters in Inches.		Thickness.	Weight in lbs. per Foot.		Threads per Inch.	Couplings.		
	External.	Internal.		Plain Ends.	With Couplings.		Diameter.	Length.	Weight, lbs. per Ft.
				Standard Casing.					
12½	13.000	12.482	0.259	35.243	36.500	11½	14.025	6⅛	37.499
10⅝	11.000	10.552	0.224	25.780	26.750	11½	11.911	6⅛	28.536
8¼	8.625	8.191	0.217	19.486	20.000	11½	9.413	5⅛	6.461
6⅝	7.000	6.538	0.231	16.699	17.000	11½	7.664	4⅝	10.225
5 3/16	5.500	5.192	0.154	8.792	9.000	14	6.078	4⅛	6.200
				Drive Pipe.					
12	12.750	12.090	0.330	43.773	45.358	8	13.950	6⅝	47.220
12	12.750	12.000	0.375	49.562	51.067	8	13.950	6⅝	47.220
10	10.750	10.136	0.307	34.240	35.628	8	11.950	6⅝	40.108
10	10.750	10.020	0.365	40.483	41.785	8	11.950	6⅝	40.108
8	8.625	7.981	0.322	28.554	29.303	8	9.588	6⅛	24.343
8	8.625	7.917	0.354	31.270	32.334	8	9.882	6⅛	31.320
6	6.625	6.065	0.280	18.974	19.408	8	7.473	5⅛	13.956
4½	5.000	4.506	0.247	12.538	12.758	8	5.723	4⅛	7.439
				Californian BX Casing (Medium Weights).					
12½	13.000	12.360	0.320	43.335	45.000	10	14.116	8⅛	54.508
10	10.750	9.902	0.424	46.760	48.000	10	11.866	8⅛	45.365
8¼	8.625	7.775	0.425	37.220	38.000	10	9.627	8⅛	33.096
6⅝	7.000	6.214	0.393	27.731	28.000	10	7.698	7⅝	17.943
				Californian Drive Pipe.					
4½	5.000	4.506	0.247	12.538	12.850	10	5.686	6⅛	10.734
4½	5.000	4.424	0.288	14.493	15.000	10	5.923	6⅛	14.299
				Inserted Joint Casing.					
				Without Couplings.			Length of Joint.		Diameter of Swelled Part.
12½	13.000	12.482	0.259	35.243		11½	2.073		13.384
10⅝	11.000	10.552	0.224	25.780		11½	1.873		11.314
9⅝	10.000	9.582	0.209	21.855		11½	1.773		10.284
8⅝	9.000	8.608	0.196	18.429		11½	1.673		9.258
7¼	7.625	7.263	0.181	14.390		14	1.505		7.877
6⅝	7.000	6.652	0.174	12.685		14	1.442		7.238
5⅝	6.000	5.620	0.190	11.789		11½	1.373		6.246
4¼	4.500	4.216	0.142	6.609		14	1.192		4.674



A B

Fig. 93.—Casing Elevators.

A. Type that can only be opened by lowering the links.
B. ,, ,, be opened without ,, ,,

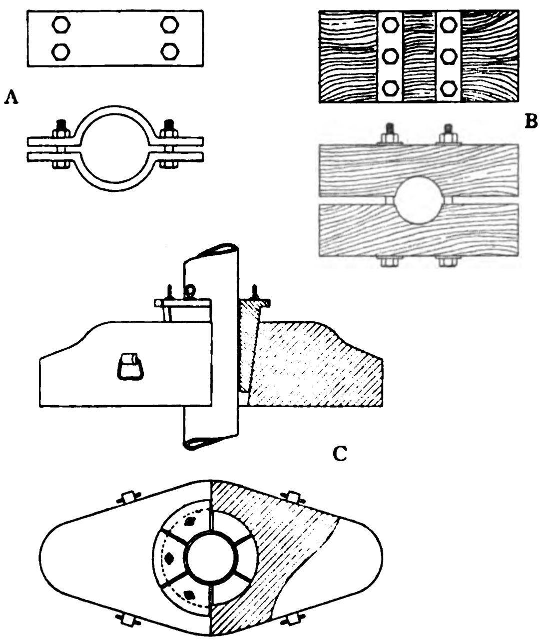
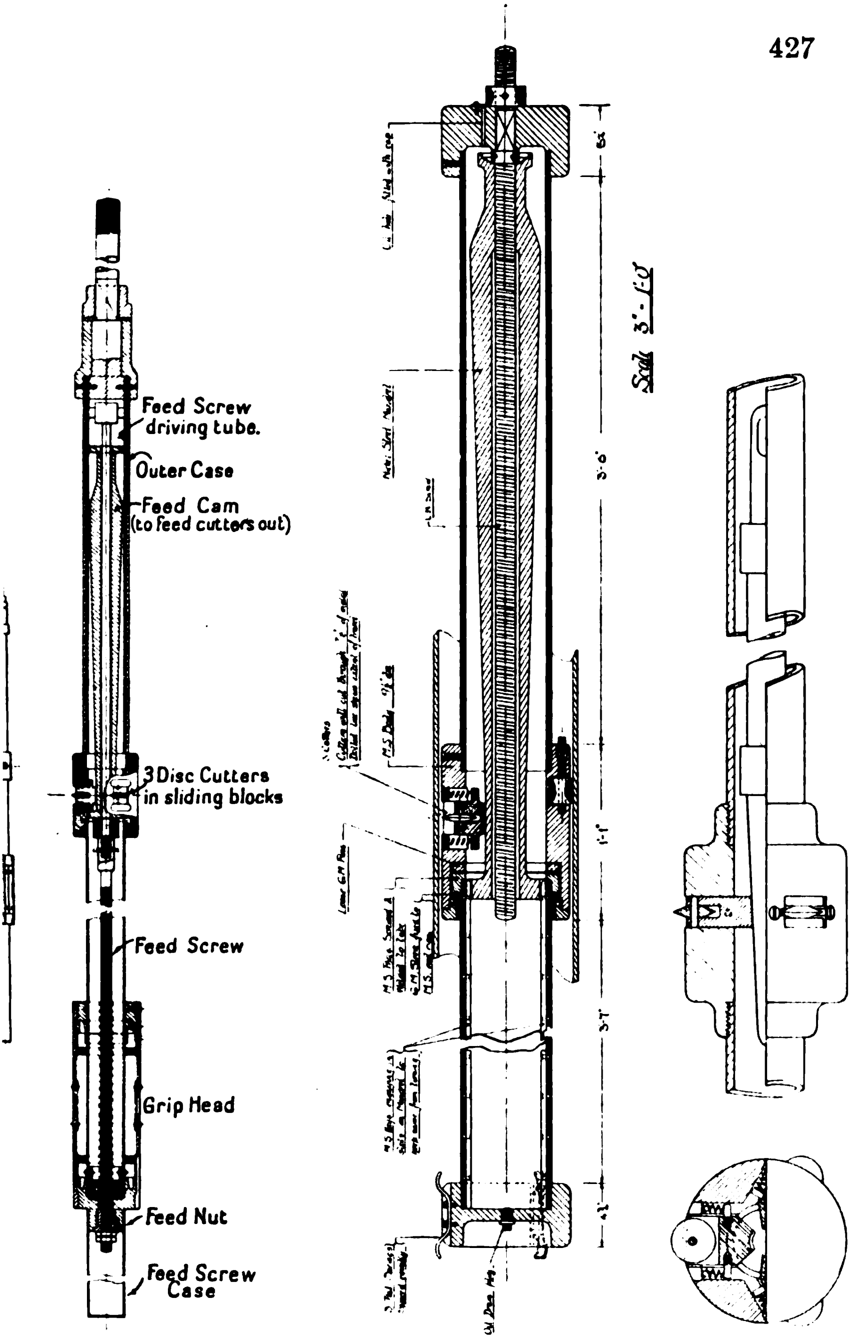


Fig. 94.—Casing Clamps and Spider.

A. Iron Clamps. B. Wooden Clamps. C. Spider or Wedge Block.



A B C

Fig. 95.—Tube Cutters.

A. Positive Acting Tube Cutter. B. Positive Acting Tube Cutter with Internal Feed Screw. C. Cutter with Weighted Mandrel.

project beyond the cylindrical body. At the bottom is another set of guides and gripping rollers.

The pressure cylinder having been filled with liquid, which is preferably the same as that in the bore hole, and the cutter pistons being withdrawn into the cylindrical body, the tool is lowered down to the requisite depth. The boring rods are then rotated in such a direction that the ratchet teeth slip; and the lower part of the tool remaining stationary, the solid rod will be forced down into the liquid in the pressure cylinder, and consequently the cutter pistons will be forced outwards, until the cutting discs bear against the inside of the tube to be cut. On then reversing the direction of rotation, the ratchet teeth engage with each other, and the whole tool is rotated in the tube, the cutters doing their work. When the cut has been completed, the solid rod is forced still further down into the pressure cylinder, and the whole tool can be withdrawn from the bore hole.

Another form of casing cutter of American design has a body very similar to that of others in respect to the cutters, but it is lowered into the well on tubing, and the cutters are pressed outwards by a weighted, tapered spindle, which is suspended by a wire rope inside the tubing. The tapered spindle coming into contact with the inner ends of the cutter holders, forces them outwards when weight is thrown on to the spindle by slackening the rope. C, Fig. 95, shows this type.

When cutting casing, the column should be kept in a state of light tension by jacks, so that separation takes place when the severance is nearly completed, thereby preventing the breakage of the cutters through the weight of the cut tubes being thrown upon them.

Casing is sometimes severed in wells by exploding a charge of explosive at the desired point, and at other times the casing is split with a slitter at the collar, so that a pull on the column causes the threaded portion to collapse.

Recovering Lost Casing.—In well boring a column of casing sometimes falls through carelessness or accident in lowering, or parts in the well through a faulty socket or screwed end; it may also become severed through damage. A common class of appliances for recovering casing that cannot be reached from the surface is

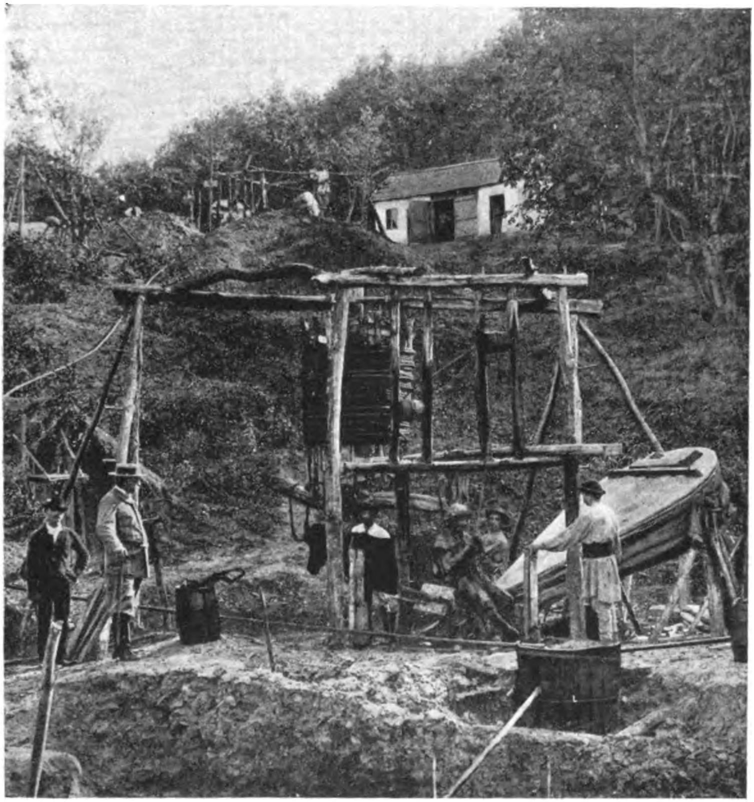


FIG. 107.—SINKING OIL SHAFTS BY HAND.

Sinking Shafts by Hand in Bushtenari Oil-Field of Roumania.
Sinking Pits by Hand in the Binagadi Oil-Field of Russia.

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PLATE XXXI.

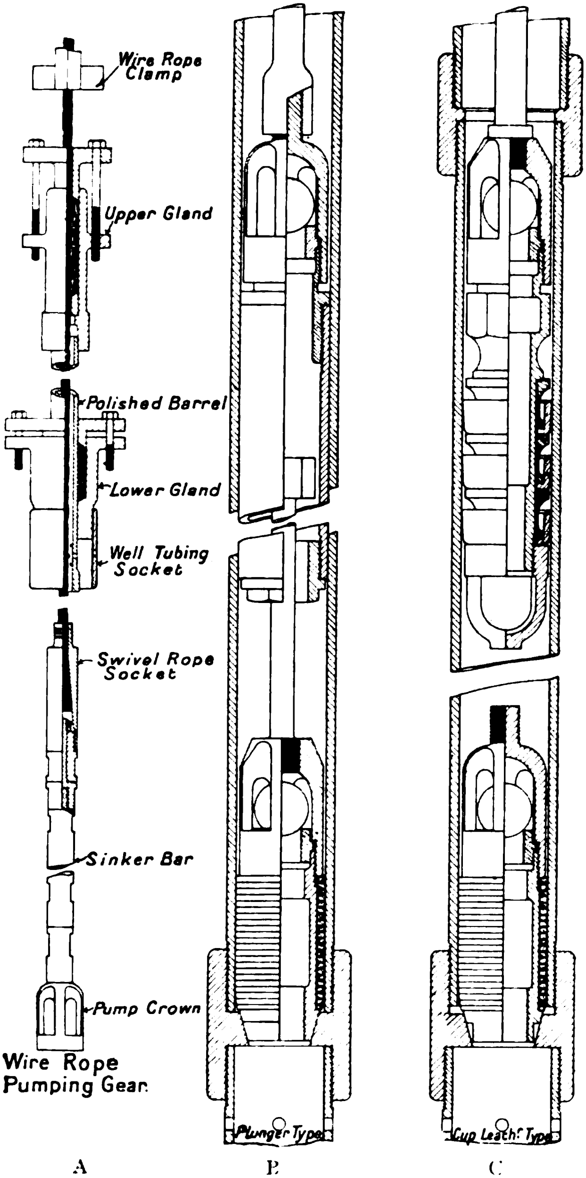

FIG. 109.—DEEP WELL PUMPS.

A. Arrangement for Wire Line Pumping.

B. Plunger Pump, with means for withdrawal of Suction Valve.

C. Common Cup-Leather Type of Pump.

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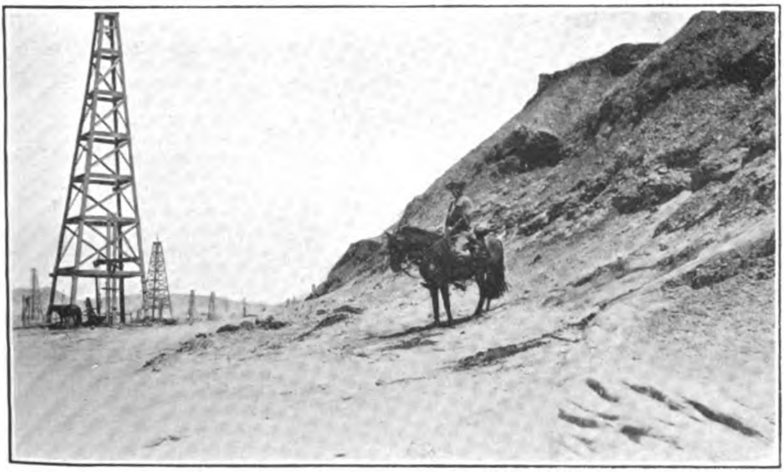
A



B

FIG. 112.—VIEWS IN THE PERUVIAN OIL-FIELDS.

A Showing method of Jerker line transmission over broken country.
B Showing well being pumped by Jerker lines, also the sudden change of barren and hard calcareous sandstone to an oil-saturated sand (on which the horse is standing). When the sand is disturbed the dark discoloration of the sand is visible.

[To face page 466.

shaft, takes the drive by the belt, as well as acts as a flywheel in storing up energy to smoothly pass the dead centres. The connecting rods attached to the eccentrics have guides working in bushed bearings where the motion is transformed to a horizontal movement (see Fig. 114).

Considerable care is needed in arranging the work of a large pumping station to deal with forty to fifty wells averaging, say 1,200-1,500 ft. deep, in order to equally distribute the load.

Jerker or Transmission Lines.—Until a few years ago, transmission or "jerker" lines were generally composed of timber, and even now this practice occasionally prevails. The size of timber used for jerker lines naturally depends upon the power to be transmitted, but they vary from 8 in. by 4 in. on main lines to 3 in. by 2 in. on branch lines. The rods are coupled together by flat sheet-iron straps, through which a few bolts are inserted and tightened up. The jerker lines are suspended by wooden or iron swingers in swing brackets, placed at sufficiently close intervals to prevent any undue sag between the points of suspension. Each swing bracket acts as a lateral guide in addition to a support, so that side wind pressures do not deflect the rods. Friction is reduced to a minimum by the attachment of a strip of wood against which the swinger alone rubs if deflected by wind. Motion is transmitted to any desired direction by occasional bell cranks or change wheels, from which tensional rods are led off in the direction of wells required to be operated.

When iron rods are used as transmission lines, they are provided with a clasping device which allows the rods to be quickly coupled together, and at each joint a projection is provided by which they may be suspended on swingers from suspension brackets. Rope transmission lines are manufactured from thick iron wire, and are coupled together by special fasteners provided for the purpose.

A very simple and effective way of transmitting and deflecting tension rods is to use pulleys mounted horizontally or vertically as required. At each pulley a short length of chain is inserted to accommodate the change of direction, and at each well a wire line can be led over the top derrick pulley and direct on to the pump.

Multiple pumping reduces costs considerably when there are no technical objections to its introduction. Where the oil is of light density, unaccompanied by much sand that would necessitate frequent pulling and cleaning, and the contours of the ground

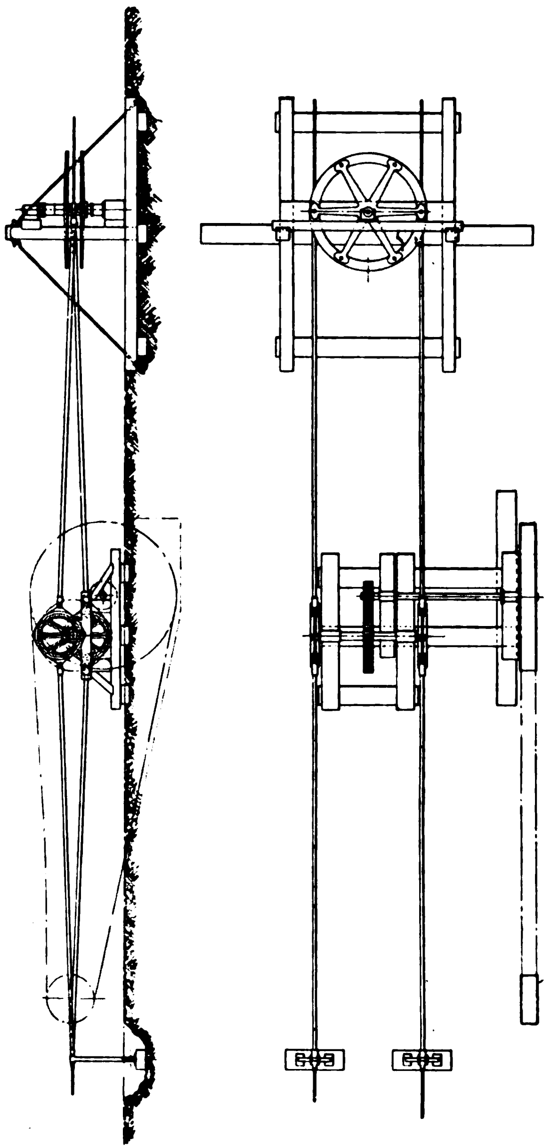


Fig. 114.—Pumping Frame for Operating Large Groups of Wells.

present no obstacles to the deviation of jerker lines, the cost of extraction may be very low, although the mechanical efficiency of

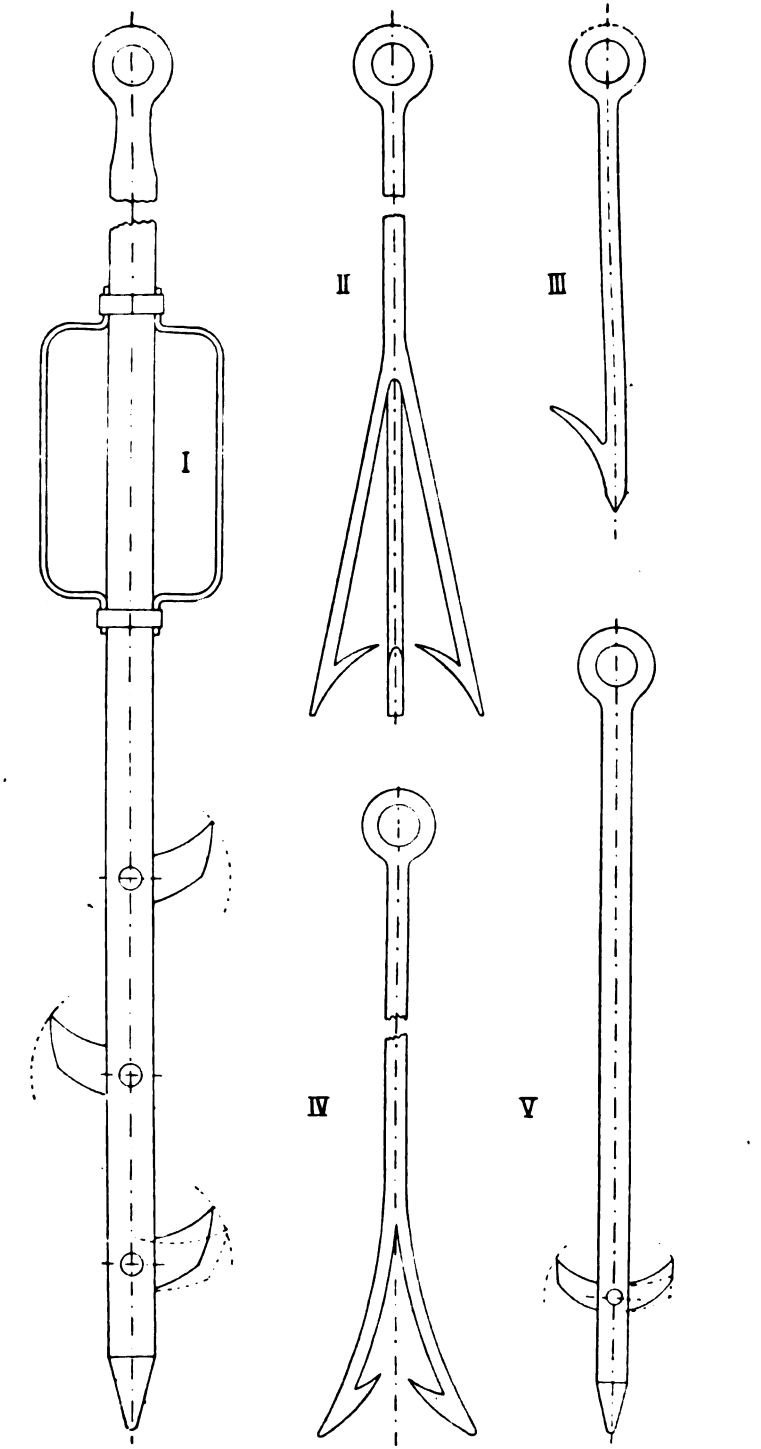


Fig. 119.—Fishing Tools for Recovering Lost Bailers

The larger sizes indicate with 60 lbs. steam pressure as much as 150 H.P., and will raise a 12-in. by 60-ft. bailer at the rate of 1,500 ft. per minute. The smaller sizes are used for bailers up to 8 and 9 in. in diameter. With the steady exhaustion of oil-fields the level of liquid progressively falls, and in many parts of the Baku fields the wells have now only 20-50 ft. of liquid, or are even dry at times, although formerly they had levels measuring in hundreds of feet, and gave as much as 300 tons of oil daily by bailing, but there are few now which will yield even 50 tons daily

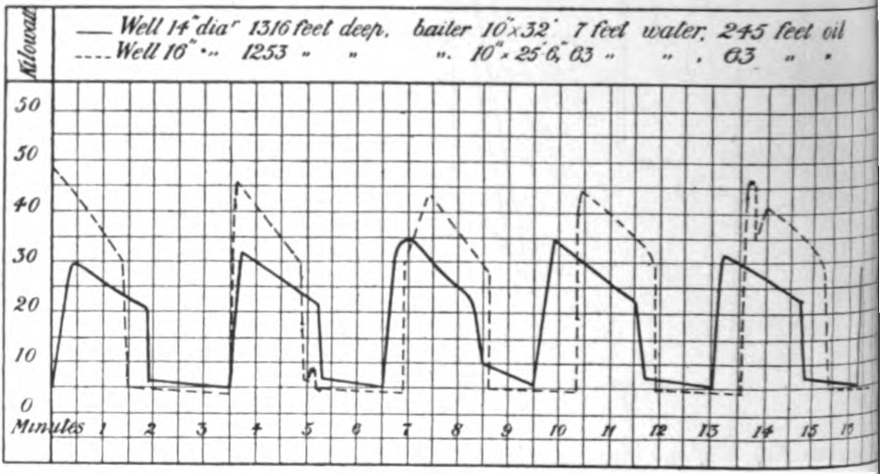


Fig. 120.—Power Diagram of Bailing Well.

Diagram plotted from Data furnished by Recording Wattmeter which intercepted the Current supplying a Motor bailing an Oil Well.

owing to the process of exhaustion which is proceeding. From many wells several times as much water as oil has to be bailed to secure a production.

The general adoption of electrical energy for pumping and bailing enables accurate records of the work to be obtained by the introduction of a recording kilowatt meter. Variations of load give a clue to the state of the well, and time intervals indicate the attention and skill displayed by the attendant. Fig. 120 shows diagrams recorded by two moderate sized wells in the Baku oil-fields of Russia.

Previously to the use of electrical power, recording apparatus first discharge after admission of air is exceedingly violent, owing to the formation of a piston of air beneath a long column of unaerated fluid. Variations of the oil level are indicated by fluctuations of the air pressure gauge at the mouth of the well, where it is customary to have one pressure gauge on the compressor side and another on the air-lift side of the valve which adjusts the air admission.

If the fluid in the well falls, the discharge becomes intermittent, but can, if small, be made continuous by increasing the volume of air. There is, however, a limit after which a continuous discharge cannot be induced, and the action either proceeds intermittently, each flow of liquid commencing with a full bore flow of unaerated oil followed by a violent discharge of gas and oil spray, or the discharge takes the form of a constant spray. With the intermittent or spray action the efficiency of the plant falls enormously, as will be seen from the figures below, but, nevertheless, the cost of its working is many times repaid in special cases.

Most Russian wells yield a certain proportion of water with the oil, and often a considerable amount of sand is raised in addition; indeed, its removal, as has already been explained, is usually necessary to keep the well from "plugging." The aeration and violent agitation of oil and water in certain proportions when an air-lift is in operation, leads to the occasional formation of emulsions, some of which defy all simple measures of separation. Some emulsions are discharged from the air-lift in congealed grey masses of the consistency of butter, whilst others are fluid and have the consistency of cream. Many such emulsions liquefy and separate in a few minutes, but some, containing up to 30 per cent. of water, neither separate after lengthy settlement in open tanks nor even permit of any mechanical separation. This latter class of emulsion is not common, and usually producers are not much troubled by its formation.

Great quantities of sand sometimes cause the air-lift to work erratically for a while and may entirely stop its action, but usually the sand eventually gets freed and steady working is resumed. At such times the author has seen a thick fluid containing over 50 per cent. sand discharged for hours before the well was cleaned and normal working recommenced.

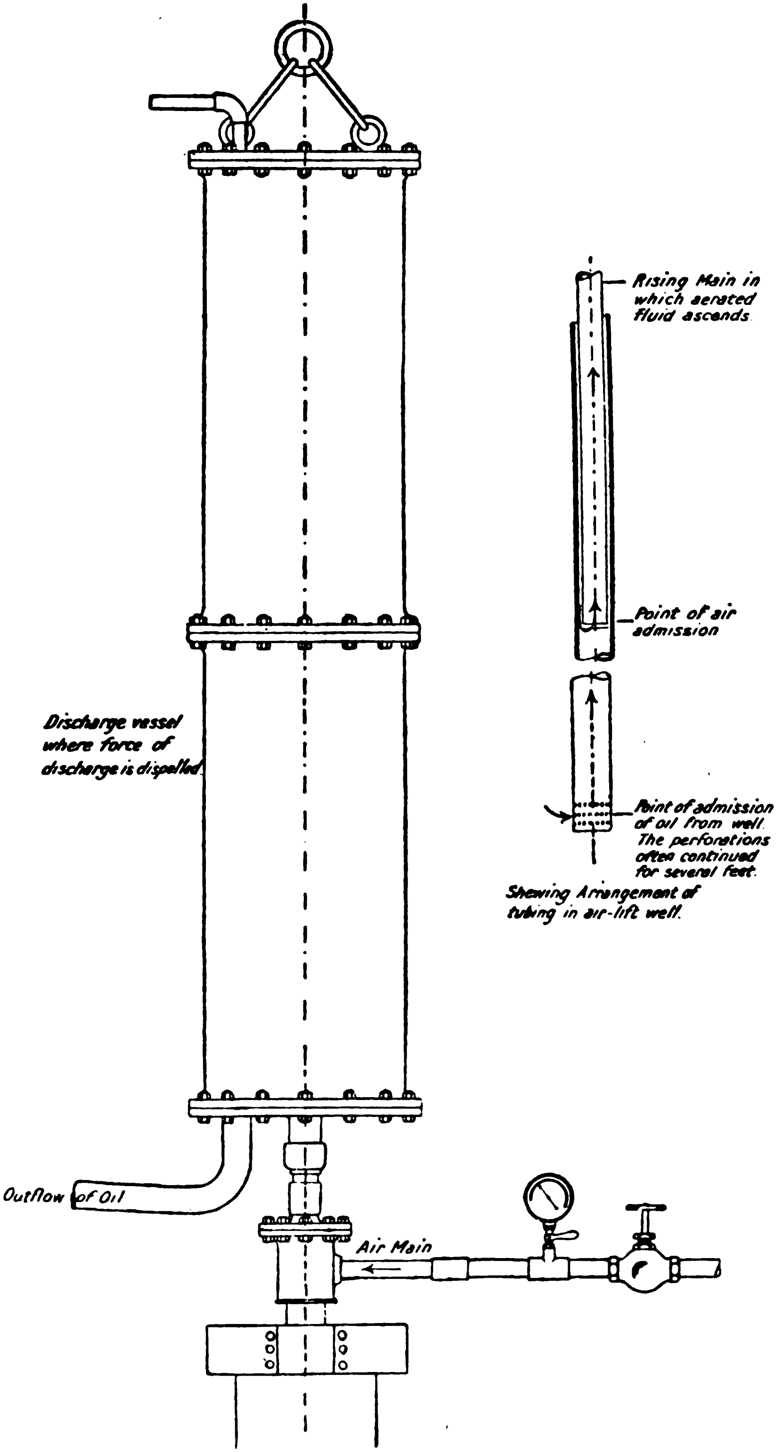


Fig. 123.—Common Arrangement of Air-lift.

Oklahoma law requiring the retention of 50 per cent. of the open flow of wells.

Some loss of gas without performing work is unavoidable but deliberate waste on a large scale is no longer justifiable in any but perhaps a few cases where its control is difficult and dangerous, and its intimate mixture with the oil prevents any isolation. The greatest loss of potential energy undoubtedly arises from the excessive number of wells sunk in a definite area, each of which, in most cases, daily belches forth into the atmosphere, gas liberated without performing more than a fraction of its possible power.

A witness in evidence before an American Commission, referring to the uncontrolled waste in the Glenn pool of Oklahoma, submitted that in this one field $11,250,000 was spent in sinking 2,500 wells when 706 should have sufficed to drain the area, costing only $3,177,000. The wasteful development following local excitement resulted, he contended, in the price of oil falling from $1.31 to 35 cents and even 20-30 cents per barrel in special cases, and the value of properties being reduced by more than 50 per cent.

Perhaps the most effective way of utilising natural gas is to allow wells to flow naturally by heads where possible, after the insertion of a diameter of casing suitable to their requirements. In these circumstances oil accumulates in a supersaturated state till the column is lighter than the atmosphere, when it starts flowing, the rate of expulsion increasing rapidly after once the oil is put in motion on account of the expansion of gas following reduced pressure. This procedure is only possible when the wells are widely spaced so as to avoid the influence of draining on the sands by rival operators less scrupulous about waste.

Gas pressures are always referred to in terms of atmospheric pressure, but the imposition of a partial vacuum is equivalent to an increased pressure of equal amount, in fact it is more in the case of most petroleums, as at earth temperatures diminished pressure results in the volatilisation of light products. Gas so formed in the earth is an agent of transportation for the oil, and that such volatilisation does take place under reduced pressure is clearly shown by the increased percentage of condensable products in gas extracted from wells under a partial vacuum.

Operators frequently take advantage of a partial vacuum when igns of exhaustion appear, and in nearly all cases improved yields f oil result. Oil-fields producing asphaltic oils of light density an have their life greatly prolonged by using vacuum pumps or xhausters on the wells, but where paraffin oils exist, the increased eposition of wax may more than neutralise any improvement esulting from diminished pressure. The use of vacuum pumps by ne operator is quickly reflected in the returns of neighbours not o equipped where wells are not widely spaced, consequently the ntroduction of the system is closely followed by its general doption.

Exhausters can be designed as single units operated by the valking beam or jerker line that transmits motion to the pump, or vhere wells are not too widely spaced, by the installation of a central exhauster connected to pipes that lead to the wells. It is carcely necessary to emphasise the importance of air-tight fittings ıbout the wells for the maintenance of a considerable vacuum vithout great expense of power.

(6) *Unskilful Extraction of Oil.*—Whatever the process of extraction, judgment gained only by experience and study of ocal conditions can decide on the best manner of performing he work. Whether the well be pumped, bailed, swabbed, or operated by air-lift there is a speed of extraction or a periodicity of working that is best adapted to each case. Oils betraying a disposition to deposit solid hydrocarbons require especial attention to ensure a maximum safe rate of yield. In some wells the level of oil cannot be reduced below a certain point without eruptions of gas, inrushes of sand, or influx of water, all of which can be avoided by the maintenance of a correctly ascertained speed of working. Some wells that become exhausted by pumping or bailing give best results by being operated several times daily, others give the highest yields when worked one or two days weekly, a high level of liquid collecting in the interval of repose.

Experience has shown the wisdom of not reducing the level of liquid below the oil-bearing stratum in fields where paraffin oils occur, and means have been devised, and are sometimes the rupture of a fuse, steam is automatically introduced to suppress any fire. For heavy viscous oils the vessel is heated by steam and clad with some non-conducting material to conserve heat.

An electrostatic pressure of from 10,000-15,000 volts is applied to the inner electrode, and the observed tendency of globules of water to form chains is defeated by the rotation of the electrode causing these strings to break after being lengthened, and incidentally, at the same time, increasing the efficiency of the apparatus, and decreasing the consumption of power. Quasi-emulsions are abstracted from the oil by its passage through a water trap and filter prior to its introduction to the vessel; and subsequent separation of oil and water is effected by passing the treated mixture into a second water trap.

It is claimed that each unit treater will treat from 50-150 barrels (7-21 tons) a day, according to the gravity of the oil and amount of water, and that the power consumption is about 37 kw.-hours per day—29 kw.-hours for the treatment, and 8 kw.-hours for the power of rotation. At 2 cents (1d.) per kw.-hour the cost per unit is therefore about 75 cents (3s.) per treater per diem, or say $\frac{75}{100}=0.75$ cent per barrel on the basis of 100 barrels per day treated.

Other systems used in California are described by Messrs Paine & Stroud.[1] One method suitable for the least obstinate emulsions provides for the passage of oil through a finely perforated pipe in the base of a tank containing some 10 ft. of water. The water is heated to about 200° F. by a steam coil, and in the passage of the emulsion through the water separation is effected and the oil accumulates on the surface and is led away.

Another system is described in which the emulsified oil is raised to a temperature of from 375°-425° F. by passage through retorts. The heated oil and vapours are led into an evaporator where the oil flows down in a fine film, allowing the escape of water vapour; evolved vapours are led off to a condenser after both these and the escaping oil have been used for heating

[1] "Oil Production Methods," by Paine & Stroud, Western Engineering Co., San Francisco.

change the form of rig to suit the type of power. Electrical power is usually removed from the province of probability for prospecting, owing to the absence of available sources of power, and the high initial outlay a generating plant implies before the commercial worth of a district has been demonstrated. Where, as is frequently the case, small quantities of crude petroleum can be extracted from hand-dug pits, certain types of oil engines can be employed with suitable drilling apparatus.

Not quite the same considerations influence the choice of power on a working oil property as on a prospecting venture where a certain amount of uncertainty as to the future exists. The scarcity or prevalence of fresh water or water of any character in the vicinity largely influences the choice of power, although such features as means of transport, character of ground, and topography have an important bearing on the case. In many oil regions fresh water is very scarce although there is an abundance of salt water, whilst in other cases local waters are so contaminated with salts in solution and organic impurities that their direct employment in steam boilers is attended with great risk.

The relative cost of wood, coal, and oil, and the existence or the absence of natural gas affects the problem of power considerably, whilst the system of drilling dictated by local conditions also influences the choice of power. The climatic conditions, distance apart of individual wells, and average time taken to complete wells in the district also enter into one's calculations when deciding upon the nature of power to be adopted. Sometimes conditions justify the installation of evaporators for the production of fresh water from sea or other bad water, for employment in boilers, consequently brief particulars of such plants are given in a subsequent paragraph. The use of electrical power for oil-field work is extending, but its general adoption has been delayed by the disinclination of manufacturers of electrical plant to study the peculiar duties the motors have to perform whilst ensuring safety, economy, and reliability.

Steam Boilers and Accessories.—Where there is a moderate supply of fresh water, the use of a multitubular portable boiler is customary for oil prospecting work. Special portable boilers, often known as the Colonial type, are made in sizes for evaporating

1 lb. of steam per lb. of oil, the following quantities of gaseous products would be formed :—

CO_2 - - - - - - - - -	3.15 lbs.
H_2O { 1.26 lbs. for combustion of oil / 1.00 lb. used by burner } - - - -	2.26 „
N (14.75 lbs. air, less 3.41 lbs. of O used in combustion) -	11.34 „
Air (50 per cent. excess) - - - - -	7.38 „
Total flue gases - - - - -	24.13 lbs.

There is in the above mixture—

$$\frac{3.15}{24.13} \times 100 = 12.6 \text{ per cent. of } CO_2.$$

$$\frac{2.26}{24.13} \times 100 = 9.36 \quad „ \quad „ \quad H_2O.$$

The complete oxidation of 1 lb. of C to CO_2 results in evolution of 14,650 B.T.U.
„ „ „ H to H_2O „ „ „ 62,100 „

Therefore—

0.86 × 14,650 = 12,600 B.T.U. are liberated by combustion of carbon.
0.14 × 62,100 = 8,694 „ „ „ „ hydrogen.
21,294 „ „ „ „ 1 lb. of petroleum.

The calorific value of 1 lb. of crude petroleum of the above composition is, therefore, 21,294 B.T.U., and the evaporative power

$$\frac{21,294}{966} = 22 \text{ lbs. of water from and at } 212° \text{ F.}$$

In practice the water passes through the flues as steam, so that the heating value of the oil must be reduced by the latent heat of steam, that is—

.14 × 9 lbs. × 966 = 1,217 B.T.U., or 5.7 per cent., reducing heat value to 20,077 B.T.U. per lb.

Again, products of combustion and excess of air carry away to the atmosphere, in practice, the following amount of heat for each 1° F. of temperature, neglecting slight corrections for temperature :—

		Specific Heat.	
Carbon dioxide	- 3.15 lbs. × .216 =	.680	B.T.U. per 1° F.
Steam	- 2.26 lbs. × .479 =	1.083	„ „
Nitrogen	- 11.34 lbs. × .244 =	2.765	„ „
Air	- 7.38 lbs. × .238 =	1.765	„ „
Total carried away in gases	-	6.293	„ „

If flue gases have an escaping temperature of 600° F., the eat carried away and lost with air temperature of 60° F. is $(600° - 60°) \times 6.293 = 3{,}400$ B.T.U. per lb. of fuel burnt, approximately 17 per cent. of the heat value of an oil of 20,000 B.T.U. n one case the author recorded a flue temperature at base of himney of 815° F. when the loss was $\frac{(815° - 60°) \times 6.293}{20{,}000} = 23.7$ er cent., about 10 per cent. higher than was necessary with conomical running.

Petroleum fuel of 20,000 B.T.U. calorific value, devoid of ll impurities, should give in a Lancashire boiler with a flue emperature of 450° F. an evaporation of about 16.25 lbs. of vater from and at 212° F., equivalent to a conversion of 78.5 er cent. of the heat value of the fuel.

Flame temperature of the combustion of carbon and hydrogen s as under:—

	In Air.	In Oxygen.
C to CO_2	4,988° F.	18,440° F.
H to H_2O	4,554° F.	12,202° F.

Water contamination has a very serious influence on the calorific value of oil. Orde[1] and Vivian Lewis have written on this subject. Five per cent. of water reduces the calorific value by about the equivalent of an evaporation of 1 lb. of water, or between 6 and 7 per cent. A simple way of estimating the calorific value in B.T.U.'s of an oil from an analysis is

$$\text{B.T.U.'s} = 14{,}500\ C + 62{,}100\left(H - \frac{\text{Oxygen}}{8}\right).$$

Feed-Water Heaters.—Where batteries of boilers are erected, it is now customary to introduce feed-water heaters (economisers), superheaters, and other devices to save fuel, especially where salt water is in use with its accompanying serious waste of fuel. When fresh water is fed to boilers, the feed-water heaters can be placed in the flues, but when the feed is salt water, or other very hard and untreated water, exhaust steam only should be used, or a deposit of lime or other salts will form and choke the feed heater. By

[1] Paper on "Liquid Fuels," *Inst. Mech. Eng.*, July 1902, by Mr Orde.

which, by multiplying the effect, the following results can be obtained from the evaporation of each gallon of water :—

Single effect -	- 1.8 gals. of water per gallon of water directly evaporated.				
Double effect	- 2.4	,,	,,	,,	,,
Treble effect	- 2.9	,,	,,	,,	,,
Quadruple effect	- 3.3	,,	,,	,,	,,

From the above it will be seen that with an evaporation of 14 lbs. of water per lb. of oil fuel, 1 lb. of oil will produce 46 gals. of water in a quadruple effect plant.

The last evaporator units are worked under a high vacuum to reduce the temperature of evaporation, and the dense impure water which passes in succession through each unit is drawn off the last evaporator by a brine pump. The feed-water pump and air pump exhaust into the condenser, and the evaporators are made in such a way that the deposited salts can be easily dislodged from the tubes and cleaned out at intervals.

A triple effect evaporator plant producing 350 tons of fresh water daily from sea water on an oil-field was run at the cost below :—

Running and maintenance - - -	$0.113	per ton	
Repairs and renewals - - -	0.056	,,	
Depreciation - - - - -	0.050	,,	
Administration, etc. - - - -	0.057	,,	
Fuel (gas at 10 cents per 1,000 cub. ft.) - -	0.005	,,	
Total cost - - - -	$0.281	,,	= 1s. 2d.

Steam Mains.—The following hints on the construction of steam lines may prove helpful to those unacquainted with oil-field conditions. All pipes should be kept above ground for observation, but if laid beneath the ground level they must be well insulated and surrounded by cinders or other porous material to allow water to drain away. To avoid impeding movements of persons and goods on the property steam mains are usually carried overhead on standards at sufficient height for objects to pass beneath. These standards are frequently constructed from discarded casing or eroded piping, to which the steam pipes are attached by clips, or on which they rest in suitable crown brackets. Wooden standards should be avoided owing to the damage they sustain in a fire, and the danger from rot, especially in the tropics.

mostly of a temporary nature, are of the non-condensing type, free from all refinements that would imperil their safety in the hands of unskilled oil-field attendants to whom machinery is largely entrusted. In those fields where other and more convenient, or more economical, sources of energy have been introduced, operators have often hesitated to scrap the large quantities of plant in hand for which no ready market is found.

Drillers almost exclusively prefer a steam engine owing to its wide latitude in power, flexibility in speed, and the way in which it withstands the roughest usage, that no amount of supervision will prevent. Governors are never entertained, and promptly put out of action if fitted to drilling engines, thus enabling the engine to be run at a speed that would alarm as well as surprise the manufacturers themselves. Cable drilling is mainly performed by single-cylinder, horizontal, reversing engines varying from 8 in. × 12 in. to 12 in. × 14 in., weighing from 1-2 tons. The smaller engines are for shallow drilling, the large for deep wells of 2,500-3,500 ft., and often of considerable initial diameters. The main features distinguishing a drilling engine are (*a*) the attachment of an equilibrium valve at the steam admission, or a valve with rope pulley that can be actuated from a distance; (*b*) levers enabling the reversing gear to be operated from the rig by a rope or rod; (*c*) great strength and absence of finish; (*d*) detachable fly-wheel rims. Sometimes a feed pump and exhaust steam feed-water heater are attached to the engine.

Sensitivity is the chief object to be attained in cable drilling, and it is the ready response of the steam engine to the influence of variable resistances that appeals to drillers. During the descending stroke of cable tools the engine races and permits a harder blow being delivered, and on the ascending stroke the engine slows up, thus diminishing the strain on the cable and rig. Flexibility is assisted by the use of a fly-wheel with detachable rims that can be added to or be removed to suit the depth of well, weight of tools, and speed of running.

Large diameter wells, sunk in some of the Roumanian and Russian oil-fields, call for engines of much greater power, and double cylinder 12 in. × 16 in. stroke are frequent, especially where low pressure steam (60 lbs.) is used, and long transmission lines often

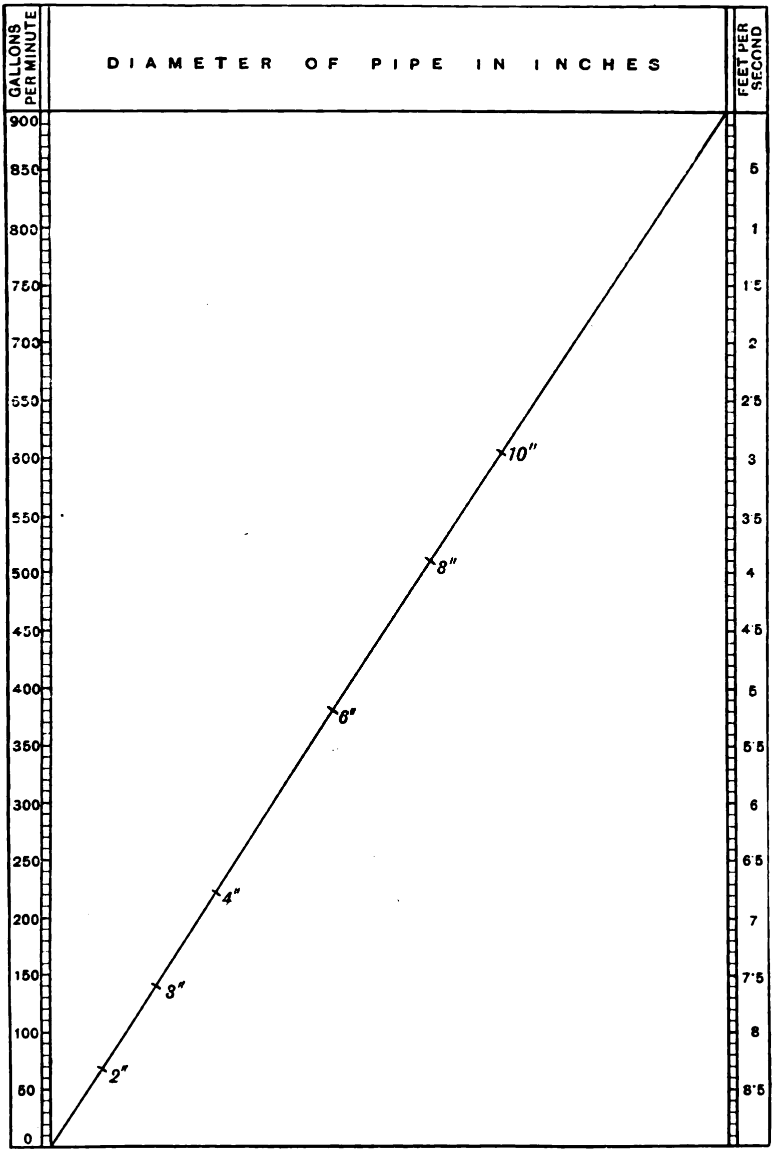


FIG. 136.—PIPE-LINE CHART ENABLING ONE OF THE THREE FACTORS TO BE DIRECT IF THE OTHER TWO ARE KNOWN, VIZ.:—

Imperial gallons per minute.
Velocity in feet per second.
Diameter of pipe in inches.

By placing a straight-edge across the two knowns, the third may be read off at the point of intersection.

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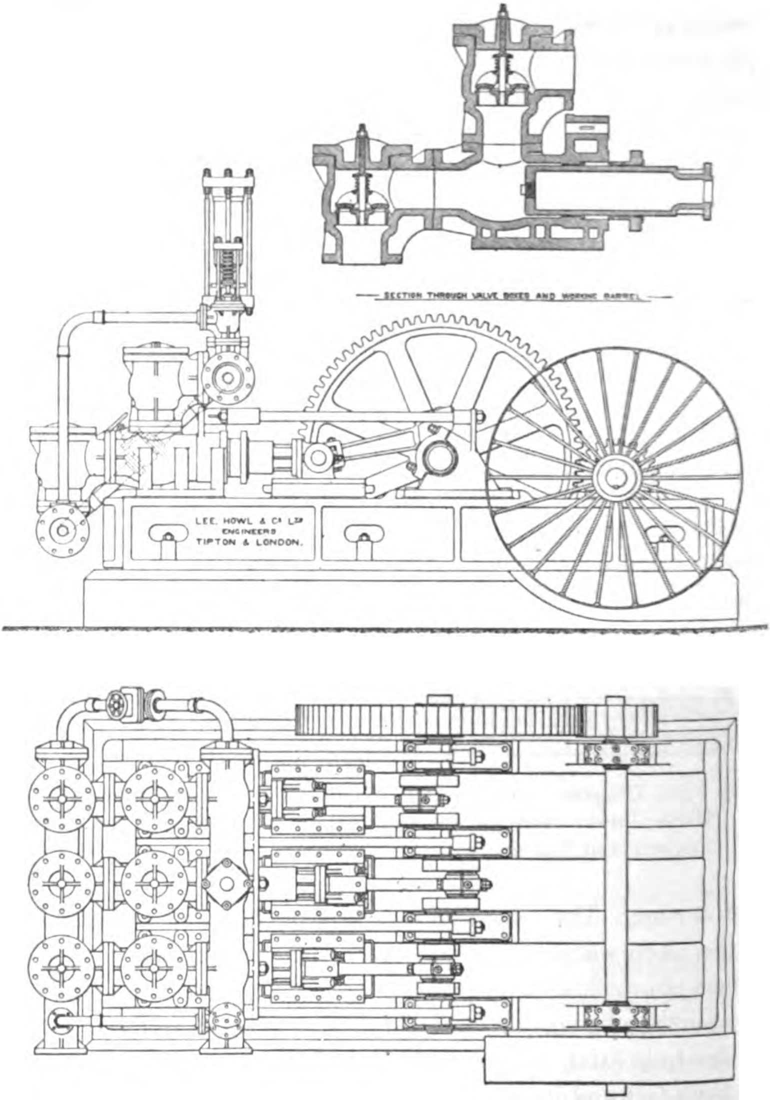

TRIPLEX PUMP FOR PIPE LINES

Fig. 138.—Typical High Pressure Gear-Driven Ram Pump.

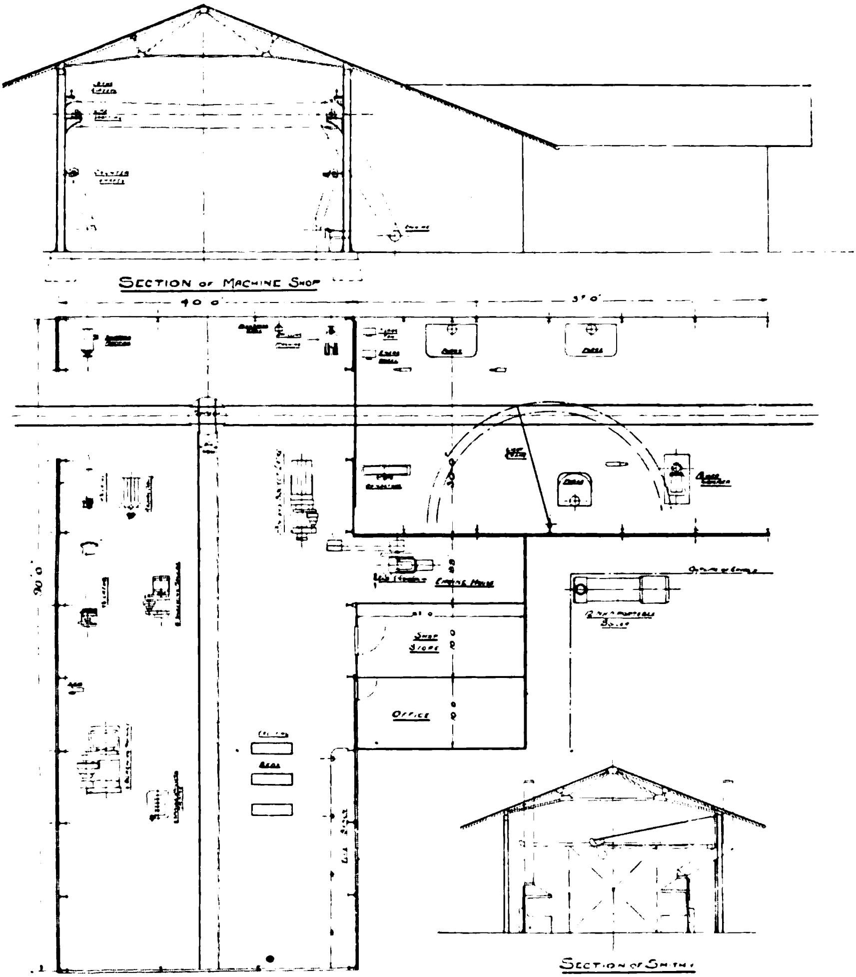

FIG. 141.—TYPICAL MECHANIC SHOP FOR AN OIL PROPERTY.
(Designed by Thompson & Hunter.)

Tools in Shop.

2 Lathes	1 Multiple Spindle Drill.	2 Forges.
1 Hollow Headstroke Lathe.	1 Screwing Machine (bolts).	1 Grindstone.
1 Radial Drill.	2 Screwing Machines (casing).	1 Steam Hammer.
1 Standard Drill	1 Shaper.	1 Fan.

[*To face page* 562.

impossible to say from an observation of the fire-box whether the boiler was under fire.

The theoretical amount of air required for the combustion of gas can be calculated from its analysis, in the same way as oil has been treated in Chapter XI. Assuming a gas of .650 density (compared with air) to contain 78 per cent. by weight of carbon and 22 per cent. of hydrogen, the air required for combustion would be 16.4 lbs., or 220 cub. ft. per lb. of gas. The volume of 1 lb. of the gas would be $\frac{13.4}{.65} = 20$ cub. ft., consequently $\frac{220}{20} = 11$ cub. ft. of air, would be required per cubic foot of gas for complete combustion.

Gas-Gasoline Extraction.—The high commercial value assigned to oils of light density, vaporising almost entirely below a temperature of 150° C., has fostered the extraction of light hydrocarbons that usually accompany most oil-field gases, and especially those associated with light gravity oils. Those gases, mainly composed of methane, whose critical temperatures preclude their commercial liquefaction, are generally known as "dry," whilst others which yield from 1-4 gals. of liquid per 1,000 cub. ft. of gas under pressures of from 50-500 lbs. per square inch are referred to as "wet," for the purpose of classification. There is no line of distinction between the two, and the term admits of no scientific definition, as many gases commercially "dry" do yield some condensates at certain temperatures and pressures.

Investigations have shown that the chief gaseous products which condense under moderate pressure and practicable reduction of temperature are of the paraffin series; indeed, normal pentane (C_5H_{12}), hexane (C_6H_{14}), and heptane (C_7H_{16}); but even these have vapour tensions at atmospheric pressure that prevent their commercial use in practice unless absorbed by heavier and more stable hydrocarbons. For the commercial extraction of liquid hydrocarbons it is necessary that there should be a fair percentage of products whose vapour tension does not cause their entire evaporation when briefly exposed to the atmosphere. Experience has shown that there is no need to "weather" the "wild" liquids to secure reasonable stability, as intimate admixture

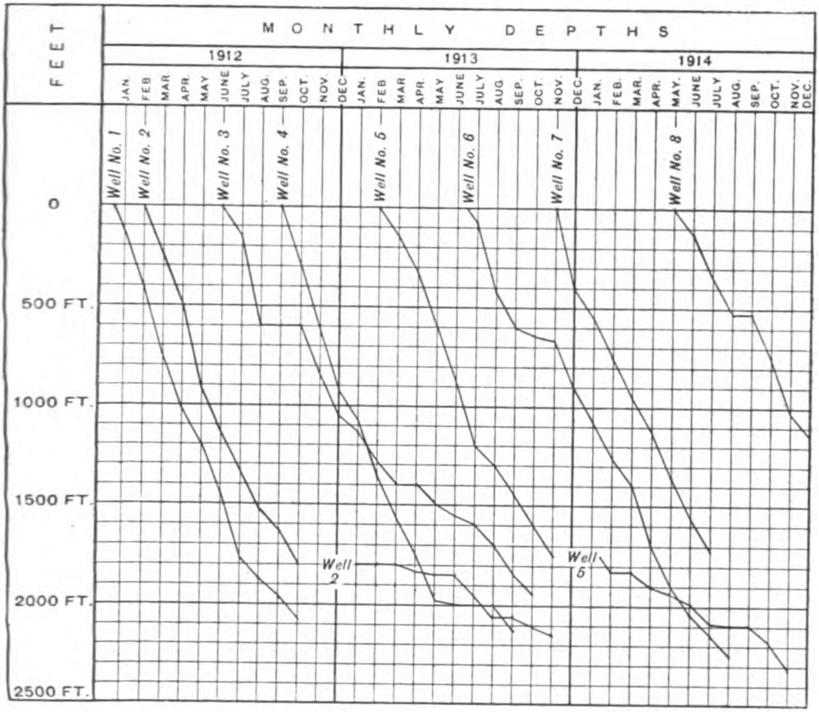

FIG. 147.—GRAPHIC REPRESENTATION OF DRILLING PROGRESS.

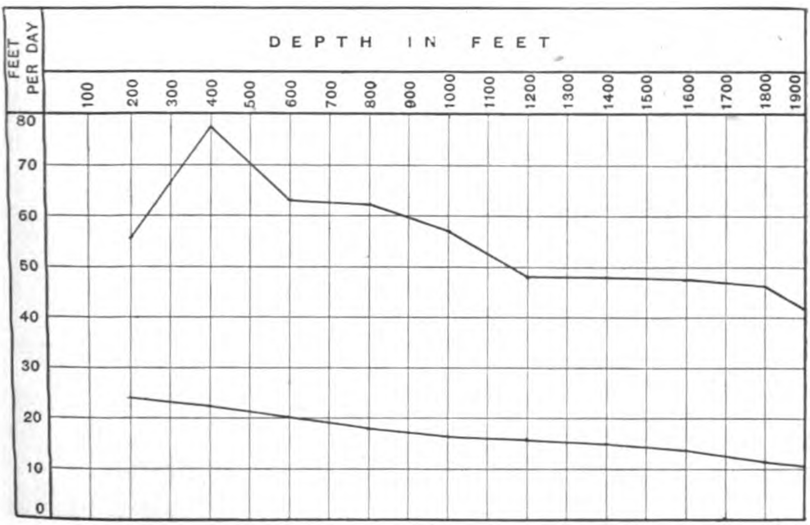

FIG. 148.—DIAGRAM SHOWING THE RELATIONSHIP OF SPEED OF DRILLING TO DEPTH IN TWO TYPICAL OIL-FIELDS.

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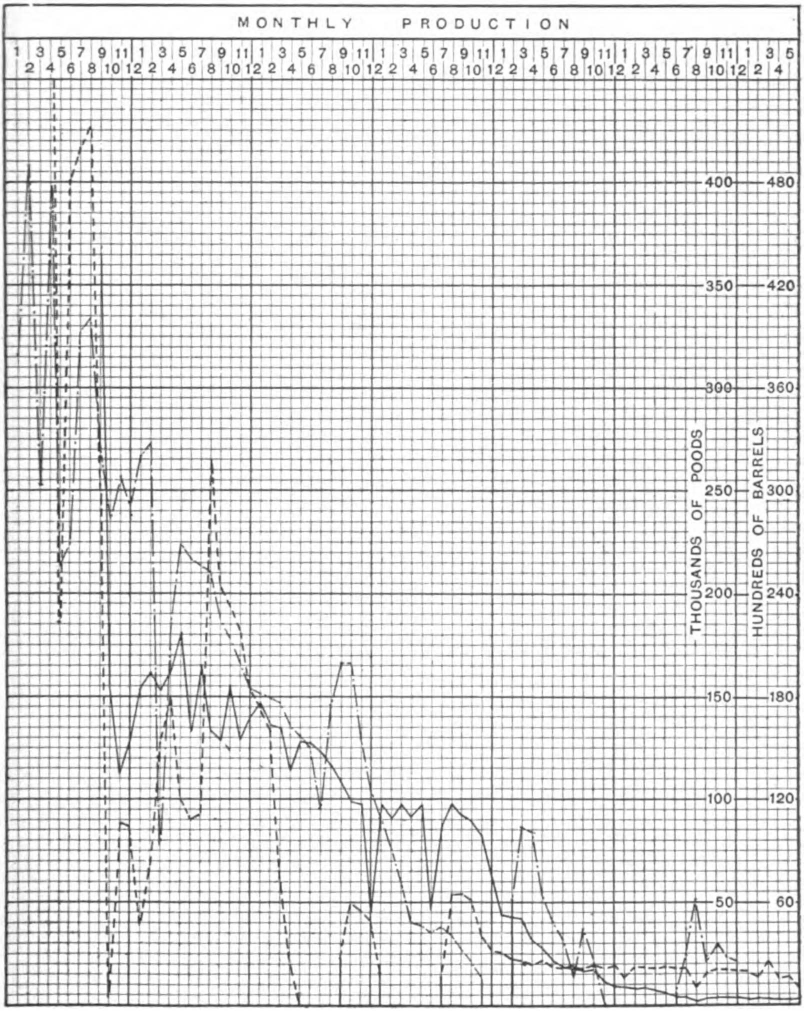

FIG. 149.—PRODUCTION CHART OF A GROUP OF GROSNY (RUSSIA) WELLS.

The diagram shows the irregular production of wells in their early lives, sometimes being out of commission, due to formation of plugs and need for periodical cleaning. The productions apply to equivalent periods of the lives of wells.

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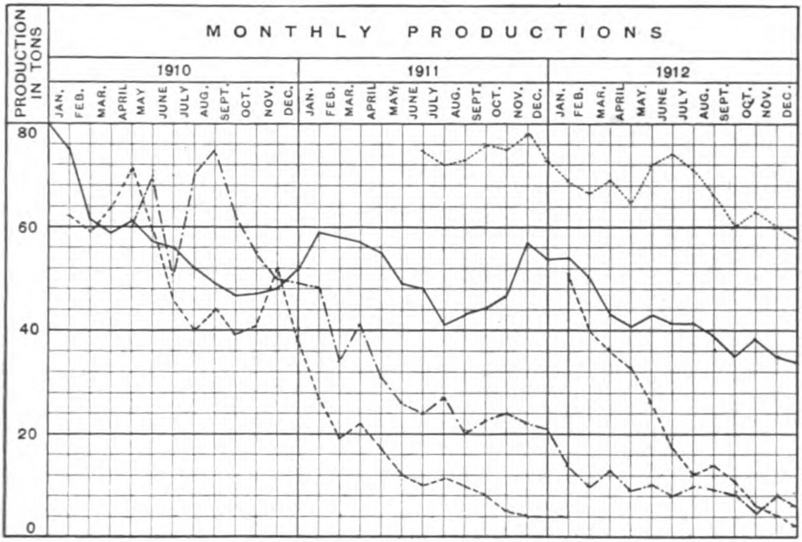

FIG. 150.—PRODUCTION CHART OF INDIVIDUAL WELLS.

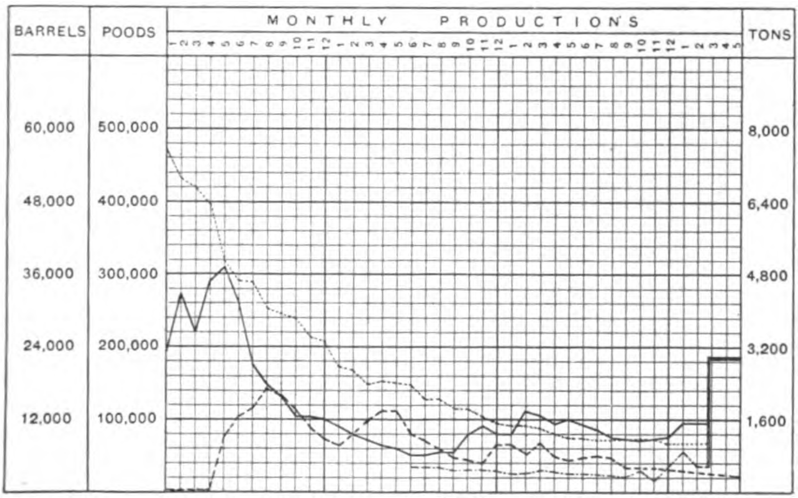

FIG. 151.—CHART SHOWING PRODUCTIONS OF A GROUP OF COMPANIES IN SHIRVANSKY POOL, MAIKOP.

(Two months from the end three companies amalgamated.)

[To face page 594.

Department (at the Head Office) with the respective material disbursements and wage sheets. Any difference must of course be explained by the Superintendent of the workshop concerned, and, if the same simply represents waste, this must be written off as a general overhead charge.

The method of costing in the workshops is a question that one cannot deal with in the limited space of one chapter. It is a question that has been treated at great length in many special works issued on the subject. Suffice it to say in the present article that the Technical (or Oil-Fields) Manager should every day see and confirm all orders given by the workshop to the Materials Store, as also all orders for work given by the various departments to the workshops.

Boring.—Each day the Head Drilling Superintendent will collect from each driller or boring contractor his returns for the day, on forms approximating to those on p. 317, which will be handed to the Technical Manager, thence passing to the General Manager.

These returns will be entered up daily into the Boring Journals kept at the Head Office. A separate book may be kept for each well, or a loose-leaf journal kept.

Production.—The distribution of the production amongst the individual wells is practically always a weak spot in oil-fields organisation. In the case of bailing wells, one has to consider the size of the bailing bucket, and the method and speed of bailing, in conjunction with the respective quantities of oil and water in the well. In the case of wells being pumped or worked by air lift, there is probably a possibility of adopting more accurate means, by measuring the oil in tanks, but this of course requires more or less individual attention for each well throughout the whole twenty-four hours of the day. As, however, owing to danger from fire and the necessity for economy in plant, it is generally necessary to take the oil away from the well to some central storage as quickly as possible; it is, as a rule, impracticable to leave the oil in the measuring tanks a sufficiently long time to allow the water to settle off from the oil; furthermore, it is an

MECHANIC SHOP.

Order No.

....

Order handed in..19.........

Order completed..19..... ...

Date.	No. of Requisition of Material.	Material.						Labour.										Total Cost of Order.
		Description.	Quantity.	Weight.		Price.	Amount.	Blacksmith.	Strikers.	Fitter.	Turner.	Planing and Slotting.	Drilling.	Apprentices.	Rough Labourers.	No. of Wages Sheet.	Amount.	
				Cwt.	Lbs.													

FORM 2.

THE MASLO PETROLEUM COMPANY, LIMITED.

PLOT No. III.

Requisition No...... ....

From the Oil-Fields Office to the Head Office.

..................................19.........

Description of Goods.	Quantity.	Weight.	Measurement.	Notes Made at Head Office.			For What Purpose Required.	Balance in Hand.
				To Whom Order Given.	Price.	No. of Returns.		

FORM 9.