THESIS

Subject THE ORIGIN AND ACCUMULATION OF PETROLEUM.

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THE ORIGIN AND ACCUMULATION OF PETROLEUM..

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by

Aloys Philip Hodapp

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Requirements for the Degree of Master of Arts.

Contents.

R E P O R T

of

COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School, have read the accompanying thesis submitted by A. P. Hadoff for the degree of Master of Arts They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of ______________

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THE ORIGIN AND ACCUMULATION OF PETROLEUM.

Introduction.

In this paper I shall attempt to sum up the present knowledge on the structural relations, accumulation and origin of Petroleum. I shall, however, place special emphasis upon some of the more recent ideas on origin and accumulation, especially those developed in the United States where the industry had its inception and where more systematic prospecting has been done, than in foreign oil regions.

The latter part of the paper will be devoted to the description of a series of laboratory experiments bearing upon the origin and accumulation of petroleum as related to the affinity of oil for clay.

REVIEW OF THEORIES ADVANCED TO ACCOUNT FOR THE ORIGIN AND ACCUMULATION OF OIL.

Origin of Petroleum.

The question of the origin of petroleum, like many other problems of economic geology, has been a subject of extensive discussion and speculation. In spite of the time and thought expended in this field, the problem appears to be still only partially solved.

Many theories have been advanced, all of which may be grouped under two heads, inorganic and organic. The first is primarily the theory of chemists, who hold that oil and gas were probably formed by water coming in contact with deeply buried and highly heated carbides of iron, manganese and other metals. Under these conditions it is thought that chemical reactions would take place whereby the hydrocarbons making up oil and gas, would be formed. Some compounds which closely resemble refined petroleum have been produced in the laboratory from cast iron.

Inorganic theory.

The first inorganic theory was advanced by Berthelot, who suggested that infiltrating water might react with the alkali metals in the interior of the earth to form acetylene and other hydrocarbons.

The name most generaly associated with this inorganic theory is that of Mendelieeff who published his view in 1877. He held that much of the interior ofthe earth consists of iron, and further suggested that the metal occurs there in combination with carbon. From his experiment he was then led to suggest that the action of water on the iron carbide would yield petroleum.

The geological arguments advanced by supporters of the inorganic theory may be summed up as follows:

(1) The absence of a sufficient quantity of organisms in many petroliferous formations.

(2) The difference between the oils produced by artificial distillation of coal, etc. and the natural petroleum oils.

(3) The very general distribution of petroleum in the earth's crust, regardless of the geologic age of the rocks containing it.

(4) The connection between igneous rock, volcanic activity and petroleum.

These apparent objections to the organic theory have been almost entirely removed by later investigation. The difficulty of understanding how present known deposits of oil could have reached their present position, may be advanced as an argument against the inorganic theory as a whole, but recent investigation on the optical activity of petroleum has practically eliminated serious belief in the inorganic theory as the source of the economically valuable petroleum deposits of the United States.

Organic Theory.

The theory of the organic origin of petroleum has long been accepted by the majority of geologists. The method, place and time of this transformation of organic matter into petroleum, is not so universally agreed upon however.

Edward Orton says:[1]

"The statements now presented---bring before us two main views as to the origin of petroleum, viz:

"(1) Petroleum is produced by the primary decomposition of organic matter, and mainly in the rocks that contain the organic matter. Of this view Hunt is one of the chief advocates.

"(2) Petroleum results from the distillation of organic hydrocarbons contained in the rocks, and has generally been transferred to strata higher than those in which it was formed. Newberry and Puckham have been quoted at length in support of this general theory. Newberry holds that a slow and constant distillation is in progress at low temperature. Peckham refers the distillation of the petroleum of the great American fields to the heat connected with the elevation and metamorphism of the Appalachian mountain system."

With reference to the age of Petroleum deposit

(1). Orton, E. Kentucky Geol, Survey. 1891, p 42.

Orton says:[1]

"These three views, as to the date of the origin of petroleum and gas, are seen to cover almost all the possibilities in regard to the subject. Hunt believes petroleum to have been produced at the time that the rocks that contain it were formed, once for all. Newberry believes it to have been in process of formation, slowly and constantly since the strata were deposited. Peckham refers it to a definite but distant time in the past, but long subsequent to the formation of the petroliferous strata. He supposes it to have been stored in its subteranean reservoirs from that time to the present."

Orton objects to the distillation theories of Newberry and Peckham on the grounds that they do not harmonize with the geological facts in the main oil fields. The essential point in Hunt's theory, "that it results from the primary decomposition of organic substances," he accepts in his earlier writings; but he fails to accept his view that it was produced con-

(1) Orton, E. Ky. Geol. Survey, 1891, p 42,

temporaneously with the rock. In his later writings he seems to have felt that this theory was not substantiated by the facts.

He firmly believes that petroleum is a primary product and that the related bitumens are derived from it. This is shown in his report where he says:(1)

"(1) Petroleum seems to be, when thus protected from the air, one of the durable forms that organic matter can assume. There seems to be no reason to believe that it is less permanent that coal. Stored in the rocks in the morning of the world it can apparently remain in this condition through the vast and indefinite ages of geology."

In the time that has elapsed since the publication of these views, the chief advance, relative to the formation of petroleum, is the formulation of the theory that the first step in this formation is the differentiation of the fatty materials from the plants and animals by a bacterial action. Most geologists now substantially agree upon this point. Upon the manner,

(1) Orton, Ed. Bulletin No. 30., N. Y. State Museums (1899).

time and place of the transformation of these fatty materials into petroleum, however, there is no such unanimity of opinion.

A review of the literature on this phase of the subject shows that the greatest number of writers still hold that the production of petroleum from this fatty matter is brought about by some form of pressure or temperature after it has been buried in the rock sediments. Among the prominent advocates of this theory are David Abele, Dr. F. W. Clarke, Engler and Cunningham-Craig.

Although it cannot be denied that petroleum can be produced by a process of distillation from organic matter enclosed in the rocks of the earth's crust, the arguments advanced by Orton against such pressure distillation of organic debris as a probable source of supply for our principal accumulations of petroleum are just as valid when applied to the transformation of buried fatty materials to petroleum. Dalton and Clarke have added materially to the arguments of Orton, and many geologists now feel that they are in full accord with the facts derived from observation.

In the tenth Census of the United States, page 82, we find an early statement by Hunt in which he indicates the probability that the formation of petroleum is, or may be, contemporaneous with the deposition of the sediment.

This fact has been more clearly stated by Murray Stuart.[1] He says: "The oil represents a contemporaneous flow and was deposited in practically its present state." In adopting the existing theory of the production of petroleum from the fatty material of plants and animals in the sediment, to his new idea of the sedimentary origin, not of a secondary nature, in the deposits, he says: "For this purpose it is necessary that the decomposition of the organic bodies should have proceeded elsewhere than in the strata themselves and yet in such a place that the oil would be retained and collected until it was liberated upon the surface of the rivers which were depositing the sediments."

(1). Stuart, M. Geological survey of India, Vol XL Page 320.

Munn, who also holds to the contemporaneous formation of petroleum with the sediments containing it, believes, on the contrary, that it is generated in the loose mud and sand on the sea bottom, and escaping, probably as microscopic globules. He says:(1) "Because of the great affinity of oil for clay, each of these tiny globules immediately after being formed eagerly seized upon the first small particle of clay with which it came in contact and completely enveloped all exposed parts of it."

Both Stuart and Munn have limited their discussion to petroleum found in shales or related sandstones into which it probably migrated. Munn's idea as stated above is based upon the supposed affinity between clay and oil. Stuart,(2) moreover maintains that: "The deposition of oil is purely a matter of gravitation. The oil becomes mechanically mixed with the sediment and the fineness of that sediment renders it impossible for the oil to separate itself; the mixture of the sediment and the oil, being still of higher specific gravity than water, falls to the bottom and is deposit-

(1). Munn, M.J., Economic Geol. Vol. IV No. 6. P. 519. (Sept, Oct. 1909.

(2). Stuart, M. Geol. Survey of India Vol XL. p. 324.

ed as a sedimentary deposit."

We have here in contradistinction to the pressure distillation theory, one which supposes the formation of petroleum from similar materials, by natural processes at the surface of the earth, and its contemporaneous deposition with those sediments with which it is originally connected.

As can be easily seen this theory would be absolutely worthless unless petroleum actually forms at the surface of the earth under natural conditions.

Upon investigating the literature upon this subject, it was found that observations in various parts of the world fairly well establishes the fact that petroleum is formed at the surface of the earth in such relation to sediments as might permit their deposition in the manner indicated.

Dalton,(1) in his recent article on the origin of petroleum says: "In 1899 Lesquereux*****referred to the recent formation of a liquid akin to petroleum in Sardinia and Sweden."

(1) Dalton, Economic Geol. Vol. IV No. 7. pp. 603-631 (1909)

In the same article he refers to other observations of a similar nature as follows: "Natterer describes the occurrence of petroleum in the mud of the Mediterranean sea floor between Cypus and Syria, and in the sea water immediately above the bottom; it was also f und in the Gulf of Suez, and in each case ammonia and iron sulphide or sulphur occurred with the oil."

Newberry says:[1] "That in the Bay of Marquette, where the shore consists of peat overlying Archean rocks, bubbles of marsh gas arise, together with drops which cover the water, in spots, with an oily film."

In the same volume we find:[2] "E. Sickenberger has shown that in small bays of the Red Sea, where the salinity reaches 7.3 per cent., petroleum is actually forming as a scum upon the surface of the water.***. The association of gas, oil, salt, sulphur and gypsum, which some writers have taken as evidence of former volcanism is much more simply interpreted, both chemically and geologically, as due to the decomposition of organic matter in shallow, highly saline water near the margins of the sea."

(1) Clarke, Date of Geochemistry p. 701.
(2) " " " " p. 699, 200.

Dr. David White[1] recognizes the formation of other bitumens by organic processes in stagnent or quiet waters, but upholds the pressure distillation theory for the formation of petroleum.

It appears, therefore, that the actual formation of petroleum at the surface is as well established as any of the facts upon which the pressure--distillation theory is founded.

APPALACHIAN OIL FIELDS.

One of the most important ideas regarding the geology of petroleum during its early development referred to the nature of the reservoir rock. Upon this subject geologists and prospectors were divided into two groups and their views were widely discussed and insisted upon by the members of each. One contended that the oil was contained in the interstitial spaces between the grains of the containing oil rock while the other maintained with equal emphasis that the oil occurred only in open fissures. For the first twenty-five years of oil development the latter of these two

(1) White, D. Economic Geol. Vol 3, No. 4. p. 308.

ideas was more widely accepted because it seemed to account adequately for all known phenomenon and did not tax the imagination to as great an extent as the former.

Regarding the structural relation of oil very little seemed to have been accomplished during this early period. Only two men, T. Sterry Hunt,[1] and E. B. Andrews[2] seemed to have realized the importance of this subject. Andrews first noted that oil was confined to the Volcano anticline in West Virginia and Ohio and not found in the horizontal rocks on either side. His paper, "Rock Oil, its Geological Relations and Distribution, " was published in 1861. In this paper the auther described the anticlinal structure and the occurrence of oil, but explained its existence as due to fissuring in the sandstone during the folding process. He says that fissures are more abundant in the anticlines thus forming reservoirs which caused the oil to accumulate in that locality.

Hunt, however, seemed to have had the idea that is

(1) Andrews, E.B. American Journal Sci. 2d Ser., Vol 32, pp. 85-93.

(2) Huht, T. Sterry, Canadian Naturalist, Vol.6, pp. 241-255.

now prevalent concerning the oil reservoir and the effect that structure has on the accumulation of oil. Hunt also, gives the first suggestion of the idea that later developed into the anticlinal theory. He said: "These wells occur along the line of a low bread anticlinal axis which runs nearly east and west through the western peninsula of Canada, and brings to the surface in Enniskillen the shales and limestones of the Hamilton group, which are there covered with a few feet of clay. The oil doubtless rises from the coniferous limestone, which as we have seen contains petroleum; this being lighter than the water, which permeates at the same time the porus strata, rises to the higher protion of the formation, which is the crest of the anticlinal axis, where the petroleum of a considerable area accumulates and slowly finds its way to the surface through vertical fissures in the overlying Hamilton shales, giving rise to the oil springs of the region."

The Canadian Geological Survey published a statement (1) similar to Hunt's, in 1866 in a report of progress by Sir. Wm. E. Logan; but there is considerable evidence of Hunt's priority.

The conditions necessary for an adequate oil reservoir were first stated by A. Winchell as follows: (2) "Where the shales are covered by an impervious layer, as of shale or plastic clay, the oil and the gas elaborated are retained in the rocks, filling cavities by driving the water out by elastic pressure, and saturating porus strata embraced in the formation, or intervening between it and the impervious cover above."

These same conditions were more clearly stated by Dr. J. S. Newberry thus: (3)

"This structure consists of a great mass of carbonaceous strata below, more or less disturbed or loosened, from which oil is supplied in a constant and relatively copious flow; above this, strata of porous jointed sandstone, serving as reservoirs where the constant product of oil and gas may accumulate for ages; still higher,

(1). Canada Geol. Survey, 17th Report of Progress p.233.
(2). Winchell, A. Am Jour. Sci. 2d. Series, Vol. 39,p. 352.
(3). Newberry, J.S. Geol. Survey of Ohio, Vol 1. p. 160.

aggillaceous strata, impervious in their texture, and not capable of being opened by fissures, forming a tight cover which prevents their escape."

These citations indicate general agreement as to favorable structural conditions. There was, however, at the end of this early period very little agreement regarding the factors affecting the circulation and accumulation of oil. With the organization of the Second Geoligical Survey of Pennsylvania in 1874, an excellent opportunity for the solution of the various oil problems was offered. Mr. J. P. Lesley, the director appreciated this opportunity, and with an efficient corpse of assistants made special studies in oil and gas which resulted in five volumes on this subject. In spite of the great opportunity offered for the study of the structural relations and accumulation of oil one searches in vain for a comprehensive discussion of these problems. On account of this fact these volumes were of little practical value to prospectors in search of new fields. In the report of the southwestern part of the state Stevenson considers the influence of anticlinal structure but seems to consider it of but slight importance. His statement referring to this matter follows: (1). "Experience having shown in Western Virginia and southwestern Pennsylvania that oil could be produced in economic quantities only where there seems to have been some decided disturbance of the strata, those engaged in procuring this oil came to regard this disturbance as necessary to the original production of the oil itself. But a few considerations, I think, will suffice to show that the oil in no wise owes its origin to disturbances of the strata, and that the only effect of the disturbance has been to provide reservoirs for the oil in the rock already oil-bearing."

In the preface of Oil report No. I. by Lesley, the following statement occurs:(2)

"The supposed connection of petroleum with anticlinal and synclinal axes, faults, crevices, clevage planes, etc., is now a deservedly forgotten superstition.

(1) Stevenson, Penn. Geol. Survey, Report K. pp 394-395.

(2) Lesley J.P., Penn Geol Survey Report K. pp 393-394

Geologists well acquainted with the oil regions never had the slightest faith in it, and it maintains its standing in the popular fancy only by being fostered by self-assuming experts who were not experienced geologists."

Later at a meeting of the American Institute of Mining Engineering he expressed his feelings regarding the matter as follows: (1).

"It is impossible***that any arrangement of water, oil and gas can occur in deep oil rocks, such as occur in a bottle*****It therefore seems to be irrational to assign any importance whatever to the extremely gentle anticlines of the gas-oil region."

With this attitude of the director of the department in mind, it is easy to understand why so little has been done by the members of the Pennsylvania survey, in solving this phase of the oil problem.

Mr. F. W. Minshall, a practical oil man of Ohio began an investigation of the Volcano anticline in 1878, along the lines of Andrew's and Hunter's earlier invest-

(1) Lesley, J.P. Trans. Am. Inst. Min.Eng. Vol. 14,pp654-655.

igations. His complete results were never published but Volume ten of the Tenth Census contains a brief quotation in which he states in part: "***We may safely conclude that the productive oil territory of West Virginia must be confined to the summits of anticlines or local rolls similar to the White Oak Line."

This brings the review of the structural relations and accumulation of petroleum, in a brief discussion, down to 1885. These facts show that up to this time no serious attempt had been made to solve the problem of the relation of structure to, and the forces operating in the circulation of oil through the rocks in its process of accumulation. This condition forced prospectors to rely upon "wildcatting" in locating new oil pools, and when found again relying upon good fortune in determining their extent.

Notwithstanding the early general statements of Hunt and others with reference to the anticlinal theory the credit for formulating this theory, of working out many of its details, and applying it practically to the finding of new fields belongs to I. C. White.[1] In discussing the introduction of this theory, White stated that it was not new but that it had not been formulated in such language as to be of practical value. In his work he was assisted by Wm. A. Earseman, an oil operator. White began this work in 1883 soon convinced himself that the theory would explain most of the facts observed in the Pennsylvania district; but he did not gain confidence enough in his theory to publish it until 1885.

Says he[2] "After visiting all the great gass wells that have been struck in western Pennsylvania and West Virginia and carefully examining the geological surroundings of each, Ifound that every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that have been bored in synclines on either side furnish little or no gas, but in many cases large quantities of salt water*** But while we can state with confidence that all gas wells are found on the anticlinal axes, the converse of this is not true, namely, that great gas wells may be found on all anticlinals."

(1) White I. C. W. VA. Geol. Survey, Vol. A. pp 48-64.

(2) White, I.C. "The Geology of Natural Gas" Science, Vol.6 June 26, 1885.

In a theory of this kind the limitations become quite as important ~~as~~ as, or even more so, than the theory itself; and hence I have given considerable thought to this side of the question, having formulated them into three or four general rules (which include practically all the limitations known to me, up to the present time, that should be placed on the stated that large gas wells may be obtained on anticlinal folds), namely:

(a)"The arch in the rock must be one of considerable magnitude.

(b)"A coarse or porus sandstone of considerable thickness, or, if a fine grained rock, one that would have extensive fissures, and thus in either case render capable of acting as a reservior for the gas, must underlie the surface at a depth of several hundred feet (500-2500).

(c)"Probably very few or none of the grand arches along the mountain ranges will be found holding gas in large quantity, since in such cases the

Plate I.

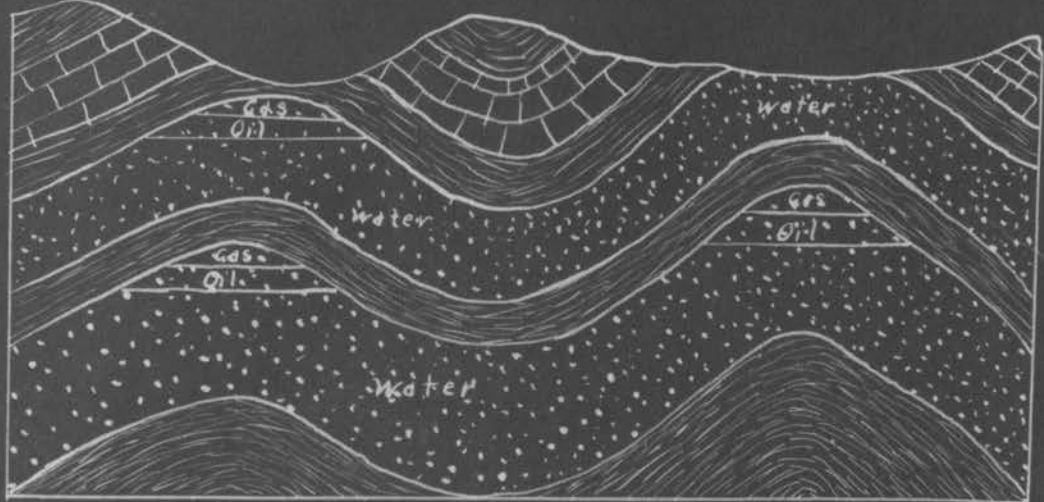

Fig 1. Diagram showing the accumulation of oil and gas in anticlines in a series of folded sands saturated with water.

Fig 2. Diagram of a series of folded sands in shale showing the accumulation of Oil in the synclines in the absence of water.

disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago have escaped into the air through fissures that traverse all the beds.

(d) "Another limitation might possibly be added, which would confine the areas where great gas flows may be obtained to those underlain by a considerable thickness of bituminous shale.

(e) "Very fair gas wells may be obtained for a considerable distance down the slopes from the crests of the anticlines, provided the dip be sufficiently rapid, and especially if it be irregular or interrupted with slight crumples. And even in regions where there are no well marked anticlinals if the dip be somewhat rapid and irregular rather large gas wells may occasionally be found, if all other conditions are favorable."

It is evident that a theory of this type can apply only to saturated rocks although White does not clearly state this fact. This may be due to the fact that the work of White was in saturated rocks.

When oil was discovered in Ohio Edward Orton, set out to determine the causes and conditions affecting its accumulation. He soon succeeded in working out the geologic structure which he found contained only one prominent flexure, thus simplifying his problems to a considerable extent. His result seconded White's conclusions in demonstrating the adequacy of the anticlinal theory. He found, however, that certain modifications were necessary in applying it to the Ohio fields. As stated by White the anticlinal theory provided only for the accumulation of oil in anticlinal folds. Orton however, made an important addition by recognizing "terrace" structures as favorable to the accumulation of oil.

In his first statement regarding "terrace" structure Orton says:(1) "In the old fields and in the new alike, irregularities of dip, involving change of direction suspension, or unusual increase, have been found connect-

(1) Orton, E. Geol. Survey of Ohio, 1886 p. 21.

Plate II.

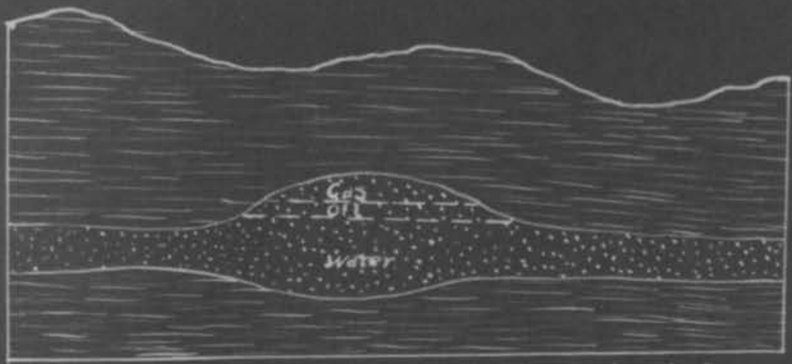

Fig 1. Diagram illustrating the accumulation of oil and gas in a lens of sandstone in shale.

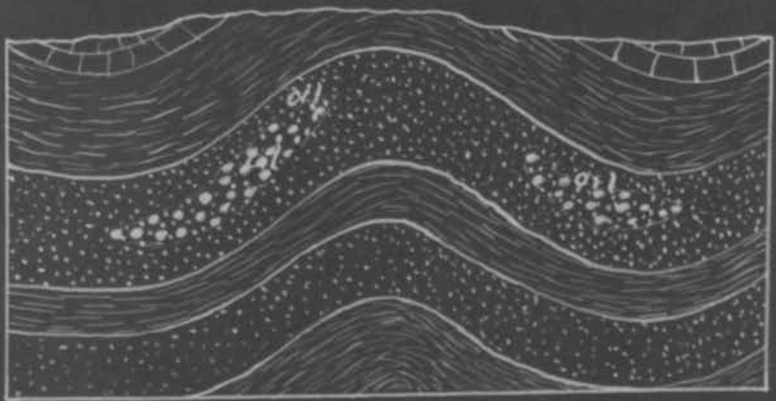

Fig 2. Diagram showing accumulations of oil in lenses of coarse material in fine sand.

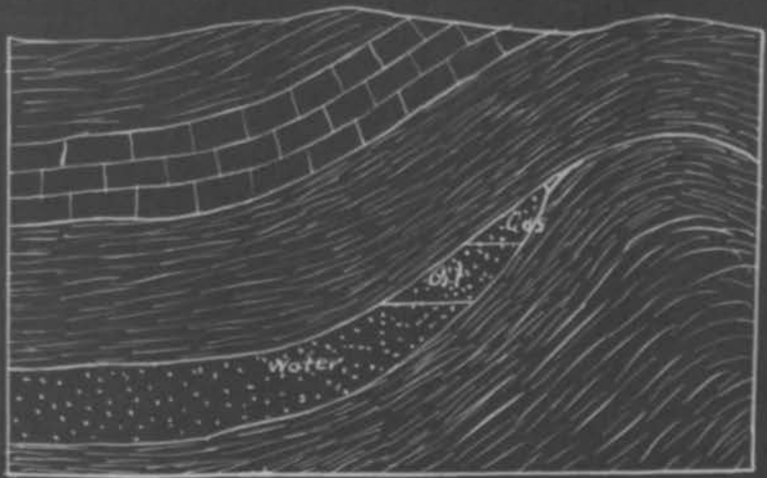

Fig 3. Diagram showing accumulations of gas and oil in a typical lenticular sand in folded shale.

ed with the large proportion of both oil and gas in every instance where careful examination has been made. The composition of the series involved is identical for many thousand square miles, but so long as uniformity of dip is maintained, there is no valuable accumulation. As soon, however, as this uniformity is broken in upon the valuable stocks of gas and oil came to light."

This terrace structure has probably been influential in the accumulation of oil in the Ohio and Indiana fields. From this time up to the close of the nineteenth century very little addition to the knowledge of oil accumulation was made. White seemed to feel that the matter was entirely settled. In two later volumes of the Geological Survey of West Virginia he reviewed his fight for the establishment of the anticlinal theory, but did not seem to realize that his new idea would have to be greatly modified in applying it to field conditions.

The most recent development of ideas regarding accumulation of oil have been furnished by geologists of the Federal Survey. In 1900 M. R. Campbell and several

Fig 1. Diagram showing the accumulation of oil and gas in terraces or arrested anticlines.

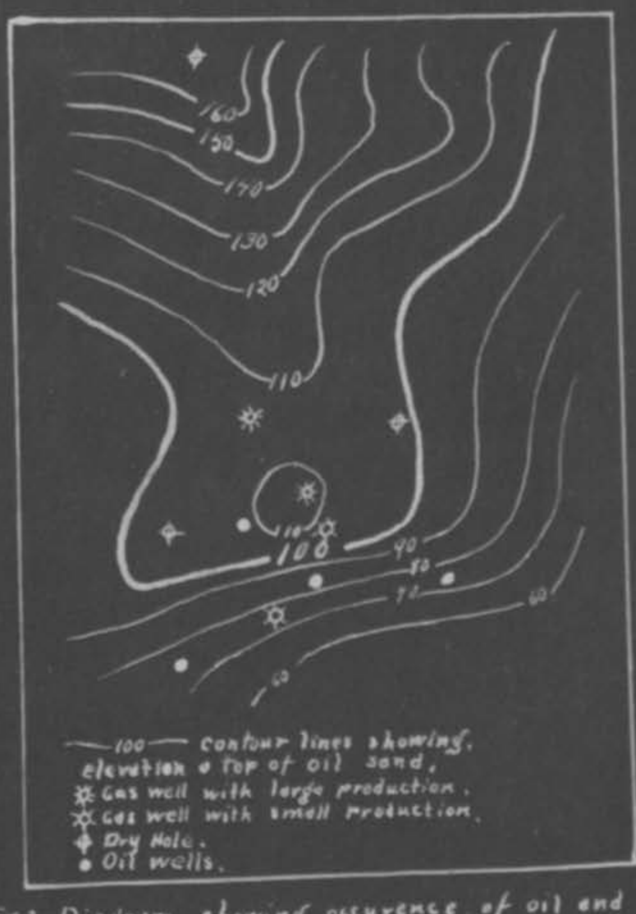

Fig 2. Diagram showing occurence of oil and gas on structural-terrace. (After Clapp.)

assistants began a survey of the Pennsylvania regions with special emphasis upon geologic structure. W. T. Griswold and M. J. Munn, about the same time, did similar work in Ohio, where they obtained the most accurate and detailed representation of geologic structure that had ever been attempted.

During the recent period almost every worker had discovered that the anticlinal theory would not apply to dry rocks, and that all of the lower sands in southwest Pennsylvania are dry. Mr. L. H. Woolsey was the first to state it in an oil report. He says: (1)

"If the sand holds much water, oil should occur high on the flank (of the anticline); if little water low on the flank; if none near, the bottom of the syncline."

F. G. Clapp in his study of the southwestern corner of Pennsylvania found that the lower sands are almost universally dry and that the pools of oil do not follow the rules of the anticlinal theory. He states:(2) "Considerable doubt has been thrown on the anticlinal theory by oil and gas operators, on account of various apparent

(1) Woolsey, L.H. U.S.G.S. Bull. 286 p 81.

(2) Clapp, F.G. Geol. Atlas of the U.S. Folio No 146 1907.

exceptions to its application. By most geologists the theory is now accepted, not, however, as indicating absolutely the limitations of the occurrence of oil and gas, but as expressing the general relations of their occurrence to geologic structure, such relations being subject to many modifying conditions. Some of the most important modifying conditions are (1) the presence or absence of salt water in a given region or in a given sand; (2) the continuity and shape of the anticlines--whether they are rising or pitching; (3) the porosity of the oil rock--that is its capacity to hold oil; and where the rocks are saturated, (4) the height of the water level."

In explaining the irregular distribution of oil in the synclines of dry rock Clapp and Stone say:[1]

"The structural position of the oil pools and the dryness of the rocks in Green County suggest the hypothesis that oil accumulated in pools after the formation of the rocks, while they were yet saturated with water, but that with the recession or disappearance of the water the oil moved by gravity back down the slope of the bed to its

(1) Clapp F. G. and Stone R. W. U.S.G.S. Bull. No. 304 p 82, 1907.

present position. Under these conditions the oil would be stopped in its downward progress by a reversed dip, by a dip of low angle, or by increased density or thinning out of the reservoir rock."

Since the establishment of the anticlinal theory, the important additions as outlined above seem to be (1) that the conditions of accumulation are different in saturated and unsaturated rocks; (2) that in saturated rocks the water level may vary in different portions of the same sand; (3) that the water level may have varied from time to time in past geologic ages, and that the dry sands of the present day, may previously have been saturated; and (4) under some conditions the oil moves up the slope and under other conditions down the dipping porous beds.

The conclusions of Griswold and Munn[7], are practically the same as those of Stone and Clapp. With particular reference to unsaturated rocks they say: "In dry rocks the principal points of accumulation of oil will be at or near the bottom of the synclines

(7) Griswold W.T and Munn M.F. Bull, U.S.G.S. No, 318 p. 15, 1907.

Plate IV.

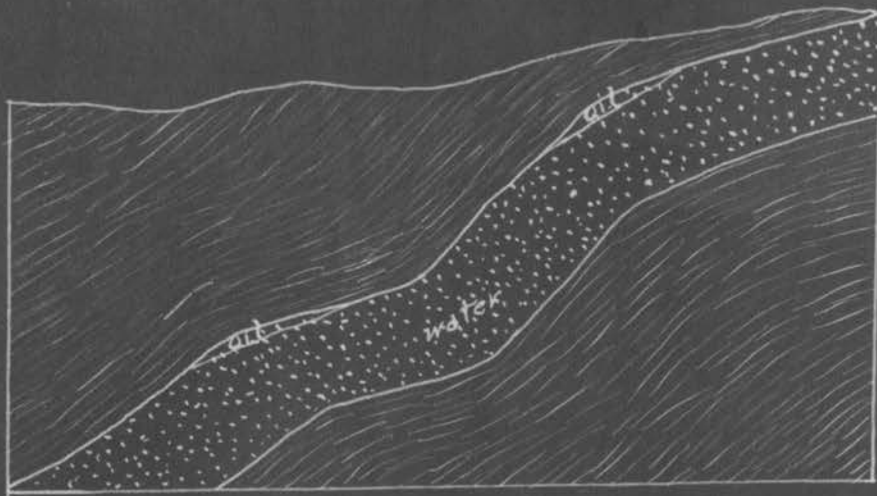

Fig 1. Diagram showing the accumulation of oil in a monocline at points of change in dip.

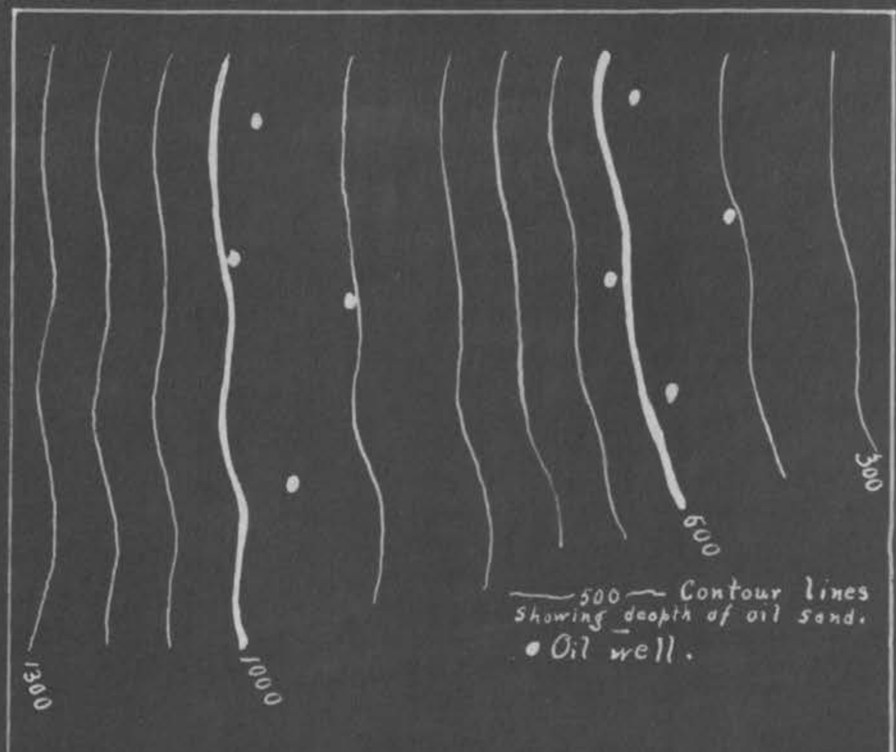

Fig 2. Structural map of the oil sand in the above figure, showing oil pools coincident with points of change in monoclinal dip.

or at the lowest point of the porous medium, or at a point where the slope of the rock is not sufficient to overcome the friction, such as structural terraces or benches."

Griswold says:(1) "The condition of saturation with water is not the same in different sands. Experience has shown that the older or lower beds in the Appalachian field contain a smaller area of completely saturated rock than the upper or younger sands. The lower sands seem to be almost entirely dry, only the very lowest points in the center of a structural basin showing any considerable quantity of salt water."

In two recent papers M. J. Munn discusses the circulation and accumulation of oil, and in this connection presents many new ideas and questions many of the old ones, which have been considered well established. In these papers he presents the hydraulic theory of oil accumulation.

He says:(2) "The central idea of the theory is that the principal active agents of oil and gas accumulation

(1) Griswold W.T. U.S.G.S. Bull. No. 346 pp 20-21, 1908.

(2) Munn, M.J. Economic Geol. Vol. 4, 1909, pp. 141-157 & 509-529.

is moving water under both hydraulic and capillary pressure. It assumes that oil and gas have originated from organic matter, both animal and vegetable, entombedin the sedimentary rocks when they were deposited." Later in his paper he says: "To this idea may be added another of equal value--the pools of oil and gas are held in place by water under hydraulic and capillary pressure which effectively seals up all the pores of the surrounding rocks and prevents the dissipation of pressure by diffusion."

He summarized its advantages over the anticlinal theory as follows: (1) "It provides an adequate means of forcing the oil and gas from the shales into the pay streaks of the sandstone or other porous beds. (2). It provides a means of preventing diffusion by sealing up the pore space surrounding oil and gas pools by water under either hydraulic or capillary pressure. (3) It provides an ample source of pressure in both oil and gas pools, (4) It furnishes a better explanation of the structural position of pools of oil and gas, especially in the Appalachian region."

Another point worthy of attention was brought out by David T. Day[1] who tried to separate crude oil into various fractions by the use of dry fuller's earth. He succeeded in his experiments and incidentally showed that oil diffuses very readily through a dry fine grained material. The circulation of oil through shale may be explained by this hypothesis, but would result in dissemination rather than accumulation, unless moisture is present to prevent this process of diffusion.

The general results outlines above, although obtained in a study of the Appalachian field, apply equally well to the fields of Ohio, Indiana, Illinois, Kansas, Oklahoma and many regions in the Rocky Mountains.

In the middle continent field, it has been suggested by R. S. Blatchley[2] that the reservoir may deviate from the horizontal from other reasons than deformation. He says: "Some question has arisen as to whether these minor arches are true anticlines of

(1) Day, David T. Science, New Series, Vol. 17, 1902

(2) Blatchley, R. S., Ill. Geol. Survey Bull. No.16.

In this case the limiting lateral dry holes are not water or gas wells but are dry because the productive sand is pinched out."

Johnson believes that barrier beaches and salt marshes are closely connected with the origin and accumulation of oil. He states that the barrier beaches off the coast of Long Island are similar in texture to our best oil sands, and are surrounded by conditions that would be expected to produce elongated sand bodies, contiguous to organic shales. These types of sand deposits associated with lagoon muds rich in organic remains, are significant.

Gulf Coast Saline Fields.

In developing the oil regions of this country geologists, operators and drillers have gone from the Pennsylvania fields to those of the Gulf Coast and West with the preconceived notion that all oil districts were of the same general type. This has lead to the application of old methods to the new regions often with disasterous results, which forced operators and geologists to recognize that different conditions prevailed, presenting new and unsolved problems. This was clearly illustrated in the development of the Gulf Coast Salines.

Captain A. F. Lucas was the first to recognize that the Gulf coast field differed from those already explored. For years he had explored the salt beds of Louisiana and was the first to appreciate the dome structure of these deposits. He also believed that these domes contained oil in addition to salt and sulphur. In 1901 he struck his famous gusher or spindletop at Beumont, Texas and demonstrated the correctness of his theory.

In summing up the knowledge of these saline fields, it is important to consider the structural association of the pools, the origin of the domes and their relation to faults and lines of weakness in the earths' crust. The development of this field has been so recent that it is difficult to get facts which are generally

Fig 1. Map illustrating surface topography of the Vinton dome, La, (the elevations are shown by structure-contour lines). (After Clapp)

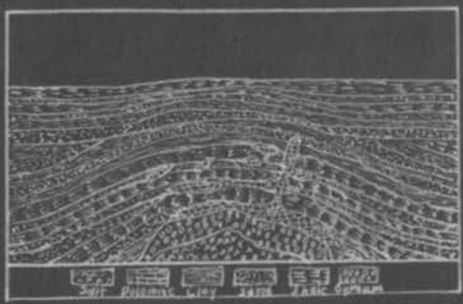

Fig 2. Cross-section of the Spindle Top oil field, Texas. An example of the saline-dome type of quaquaversal structure (After Hager).

Fig 3. Map showing distribution of saline domes and hypothetical fault lines in southern Louisiana.

accepted. It is well known that the nucleus of the domes are salt or salt and sulphur at the sides of which strata are upturned forming a favorable condition for oil accumulation. As far as known the salt case extends indefinitely downward for the deepest wells have failed to reach the bottom of the mass.

Theories explaining these structures have been advanced by R. T. Hill,(1) Mr. Lee Hager,(2) and Mr. G. D. Harris.(3)

G. D. Harris seems to have given the most thought to the subject and put forth the most reasonable hypothesis to account for the structure. His hypothesis will be the only one considered in this connection.

Although Harris seems to have been convinced of the dome structure as early as 1899, he does not make any formal mention of it until the publication of his 1907 report. In this he says:

"The longer we study these peculiar structures the more convinced are we that although they may be located along lines of weakness, faults a fractional

(1) Hill, R.T. Jour. of the Franklin Institute Vol.154 pp.143-156, 225-238, 263-281)

(2) Hager, Lee, Eng. and Min. Jour. Vol. 78, pp 137-139, 180-183.

(3) Harris, G. D. Geol Survey of La.Bull. No 5, pp 8-9, 1907 and Bull No 7, pp 59-83, 1908.

anticlines, they are not due, to any great extent, due to tangential, mountain making forces, nor to volcanic upheavals, nor igneous plugs, as has recently been suggested, but to the slow acting, little understood, concretion forming forces as well as the power of crystalization."

In a more complete discussion in his 1908 report he says: "We believe there is practical unanimity now among geologists regarding the secondary nature of the salt masses so frequently met with in Louisiana and Texas domes. In nearly every case, we believe, the various writers quoted above have come to this conclusion independently and in spite of a very strong early inclination toward a normal or 'salt-pan' origin. We believe all will admit that water has been the dissolving and transporting agent. The main difficulties in the whole matter have been (1) how can rising columns of water be made to precipitate their salt, even though saturated, and (2) what is the force that lifts up a certain hundred or thousand feet of superficial strata in limited areas almost never two miles across. The remarkable circular form of the domes and their quaquaversal dips and the extent of their proven vertical movements in comparison with their diameters--these two are troublesome factors.

"In brief we answer (1) precipitation is due to decrease in temperature and (2) the requisite uplifting force is amply accounted for by the power of growing crystals."

This hypothesis is the most logical yet presented to account for the salin domes and is the most important contribution to our knowledge of this field.

Although Lucas and Harris have contributed considerable information regarding these fields, there are many problems connected with them that are still unsolved. Among these is the mode of origin of the oil. Recent discovery of the igneous plugs, having many of the phenomena observed in the Texas field, along the Mexico coastal plain, offers strong support to Hager's volcanic hypothesis of oil formation in these fields.

CALIFORNIA FIELDS.

The California fields offer new features not found in any other regions. There is very little similarity between this greatly folded, and highly fractured region and the fairly regular oil sands with their flat lying conformable beds of the Eastern fields.

In the hard rocks of the Eastern region it had long been recognized that faults furnished avenues of escape of both oil and gas. But in California Cooper (1) found that faults in the soft Tertiary rocks of California, sealed themselves and acted as barriers. He says in part: "If an oil bearing bed ascending to the North be interrupted by an east and west fault the further ascent of the oil northward will be arrested and then an abundant supply of oil may be obtained by boring on the south side of the fault."

The most important contributions to knowledge concerning the California oil fields was furnished by Ralph Arnold, Robert Anderson and Harry R. Johnson. Their work is of recent date and has not been entirely verified but the results have been of great value to practical oil men.

(1) Cooper, A.S. California State Mining Bureau.
Bull. No. 16, page 21.)

The important scientific contributions of these authors deal with (1) the causes of migration of oil and (2) the conditions affecting this migration. Concerning the cause of migration they say:(1) "This migratory faculty may be ascribed entirely to the presence of the associated gas which would cause the oil to fill every crevice offering a point of escape or a point of lodgment."

In a later report,(2) they refer to diffusion as a cause of migration in the following terms: "This cause (of the migration of oil from its source)***(is) the tendency of oil to migrate by diffusion through certain media such as dry shales.

Regarding the conditions affecting migration these authors conclude that, "The condition of the rocks is the chief factor that controls the matter of where the oil is stored most abundantly."

The usual barriers are dense impervious rocks but in some places "the residual or heavy hydrocarbons that are left upon evaporation of the lighter substances

(1). Arnold, Anderson and Johnson, U.S.G.S. Bull. No. 322 pp. 73-74.

(2) Arnold, Anderson and Johnson, U.S.G.S. Bull. No. 357 p. 113.

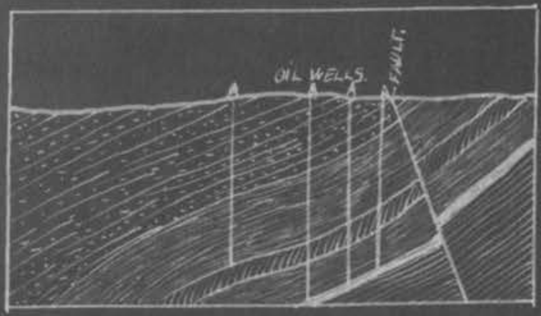

Fig 1. An oil pool in California sealed in by a fault line. (After Arnold Bull. 309, U.S.G.S.)

Fig 2. Hypothetical Example of an Oil pool in the arkose zone between granite and Potsdam sandstone, in province of Quebec.

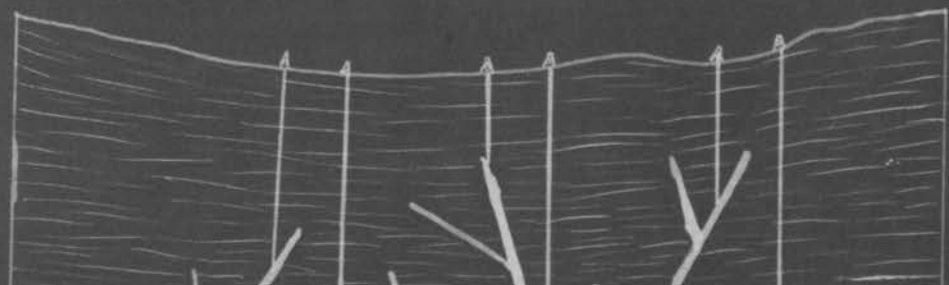

Fig 3. Diagram showing accumulation of oil in fissures in shale. (Florence field type Colo.)

originally in the contained petroleum, seal the outcrop and hinder orpprevent the escape of the oil from below. (1). This is apparently a common occurrence with the he heavy California oils.

COLORADO FIELDS.

Many small oil fields have been discovered in the Rocky Mountain region. The conditions in most of these fields resemble those found in the Appalachian region. The Florence field of Colorado presents exceptional features worthy of consideration.

Although many geologists have attempted to explain the occurrence of oil in this basin-shaped depression, the most satisfactory explanation has recently been offered by Mr. C. W. Washburne (2). Referring to the distribution of the oil-bearing beds he says: "The oil does not follow any bed or series of beds in the shale. As shown by the outcrop, the oil zone does not contain any sandstone or other porous beds capable of acting as reservoirs. The oil lies in joints and fissures. This statement is made without

(1) U.S.G.S. Bull. No. 398, p 186

(2). Washburne, C.W., U.S.G.S. Bull. No. 381, pp 521-522.

reservation, because the writer believes that it is fully justified by consideration which cannot be presented fully in this paper. The evidence consists of (a) observations on the correspondence in direction of the major joints observeable in the rocks at the surface with the allignment of wells which have interfered with each other; (b) the fact that many wells have been drilled within a few feet of each other without encountering oil at the same depth; (c) the fact that gas struck in a shallow well often immediately ruins an adjacent well several hundred feet deeper by tapping the source of pressure; (d) the fact that many wells drain adjacent wells that are very much shallower; (e) the indications of vertical connection between the oil bodies shown by marked increase in maximum pressure with depth; and (f) the dissimilar pressures in adjacent wells of the same depth.

"Corroborative evidence is furnished by the drillers who report "Crevices" in most of the wells**In numerous cases**large quantities of water have been poured into the well without moistening the shale sufficiently to enable drilling to proceed, and the conclusion of the drillers that the water has been used up in filling a crevice is probably correct. Less certain are some other observations, such as the reported dropping of tools as much as 20 feet below the distance drilled."

According to Washburne the wells in this field penetrate shale throughout their entire length, in some cases 2500 feet. The pool occupies a synclinal basin of Pierre shale and lies east of Canon city.

Concerning the forces which have caused the accumulation of oil in the Florence field Washburne says:(1) "The concentration of the oil has probably been brought about by water which is able to shove the oil before it on account of its great capillary pressure due to great surface tension. The oil is hemmed in above by the ground water and below by artesian water in the Timpas Limestone and subadjacent sandstone of the Carlile. The ground water supersaturates the shale for a distance of 300 to 500 feet from the surface."

These quotations seem to show that Washburnes general conclusion is that geologic structure has had

(1) U.S.G.S. Bull. No. 381 pp 523-523.

no effect upon the accumulation of oil in the Florence field; that oil is present mostly in open fissures and held there by water on the same principal as damp fuller's earth furnishes an impossible barrier to the migration of oil.

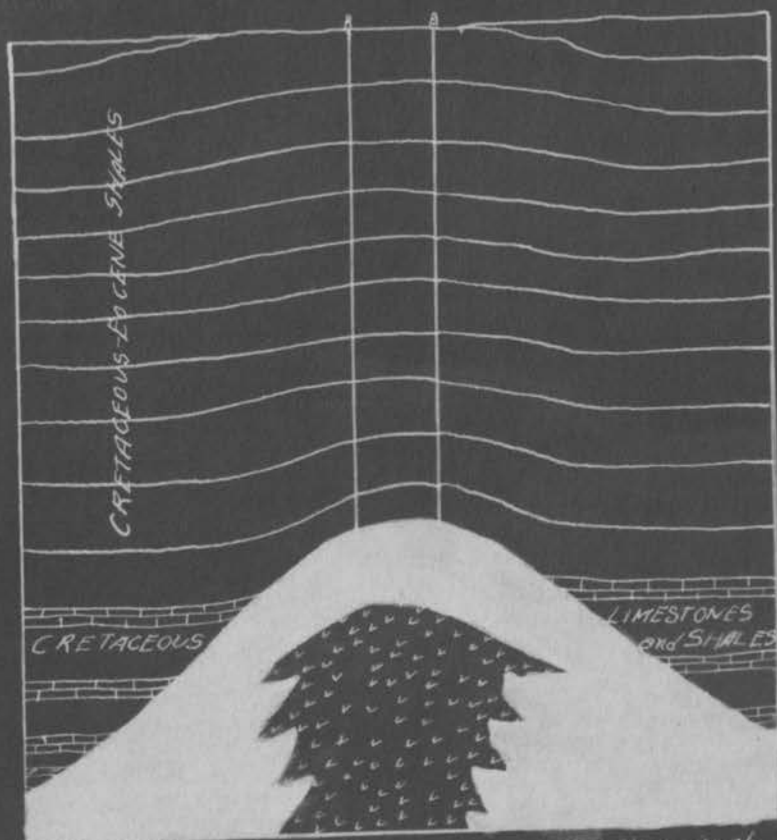

Fig 1. Hypothetical section of basalt intrusion penetrating the series of Cretaceous limestones and shales without disturbing the Cretaceous-Eocene shales and giving rise to a dome of fractured and porous material, effectively covered with an impervious cap-rock. The large proportion of some of the Mexican gushers can readily be accounted for on this hypothesis. (After Garfias in Jour. of Geol.)

Plate IX.

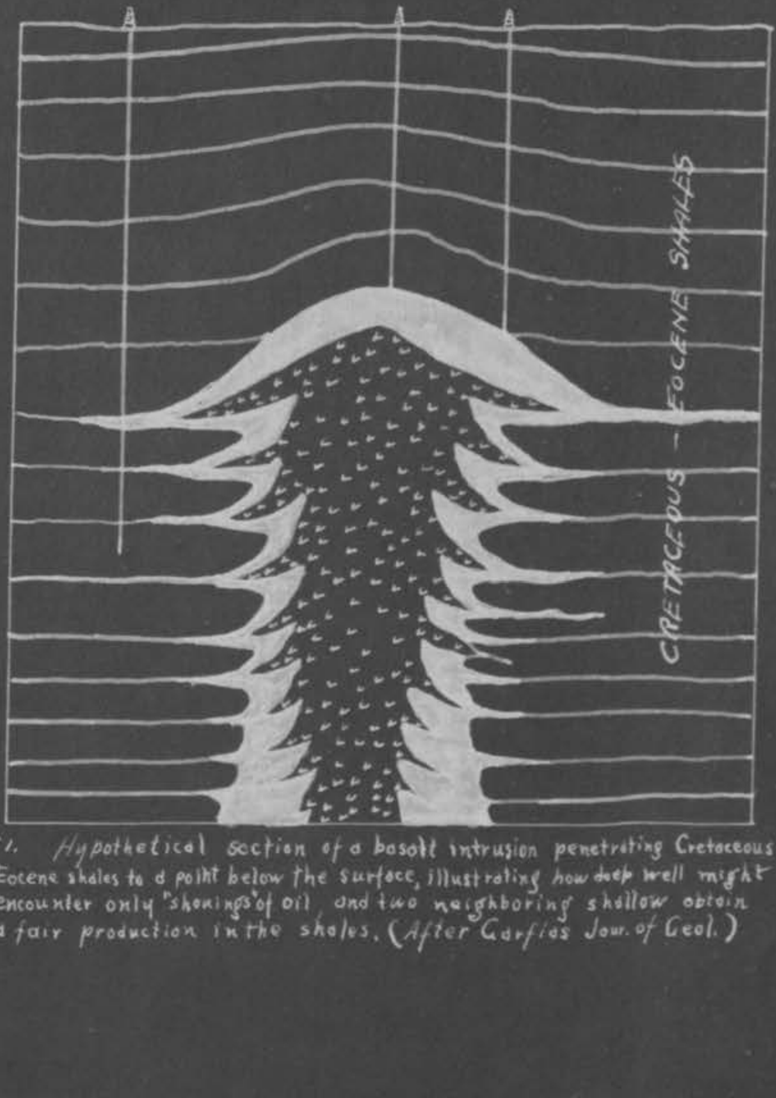

Fig 1. Hypothetical section of a basalt intrusion penetrating Cretaceous-Eocene shales to a point below the surface, illustrating how deep well might encounter only "showings" of oil and two neighboring shallow obtain a fair production in the shales. (After Garfias Jour. of Geol.)

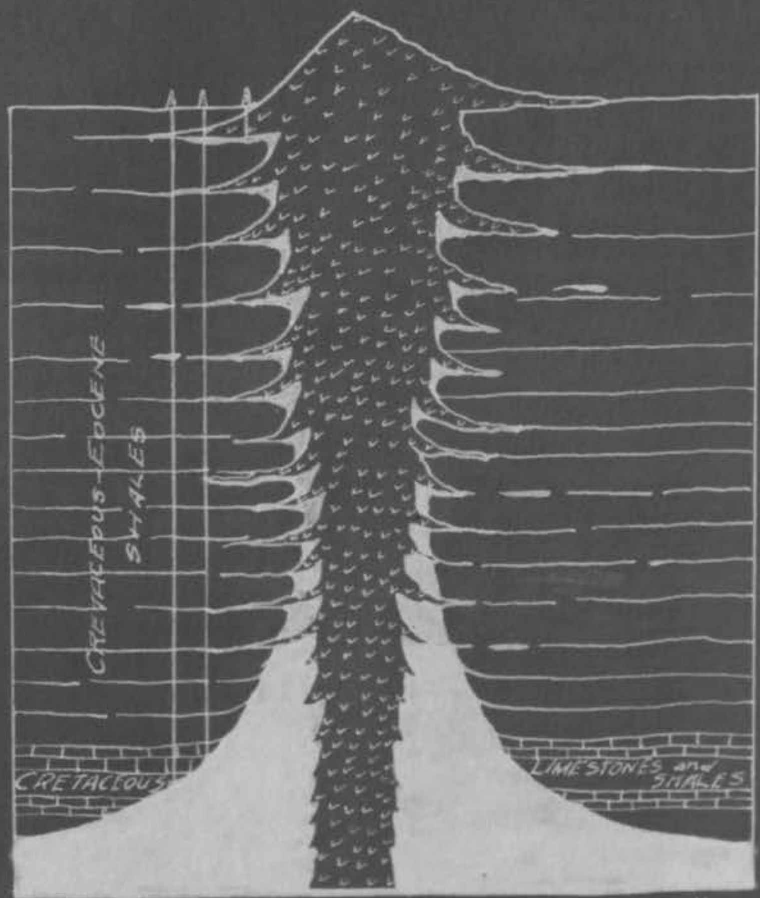

Fig 1. Hypothetical section showing basalt intrusion reaching the surface and resultant conditions in the intruded beds, conducive to the accumulation of oil. The two deep wells tapped the oil zone after penetrating the basalt, while the well nearest to the cone was abandoned in the basalt. (After Garfias in Jon of Geol.)

Experimental Investigations Relating to the Origin and Accumulation of Petroleum.

The following pages describe a series of experiments made with the hope of finding more definite information concerning the supposed affinity between oil and clay, and to determine if possible its bearing upon the origin and accumulation of petroleum.

Samples of seven different clays were used. These were finely pulverized, separately, in a morter to a fineness comparable to the small clay particles which are usually found in turbid streams and form shales like those that are present in some oil bearing regions. These clays were then weighed out into portions of ten grams each and introduced into different test tubes, each of which contained 30cc of water which had been previously agitated with crude petroleum having a specific gravity of .7975, and allowed to stand for three hours to permit the water to take into solution any of the soluable parts of the oil. To one of these mixtures of clay and water .50cc of crude oil was added, after which the mixture was thoroughly agitated for on e minute and allowed to settle. After settling it was found that the water and sides of the test tube were entirely free from oil which was carried to the bottom by the clay particles. This process was repeated until the ten grams of clay had carried down 2.5cc of oil, completely. Upon adding more oil, however, and repeating the process it was found that a slight film of oil was evident upon the surface of the water.

Ten grams of the same clay, in 30cc of water, were then treated with 2.5cc of oil and thoroughly agitated. It was found that when the process of agitation and settling had been completed, that all the oil had been carried to the bottom by the settling sediment. The amount of oil added at one time had no effect upon the total amount carried down by the sediment tested. In neither case, however, would it carry down more than 2.5cc of oil. Ten grams of clay when compressed into shale will occupy about 3.58cc and that amount of shale when pulverized will carry down 2.5cc of crude oil. These test tubes were allowed to stand quietly for four months, observations being taken daily to note any indications of petroleum escaping from the sediments in the bottom of the tubes. At no time during this period was the slightest trace of oil liberated. This leads to the conclusion that fine clay sediments have the power of holding oil in confinement for, at least, four months.

Similar experiments were performed with the other six types of clay. There was but slight variation in the amount of oil carried down by the various sediments, and held in confinement at the base of the tubes. The smallest amount of oil that any one of the sediments carried down was 2cc. Upon investigation it was found that this was an arrenaceous clay which, upon microscopic examination, showed about 20% of sand grains. Two other clays, that did not carry down the maximum amount of oil, were found to be slightly sandy. The more sandy of the two carried down the lesser amount of oil.

Equal amounts of clay were mixed with varying amounts of very fine sand, and ten grams of each treated as outlined in the above experiments. In every instance, the amount of oil carried down by the sediments varied inversely as the amount of sand present. Pure quartz sand was powdered and passed through a 200 mesh sieve and treated in the same way as the clays in the above experiments. No appreciable amount of oil remained confined in the sediment. Powered emery of equal fineness was found to be a very effective agents in carrying down oil, and holding it in confinement.

The effect of the fineness of the material used upon the results was determined by taking clays of the following degrees of fineness: Clay which passed through sieve No. 40 and was caught upon sieve No. 60; that which passed through sieve No. 60 and was caught upon sieve No. 80; that which passed through sieve No. 80 and was caught upon sieve No. 100; and that which passed through sieve No. 100 and was caught upon sieve No. 200 were agitated with oil and water as in the above experiments. Although not quantitatively accurate, because of the slaking effect of water and agitation upon the clay, the test showed clearly that the amount of oil sinking with the sediment increased markedly as the fineness of the original fragments of clay increased. This same result was shown more accurately by emery of the same degrees of fineness mentioned above. This greater accuracy was due to the fact that the fineness of the material was not changed so readily by agitation and water.

These experiments show that the amount of oil a sediments carry down and hold in confinement increases rapidly with the fineness of the material. Very little is caught by clay which has passed through the sixty mesh sieve and collected on the eighty mesh sieve.

Munn (1) concludes that the clay particles are enveloped in oil, says he: "Because of the great affinity of oil for clay, each of these tiny globules immediately after being formed eagerly seized upon the first small particle of clay with which it came in contact and completely enveloped all exposed portions of it."

To ascertain how the oil was carried down by the clay particles, the sediments from the various test tubes used in the above experiments were examined under the microscope. This revealed the fact that oil was confined as very small globules separated from each other by clay particles filling the inter-globular spaces. In no case

(1) Munn, M.J. Economic Geol. Vol. IV p 519.

In no case were particles of clay confined in globules or surrounded by a film of oil. Further examination of oil laden sediments with the high power microscope showed that the globules, although microscopic in size, were larger than the individual particles of clay. They were apparently surrounded on all sides by particles of clay adhering to their surfaces.

From this microscopic examination alone one might logically conclude that the oil globules and clay particles are simply in the form of a mechanical mixture from which the oil globules find it impossible to escape because of the fineness of the clay particles. This conclusion is stated by Stuart (1) in his explanation of the sedimentary deposition of oil. The results obtained in the above experiments show that all forms of sediment of equal fineness are not equally effective in the sedimentary deposition of oil and that clay is much more effective than fine sand.

To determine whether the oil and sediment went down as a mechanical mixture or whether each droplet was surrounded by enough sediment to sink it, ten grams of

(1) Stuart, M. Geol. Survey of India, Vol. XL, p320.

flower of emery were added to 30cc of water and thoroughly mixed. To this mixture a large excess of crude petroleum was added, and the contents thoroughly agitated from one minute and allowed to settle. In this way the maximum amount of oil was carried down by the sediment. As the settling process progressed, the sediment could not hold in confinement all of the oil it had carried down. This was made evident by the formation of an oil globule on the surface of the settling sediment. This globule grew in size until it had gained sufficient buoyancy to break away from the surface of the sediment and rise to the surface of the water above the settling sediment. Another globule then began developing and soon rose to the surface. This process continued until all the excess oil was expelled from the settling sediment.

All the escaping globules of oil were covered by a coating of sediment which was carried to the surface by the ascending globules. As these globules combined with the excess oil at the surface of the water, all the sediment except a film clinging to the lower side of the layer of oil, was liberated and again dropped to the bottom of the tube. The wieght of the sediment clinging to the lower surface of the layer of oil was sufficient to produce a conspicuous downward bulge to that surface of the oil.

This experiment shows marked adhesive affinity between oil and the sediment which carries it down. This affinity of oil for sediment is not as great as the cohesion between the particles making up the oil globules. This is shown by the fact that the particles of oil always retain their spherical form, under conditions of freedom, and do not surround the particles of clay or other sediments.

The experiment cited above and the microscopic examination showed, however, that under conditions named no particles of clay or other sediments were enveloped in oil but the globules were invariably clear a and free from sediments within, the clayey material adhering to the exterior of the globules.

It appears, therefore, that the oil is first broken up into small independent particles by agitation in the turbulent water. These particles immediately assume sperical forms, due to surface tension, because of the non-miscibility of oil and water. These tiny oil globules do not coalesce, at first, because they are held apart by the particles of sediment in the turbid water; but as they come in contace with particles of sediment, these small particles adhere more and more to the globules of oil. This process continues until the specific gravity of oil and adhering particles combined exceeds that of water, and consequently the mass settles, apparently as a mechanical mixture of oil globules and mud particles. When the number of oil globules is sufficiently great some of them probably come in contact and under these conditions coalesce until they are sufficiently buoyant to rise to the surface against the settling mud particles. As noted above this results in a layer of oil on the surface of the water, when the percentage of oil added is in excess. In general, the oil-bearing sediment consists of numerous globules of oil scattered among solid mineral particles which are impervious to water or oil and practically imcompressible. All of the cavities around and between the particles of this mixture are filled with water. This suspended material, as is evident from the settling process, is pervious to water, allowing it to pass through freely until it is compressed so compactly that the passages between the grains become so minute that they become ineffective. The fact that the sediments in the above experiments held the oil in confinement long periods of time without the slightest indication of escaping oil, indicates that these sediments are impervious to oil. This condition is produced by the fineness of the particles and their adhesive affinity for oil, combined with the fact that the spaces between the particles are filled with water, thus preventing capillary escape.

The above experimental data which supports the field evidence offered by Stuart (1) and Dumble (2) favors the conclusion that oil which is known to form on the surface of the earth by bacterial action under natural conditions, at ordinary temperatures, may be deposited as petroleum with fine sediments, especially clay, of contemporaneous age.

(1) Stuart, M. Record Geol. Sur. of Ind. Vol. XL pt 7 1910 pp 320-333

(2) Dumble Bull. of the Am. Inst of Min. Eng Mar 1914 pp 501-512

In general all this data appears to justify the theory that some petroleum is deposited, as such, by settling with fine clay.

ACCUMULATION OF PETROLEUM.

The pooblem of oil accumulation has been under investigation for half a century. Among others, T. Sterry Hunt and E. B. Andrews long ago recognized certain relations existing between oil accumulations and anticlinal structure. Edward Orton and I. C. White however, developed the theory and applied it to field study.

The anticlinal theory is, in brief, that oil and gas were originally widely disseminated throughout the formations, and their segregation is believed to be due to the difference in specific gravity between gas oil and water. According to this theory if a poreus stratum contains these substances, when defommation into folds is produced by geologic causes, they will arrange themselves according to specific gravity; the gas, being lighter, will be driven toward the crest of the anticline, the oil will be floated on top of the water below the gas, while the water fills the space below.

The writer does not question the generally accepted conclusion, that oil accumulations are closely related to structural features. But the results obtained in the experiments already described, and others that will be described in the following pages throw considerable doubt upon the effectiveness of simple difference in gravity as a force producing migration and accumulation of oil.

ACTION OF GRAVITY.

The fact, that oil was held confined by fine clay for four months, indicates that the difference in gravity between oil and water in ineffective in separating oil from the confining sediments. Oil and clay were agitated with 30cc of nearly saturated salt water, and allowed to stand for four months. No oil was liberated from the sediment during that period in spite of the increased power of gravity as a separating force.

To test the effectiveness of gravity in porous sand, saturated salt water was introduced into a test tube, containing one inch of sand, which had passed through the 40 mesh sieve and collected upon the 6 0 mesh sieve, until its pour space was entirely filled. . . . . Following this a few drops of petroleum were introduced; upon this another inch of sand was placed, and the remainder of the tube filled with salt water. The position of the oil was carefully marked after the sand had become entirely satumated. This tube was then allowed to stand undisturbed in a vertical position for three months. At the end of this period there had been no vertical migration of the oil, it having retained its original position in spite of the difference in gravity between oil and salt water. Upon agitating the contents of the tube, thus breaking up the oil into small particles, it quickly passed up through the sand to the surface of the water.' This experiment shows that, without the assistance of other forces, the difference in gravity between oil and water is ineffective, even in porous sand, unless the particles of oil are as small as the interstitial spaces between the sand grains.

ACTION OF PRESSURE

Into test tubes,containing the water and oil laden sediments,sand of varying degrees of finenasss were introduced in horitontal and inclined layers and lenses. By means of a loose fitting plunger pressure was applied to the surface of the sand in the various tubes. This resulted in a conspicuous compression of the sand and oil laden sediments and liberation of much oil from the sediment below the sand. The liberated oil passed up into the sand and occupied the more poruus layers, where it remained as conspicuous layers and lenses. The amount of oil liberated depended upon the amount present and the force applied to the plunger. In no case, even where long periods of time were involved, did the oil pass through ~~but~~ the sand to the surface of the water above but all migration was from one sediment to another. Where the sand above the oil sediment was of uniform fineness, the oil, in its migration, followed a vertical path; but where sands of varying degrees of porosity came in contact with the oil laden material the path followed by the oil was a selective one. In all cases it followed the pather of least resistance. This fact was most evident where the porous layers of sand were inclined upward at an angle of 30° to the surface of the oil sediment. The oil forced from this sediment by pressure entered the porous strata and followed the inclined path afforded by them, and did not enter the less porous layers until the porous material had been entirely filled by oil. In general, when the proous layers were inclined the oil did not pass vertically upward into the next layer above but followed the inclined channel afforded by the porous layer.

Ten grams of oil-laden clay were thoroughly mixed with 30cc of water and then filtered to remove the greater part of the water from the mixture. The clay, collected upon the filter paper, was placed in a screw press and pressure applied. Considerable quantities of oil were forced from the clay by this direct pressure. No oil was separated from the clay by the filtering process. This was shown by the fact that the filtrate was free from all trace of oil.

ACTION OF MOVING WATER.

A tube open at both ends, the opening at one end being sufficiently small to prevent the escape of coarse sand, was filled with alternate layers of dry sand and sand containing oil. This filling was then compacted with a plunger, and the tube then connected with a rubber tube through which water under a slight pressure was passed. As the water passed slowly through the interstitial spaces in the sand, it pushed a large part of the contained oil before it and out the small end of the tube. This same experiment was performed with the tube in various positions with the result that the oil was forced out with equal facility, whether the water moved vertically upward, downward or horizontally.

Similar experiments were performed with clay as the oil containing sediment, and although the movement of the water was much slower it proved to be a very effective agent in removing oil from the clay. When a layer of clay was placed in the sand between the outlet of the tube and the oil containing layer, the moving water, which was very slow, still removed much of the oil from the sediment and carried it into the sand above through which it passed readily. Upon reaching the lower surface of the overlying layer of c clay its progress ceased and the water passed on through free from oil, the oil remaining confined below the clay. These experiments support the conclusion of Munn (1) that moving water is the dominant force operating in producing economic accumulation of oil. Although the above results were obtained in connection with mixtures of oil and clay settled as in sedimentary deposition, the forces involved would be equally effective in the case of oil originating from organic matter deposited with the sediment and transformed into oil later. The greater proportion of oil from material fractionated after burial was probably produced before consolidation of the sediments, when bacterial action was still in progress. What ever idea of origin is accepted geologists generally agree that the petroliferous sediments were deposited in the ocean, and consequently must have been saturated

(1) Munn, M. J. Economic Geol. Vol. IV, pp 509-529.

with water. In time this petroliferous mud became covered with beds of sand and other sediment until they were deeply buried. The action of gravity and the weight of the material above would result in a compression of these beds, thereby reducing their volume. During the early stages of this compression water alone was probably forced from the mud, because there was ample room for the water to pass between the particles of clay without disturbing the globules of oil. However, as the bed became more compressed the oil globules were deformed and made to occupy part of the interstitial spaces between the particles of clay. After this stage of compression was reached oil was forced from the clay into the porous sand above, by pressure and moving water. The settling precess forced the water to pass through the pores of the settling sediment into the layer above. The water in this layer at the same time was forced upward into overlying layers. In passing through the oil-laden clay this moving water, assisted by the pressure of the overlying layers, removed large quantities of oil and carried it into the overlying sand. As this water and oil fromtthe lower strata entered this sand,the water,in pore spaces of this sand,was forced upward and the amount remaining in the clay was gradually decreased as compression progressed . . . .

. . Thus the percentage of oil in the sand was increased and water decreased, at the expense of the shale. After this stage is reached the difference in gravity between oil and water undoubtedly becomes an effective agent in the accumulation of oil in local reservoirs. This is especially true if the oil is forced from the clay in very small particles.

SUMMARY AND CONCLUSIONS FROM EXPERIMENTAL DATA.

Sediments have a marked power of carrying down oil as they settle.

This power varies with different kinds of sediments.

The amount of oil carried down depends upon the fineness of the material and its adhesive affinity for oil.

The oil is carried down as very small globules which are mechanically mixed with the sediment.

Clay is the most effective natural sediment in carrying down oil.

Difference in gravity between oil and salt water is not sufficient to separate oil from clay sediments.

Compression of the sediment by pressure forces out much of the oil.

Flowing water is a very effective agent in causing oil to migrate.

The rate of migration greatly affected by the size of the particles of oil.

Oil which has been formed on the surface of the earth under natural conditions, may be carried down as a sedimentary deposit by fine clay contemporaneously with it.

Although, many forces such as difference in gravity between oil and water, capillarity, internal heat and others, may have influenced greatly the accumulation of oil, pressure and moving water are shown experimentally herein to be competent forces in oil accumulation.