THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report
of
Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Omer Francis Ernster for the degree of Master of Science
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 Master of Science.

W. H. Emmons
Chairman

Carl O. Dunbar

W. H. Hunter

June 192[illegible]

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report
of
Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Omer Francis Ernster final oral examination for the degree of Master of Science. We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota

June 1940

Chairman

Carl O Dunbar

J. H. Hunter

THE RELATION OF STRUCTURE TO OIL ACCUMULATION

A Thesis Submitted to the Faculty
of the
Graduate School
of the
University of Minnesota

by

OMER FRANCIS ERNSTER

In Partial Fulfillment of the Requirements
for the degree
of
Master of Science

May 1, 1920.

TABLE OF CONTENTS.

INTRODUCTION

In this paper I shall attempt to sum up the theories that have been advanced in regard to oil accumulation. I shall, however, place special emphasis upon one of the more recent theories and try to show its relation to various fields in the United States.

A short description of the recent work done by G. A. Thiel on oil accumulation is given with an account of laboratory experiments I conducted along the lines indicated by him.

THE ORIGIN OF PETROLEUM

Petroleum is a complex mixture of compounds of carbon and hydrogen some of which are solid at ordinary temperatures and pressures while others are light gases. It often contains many impurities such as sulphur compounds, oxidized and nitrogenous substances, etc.

There are several regular series in which carbon and hydrogen unite as is shown in the following table.[1]

Generalized Formula	Name of Series	Most abundant in oil from
$Cn\ H_{2n+2}$	Paraffin	Pennsylvania and in natural gas.
$C_n\ H_{2n}$	Olefin and poly-methylene	Russia, California and Cuba.
$C_n\ H_{2n-2}$	Acetylene	Texas, Louisiana and Lima-Indiana.
$C_n\ H_{2n-4}$	Rare	Lima-Indiana and California.
$C_n\ H_{2n-6}$	Benzene	Nearly all fields in small quantities.
$C_n\ H_{2n-8}$	Rare	California.
$C_n\ H_{2n-10}$	Rare	
$C_n\ H_{2n-12}$	Includes naphtholene $C_{10}H_8$	California and Cuba.

Each of these series has many members differing in physical characteristics. The following list shows part of the lower mem-

---

[1] Johnson and Huntley, 'Oil and Gas Production'.

bers of the paraffin series.

Paraffins from Pennsylvania Petroleum

NAME	CHEMICAL SYMBOL	BOILING POINT C°	GRAVITY BAUME at 68°F	COMMERCIAL NAME
Methane	CH_4	-164.0	-	Natural Gas
Ethane	C_2H_6	-84.1	-	
Propane	C_3H_8	-37.0	-	Gasol
Butane	C_4H_{10}	+1	-	
Pentane	C_5H_{12}	37	-	Gasoline
Hexane	C_6H_{14}	69	83	
Heptane	C_7H_{16}	98	75	
Octane	C_8H_{18}	125	69	
Nonane	C_9H_{20}	150	65	Kerosene
Decane	$C_{10}H_{22}$	173	62	

The list of liquid paraffins extends in regular C_nH_{2n-2} order up to Hexadecane $C_{16}H_{34}$ and solid paraffins extend from there up to Pentatriacontane $C_{35}H_{72}$ with one or two possible exceptions.

Natural gas consists mainly of Methane CH_4 of the paraffin series. Some Ethane C_2H_6, Hydrogen, Nitrogen and Carbon Dioxide are often found in small amounts.

The gases consisting mainly of Methane with small amounts of Ethane and Nitrogen are called 'dry gases'. Those containing larger amounts of Ethane and the heavier paraffins up to Hexane C_7H_{16} are termed 'wet gas' a 'casing-head gas' because oil may be extracted from it. It usually occurs in oil producing fields and is often yielded with the oil.

Oil and gas are considered together in this paper as the origin and accumulation of the two are closely associated.

The question of the origin of petroleum has been the subject of extensive study and discussion. The evidence is abundant but conflicting and the conclusions arrived at depend upon the weight given the various groups of facts.

A brief outline of the different theories will be given but no attempt will be made to go into them in detail. The different theories fall into the following groups.[1]

- A. Cosmic
- B. Inorganic
- C. Organic
    - a. Material
        - 1. Plant, especially diatoms and salt marsh plants
        - 2. Animal
    - b. Method
        - 1. Bacterial formation
        - 2. Heat
        - 3. Compression with heat.

COSMIC THEORY

This theory advance by Sokoloff [2] is sustained by the fact that hydrocarbons are found in meteorites. Therefore they may have formed a part of the original earth material. This theory receives little consideration now because both the other theories have many more facts to sustain them than the Cosmic theory has.

---

1. Johnson and Huntley, 'Oil and Gas Production', p. 18.
2, N.V.Sokoloff. Bull.Soc. imp & nat. Moscov,New series,Vol.3,1890 p. 720.

INORGANIC THEORY

There have been various inorganic theories advanced but the one that has attained the most prominence is that of D. Mendeleef.[1] This theory assumes that there are large amounts of metallic carbides in the earth which react with descending waters to form hydrocarbons. Laboratory experiments by Hahn, Williams and Cloez on the production of hydrocarbons from cast iron support this theory. E. Coste, Mendeleef, Moisson and Ross are among the chief supporters of the inorganic theory.[2]

The arguments advanced by supporters of the inorganic theory are briefly summed up as follows.[3]

1. Absence of an adequate quantity of organized life in many petroliferous formations.

2. The differences between natural petroleum and that produced by the distillation of organic material such as coals, etc.

3. The wide spread distribution of petroleum regardless of the age of the rocks.

4. The connection between Igneous rocks, Volcanic activity, Mud Volcanoes, etc., and the occurrence of petroleum.

ORGANIC THEORY

The theory of the organic origin of oil and gas seems to be the most generally accepted one at the present time. However, there is a great diversity of opinion as to the original material from which the oil and gas was obtained and the method by which it was formed.

---

[1] Jour. Chem. Soc. Vol 32, p.283.
[2] Trans. Inst. of Mining and Metallurgy, Vol 21. 'Fallacies in the Theory of the Organic Origin of Petroleum' by E. Coste.
[3] Calton, L.V. 'On the Origin of Petroleum', Econ. Geol. Vol 4, 1909, p. 606.

1. Vegetable Origin.

A concise statement of the Vegetable Origin of Petroleum is given by Craig.[1]

> " Petroleum is formed from the remains of terrestrial vegetation, accumulated in clays, sands, or actual beds (which under other conditions would develop into carbonaceous shales, sandstones, and seams of coal or lignite), by material processes which can be not only reproduced in the laboratory, but can also be proved to have taken place in the past and are taking place at the present day."

The plant material, especially diatoms and foraminifera, such as are found associated with oil in the California fields,[2] was deposited in the shale beds. Decomposition of this vegetable matter either by Bacteria, Heat, or pressure and heat gave rise to petroleum.

2. Animal Origin.

Animal matter, such as the remains of mollusks, fish, and other marine animals, was buried, after being partly decomposed, and later became compressed and cemented in sandstones and shales. Fuller[3] lists the following organisms as possible sources of oil and states that they are all present in the rocks of the Appalachian field and that all are capable of affording oily hydrocarbons by natural distillation:

Vegetable: 1. Woody or cellulose plants, spores, seed envelopes etcetera.
2. Fucoids.
3. Algae.
4. Micro organisms, etcetera.

Animal: 1. Fish.
2. Mollusks.
3. Micro organisms, etcetera.

---

[1] E.H.Cunningham Craig, Oil-Finding, p. 11.
[2] Arnold and Anderson, V.S.G.S. Bull.322,109; Anderson and Pack, V.S.G.S. Bull. 603,198;
[3] Fuller, M.L., Appalachian Oil Field, Bull.Geol.Soc. Am. Vol 28, No. 3, 1917. p. 638.

Engler's statement of the various stages in the process of the formation of petroleum from organic matter, as given by Dalton[1] is as follows:

1. Putrefaction, or fermentation, by which albumen and cellulose, etc., are eliminated. Fatty matters (and waxes), with a small quantity of other durable material and possibly fatty acids from the albumen remain.

2. Occurs partly during the first stage: saponification of the glycerides and production of free fatty acids, either from action of water or ferments, possibly both. The waxy esters are either partly or wholly hydralysed. The residues from many crude oils are probably due to lack of completion of these actions.

3. CO_2 is eliminated from the acids and esters, water from the alcohols, oxy-acids, etc., leaving hydrocarbons of high molecular weight containing oxy-compounds, cf. the intermediate product like ozokerite of Kramer and of Zalosiecki, who also regarded that material as representing an early stage in the formation of oil.

4. Formation of liquid hydrocarbons and violent reaction with 'cracking' into light or gaseous products = formation of protopetroleum.

An added impulse has been given to the Organic theory by the discovery that petroleum would rotate the polarised ray. Rakusin and Lewkowitsch pointed out that this rotation could be produced by the alcohols, cholesteral and phytosteral, elements found in animal and vegetable fats respectively. Oil derived from inorganic materials is entirely inactive. E. Coste[2] in answer to this argument says it only holds for artifically made petroleums but

[1] Dalton, L.V. 'On the Origin of Petroleum', Econ. Geol. Vol IV, 1909, p. 625.

[2] Trans. Inst. Mining & Metallurgy, Vol 21, p. 175.

that the natural petroleum might have obtained the cholesteral and phytosteral from the rocks of the earth.

White[1] states that every attempt to apply the inorganic theory to the study of old oil fields, or to the discovery of new ones, affords cumulative evidence of its inadequacy. Frederick G. Clapp, L. V. Dalton, M. Stuart, E. Orton, and others are prominent supporters of the organic theory.

A general review of the literature on the origin of petroleum seems to establish the following, although the question is far from being settled:

1. Present evidence favors the organic origin of petroleum from animal matter.

2. A small amount is probably derived from the fatty portion of plants.

3. The association of oil and gas with volcanic features, such as the presence in igneous dikes and plugs, in the Gulf Coast plain of the United States and Mexico, suggests that there may be some relationship between igneous activity and the occurrence of oil and gas.

4. The optical and geologic evidence is decidedly against the inorganic origin of petroleum.

---

1. White, David, 'Open Mindedness in Studies of Oil', The Oil and Gas Journal of Tulsa Okla. Vol. 18,no.46, Apr. 15,1920,p.74.

THEORIES ADVANCED TO ACCOUNT FOR THE ACCUMULATION OF PETROLEUM.

The recognition of petroleum in sedimentary rocks early led to the belief that it is not usually found where it was originally formed. The present "pools" indicate at least some migration from the beds of origin, with a subsequent accumulation in the rock formations where it now occurs.

Munn[1] has stated, "There is no fact more clearly established by geologic studies of oil and gas pools than that structure is an important factor of accumulation* * * * * *but that it is the most important and the controlling factor can by no means be so easily proved".

The various types of structure in which oil or gas accumulations are given by Emmons[2] as follows:

Oil accumulates in
- I. Elevated parts of structures
    - 1. Domes and anticlines. Fig.1.
    - 2. Sealed monoclines.
        - a. By shale beds uniting where a lense of sand pinches out. Fig.2.
        - b. By faulting. Fig.3.
        - c. Cementation of the reservoir rock above. Fig.4.
        - d. Closing of openings by drying of asphalt deposits. Fig.5.
        - e. Unconformities. Fig.6.
- II. Flat parts of structures
    - 1. Acline. Fig.7.
    - 2. Terrace. Fig.8.
- III. Depressional parts of structures
    - 1. Syncline. Fig.9.

---

[1] Munn, M.J., Econ. Geol. Vol 4, 1909, p. 156.

[2] Emmons, W.H., University of Minnesota.

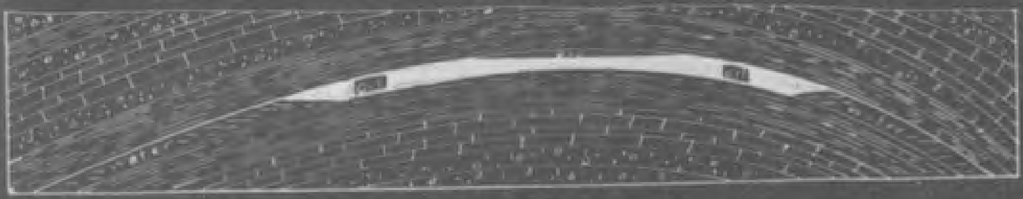


Fig. 1.
I, 1. ANTICLINE.

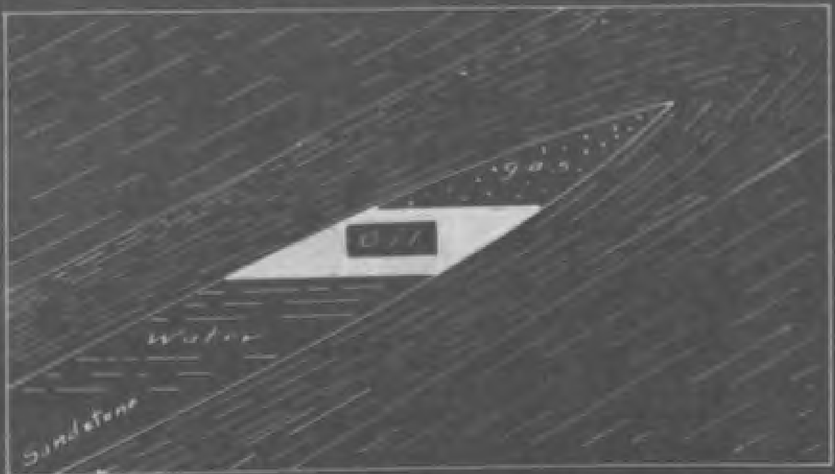


Fig. 2.
I. 2. a. SAND BED PINCHING OUT IN SHALE.

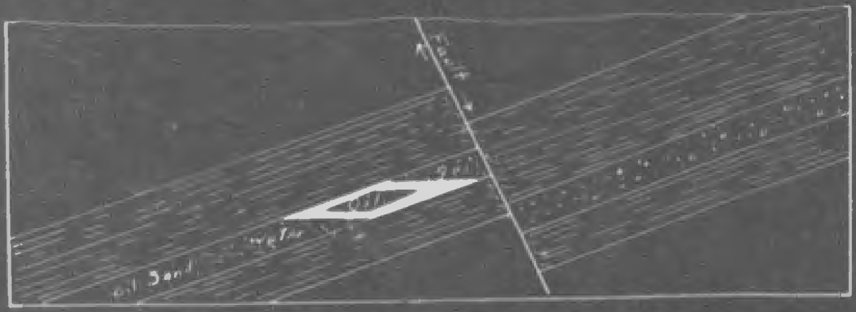


Fig. 3.

I. 2. b. SEALED BY FAULTING.

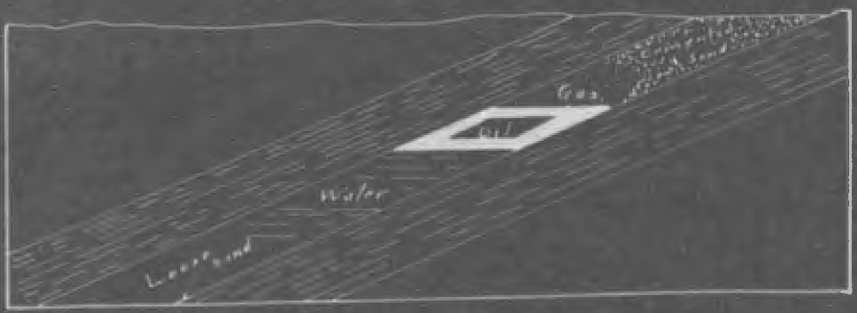


Fig. 4.

I. 2. c. CEMENTATION OF THE RESERVOIR ROCK.

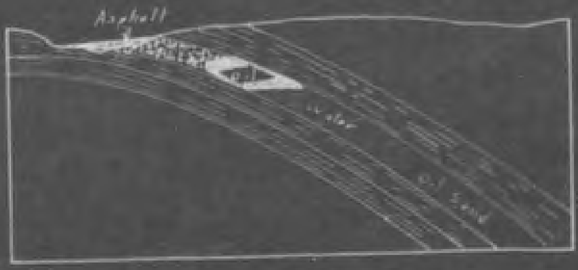


Fig. 5.

I. 2. d. SEALED BY ASPHALT DEPOSITS.

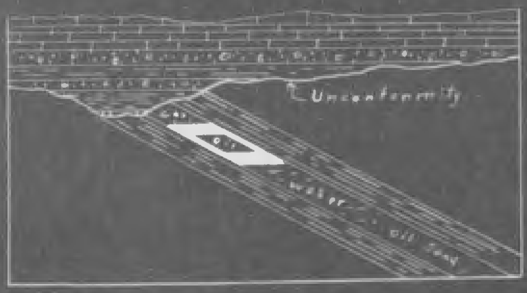


Fig. 6.

I. 2. e. SEALED BY AN UNCONFORMITY.

Fig. 7.

II. 1. ACLINE.

Fig. 8.

II. 2. TERRACE.

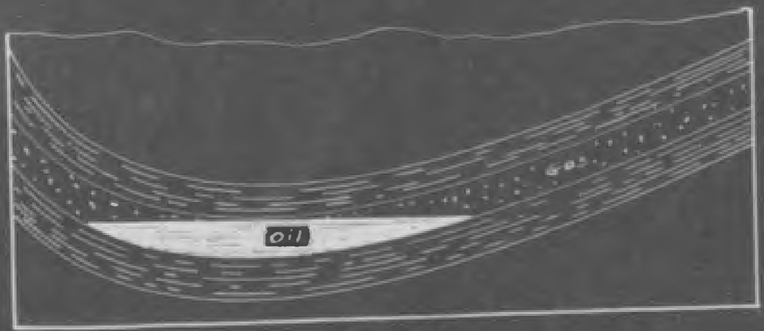


Fig. 9

III. 1. SYNCLINE.

Numerous theories of oil movement and accumulation have been advanced, to account for the migration of oil and its accumulation in pools. The more prominent ones advanced are:

1. Anticlinal theory.
2. Hydraulic theory.
3. Theory of Capillary Concentration.
4. Theory of Selective Segregation and Gravitational Separation.
5. Filtration theory.
6. Diastrophic theory.

THE ANTICLINAL THEORY.

The term "Anticlinal Theory" is often used in place of "Anticlinal accumulation" to mean that oil is found in anticlines without reference as to the method of accumulation. This error is not only common among oil field men with no geological training but is also found in articles published by geologists as is shown in an article by Dorsey Hager[1] presented at the New York meeting (February,1917) of the American Institute of Mining Engineers. Hager's opening statement is "The information given in the accompanying table is submitted as evidence confirming the application of the Anticlinal theory and the value of geology in the Kansas and Oklahoma oil fields". He then lists 75 pools giving the type of structure and whether found by "wildcatting" or by geological surveys.

His conclusions are:

1. Of 75 pools listed all but four are on well defined structure.

2. Of the list 60 per cent are on domes or anticlines; 20 per cent are on terraces; 14.7 per cent are on undivided domes and terraces, and 5.3 per cent are on lenses.

3. Of the 45 pools found in 1913 and later 66 2/3 per cent were located by geologists.

4. (a) "The Anticlinal theory holds in Oklahoma and in Kansas."

(b) "The geologist is playing a most important part in the development of those oil fields."

Nothing is said in the article about the method of accumulation and the fact that all but 5.3 per cent are found on anticlines

---

[1] Hager, D.!The Evidence of the Oklahoma Oil Fields on the Anticlinal T.A.I.M.E. Vol. 56, p. 843.

or terraces is held as proof of the "Anticlinal theory". None of the authors of the various theories deny the importance of anticlinal accumulation, and they seek to harmonize their new theories with it so the fact that oil is found on anticlines in Kansas and Oklahoma could in a similar way be taken as proof of any of the theories. It will be seen that the "Anticlinal theory" as modified by Griswold[1] does not limit oil accumulation to anticlines but also covers the cases where oil is found in synclines, monoclines, terraces and lenses.

The Anticlinal theory as originally developed by Orton, White, and others, has been somewhat modified by Griswold. The following is his statement of this theory.[2]

The ultimate source of the oil is not taken up by him but starting with it already in the porous sandstones his theory deals with its circulation through the rocks and the conditions leading to its accumulation in commercial deposits.

The porous rocks into which oil and gas enter may be saturated with water or they may be dry.

If the rocks are dry, oil entering them will flow down as long as gravity overcomes the friction and the capillary attraction. The gas will diffuse with the air or water vapor contained in the rocks.

If, however, the penetrated porous rock is completely saturated with water the oil and gas will tend to segregate according to their relative specific gravities. Here the oil and gas will remain unless the dip of the strata is sufficient to allow the dif-

---

[1] Griswold, W.T. and Munn, M.J., "Geology of Oil and Gas Fileds in Steubenville, Burgettstown, and Claysville, Quadrangles, Ohio, W.Va., and Pa." U.S.G.S. Bull. No. 318, 1907, pp13-14.

[2] Same.

ference in the specific gravities to overcome the friction of the particles of oil and gas in which case they will gradually move up the slope until they reach the surface or are arrested by an impervious layer of rock.

In case the rocks are only partly saturated with water a combination of the two processes will take place. Oil entering above the line of saturation will move downward till it reaches that line and the oil entering below the line of saturation will move up to the top of the water, and the oil accumulated will take place along the line of contact between the dry and saturated sand. Gas entering either above or below the line of saturation will find its way up into the dry sand where it will mix with the air or water vapor contained in it.

These statements are based on the assumption that the oil bearing rock is homogeneous throughout and will not prevent the oil from moving with equal freedom in every direction. This is rarely the case in nature. Sandstones are noted for their irregularity in composition, as regards both the size of the individual grains of sand and also the kind of cementing material. If an oil bearing rock, cemented, contains areas of fine grained sandstone, the particles of which are small and the interstices filled with impervious cement, these areas will be barren and may even act as barriers against the movement of the oil and gas.

Objections to this theory were raised by Malcolm J. Munn[1] on the basis of observations in the oil pools of the Sewickley Quadrangle, Pennsylvania. Munn contended that the difference in specific gravity

---

1. Malcolm J. Munn 'Studies in the Application of the Anticlinal Theory of Oil and Gas Accumulation', Econ.Geol. Vol IV, 1909, pp. 141-157.

between the oil and salt water, which he calculates at 0.2646, would not be sufficient to cause the separation and the movement of the oil along the strata. At a minimum dip of 1 foot to 50 feet the force available for movement along the dip was calculated to be about .0067 of the weight of the globule of oil. There are several constant forces acting in opposition to the movement of the oil. These are mainly: molecular repulsion of oil and water, capillary adhesion, interstitial molecular cohesion and both static and kinetic friction. While Munn does not furnish figures on the force necessary to overcome these opposing forces he does not believe that the force due to the difference in gravity would be sufficient to overcome them.

Marcel R. Daly[1] in discussing the same point cited the following experiment. A slab of oil bearing sandstone was planed, but not ground, so that the grains of sand remained entire. The slab was then immerged in some salt water, in a horizontal position and a drop of oil was loosened in the water under the slab. The oil rose to the bottom of the slab and remained there while the slab was horizontal. The slab was then inclined gradually until the drop of oil was set in motion. At no time was Daly able to get the drop in motion for any such angle as 2°. As this is larger than the dips found in many fields he concludes that there must be some other force besides the difference in gravity to cause movement.

Munn[2] also points out that if the Gravitational theory is used the oil pools in the hundred-foot sand of the Sewickley Quadrangle should be near the top of the sand or in the upper pay streaks

---

1. Daly, Marcel R. 'The Diastrophic Theory', Trans.A.I.M.E. Vol LVI 1916, p. 736.
2. Econ. Geol. Vol 4, 1909, p. 153.

leaving the lower ones to salt water exclusively.

The fact is, however, that there is no such separation and a lower pay streak may frequently be found to furnish a greater per cent of oil to water than another located higher in the sand. In order to explain such relations, Munn introduced the Hydraulic theory.

THE HYDRAULIC THEORY.[1]

This theory makes hydraulic 'not hydrostatic' pressure and capillarity the chief force in the accumulation of gas and oil. The oil is supposed to have originated in the rocks before their consolidation. As it was formed it gathered on particles of clay forming a thin coating. As the beds are slowly compressed the space between the grains is reduced and the water which fills the interstices is forced out of the shale up into the sandstone. As the bed becomes more compact the particles of clay are pressed more closely together and the water, that is forced through the interstices, will tear the oil loose from its moorings and carry it along as a more or less complete emulsion of oil and water. The general effect of this movement is to increase the percentage of oil to water in the sandstone yet probably leaving a large amount of oil in the shale. The movement of the mixture of oil, gas and water through the different beds would not be uniform and when two or more moving masses of water conflict, eddies would be formed and bodies of oil and gas would be trapped and held. A pool once formed is held in place by water and capillary pressure which seals up the pores of the surrounding rocks. The structural position of the pool would depend upon the direction of movement of the invading water with reference to the dip of the rocks. If the movement of the water was caused by hydraulic pressure the position of the pool

---

[1] Munn, M.J., Econ. Geol. Vol IV, 1909.

would comform fairly closely to structure lines. If the movement with the dip was by capillarity the varying porosity of the sand would be the controlling feature and the resulting pools would probably bear little relation to the structure.

THE THEORY OF CAPILLARY CONCENTRATION.[1]

To account for the occurrence of oil in the more porous parts of a sand reservoir, Washburne introduced the Theory of Capillary Concentration.

Capillary force is a function of surface tension, density of the liquid, diameter of pore space, contact angle and the acceleration of gravity. Washburne gives the following values for surface tension:

Water - air	at $20^\circ C$	75.6	degrees	per	Cm.
Salty water	"	79.0	"	"	"
Refined oil	"	26.4	"	"	"
Crude oil	"	24.1	"	"	"

It will be seen from the above table that water has about three times the surface tension of crude oil, and since capillary force varies directly as the surface tension of the liquid and inversely as the diameter of the pore, the constant tendency of the capillarity is to draw water into the finest openings displacing any oil or gas that might be there. In this way the water forces the oil and gas along and finally concentrates them in openings having the least capillary power. The water in sand would force oil and gas out of the small pores in shale into the coarser grained sand.

The amount of pressure developed by capillary action for the temperatures prevailing at various depths has been calculated by Johnston and Adams.[2]

---

1. Chester W. Washburne, 'The Capillary Concentration of Gas and Oil', T.A.I.M.E. Vol 50, 1914, pp. 829-858.
2. Jour. Geol. Vol XXII, pp. 1-15, 1914.

Approximate Maximum Capillary Pressures
Diameter of Pores, 0.0002 mm
Temperature gradient, 1°C per 30 meters

Depth Meters	Capillary Pressure, Atmospheres.	Depth Meters	Capillary Pressure, Atmospheres
100	15.0	2000	12.1
200	14.6	5000	7.8
500	14.1	10000	1.0
1000	13.6	20000	0.0

From this table it is seen that capillary pressure decreases to about half at depths of 5000 meters, below this point it becomes practically ineffective. The rate of decrease in the surface tension of all but the lightest hydrocarbons is much less than that of water for each increment of temperature, so that the surface tension of water does not have such a great excess over that of oil at these depths.

Johnson has suggested that the gas carries oil up as a film around the bubble. If a bubble of gas rising through water comes in contact with a drop of oil they will uhite and both ascend together. This film of oil is extremely thin and the volume of gas required to move a small quantity of oil would be very large.

In regard to the effects of gravity it has been shown that a drop of oil placed on the bottom of a vessel will remain there indefinitely unless the vessel is disturbed.

Following working hypothesis is suggested to explain the common anticlinal distribution of oil.

1. Oil and gas must be gathered in the sands by capillary concentration.

2. Oil and gas must be segregated by the effects of surface

THE THEORY OF SELECTIVE SEGREGATION.[1]

The chief supporters of this theory are Johnson and Huntley. These workers believe that the oil is formed in shales and is later concentrated in the pools where it is found. The main causes of the movement are given as follows:

1. The compacting of the strata by the weight of the gradually increasing overburden. Since the compacting increases with depth the movement will be upward from points of maximum compacting. Mud, while being reduced to relatively dense shales, will give up its liquid contents to the beds of sand that are not capable of an equal reduction in volume. Thus the water and oil will be forced into the porous sandstones and up along them in the direction where the overburden is less heavy.

2. The increase in temperature as the rocks become covered to a greater depth. The expansion of fluid and gas is so much greater than the rock that they must be forced in general upward.

3. The pressure produced by the formation of new dynamo-chemical gas due to increased temperature and pressure. Johnson and Huntley[2] state, "In the eastern fields there is an apparent increase in the proportion of gas to oil and water with depth".

4. Reduction of the volume of voids by cementation during consolidation.

5. The oscillation of the earth in depth will cause changes

---

1. R.H.Johnson and L.G.Huntley,'Principles of Oil and Gas Production" 1st Ed. 1916, pp 44-51.
2. Ibid.

in temperature and pressure.

6. In shallow depths surface water might flow through the reservoir from higher to lower levels.

7. Connection of the bed to the surface by erosion or by a fault permitting lighter oils and gas to escape and finally displacement of the heavier oils by water.

The mixture moving through the reservoirs has only a small proportion of oil and gas to water and some segregation must be effected before commercial pools are formed.

Johnson and Huntley state that there are three agencies acting to segregate the oil, gas and water and to retain them in the reservoirs.

1. Capillarity. The force of capillarity in a small pore rock is such that gas in a large pore reservoir cannot ordinarily force its way through. Also the lower capillarity of oil tends to keep it in the larger pores while the water tends to move from the larger pores to the smaller ones.

2. Immiscibility. The immiscibility of water and oil prevents their intermingling and oil will not readily flow through a water wet porous rock nor will water penetrate an oil wet porous rock readily.

3. Relative viscosity. Oil is usually more viscous than water and so will not penetrate small pores as easily as the less viscous water.

Gravitational separation is considered only in so far as it acts without the interference of capillarity and when movement takes place.

THE FILTRATION THEORY.[1]

The filtration theory deals more with the causes of variation in the characteristics of oil found in neighboring pools than with the causes of the accumulation.

Day[2] states that while the oils often vary greatly in short distances they usually contain some characteristics in common which would indicate that they had been derived from the same parent liquid.

Experiments conducted by Day and by the U. S. G. S.[3] under his supervision showed that when a glass tube tightly packed with dry fuller's earth, and one end is allowed to stand in crude oil, the oil diffusing up through the clay fractionates to a considerable extent. The oil which rises highest in the tube is found to be of the lighter gravity and entirely colorless. On fractionation by distillation of this upper, lighter portion some of the heavier oils and even paraffin wax is found but only in a very small proportion. The lower portion may be almost solid and of darker color than the original oil.

This fractionation by diffusion is similar to fractionation by distillation but is not so complete.

Dr. C. Engler[4] has shown that there is no chemical change af-

---

1. Day, D. T. Science N.S. Vol 17, 1902.
2. Day, D. T. T.A.I.M.E., Vol XLI (1910), p 220.
3. Bull. U.S.G.S. 365,(1908).
4. Dr. C. Engler, Zeitschrift fur angewandte Chemie, Vol XIV No. 36
   p. 889,(Sept. 3, 1901).

fected by this process but merely a mechanical seperation of liquids from liquids.

When the sands were mixed with water to drive off the oil it was found that another partial fractionation was effected, and that a heavy oil equal to about 1/3 or 1/4 the entire oil remains in the clay.

The sise of the capillaries seem to be the controlling feature of fractionation. The smaller the openings the more complete the diffusion will be.

When water penetrates the fine shales, where the oil is present, it will drive the oil up into the more porous strata where it will accumulate in pools of light or dark oil depending on the amount of fractionation that has taken place.

Once the oil has been driven from the shale it cannot reenter it until the moisture has been driven out, for the capillary attraction of water is greater than that of oil. Washburne[1] gives the ratio of capillary force of water to that of oil as three to one.

---

[1] Chester W. Washburne, T.A.I.M.E., Vol 5, 1914.

THE DIASTROPHIC THEORY.

One of the later theories of oil accumulation is that advanced by Daly,[1] who starts with the assumption that petroleum is of organic origin and so would first exist as minute globules disseminated throughout the sediments which contain the parent matter.

As the thickness of sediments becomes greater the beds containing the organic parent matter are compressed and the water, oil, and gas are squeezed out into the less compressible beds such as sandstones. During this migration there will be a tendency for the globules of like material to unite when they come in contact causing a slight concentration in the sandstone. Capillary tension helps this segregation for the water tends to penetrate the smaller pore spaces forcing the oil and gas into the larger openings.

Horizontal pressure, due to diastrophism, will compress the sands and tend to force the oil to some zone of less pressure. When the force becomes great enough the beds will buckle forming anticlines. This will relieve the pressure, especially at the crests of the anticlines and the water and petroleum will be forced up in them while the bottoms of the synclines where the pressure is greatest will hold only the water that fills the smaller pores.

Daly divides the process of accumulation into five states as follows:[2]

---

[1] Daly, M. R. "The Diastrophic Theory of Oil Accumulation", Trans A.I.M.E. Vol 56, 1916, p. 733.

[2] Daly, M. R. Ibid, p 748.

IST STAGE

The oil proceeding from organic remains, perhaps still in the process of decomposition * * * * * * is at first distributed in the water-laden sediments of the geosynclines of deposition in the state of disseminated particles.

2ND STAGE

The increasing compression, due to the continuous accumulation of superimposed strata, expels an increasing amount of the water of deposition with its contents of hydrocarbons, from the original layers,* * * * * * to some other layer less affected by it.

3RD STAGE

As soon as the orogenic movement begins, a more or less horizontal compression, due to the thrust, takes place and becomes added to the vertical pressure due to the superincumbant weight.* * * The waters which saturate the strata are submitted to the effect of this unequal pressure and move from the highly compressed regions to the lesser compressed ones, carrying the hydrocarbons with them in their course, finally collecting in the pools parallel to the folds.

4TH STAGE

A new stage would be reached by gradual reduction of the water content of the strata, producing consequent changes in the level of complete saturation and in the local disposition of the pools by gravity.

5TH STAGE

A new period of folding may take place, in which the thrust may or may not have the same direction as the previous one. New zones of compression and decompression may be created, and the liquids may be put again in motion. The results may become very intricate, especially if the strata are deformed to a large extent.

An experiment tending to support the pressure theory of the origin of oil was made by McCoy and Trager.[1] Oil shale was placed in a tube, the walls of which were thinner in the central zone. Pistons were inserted and pressure applied until the tube bulged at the thin part in the center thus causing the shale to flow. Solution tests were taken before the shale was compressed and no indication of liquid hydrocarbons was found. In some cases after compression small globules of oil could be seen in the shale with a hand lens and in all cases solution tests gave strong coloration. The pressure was applied slowly so that no appreciable amount of heat was developed. See fig. 10 and 10 A.

The origin of pressure in oil fields has been accounted for by various authors, in the following ways.

1. Hydrostatic pressure.
2. Weight of superincumbant strata.
3. Gradual accumulation of the enclosed gas.
4. Capillary diffusion.

Daly[2] raises objections to all of these theories to account for the pressures observed in various oil fields tho they may have a more or less important effect on some fields. The theory advanced by Daly is that diastrophism causing compression of the beds forces the water oil and gas up into the more porous beds under considerable pressure. This pressure would not be equal at all places as the amount of original pressure applied before deformation would depend on the character of the rock. The loss of head due to in-

1.McCoy, A. W. 'Notes on Principles of Oil Accumulation', Jour.Geol. (1919), Vol 27, pp 252-262.

2. ~~Daly, M. R. Ibid, p. 750.~~

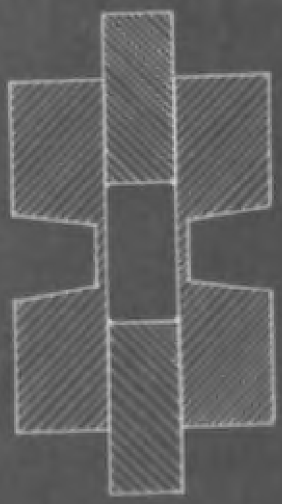


Fig. 10.
BEFORE COMPRESSION.

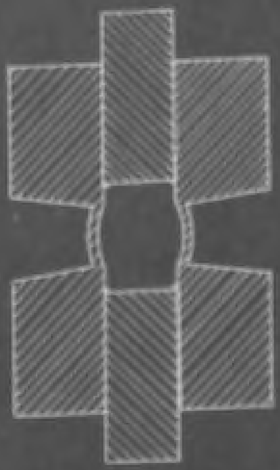


Fig. 10 A
AFTER COMPRESSION.

(After A.W.McCOY)

equal porosity of the rock through which the water oil and gas are forced would also affect the pressure.

During the migration the motive pressure would be dynamic and the water oil and gas would be carried along and stored under considerable pressure. After the deforming pressure had been relieved there would be a tendency for pressure to force the water and oil back. This pressure, however, is essentially static and would not be great enough to force the material back.

Water and oil are only slightly compressible and a very small reduction in volume would mean the presence of great pressure. Gas, on the other hand, is highly compressible and a great increase in pressure, at constant temperature, would mean a great reduction in volume. This would indicate that that pressure stored up would be in the form of compressed gas.

For retaining the gas the preventing its escape through the subcapillary openings in the cover rock the effect of surface tension is used. Jamin, a French physicist, pointed out that if a capillary tube is filled with drops of water interspaced with air, a pressure may be applied to one end.of the tube which will not be transmitted to the other end. If there are a large number of drops in the tube the amount of pressure on the ends might vary by several atmospheres.

A drop of liquid will be limited on both ends by a Meniscus. (See Fig. 11) This is caused by the tension of glass and air, glass and liquid, and air and liquid. The two first sets of forces are parallel to the axis of the tube and being equal and directly opposed at both ends of the drop, will neutralize each other. The third set of forces, caused by the tension of air and liquid, is

Fig. 11.

MENISCUSES FORMED BY A DROP OF A LIQUID IN A CAPILLARY TUBE.

tangent to the meniscus all around the tube and makes an angle θ which is the "angle of contact'. This angle will have a definite value for oil or ground water. When the pressure is equal at both ends the meniscuses are identical, and so are the angles of contact θ and θ'. By increasing the pressure P at one end of the tube the meniscuses will alter their curvature and the angles will change. The angle θ in front of the pressure P will be decreased and θ' will be increased. The tension T will tend to resist the movement of the drop. As T acts in the direction of the angle of contact the force acting along the axis of the tube equals $T \cos \theta$. As the angle θ decreases the force $T \cos \theta$ increases and as the angle θ' increases the force $T \cos \theta'$, which acts with the force P decreases. The difference will be a resistance against motion expressed by $T(\cos \theta - \cos \theta')$, which approaches T as θ approaches 0 and θ' approaches 90°. A large number of drops in a tube would build up considerable resistance.

The pores in a shale would act the same as a capillary tube. Daly, using the data of Van Hise[1] that openings in most clays, shales, and slates are subcapillary, and defining subcapillary openings as those which are 0.0002 mm. and less in diameter, found that a few feet of clay, shale, or slate would be enough to seal up a pressure of 1,200 lb. per square inch.

The same process might apply for the sealing up of oil and gas pools laterally. The opening in the sand are capillary and a greater distance would be necessary to complete the seal. In this zone, which caluclation shows to be a few hundred feet wide, there would be a gradual decrease in pressure from the inside to the outside, a feature which is readily observed in the field.

[1] Van Hise, 'A Treatise on Metamorphism', Monograph 47, U.S.G.S. (1904), p. 138.

THE EFFECT OF GAS AND PRESSURE ON OIL ACCUMULATION.

The latest data published in regard to oil accumulation is an account of experiments conducted by George A. Thiel under the direction of W. H. Emmons of the University of Minnesota.[1]

Thiel took a piece of glass tubing four feet long with a one inch bore and bent it in the form of an anticline with the limbs diping about 15 degrees. Crushed quartzite, which had passed through a twenty mesh screen was treated with a mixture of three parts crude oil and one part kerosene and allowed to stand a short while so that all the oil, except that held by adhesion and capillarity, was drained off.

The sand was placed in the tube and saturated, during filling, with sea water carrying one half of one percent acetic acid. Four inches at each end of the tube was filled with fine ground dolomitic limestone. Tight fitting corks were inserted and blocked to hold them in position.

The acidified sea water coming in contact with the limestone in the ends of the tube generated carbon dioxide gas which diffused throughout the system and develloped considerable pressure.

After the tube was placed in position (see Fig. 12) and pressure was generated the oil rose to the top of the tube throughout

---

[1] Thiel, G.A. 'Gas an Important factor in Oil Accumulation', E & M J. Vol 109, No. 15, p.888.

Fig. 12.

GLASS TUBE FILLED WITH OIL-SAND AND SEA WATER, WITHOUT GAS.
EXHIBITS NO EXTENSIVE ACCUMULATION OF OIL.

Fig 13.

GLASS TUBE SHOWING GROUND DOLOMITIC LIMESTONE INTRODUCED AT A AND A'. THE SYSTEM WAS FILLED WITH OIL SOAKED SAND AND ACIDIFIED SEA WATER.

Fig. 14.

GLASS TUBE SHOWING THE RESULTS OF FORTY EIGHT HOURS' ACTION ON TUBE AS SHOWN IN FIG. 13. A AND A', DOLOMITE; B AND B' SEA WATER IN SAND; C AND 'C' SEGREGATION OF OIL IN THE SAND; D, ACCUMULATION OF GAS IN SAND.

(after Thiel.)

its length. At the end of forty-eight hours the oil had left the sand in the lower parts of the limbs BB' Fig. 14 and had accumulated at CC' in the upper portion. At the top of the anticline D there was an accumulation of gas. The line of demarkation between the water saturated sands BB' and the oil saturated sands CC' was sharp and at the same level on both limbs of the tube. The contact between the oil CC' and the gas D was also sharply defined and level.

In order to find out if pressure and gas were necessary a tube was set up with sand, oil, and water the same as before but the dolomitic limestone was left out so that no pressure was generated. This tube was allowed to remain several days but showed only small local accumulations of oil and gas in the larger pore spaces throughout the entire tube. There was no marked segregation at the top of the tube as there was when the gas and pressure was present.

On another experiment a second tube was made, and filled the same as the first except that it was inverted so as to form a syncline instead of an anticline. At the end of thirty-six hours it was found that the oil had moved away from the bottom and had moved up the limbs where it had concentrated. The line of separation between the water and oil and between the oil and gas were clear cut and level. It will be noted (see fig. 15) that in this case the oil moved directly toward the source of the gas supply and indicates that the migration of oil is not dependent on the direct movement of gas. There was some air filled pore space in the sand and after pressure had been developed, throughout the system these small bubbles rose to the top of the tube and moved along the glass until they reached the top of the accumulating oil. These bubbles might have carried

Fig. 15.

GLASS TUBE FILLED WITH OIL SAND, ACIDIFIED SEA WATER AND DOLOMITIC LIMESTONE. PLACED IN A SYNCLINAL POSITION. A,A& DOLOMITE; B,B, GAS; C,C, OIL ACCUMULATION; D,D, WATER FILLED SAND.

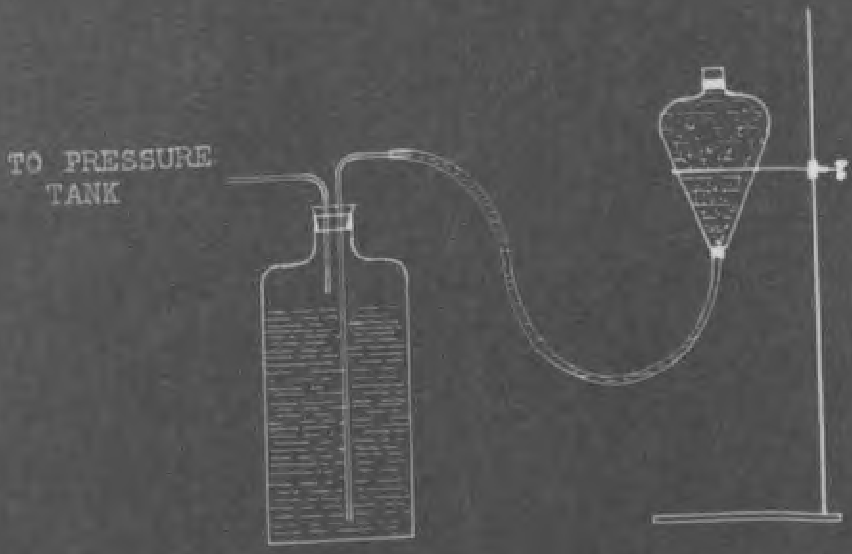


Fig. 16.

SYSTEM USED TO GET HYDROSTATIC PRESSURE ON FLASK.

some oil along as a film surrounding them but the volume of air was so much smaller than the volume of oil moved that only a very small percent of the accumulation could be accounted for that way.

The fact that the oil would rise directly against the gas pressure indicated that possibly the presence of gas was not an essential feature. In order to test this out the writer tried the following experiment.

Crushed quartzite, the same as was used by Thiel in his experiments, was mixed with oil until it had all that it could hold by capillarity and adhesion. Water was then gently mixed with this care being taken so that the oil would not be separated from the sand but that all the air bubbles would be eliminated. The sand was then placed in a flask and all air bubbles carefully removed. The flask was then connected up to a bottle filled with water.(See fig. 16). The bottle was connected with an air pump and guage in such a way that when air was pumped into the top of the bottle it would force water up through the tube giving a hydrostatic pressure on the contents of the flask. A pressure of 15 pounds was maintained for twenty-four hours but no segregation took place and the material was the same as when first placed in the flask.

The flask was then opened and part of the water drained off. A weak solution of acetic acid was then pumped into the flask along with gas from the city gas lines till a pressure of 15 pounds was obtained. The acetic acid generated gas from pieces of limestone that had been mixed with the sand. This was done so that gas would be distributed throughout the system and not be confined to a layer above the oil. By the end of the twenty-four hours there was a distinct segregation, the oil being cleaned out of the sands in the lower part of the flask and accumulating as a layer on top of the water and below the gas. This contact was clear and sharp as far as could be observed.

These results indicate that the presence of gas is necessary as well as pressure to cause the separation. Several theories have been advanced to explain the action the main one being that gas is absorbed by the crude oil and this effects its gravity enough to overcome the resistance to movement afforded by the sand.

Burrell has shown that certain California oil will absorb 15% of its volume of natural gas from Pennsylvania wells. This amount varies directly with the pressure and inversely with the temperature. Water under similar conditions as to temperature and pressure will absorb only about one tenth as much gas as the oil will. The effect of this absorbed gas on the gravity and viscosity of the oil requires more laboratory work before definite figures can be stated but it would seem that it would decrease both the gravity and viscosity and assist the segregation in the field.

RELATION BETWEEN THE FIXED CARBON RATIOS OF COAL AND THE CHARACTER OF THE OIL.

Since White, Orton, and others made their careful studies of the occurrence of petroleum it has been noted that it is intimately related to rocks that have been metamorphosed. More recent study brought out the fact that, up to a certain point, the greater the metamorphism the lighter the oil found. This factor did not receive much attention at the time as there was no way of determining the comparative degree of metamorphism.

In 1915, David White[1] advanced the hypothesis that the percentage of fixed carbon in pure coals, found overlying the oil sands, afforded a criterion for measurement.

White classifies the origin of coal, as it is now found, into two processes. The deposition of the organic matter, the action of moisture, air, temperature, bacterial action, etc., is the first stage. This is the Biochemical stage of coal formation. At the close of this stage the material is practically in the form of peat, organic muds, etc. Action is stopped by the burial of the peat under superposed deposits and the second stage begins.

The second process, called Dynamo-chemical process, deals with the alteration by compression, dehydration, lithification and induration of the deposits. Volatile matter, such as oxygen, hydrogen,

---

[1] White, David, 'Some Relations in Origin Between Coal and Petroleum'. Jour. Wash. Acad. Sci. Vol V, p. 189.

nitrogen, and a part of the carbon of the organic debris, is given up leaving lignites, bituminous coals, anthracites, or even graphites, depending upon the degree to which the volatile matter has been removed.

Similar effects will take place on the other rocks, especially the shales, in the region effected. Due to the sensitiveness of coal to the dynamic action, it is possible to recognize this action in regions where other indications are obscure and difficult to detect.[1]

Heat from igneous intrusions might cause this metamorphism but its effects would only be local.[2]

Pressure is the other dynamic cause of the alteration of the coal. It is usually spread over considerable distances and would cause a more regular alteration than that from local igneous intrusions. This regional alteration is what is usually found.

The amount of alteration in the coal beds is indicated by the percentage of fixed carbons present in the dry coals. It would be more satisfactory to use the C-O ratios but the number of analyses are so small compared to those where the fixed carbon percentage is given that it is advisable to use the latter. The difference will not materially affect the results.

The Appalachian coal region shows very clearly the effectiveness of thrust pressure as a cause of regional coal alteration. In central Ohio where there has been practically no deformation, except the formation of the Cincinnati arch, the coals carry about 55% of fixed carbon. In central Pennsylvania where the deformation

[1] U.S.G.S. Bull. 150, pp 142-145.
[2] Bureau of Mines Bull. 38, p 101.

is great the fixed carbon runs up to as high as 90%. Between the two there is a gradual series. This relation of the amount of deformation to the percentage of fixed carbon is shown in fig. 17. The structure line shows the structure of the Appalachian syncline with the folding caused by diastrophism. The greater folding accuring on the eastern edge indicates that there has been more pressure at this point. The lines dividing the fixed carbon percentages curve slightly toward the west as their depth increases. This is because the carbon percentages increase with depth due, probably, to the increased loading. The rate of downward increase has not been worked out but the indications are that the rise will continue until the higher fixed carbon ratios (over 70 per cent) is reached.

A study of the Appalachian oil fields shows that oil pools predominate west of the main axis of the Appalachian geosyncline and that east of it lighter oils and gas are found in increasing quantities until, in Eastern West Virginia you have gas pools with no oil. In the coastal plain regions of Texas and Louisiana, where the rocks are very slightly folded, the oil is of heavy grade. In the Caddo Louisiana field, where there is more deformation, the oil is much lighter.

In Wyoming, the oil in the Frontier sands of the most highly deformed fields, Elk Basin and Grass Creek, is the lightest. The heaviest oil of that Horizon is found in the Big Muddy fields which is the least deformed. The formation of the Salt Creek structure is of an intermediate type and its oil is likewise intermediate in gravity.[1]

[1] Washburne, C. W. 'Physical Principles of the Origin of Petroleum' ~~Bull. Amer. Assoc. of Petroleum Geologists, Vol III, 1919.~~

(After D. White)

Fig. 17

GENERALIZED SECTION THROUGH THE APPALACHIAN REGION SHOWING THE RELATION BETWEEN THE AMOUNT OF DEFORMATION AND THE FIXED CARBON RATIOS OF THE COALS.

If the deductions of White are well founded, and they seem to hold true in field practice, the heavier oils would be connected with the earlier and minor stresses, while the highest grade oils are usually found where the carbonization, resulting from the more intense stresses, had approached the limit of oil production. In regard to these points White[1] says:

> " According to these observations, and contrary to the views of most geologists and chemists, it would appear that the heavy oils, occurring in regions of less thrust and alteration, are the first products of oil generation, while the light oils, occurring in the regions of greater thrust, are the more refined products. Whether the latter are to be regarded as the direct result of the greater compression of organic matter or, perhaps more fractionation by geologic processes, remains to be proved. In this connection, it is to be borne in mind that the solid residues of heavy hydrocarbons, devolatilized in the shales and other strata during the destructive stages beyond the oil limits, are now in evidence as particles of carbon, causing the blackness of slates, some of which were once richly carbonaceous shales, and undoubtedly productive deposits of oil mother substance.
>
> " The stresses of a diastrophic movement may be sufficient to generate only a part of the oil and gas derivable from the organic mother substance, leaving some to be evolved under later stresses until oil is no longer produced, though gases may continue to be eliminated until the organic substance is wholly devolatilized leaving only the 'fixed carbon'. This is indicated by the artificial distillation of oil from oil shales in regions which have undergone varying degrees of carbonization, up to the oil limit, only small amounts of oil can be obtained from shales which have been carbonized beyond this limit."

In comparing oils a chemical analysis should be obtained but this is practically impossible. However in the analysis published the specific gravity of the oil is usually given and it is found that, in general, the oils may be compared according to their specific gravity. Oils of the lightest gravity (or highest degree Baumé) are of the highest rank and contain the highest amounts of

[1] White, D. 'Oil and Gas Journal', Vol 18, No.46. p 79.

saturated hydrocarbons, and hydrogen.

The Baumé scale is the one usually used in giving the gravity of oils. It increases in degrees as the specific gravity decreases Thus 10° Baumé equals a specific gravity as compared with water of 1.000, while 45° Baumé equals a specific gravity of .8000.

As was shown by White[1] in general the greater the deformation the greater the percentage of fixed carbon and the greater the deformation the lighter the grade of oil generally found. From this he concludes that the percentages of fixed carbon are an indicator as to the probable occurrence of oil and its grade. In a later paper White[2] indicates the probable relations between the characters of the coal and oil found.

Character of the Coal	Character of the Oil
Brown lignites	Heavy, 20° - 26° Baume.
Sub bituminous	Medium, 28° - 35° Baume.
Bituminous Coal	Medium to light 35°+
Semi bituminous	Light oil and gas
Coals containing over 65%F.C.	Oil has mostly disappeared.

No instances of commercial deposits of oil and gas are known where the overlying beds contain over 70 per cent of fixed carbon in pure coal (ash and water eliminated).

Occasionally an abnormally light oil is found in small quantities in an oil field. In most cases it is probably due to filtration and fractionation of the oil as it migrated through fine

---

[1] White, David, Ibid.
[2] White, David, 'Late Theories Regarding the Origin of Oil', Bull. Geol. Soc. of America, Vol 28, p. 733.

sediments. Day[1] passed crude oil through fullers earth and found that different grades of oil were obtained depending on the amount of earth used and the time allowed. The first oil to come through was of a lighter grade than the succeeding filtrates. Another possible source for the light oils would be some underlying formation of more advanced alteration.

It is found that in general the successive oil bearing formations penetrated by the drill yield an oil of progressively higher rank. This agrees with the increase in the percentage of fixed carbon found with depth as has been noted before. This may be due to the weight of superposed sediments and their resistance before giving away to diastrophic movements or to differences in the mother organic beds.

With the increase in percentages of fixed carbon and the reduction in gravity of oil with depth there must be a point at which the formations below will carry no oil. This limit or 'dead line' would depend on the fixed carbon ratio at the surface and the rate at which it increased with depth. Careful observation in the field and analyses of coal found in deep wells should give more information on this interesting and, if found practical, valuable point.

White[2] took a map showing the coal areas of the eastern part of the United States and platted the oil and gas fields, as shown by David T. Day, on it. The fixed carbon percentages of the coals of the localities from which analysis had been obtained were also platted 'Isovols' were drawn to mark each 5 per cent increase in fixed carbon. See Fig. 18.

[1] Day, D. T. Science N.S. Vol 17, 1902.
[2] White, D. Jour. Wash. Acad. Sci. Vol 5.

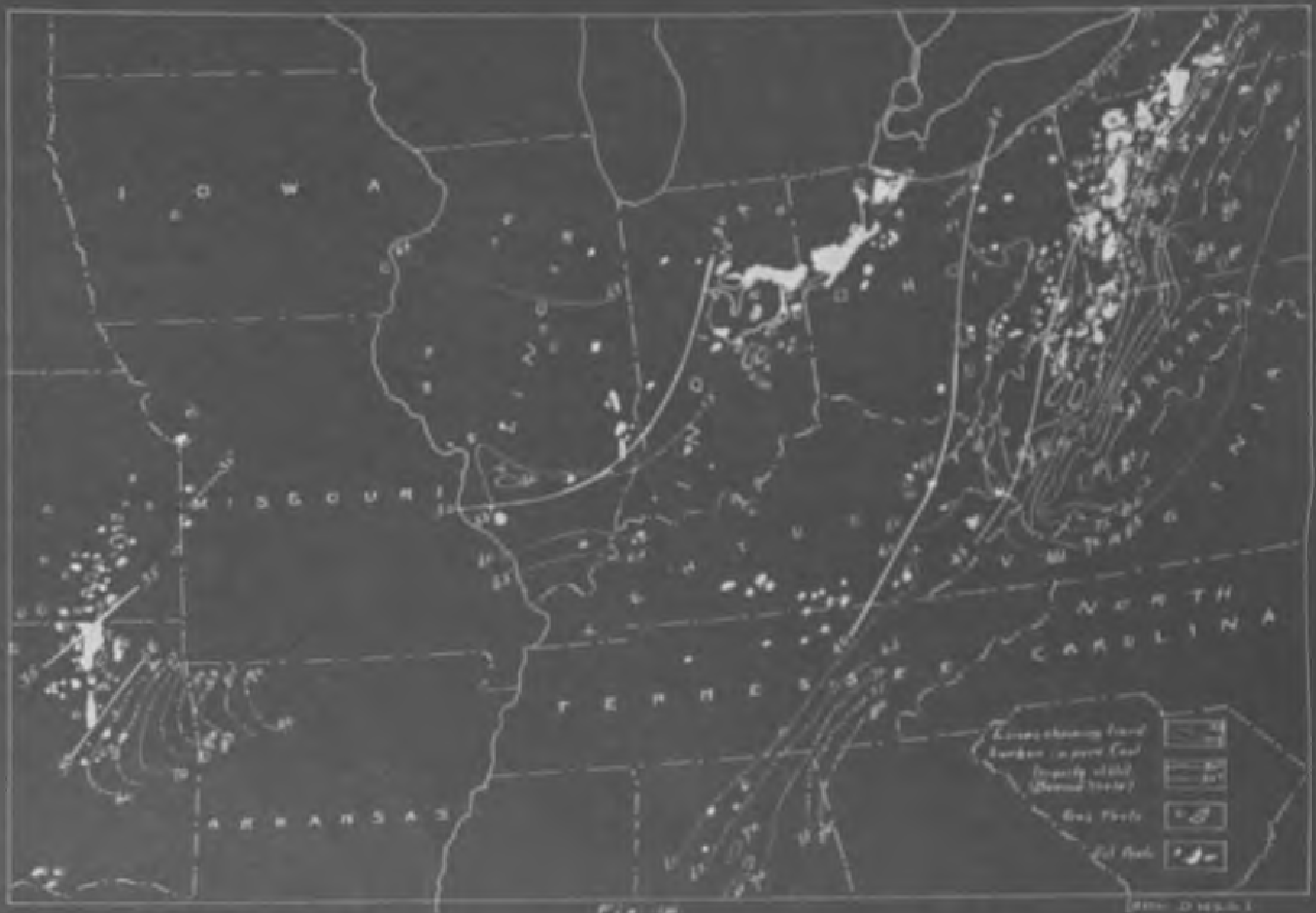


Fig. 10

REGIONAL ALTERATION OF COALS AND PETROLEUMS IN EASTERN UNITED STATES.

The degrees Baume of the oils of the various fields were platted and isovols representing 5 degrees increase or decrease were drawn. The map clearly shows the relation between the fixed carbon ratios and the specific gravity of the oils.

A table summarizing the relation of the oil and gas to fixed carbon in coal is given by Fuller.[1] This outline is more specific in its subdivisions than Dr. White's but four years of field application has developed no exceptions.

---

[1] Fuller, Myron L. "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas". Econ. Geol. Vol 14, p. 536.

****** RELATION OF OIL AND GAS TO CARBON IN COAL ******

Carbon Ratios Surface	Prevailing Characteristics of sands	Prevailing Water Conditions (in mixed formations)	Production
Over 70	Hard and tight	Water usually absent except near surface	No oil or gas, with rar exceptions.
65-70	Tight with few porous spots	Water usually absent below 1600 feet	Usually only 'shows' or small pockets. No commercial production
60-65	Variable, with porous beds of limited extent.	Water usually absent below 2500 feet. (often below 2000 feet)	Commercial pools, rar, but oil exceptionally high grade when found Gas wells common but usually isolated rather than in pools
55-60	Fairly continuous and open	Water usually absent below 3000 feet. (often below 2500 feet)	Principle fields of light oils gas of the world
50-55	Softer, less firmly consolidated, and more continuous and porous	Water usually absent below 3000-3500 feet	Principle fields of medium oils of Ohio, Indiana and Mid Continental fields
Under 50	Usually unconsolidated and porous throughout	Sands usually saturated, often with fresh water to all depths reached by wells	Fields of heavy coastal plain oils and of unconsolidated Tertiary or other formations.

RELATIONS BETWEEN THE AMOUNT OF DEFORMATION AND THE CHARACTER OF THE OIL.

In the theory advanced by White the point is brought out that the amount of alteration found in coal is closely related to the extent to which the rocks have been subject to thrust pressure metamorphism.

In the Appalachian region it was shown, Fig. 17, that the amount of deformation of the beds bore a direct bearing on the alteration of the coal. The greater the deformation of the beds the higher was the percentage of fixed carbon in the coal and the lighter the gravity the oil found.

In an attempt to show what relation, if any, exists between the amount of deformation of the rocks in an oil producing district and the grade of the oil produced, a series of cross sections of various pools were drawn. The conclusions arrived at from the study of these cross sections are briefly:

1. There is no general relation between the grades of oil produced in different pools by a like amount of deformation.

2. In a given pool, where conditions are uniform, the greater the deformation the lighter the grade of oil produced.

The cross sections were drawn to the same horizontal and vertical scale of one mile to the inch. While this scale is small and the differences in dip are hard to show it has the advantage of presenting the true relations of the structure which an exaggerated vertical scale would not.

Figure 19 shows a generalized section across the Appalachian geosyncline. This figure shows clearly that in this region there is some relation between the amount of deformation and the grade of the oils found.

The region of the Appalachian geosyncline was one of general subsidence and sedimentation from the Cambrian to the Carboniferous. In Pennsylvania approximately 30,000 feet of sediments were laid down while in Ohio they amounted to only about 6,000 feet, forming a structural basin from Pennsylvania to Ohio and from New York to Tennessee.

The organic matter in the lower beds would be altered as the weight of the superposed beds increased but the subsidence covered such a long period (estimated at 15 to 20 million years) that if oil were formed, it would not tend to migrate except possibly move into the coarser sandstones.

At the end of the Paleozoic era deep seated pressure in the Atlantic basin caused the uplift and deformation of the Appalachian region. As is shown by Bailey Willis[1] the first and greatest folding would take place on the eastern edge and as the folding progressed westward the amount would be decreased. The pressure developed would drive off the volatile matter from the coal and leave a higher percentage of fixed carbon. The effect the pressure would have on the petroleum is discussed under the Diastrophic theory, of oil accumulation.

Figure 20 shows a cross section of the Burning Spring anticline,

---

[1] Willis, Bailey. 'The Mechanics of Appalachian Structure', 13th Ann. Rept. U.S.G.S., part II.

(after M.L.FULLER)

Fig. 19.

GENERALIZED SECTION SHOWING RELATION OF THE DISTRIBUTION OF THE APPALACHIAN OILS OF VARIOUS GRAVITIES TO THE ZONE OF DYNAMIC DISTURBANCE AND TO THE FIXED CARBON PERCENTAGES IN COALS.

Volcano Field, Wood and Ritchie Counties West Virginia. The structure shows a closure of over 1200 feet and indicates the large amount of deformation that has taken place there as compared with anticlines farther west. It is interesting to note that on this structure two grades of oil are produced. A heavy lubricating oil of 30 degrees Baume gravity is found in a shallow sand about 350 feet below the surface while the sands reached at depths of 1500 to 1800 feet produce light oils of around 46° Baume.[1]

Westward in Ohio the structure flattens out and the structure on which the production is found in Center township, Woodsfield Quad Ohio is on a monocline just below the point where it forms a terrace. The dips in the district are usually less than 50 feet to the mile. Figure 21 is a cross section of this pool. The oil varies considerably but data available indicates that it is of medium grade (about 40°B).

For the Indiana pools Redwood[2] gives a gravity ranging from 34°B to 20°B indicating that they are heavy oils.

In the Allendale Field, Ill, the structure is a small flat dome (Figure 22) with a small closure. The oil in this district is heavy running from 20° to 24°B.

The fields of Wyoming show strong structures with dips up to 1000 feet per mile. The oil is usually found symmetrically around the domes regardless of the amount of gathering ground on the basin ward side. This would indicate that the sands were probably of uniform porosity. The oil in the Frontier sands of the most highly deformed fields, Elk Basin and Grass Creek, are of light gravity

---

1. W.Va. G.S. County Reports, Pleasant, Wood and Ritchie Co's, 1910.
2. Sir Boverton Redwood, 'A Treatise on Petroleum', Vol 1, p 204.

FIGURE 20.

BURNING SPRINGS ANTICLINE, WEST VIRGINIA.

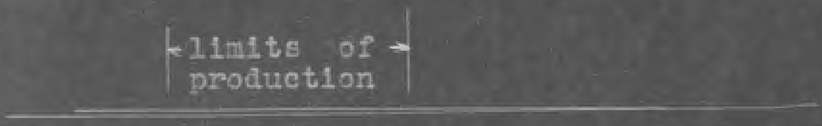


FIGURE 21.

WOODSFIELD QUADRANGLE, OHIO.

FIGURE. 22.

ALLENDALE FIELD, ILLINOIS.

ranging around 34°B.

The heaviest oil of the Frontier sands is found in the Big Muddy Field, which is the least deformed. (Fig. 23) These oils are about 20°B. The formation of the Salt Creek structure is of an intermediate type and its oil is likewise intermediate in gravity, being around 38°B. See Fig. 24. In the northern part of Wyoming a heavy oil (19.1°B) has been found in a structure which, although smaller, is as much deformed as the Salt Creek Field Wyo., where 38°B oil is found. (See Fig. 25 Warm Springs Dome Wyo).

The mid-continental field of Kansas and Oklahoma show a gradual decrease in the gravity of the oils as the fields approach the uplift of the Arbuckle mountains in Southern Oklahoma. In east central Kansas the oils, which occur in Pennsylvanian strata carrying coals of low bituminous rank, range from 30 to 32 degrees Baume. Passing southward into Oklahoma the Bartlesville pool, Glenn pool and Muskogee pool produce oil of 34°, 36°, and 38°, respectively. See Map, Figure 26. The Madill field south of and close to the Arbuckle mountains produces oil from the basal sands of the Cretaceans. This oil probably has its source in underlying Pennsylvanian strata, which were tilted and compressed in the Arbuckle uplift.

Figure 27 shows a cross section of a pool in the northwestern part of Pawhuska, Quadrangle Okla. The dip is very slight ranging from 50 feet to the mile to terraces where the rocks are flat. Oil produced in this region is about 33° to 34° Baume. A North-south section of the Glenn pool, Creek and Tulsa Counties, Okla., shows that the beds are nearly flat in that direction. Figure 28. The pool is on the limb of a pitching anticline with some closure north

FIGURE. 23.

CROSS SECTION OF THE BIG MUDDY FIELD. WYOMING.

(After V.H.Barnett. USGS)

FIGURE. 24.

SALT CREEK FIELD, WYOMING.

FIGURE. 25.

WARM SPRINGS ANTICLINE, WYOMING.

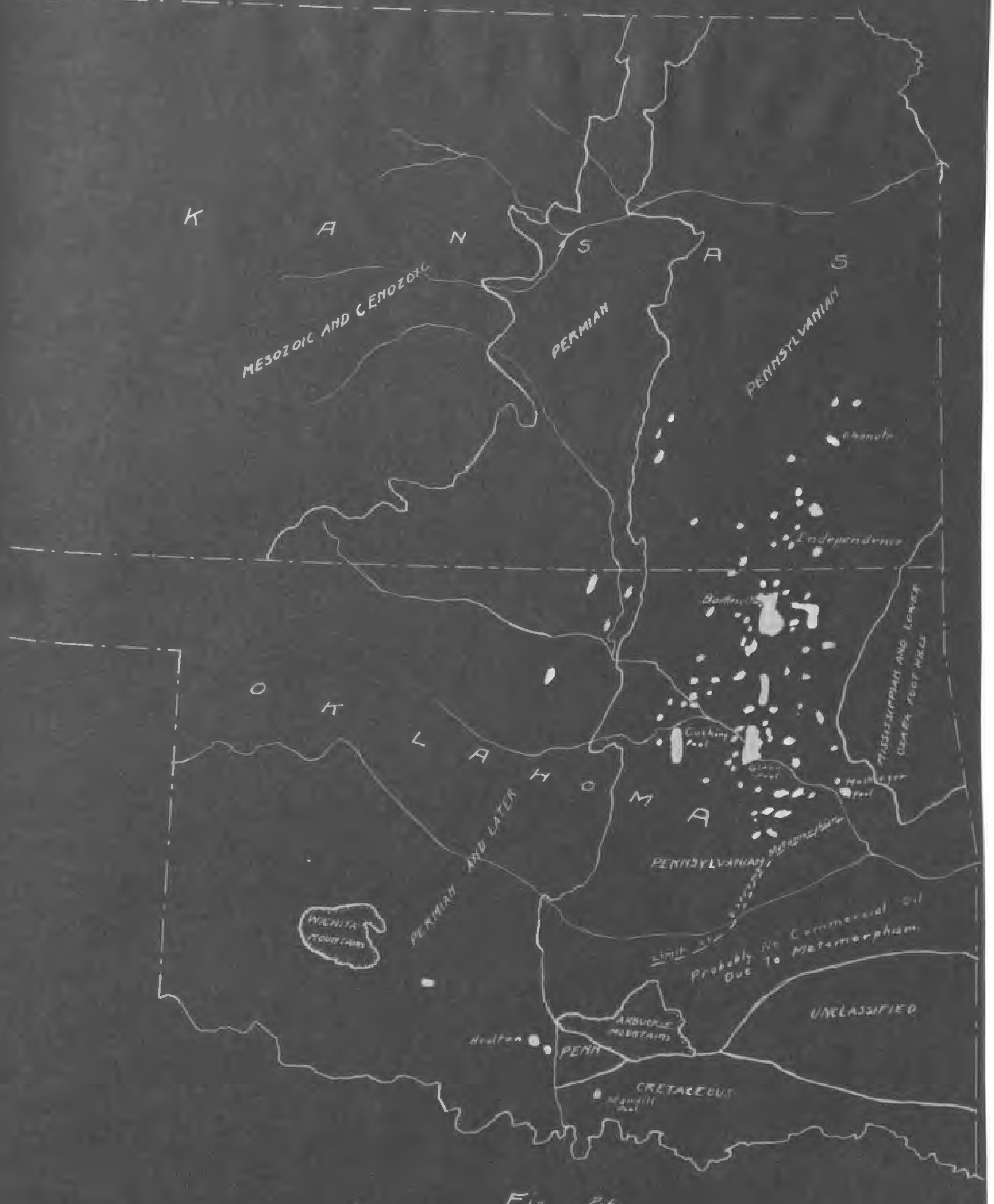
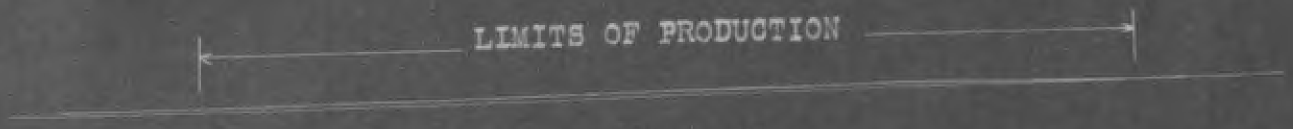


Fig. 26.

MAP OF KANSAS AND OKLAHOMA SHOWING THE LOCATION OF THE OIL POOLS.

FIGURE. 27.

PAWHUSKA QUADRANGLE, OKLA.



FIGURE, 28.

A NORTH SOUTH SECTION OF THE GLEMN POOL, OKLA.

FIGURE. 29.

CROSS SECTION OF THE DROPRIGHT DOME, OKLA.

and south but none on the east except that caused in the sands by a change in dip from 25 feet to the mile to 140 feet to the mile. The oils from the Glenn pool have a gravity of 36°Baume.

The Dropright Dome in the Cushing field Okla produces oil varying from 36 to 42 degrees Baume gravity. The structure is a good dome having a closure of 125 feet. See Figure 29.

It will be noted that in the Oklahoma fields there is a tendency for the pools to extend farther down the dip on one side of the structure than on the other. This is very noticeable in the Cushing field. In the Layton sand on the Dropright dome the oil extends down to a depth of 500 feet below sea level on the west side. On the north side where the dips are more gentle the oil is found as low as 650 feet below sea level. On the Wheeler Saddle there is a difference of 25 feet elevation between the contact of the oil and water on the west side and on the east side, a distance of less than two miles.

The Drumright Dome shows the same relations. The oil being found lower on the side with the more gentle slope and higher where the dip is steeper. An interesting problem and one of considerable economic importance is presented by this relation and with more accurate field data and experimental work some general law might be worked out for the various fields.

In California the production comes mostly from Tertiary rocks. All of the coal found in the state is of the soft lignite variety and only occurs in unimportant deposits.[1] The oil found is of the heavy grade and varies from 11° to 34°Baume. However, the average is around 16°Baume. The following is the average of a num-

---

1. Bull. 67, Calif. State Mining Bureau.

ber of samples taken from the various fields.[1]

Kern River	oil	field	average	gravity	15.16°B.
Coalinga	"	"	"	"	17.52°B.
McKittrick	"	"	"	"	16.37°B.
Midway	"	"	"	"	16.34°B.
Sunset	"	"	"	"	14.37°B.

It is thus seen that low grades of coal are found with oil of high gravities in the California fields.

In regard to the amount of deformation that has taken place there seems to be no relation unless, as seems improbable, there has been a great loss of the lighter oils. The California pools occur in beds that are highly deformed and some production is even obtained from beds that are practically vertical while other producing beds outcrop at the surface a short distance from the well as is shown on the cross sections[2], figures 30 and 31, of the Peunte Hills districts, California.[3]

The cross section, Figure 32, shows a possible solution of the problem of the occurrence of oil in the McKittrick field. Arnold and Anderson believe that there has been a big thrust fault along the line A-A' and that it buried the sand at the same time sealing up any possible seepage by the overlying shale.

Cross sections, figures 33 and 34 show ~~that~~ some of the occurrences of oil in the Los Angeles oil fields, California.

---

1. Bull. 19, U. S. Bureau of Mines.
2. The scale has been increased on these figures to allow showing the formations although the vertical and horizontal scales are equal.
3. Bull. 309, U. S. G. S.

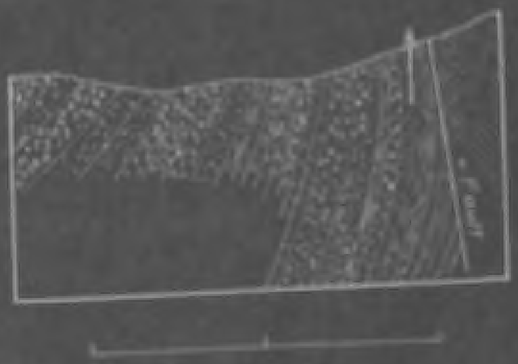


Fig. 30

Fig. 31

CROSS SECTIONS FROM THE PUENTE HILLS
DISTRICT CALIFORNIA.
(After ELDRIDGE, USGS.)

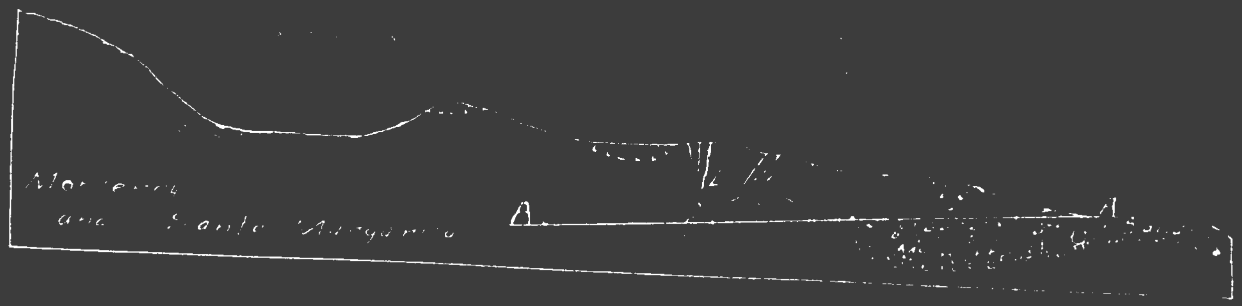


Fig 30

[illegible]

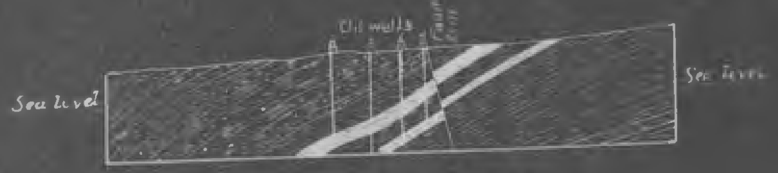


FIGURE. 33.

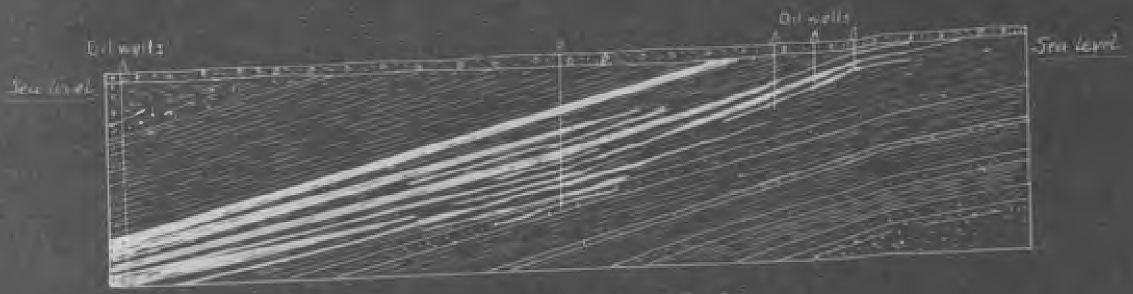


FIGURE. 33.A

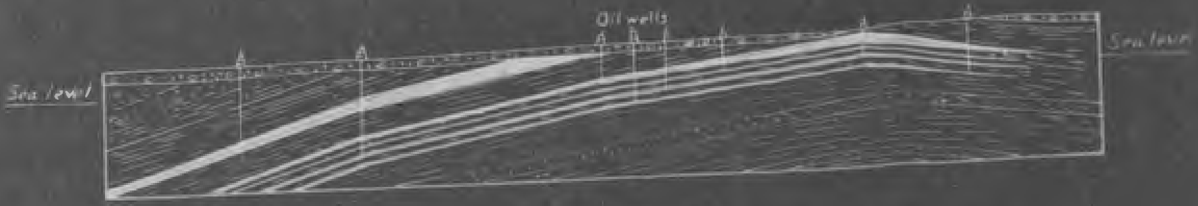


FIGURE. 34.

STRUCTURE SECTIONS THROUGH LOS ANGELES OIL FIELDS, CALIF.
(After R.ARNOLD.USGS)

In the discussion little attention has been paid to the relation between the gravity of the oil and the fixed carbon ratios for this has been discussed by White, Fuller and others in several papers and the relations clearly shown.

A possible explanation based on the theories advanced by White, for the origin and occurrence of oil, of the relations between structure and the occurrence of oil in the Appalachian field is as follows:

The occurrence of oil in the Appalachian field is briefly summarized under the following points.

1. From the east to the west of the district the amount of deformation gradually decreased.

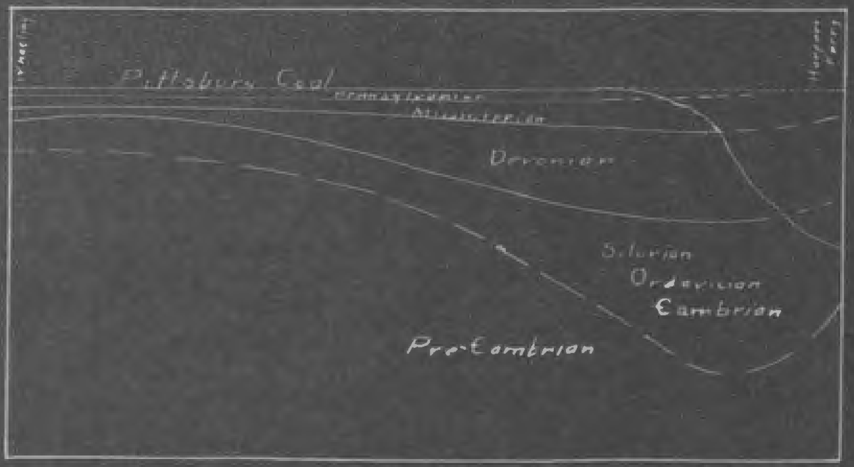
2. The largest number of pools and also the largest pools lie along the axis of the geosyncline where the folding is moderate.

3. Oil pools predominate west of the axis while east of it the largest gas fields are found.

At the close of the carboniferous period, before the Appalachian folding had occurred, the strata formed by deposition and gradual subsidence had the attitude shown in Fig. 35.[1] As pressure increased in the Atlantic basin these beds were compressed. This would be felt more along the eastern edge and, according to White, the heavy oils would be formed. The oil would pass to zones of less pressure which would be the coarser sand over or under them. As the pressure increased lighter oils would be formed and the deformation would start. The lighter oils would force the heavier out of the deformed sands and down into the undeformed strata where it would join the heavy oils being formed there. With

---

[1] Bailey, Willis, Mining and Metallurgy, No. 157, sec. 10, Jan. 1920.



After Bailey Willis

Fig. 35

CROSS SECTION OF THE APPALACHIAN REGION BEFORE DEFORMATION TOOK PLACE.

continued deformation lighter oils and finally gas would be given off. Each of these successive grades of oil produced would force the preceeding one out of the higher structures into the lower ones. As the deformation progressed from east to west it kept the heavier oil ahead of it leaving light oil and gas behind. On the western edge of the field the deformation is very slight. Heavy oils would be formed here and other heavy ones would be brought in giving an abundance of heavy oil in the western part of the field.

It is believed that a comparison of the sections, from the various producing fields, will show very clearly that no relation can be established between the amount of deformation and character of the oil found in one field and the amount of deformation and character of the oil in another. This would indicate that pressure and not heat was the great factor in the metamorphism of the organic material. Little heat would be generated by the direct compression of the beds. When deformation took place there would be considerable sliding of the beds over one another and this would cause extensive heat to be developed. It is seen that in some districts where there has been some deformation considerable alteration has taken place while in others, such as the Californian fields, where the movement has been great and consequently heat developed, only heavy oil and poor lignite coal are found.

The second point is less clearly shown and cannot be fully demonstrated or disproved until more data is available. The data furnished by the Appalachian and mid-continantal fields indicates that, in a particular field where the rocks are uniformly distributed and the force causing the deformation comes from one direction the character of the oil may be directly related to the amount of deformation.

The amount of metamorphism depends on the amount of pressure and, the rocks being uniform in character, the greater the pressure the more the rocks would be deformed. What heat is generated during the deformation though not an important factor would aid in the metamorphism.

In the various districts the controlling factors, such as the character of the rocks, amount of loading, direction and amount of thrust pressure, would vary so that it would only be under exceptional conditions where two fields would bear any relation to each other.