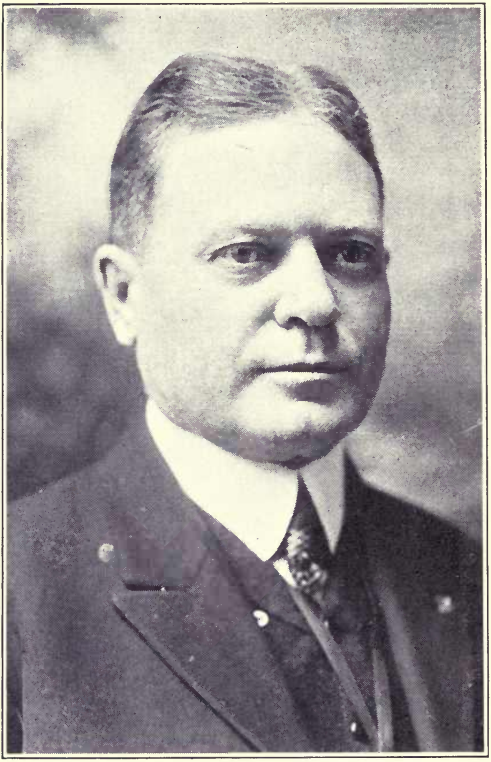

THE AUTHOR

Geological Notes on Oil Structures

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"Geological Story of the Mid-Continent Oil Fields"

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CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTORY

THE object of this booklet is to review some of the relative facts incident to the oil-producing industry of California and other States; to suggest some of the conditions existing in formations; the character and methods of determining the better known types of oil structures; and the possibilities of discovering additional areas where oil in commercially profitable quantity may be found.

As viewed from the standpoint of the technical geologist, it is not altogether easy to put the matter in a form to be quickly and fully visualized by the lay reader. The difficulty is not found to be present in the substance to be embraced, but in accurately knowing what to leave out and still maintain complete and understandable text regarding the subjects treated. If it seems that some aspects of certain of the items chosen by the writer for inclusion herein are scantily discussed, or upon the other hand if too much space appears to have been devoted to some other thing, it will be remembered that there are many sources of data of extremely various kinds of an historical, commercial, geological and economic character, which are drawn upon. The mass of information which has developed regarding petroleum, drilling, producing, marketing and other branches of the industry, and the literature covering the cognate subjects is so vast that the difficulty in treating any department of the oil business briefly is in knowing what to omit, not what to retain.

Since the Geological Departments of various of the States, the United States Geological Survey, and other public and private interests, publish many able and trustworthy bulletins, reports and other papers fully setting forth the statistics of the fields, as to barrels of production, value in money, analyses of the different grades of petroleum and other detailed and reliable information of that general type, it appears needless to repeat that matter here. Referring particularly to California, it is and has been for many years one of the chief oil-producing regions of the United States. The names of its principal fields are almost as well known to the general public as are the locations and names of its leading cities: Kern, Taft, McKittrick, Sunset, Coalinga, Westside, Eastside, Oil City, Lost Hills, Whittier, Ventura—every one of these and others are names almost as common as the terms employed to designate the articles in our living rooms. To the people of California the names of these fields are familiar not only, they are known to millions of men that have never even been in the State. Their oil output has a cash value which is measured in hundreds of thousands of dollars every week and a potential economic worth doubtless almost wholly beyond estimation. Kern County alone produces over one-tenth of the total petroleum output of the United States, though oil of higher gravity and in great quantities is annually produced in the Coalinga and other districts.

THE AUTHOR.

CHAPTER I

A GLANCE AT EARLY OIL FIELDS IN CALIFORNIA AND MENTION OF OTHER REGIONS

As LONG ago as 1896 it appeared probable that the State would develop great oil-producing areas. During that year drilling in the Coalinga district opened a flowing well. The known productive areas in the southern part of the State which had shown profitable output before that time were a considerable distance from the "Blue Goose" well near Coalinga, and the new discovery fanned the torch of activity into a blaze of excitement, which carried new drilling like a wave of heat throughout every favorable and many unfavorable portions of California. It was known that many localities appeared geologically similar to the areas in which oil had been found. That inference led to the formation of many exploitation companies, which did a lot of drilling throughout the State.

That early period of activity brought into existence many successful companies; some new fields were discovered and the known fields were widened and extended. Referring to the epoch, a publication of the California State Mining Bureau known as Bulletin No. 32, "Production and Use of Petroleum in California, page 11, says:

". . . when the excitement had passed away the production of the State had increased from two and one-half million to nearly seven and three-quarter million barrels per annum, and an enormous amount of well-invested capital remained in the business, and it had been shown that, under rational management, the production of and the prospecting for petroleum in California formed a legitimate employment for capital."

Relative to the results that followed drilling, a table of field activities tabulated on page 19 of the Bulletin shows:

"RECORD OF FIELD OPERATIONS TO DECEMBER 31, 1903

"Producing wells, 2998. Abandoned wells, 1271. Wells drilling, 159. Wells of doubtful value, 322." The record includes a total of 4750 actual drill holes put down in the State to that date, of which 2998 were productive, a proportion of successes which represents better than 60%, without taking account of any part of the 322 holes set down as doubtful.

The record of petroleum output for the year 1919 will give a clear idea of the tremendous growth of the industry during the 15-year period from 1903 to 1919. Bulletin No. 88, California State Mining Bureau, "California Mineral Production for 1919," page 23:

". . . sworn statement from the producers of 8932 wells . . . 101,073,517 barrels valued at $142,610,-563—the total is inclusive of some small output of the Los

Angeles City field." (Page 24) "from the Coalinga field 16,091,037 barrels . . . the average daily production from California wells decreases about two barrels each year. In order to maintain a given total output, new wells must be continually drilled." (P. 26) "The total production of petroleum since the date of discovery in 1875, inclusive of the production for 1919, is recorded as 1,240,198,740 bbls."

The actual cash value of this enormous production of one of the world's most vital mineral resources has not been far from a billion dollars. Again it may be repeated, the economic worth of that great addition to the State's vested riches is almost beyond possible calculation.

Bulletin 32, page 17, regarding the values of land in the various fields, reports: "Land values run from $3,500 to $5,000 per acre in the better parts of Kern River; from $500 to $1,000 at Sunset; in Midway, as high as $1,000; at Coalinga, from $250 to $4,000 or $5,000. At Kern it is customary to allow from one to two acres for each well; at Sunset, about the same; at Coalinga, from one to four acres."

It will be seen that the identical processes were operative in California which had theretofore been prevalent in all oil fields the country over. Indeed, the results of discovering oil in profitable commercial quantities in any new locality are today parallel in every respect as regards vastly enhanced prices of lands and leases. The striking of oil almost in the twinkling of an eye sends land values to unbelievably high levels. Such vast increase of value brought about in so short a period of time is the underlying cause of the compelling allurement which urges the pioneer to never weary of searching for new pools of oil. It is the magnet which attracts capital from every imaginable source to assist in pioneer drilling. Were it not for the tremendous returns which flow to the successful operators in new regions when a profitable well is brought in, it seems likely that what is known as *wildcat* drilling would not often be undertaken. It is that kind of pioneering work, however, which has kept the United States in the lead of all the countries of the earth in petroleum output. It is the character of venturing which of necessity must be kept up if the petroleum output of the country is to equal the requirements of the increased and increasing demands.

Not less potent were the Pennsylvania formations of the early Appalachian fields in firmly establishing the oil production of America upon a solid foundation, than are formations of later periods in other regions effective in keeping the industry upon such basis. The Trenton limestone of Ohio, Indiana and Illinois has done and is doing its part in oil output; though it is a formation belonging in the Ordovician era, deposited during the Silurian period, which was many ages before the Pennsylvania. The great fields of the mid-western States, Kansas, Oklahoma and Texas, the most profitable regions of oil output of high gravity refining quality ever drilled in any country, deliver their values from the Pennsylvania formations. The remarkable fields of south Texas, known as the Gulf Coastal fields, in which classification Louisiana largely belongs, release their production from formations of the Upper Cretaceous and Tertiary periods; and it is in the Upper Cretaceous that the notable wells of the Mexia, Texas, field are being drilled. The Colorado shales of the last named period are the source of the Wyoming and Montana petroleum in great part.

But it should be remembered that the mere presence of the organic shales of the thick formations of the periods named is not within itself sufficient to an area to guarantee the finding of oil in profitable amount by drilling at random. There must exist also what are called *Oil Structures* to render practicable drilling at once feasible and successful. These considerations will be discussed in later sections of this booklet, and it will be seen that they apply to all California areas with equal force to their application in other oil-producing regions, though the shales of the State are among the richest oil-bearing formations known.

CHAPTER II

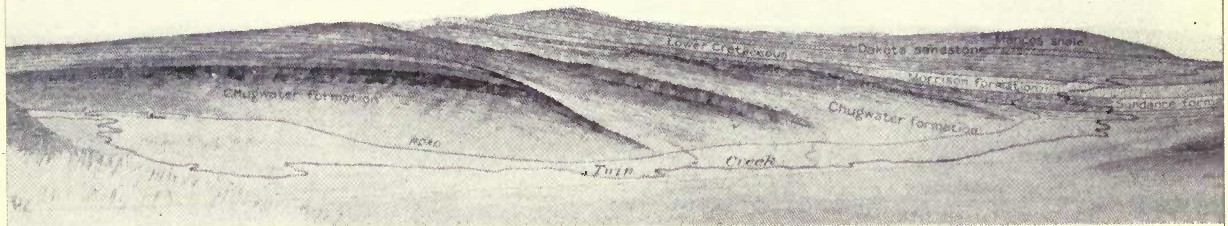
THE ORGANIC SHALES OF CALIFORNIA

IT appears to have been quite definitely established that the probable sources of the petroleum of California are in the organic shales deposited during Upper Cretaceous and Tertiary periods, though some higher gravity oils of amber and very light greenish color are thought by the present writer to come from the Ordovician—probably Silurian strata. While it may be set down as being likely that accumulations of the last mentioned grades of oil will be found in profitable quantity in properly enclosed catchment reservoirs in certain districts in and adjacent to Sacramento Valley, and in the foothills of the Coast Range in that portion of the State, no large commercial output of the peculiar oil described has yet been developed in the regions named or elsewhere in California. The chief output of the State has been and is being delivered from Tertiary shales, though millions of dollars of petroleum values have been and are being taken from strata which were saturated by the oil from rich shales of Upper Cretaceous epochs.

Examination of a topographic map of the State will be of service in giving a good idea of the regions where organic shales in great quantity may be expected. It will be noted that the land area is definitely divided into two major physiographic features: the section which occupies the extensive basin area, and the sections where uplifted strata are now represented by mountain ranges. The former was covered throughout long geological ages by the waters of an inland sea or embayment, and upon its floor there were deposited the great thicknesses of shales and sands now found to be oil bearing. That old sea was somewhat near 300 miles long north and south, and about 50 miles wide. Upon the eastward side it was enclosed by the mountain system known as the Sierra Nevadas; upon the western side its boundary was the Coast Range. For parts of successive ages the last named boundary appears to have been a discontinuous land surface made up of the summits of higher peaks, forming a chain of islands. Throughout later epochs more or less extensive earth movements closed up the gaps between the islands by orogenic (mountain-making) and tectonic (structural) actions, and by the breaking down and erosion of the existing summits, to the effectual building of a coastal mass of relatively high elevation.

Though it should not be overlooked that there are other areas in the State where profitable oil output comes from organic shales which are not an integral part of the defined geological province described, such formations are known to have been deposited during identical epochs and under conditions largely parallel with conditions obtaining in the province of the great embayment, now known as San Joaquin and Sacramento Valleys.

Cut No. 1—One Limb of Anticline



Cut No. 2—Diagram of Same

It will be seen that cut No. 1 is a view of the topography of a very definitely disclosed anticline, while cut No. 2 is a diagram of the topography shown. To obtain a correct idea of the underlying strata it is necessary that surface exposures of such formations be present in the region. These surface pictures of the relative position of the formations are best seen and most likely to be found in the localities where erosion has carried away adjacent and overlying strata, leaving the edges of the deeper formations showing in the side of creek banks, cliffs and other natural excavations and elevations.

As pictured in cut No. 2, it will be noted that the formation marked "Lower Cretaceous," which underlies the stratum marked "Dakota Sandstone," and overlies the formation marked "Morrison Formation," is determined along the slope of the highest elevation of the landscape, and that the other formations lying with it are depicted in their relative position. That place of the Lower Cretaceous member would be maintained underground in its precise relation to the other formations, and could be so mapped.

If there were conditions present which would contradict the conclusion stated with reference to the relative position of the formations underground, such facts would be plainly marked in some manner on the surface and could be taken account of in the investigation.

Within the shale formations, which were deposited in a horizontal position, as all other sedimentary formations were deposited, there were embedded vast quantities of marine plant and animal organisms. What we know as the Diatomaceous earths of California offer examples of the character of shales in which much of the petroleum of the State had origin. Shales of the late Upper Cretaceous are also of similar organic character and provide a substantial portion of the oil production which has placed California in the lead of petroleum-producing States.

In the comparatively shallow, warm waters mentioned, tremendous growths of algæ, fungi, lycopods, equisetas, filices and other forms of early plant life falling within the kingdom known as Cryptogams, choked the sea and clothed the waters throughout vast epochs. As these plants spread and multiplied and flourished, and as their decaying portions sunk to the bottom with the myriads of minute animal organisms which swarmed about and clung to their tendrils, the ooze and slime on the sea-floor gathered inch by inch, foot by foot, into hundreds and thousands of feet in thickness; for their numbers were almost infinite, their aggregate quantity almost beyond imagination, and the factor of time was so long that the mind fails to comprehend and the fancy halts before picturing its immensity. If we omit a tabular summary of the plant and animal life of the Paleozoic, which ended with the beginning of the Mesozoic era, and which tabulation and descriptions make up an extensive literature, and mention only the fact that the latter era passed with the beginning of the Cenozoic, and state that the remains of its plant and animal life provided organic sediments in quantities entirely beyond our imagination, we have not even then entered the maze of life which existed in the last named era, in which is included the Tertiary period. Nor should it be thought that the varied forms of life were less numerous, or that the multitude of individuals of the countless species was not so great, or that the vast stretch of time was more shortened for the later than for the earlier epochs. The stupendous total of organic creatures, animals and plants of land and sea, the embedded remains of vestiges of which are preserved to our examination in the shales of the Upper Cretaceous epoch and the Tertiary period, we may understand were quite abundant in quantity for the provision of the antecedents for the natural making of more petroleum than oil drillers have yet had time to find.

So, this section ends as it started with the statement that the organic shales appear to have been sufficiently determined as the source of California petroleum. Since scientists have quite fully achieved in laboratory experimentation a copy of natural processes in the genesis of petroleum, it transpires that much is accurately known about what methods were followed by Nature in making the oil we find in the ground. The learned chemists of the world engaged in such studies compound a meager quantity of ingredients and generate an ounce or more of petroleum therefrom within a few hours or a few days, while Nature used the forces and exhaustless ingredients of a world as a laboratory in which to generate billions of barrels of petroleum during multiplied millions of years of working time; and in each case similar ingredients, like forces and parallel methods are called into use. Hence, it occurs now that the origin of petroleum is in a manner quite well known, to an appreciable extent what conditions surround its making, and in a more or less definite way the methods and laws involved in the process. It is largely because of that knowledge that we understand reasonably well in what formations to expect it, and have acquired information about how to locate such formations, estimate their probable petroleum content and decide whether possible accumulation reservoirs have been provided by earth movement for the gathering and impounding of the petroleum in such formations or in contact beds.

The foregoing considerations have carried us to the point of directing some attention to the interesting methods employed in determining the age of various formations, learning under what conditions the sedimentation took place and what possible economic value such knowledge may embody.

CHAPTER III

REMARKS ABOUT IDENTIFICATION OF DEPOSITS AND DETERMINATION OF AGE, AND THE USE OF THAT KNOWLEDGE

THE profound study which has been given to every variety of rock formations throughout the world over a long period of time by men of such learning that we delight to honor them has extended our fund of knowledge to a point of actual certainty with respect to nearly all rocks. It should be said that geologists call all formations "rocks"; even the dirt in the streets and the soil in the fields are known to scientists as rocks. It was said that nearly all rocks are known which is intended to mean that it is known somewhat definitely what constitutes their material and when they were deposited in the time scale, as related to other deposits.

The remains of minute insects, equally with those of the largest serpents and biggest creatures of every kind, such as lived upon the land and in the waters; the stems and leaves of plants, marine and terrestrial alike; the shells and skeletons of every kind of land and water infesting thing of life, would most naturally be embedded in some quantity in the formations which were constantly being put down throughout every past age under bodies of water everywhere. As time passed, some of these formations would be exposed at some place upon the surface; indeed, every one of them would be uncovered somewhere upon the earth, some at one place, others somewhere else, many of them again at another place; until here and there in almost countless localities there would appear every sedimentary deposit ever put down. Embedded in them would be the impressions, moulds, casts, or rock-encrusted or fossilized remains of the varied and various species of plant and animal life which had during any period grown in the earth or the oceans, crawled upon the dry land, flown through the air, or swarmed in the water of the seas. Such fossils have enabled many of the world's most learned men, working and studying in every country upon the earth, to classify and distinguish the species and individuals of one age from like and unlike species and individuals of another. It has been found that the plants and animals of any given epoch during the vast stretch of time that has silently passed in almost infinite measure down through the dim corridors of the ages, have maintained that character of progression and so fit into the mosaic of evolving forms, as adapts them to methods of intelligible interpretation.

The beautiful shells and other fossils often seen in rocks are the actual records left along the shores of time as an ineffaceable literature of the plants and animals of past ages. If one gave a lifetime to the study of these records and to comparison of them as to similarities and differences, and extend the search to all lands upon the earth, studying them in canyons, gorges, cliffs, shores and mountainsides, and carry with him specimens of every varying kind he finds, he will be surprised and delighted in the end to see how many of them will be similar in some main essential, how many will be alike in some other particular, and how many will be wholly unlike in almost every respect. Also, he will be amazed to learn at last into how many classes he shall be compelled to divide them, and how few individual specimens there will actually remain in each class. The investigations mentioned have been pursued for many years throughout all parts of the world by thousands of learned men in a most earnest manner, and the results have been set down in careful descriptions and photographs, so that the vast amount of accurate knowledge gathered is open to the study of every one. A great architect might not have the time or means to visit every country on earth and examine the form of every style of architecture, but with photographs and exact specifications of every character of building before him, he would not mistake one style for another. That is true of the geologist regarding different formations; he must know if the exposed strata upon one side of a hill is a part of the identical strata exposed on another slope. Information of formations must be so full that two elevations taken upon what is thought to be the same formation in nearby areas will not in fact be the levels of different deposits put down during epochs separated by a time interval of possibly millions of years. Indeed, the Molluscoid forms or any other forms of the animal kingdom of the Cambrian period must not be confounded with the descendants of such marine creatures of the Permian period—separated in the time scale and rock stage by many millions of years. Such confusion would render futile the results of an examination of any region, and perilous indeed would be the employment of funds based upon such inaccurate conclusions; yet the writer has reported upon many locations of drilling wells where it was apparent mistakes of equally glaring character had been made, though not by an authority who could scientifically determine where a drill should be located.

During Upper Cretaceous times, not to search into deeper past epochs than such as are suitable to the illustration, it has been found that certain species of very minute marine plants, known as algæ, were similar in the waters of equable temperature in every sea of the world. Such plant life and others of similar and unlike character, together with the diminutive animal life of the seas, have been found to be the source of much of the petroleum coming from formations of that age. The fossils preserved in the strata render them not difficult of determination.

Later, during the Tertiary period, there seems to have been a marked development and increase of one branch of algæ, known as diatoms, so that their growth filled the waters which submerged a part of what is now the great valley area of California. Our diatomaceous shales are so named because the greater proportionate part of such shales are often almost entirely composed of the limey portion of that marine plant.

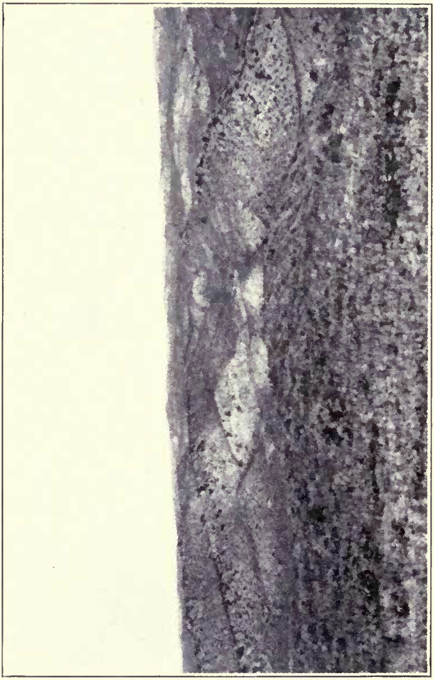
Since other forms of plant and animal life were embedded in the shales and other formations of the periods named, it becomes apparent that there is no uncertainty as to what relative time must be referred these minute specimens of organic life.

The accuracy to which age correlation and identification of strata have been carried by science will bear one full illustration: It is possible to trace with unerring assurance the physical history of the horse from his embedded remains in formations of the Eocene epoch of the Tertiary period to the present time. Similar methods are employed in the identification of the developing and changing forms of every species of plant and animal life, as such alterations were brought about by the adaptations enforced by survival. But it is especially interesting to follow the skeletons of the horse backward from his present proud and beautiful form into the inhospitable conditions of the early Tertiary, a long period of volcanic eruptions, and of widespread and almost continuous earth movements. The atmosphere was laden with noxious gases, the waters contained acids, were saline, sulphurous and choked with ashes and volcanic dust; and when such perplexities were joined to the perils of a quaking earth, avalanches, lava flows, the opening of extensive fissures where the solid strata were broken and uplifted by faulting, buckling and folding, combining to the enforcement of constant and rapid shifting of places of habitat, it is indeed marvelous that the creature survived not only, but with the multiplying stages of growth and improvement became the fleet and comely animal of our prize shows. Not less strange is it that of all the animal and plant life which has ever inhabited and clothed the planet, the myriad wonderful representatives which have descended into our day are but a scant fraction. The vast panorama of life which has in every age been spread out over the lands and in the seas has in every species changed, some falling backward and dying out, others improving and multiplying; but we know that all were of Nature and exist within the horizon of Divine provision. In that ancient system of rocks where the earliest remains of the horse have been preserved in skeletons which do not change, we learn that he was about the size of the fox squirrels of today. In the formations of every succeeding epoch from the first remains found there have been unearthed and identified hundreds of skeletons which are unmistakably the remains of horses. The writer has examined parts of skeletons of horses of the Pleistocene epoch embedded in formations of that sedimentation in Florida. In Wyoming he has seen the bones of such skeletons embedded in rocks of the early Miocene epoch. There may be seen in museums many almost wholly complete skeletons of the horse of every epoch from the first identifiable structures of his beginning to the present time. It will be remembered that the character of the herbiage changed as epoch grew into epoch with the passing of ages, and that as age followed age grasses came and flourished and developed, and that climatic and atmospheric conditions evolved environments and influences which provided better food and more favorable surroundings, hence the animal's additions of size and strength.

In the formations filling some of the hollows of such old bones, where marrow had been in the living animal, there have often been found many bony structures of insects and other animal organisms, impressions of plant leaves and stems and other remains of the living things of the earth belonging to the particular epoch of the bones when a part of the living animal. Hence, we come to the knowledge of many verifying and corroborative facts relative to the contemporary life and many of the happenings of every epoch.

The science of rocks is called Geology. The science of fossils is called Paleontology. These sciences are as essential to the successful oil driller as the science of chemistry is necessary to the steel manufacturer. The major oil-producing companies and all successful oil operators employ men learned and experienced in these professions to examine possible oil-bearing lands and select locations for drilling, as the steel maker employs chemists to advise proper alloys in right quantities for the mixing and fusing of iron ores in the blast furnace. The railway companies and others demand steel of a specified chemical composition, hence the steel maker must employ scientific advisers of learning and experience in order to deliver such grades.

The oil producer is very rarely a competent, experienced scientist, but if he wishes to locate new fields he employs capable geologists to that end. The steel manufacturer is rarely if ever a learned and experienced chemist, but he is not without the advice of men learned and experienced in that profession.



Cut No. 3—A Dome

In cut No. 3 a dome is shown. The hills of light-colored material in the central part of the picture are made up of rocks of much greater age than the formations in the crests of the ridges lying about them. If by reason of vertical action there is a body of formations pushed upward in a local area, it will be obvious that such formations as lie over that body will be elevated, and by that movement will upturn the edges of the strata which were broken by the upthrust.

It usually develops that in cases like the foregoing the domal part of the structure, the top of the dome, is subject to greater erosional activities than the surrounding material. It also follows that the disintegrated mass of formations which most definitely express the character of the action are the ends and edges of strata which were lying more deeply buried, hence are more compact, denser and harder than the formations pushed up in the central portion of the dome; therefore their upturned portions do not erode away so rapidly. The top of the dome carries greater or less thicknesses of the material which was upon and near the surface, hence surrenders more readily to the elements, leaving a depression wherein there is left upon the surface the hard formations which belong to rock stages much earlier than the surrounding rim of rocks which bound the dome.

For the reason stated, though other causes also enter into the fact, domes and anticlines will often express their highest understructure along creek and river beds and sometimes in lakes. Much of the Cherokee Shallow Oil Fields of Oklahoma are illustrative of the first; and Caddo Lake, Louisiana, of the latter.

CHAPTER IV

RELATING TO OIL STRUCTURES AND THE METHODS OF DETERMINING THEM

The dependable results gained by drilling experience throughout the world have established a vast assembly of facts relative to oil-bearing formations, and the laws and conditions which govern oil accumulation in certain areas.

The fact will not be lost sight of that there are certain imperative essentials which are antecedent to the discovery of new oil fields. Though it would be manifestly impossible to stay within the boundaries of a brief plan if we enter fully into discussion of the almost countless minor details and aspects of the less important conditions which must be considered by the geologist in locating a new field, it is possible to set down in a few short paragraphs the main factors which are of first moment.

1. The presence of petroleum-making formations must be known to exist in the sub-surface strata either directly or in contact in the inclined beds.

2. Permeable formations, such as sand, porous limestone, or other sediments in which oil could find lodgment, must be accessible to the oil-making formations.

3. The oil-making strata and the formations acting as a reservoir into which the oil has passed must occupy such relative positions as provide or have provided for the oil to move from the former into the latter.

4. The permeable formation in which the oil has had natural provision for accumulation must be enclosed by impermeable strata, or otherwise be definitely surrounded by rock formations, so that the oil draining into it could not have been lost by escape to the surface.

The foregoing conditions are interpreted as oil structures, such as the Anticline, Dome, etc., etc., of which there will be something said later. Disregard or ignorance of the absence of facts similar to such as are mentioned above has been responsible for the drilling of a very large number of holes in attempts to find oil in regions and at locations where no effort of the character should ever have been made. The shales from which oil is generated and the limestones from which it is distilled by natural processes are fairly well known throughout all of the oil-producing regions of the world. Also, the various kinds of oil structures which may be expected to contain oil accumulations, if present in a region where oil-bearing formations are believed to occupy sub-surface levels, are not usually difficult of discovery and location.

There are areas adjacent to nearly all productive oil fields which contain the shales and limestones in which the oil is found in the nearby producing area, though such formations may not lie in a favorable position or be of adequate thickness to warrant drilling. Often because of some other ascertainable reason oil should not be expected in them, such as lack of porosity in the oil-bearing members, the presence of water because of low sub-surface elevation, or some prime essential which is found to be lacking—there must be nothing of direct bearing on possible oil presence absent in any area where drilling is to be done.

In a great many areas throughout the large number of oil-producing regions of the United States, and the same facts are found to exist in fields elsewhere in the world, it has been noted that new fields have been opened in nearby or related areas after the development near the discovery well had progressed to the drilling of every feasible location in the producing field. It is often possible to follow the oil-producing and oil-bearing formations from the producing districts into related areas either near to or more distantly removed from present production. In event we are able to trace from a productive area into a nearby region the upturned edges of alternating sandstone and shale members which quite definitely express the conditions of such strata as to sequence of deposit, character and position occupied under the new region, we are enabled without much doubt to reckon upon the presence of oil in profitable amount in any structure found in the latter region.

The great fields which came at last to show almost a continuous succession of profitable wells from Robinson to Casey, Illinois, is a case in point. An untested area in that region, known to the writer, may be another case. Also, the trend of productive strata from Caney, Kansas, to Chelsea, Oklahoma, in the great Mid-Continent fields, a distance of upward of seventy miles, was traced out very well by geologists following the exposures of formations along the bases of the hills and in the cut-out channel of Verdigris River upon the western boundary of the region. The California fields located in southern San Joaquin Valley and at Coalinga offer marginal boundaries along the foothills of the Sierras and the Coast Range which are almost ideal for the tracing out of the possible oil-making and oil-bearing strata, as the upturned edges of these are exposed with their related members along the foothills mentioned.

CHAPTER V

SOME TYPES OF OIL STRUCTURES AND REMARKS ABOUT THEIR CHARACTER IN SOME WELL-KNOWN FIELDS

THOUGH all formations of a sedimentary character were deposited in a horizontal position, but rarely are they now found lying in that position in any region of considerable areal extent. The crust of the earth, though stable enough in the present epoch, has been subject to almost endless disturbances, which have had the effect of displacing the strata, and tilting, upending, breaking and rearranging the sequence of rock formations.

The planet we live upon has gradually contracted in size, causing rock strata which were deposited long ago to lie exposed upon the surface, or to thrust out their edges where erosion has carried away the disintegrated and loosened material. Many great mountain chains, peaks and summits, and many hills and ridges, with their related or corresponding depressions of valley, plain, gorge and canyon, are displayed all over the world as results of the buckling, warping, faulting and other earth movements occasioned largely by that contraction. Of course the shrinkage of the planet has been entirely too slight to be measured by any instruments of even the most delicate exactitude, but the inequalities of the surface of the earth everywhere bear legible records of the fact. These orogenic and tectonic movements, mountain-making and structural, respectively, have been taking place in the more or less solid crust of the earth throughout much the greater part of its physical history, though very surely quite more prevalent in some ages than in others. They have occurred with diminished frequency during the period in which men have lived than at any previous time, and it seems that our habitation is growing more nearly secure and is not so much beset by disturbances as period is added to period in its age.

Such movements have been of determining effect in the displacements which have provided the natural rock structures which appear to exist in all areas where oil in commercially profitable amount has been found. There are several well-known types of these so-called oil structures, though the anticline and dome are the most common and appear to be the types present in many of the areas of greatest productivity. The various forms of structure have been so definitely determined by drilling in hundreds of areas in all oil-producing regions throughout the world, and scientific measurements and mapping of the surface demarcations of such structures have been carried to such a high degree of accuracy, that it appears there has been established a series of related natural laws regarding the gathering of petroleum into catchment reservoirs. This will not be understood that the oil is contained in basins in the ground like pools, lakes or rivers upon the surface, but in sand and other porous formations, as water is contained in gravel.

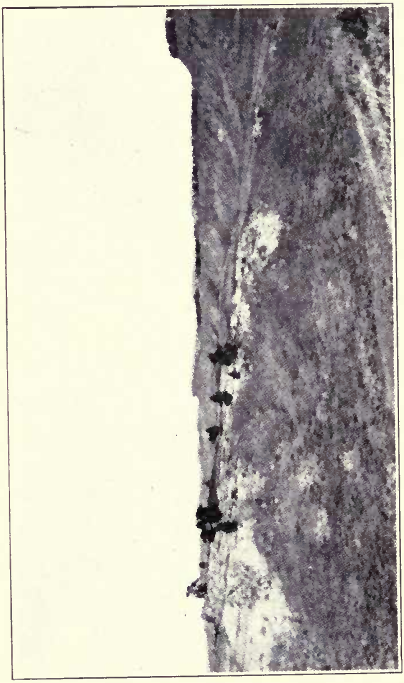
It has been said that if the oil found in any great oil structure were disseminated back into the formations from which it drained it would be impossible to drill a profitable oil well at any location upon the earth. This reflection brings us to a more detailed examination of what is meant by an Oil Structure, and what we must search for in order to locate that peculiar emplacement of the rock strata.

The most commonly known types of oil structures are named after the specific architectural build of the formations, as the anticlinal, meaning roof-like; the domal, like a dome; the terrace, a level area of the formations interrupting or ending a dip plane; etc., etc.

ANTICLINE OR ANTICLINAL FOLD: This type of structure is more common than any other. It is that displacement of the strata which forms an arch of the formations, and disposes dips upon two opposing sides from an extended apex. The inclined beds are in the place of the sides of a roof over a building and the apex is in the position of the ridge-pole.

In the section where earth disturbances were mentioned it was said that mountains, hills, valleys and other inequalities of the earth's surface were apparent everywhere. Referring to such elevations and depressions, of course it will be seen that if an upward movement developed from the buckling, folding or warping of underlying formations, there would be a more or less definite elevation of all overlying strata. Such condition would be called anticlinal, and would be inclusive as to the alternating formations and their arching similar to a layer cake bent upward across the middle—every layer would bend equally. (See Cuts 1 and 2, page 16.

It will be remembered that the formations were put down in a more or less regular position horizontally under water. They are not all sand, or all clay, or shale, or limestone, or of any one sedimentary material. In drilling wells for oil, sinking



Cut No. 4—Sealed Fault

The character of the topography shown in cut No. 4 is not unlike that of Devil's Den and the general region of that oil field in California. It requires no technical examination to determine that the light-colored sandstone ledge, shown in the left-center foreground in the cut, passes under the rocks which define the escarpment, shown upon the right and middle background of the picture.

However, it does require a very critical examination and the exercise of constructive logic in reasoning from the facts to determine positively if there be an unconformity between the former and the latter, and if a catchment area for oil accumulation in the former material might have been provided by the overlapping upper formation.

The picture in fact sets out graphically one-half of a domal structure, which in this case is a sealed fault. The facts determined by drilling disclosed an upthrust of the strata shown in the picture, leaving the formations in place towards the left, though not shown. The test well was located in this instance about five-eighths of a mile from the breakage line of the fault, just back of the highest terrace in the extreme right-hand side of the cut. Oil in good commercial quantity was found in the light-colored sandstone at a depth of 1800 feet, though there were some little seepages of it along the sandstone wall shown with the trees of evergreen variety near the center of the picture.

shafts for mining, or digging wells for our domestic water supply, we see that there is usually on top a given thickness of shale (shale was mud at first), then possibly clay, afterward limestone and then sand or gravel. The succession of these and other formations known in the ground vary with every locality; almost no two sections of any depth will be identical. Any elevation of the successive strata will of course lift all of them, and in most cases it will be found that upon one side or the other of the apex of an arched or folded area there will be a longer slope than upon the other side; and in one of the two sides (limbs of the anticline, as they are called) there will be a steeper dip than in the other. Also, in many such types it will be seen that the inclination of the beds as they dip away from the apex maintains about the same degree of pitch and will extend to a distance of several miles upon one limb of the anticline, but will be dipping at a very steep angle upon the other limb; the effect being that of a very long roof on one side and a very short, steep one on the other. The direction from which we will expect the oil to have migrated into the anticline will usually be from the long side of the roof, and in making a location for the drilling of the test well upon the structure we will select a site near the apex but somewhat upon the side of the less steeply dipping beds. There are local conditions present sometimes which would vary that logic, but they are the exceptions. Sometimes the anticline will be very regular, the limbs upon either side of approximately uniform inclination, and the apex maintain a more or less equal elevation. The selection of a location for test drilling will in such cases be approximately upon the apex. It will often be seen that the fold did not pass through the area in a straight line; indeed, such uniform straight folding is not common. The apex will be sinuous, or curved, or present a turn or various turns at sharp or more rounded angles in nearly all areas where folding has developed in very thick limestones which occupy the sub-surface levels throughout an extensive region, or in a region of prominent folding which results from vertical thrusts of deeper lying massive formations or igneous material.

In many regions where the folding has been pronounced, and the action has been in great measure common to a considerable area, the other types of structure will also be very likely found. Domes will exist, or Terraces, or Faultings or Faulted Zones, though any of the last named may be present in an area and no other form of structure be near.

A Dome or Domal Structure: A structure of this type is found to have a central elevated area from which the strata slope in every direction. (See cut No. 3, page 28.) Such condition is sometimes called a Quaquaversal structure. The description which applies to an anticlinal fold covers also the disposal of the rocks over a dome, though the inclined beds will but rarely define a perfect mathematical dome, as the limbs of the anticline will not often be uniform and regular. Some of the greatest oil fields known are upon domes. The related earth forms are similar in all such structures, though the causes underlying the existence of the dome are greatly different in various of them. An uplift of the igneous or other deep-lying rocks forms a structural build of the overlying beds which has all the appearances of the similar condition caused by the expansion which is developed by certain minerals upon crystallization, such as rock salt or gypsum; the latter occupies about one-third more space when in a crystallized than when in a massive state. The enlargement would have the effect of pushing up a body of overlying material, as an upward movement of the underlying mass would do. Some of the great fields of the southern Texas and Louisiana regions, known as the Gulf Coastal Fields, owe their existence to what are known as salt domes. Oil accumulation in the porous beds of a domal structure is a result of similar conditions and in obedience to the same laws which prevail in governing its accumulation in the anticline.

Terrace and Dip-plane Structures: The terrace structure is defined as that area which embraces a leveling of the strata. What is meant by the description may be briefly made plain by noting that there are many areas where the general inclination of the beds has all been tilted in one direction over a very wide region. Where the formations are similar and were deposited under identical conditions, and where the successive disturbances occurred contemporaneously throughout the region, and where there does not exist evidences of divergent and extraneous earth movements, the region is called a geological province. Now, upon investigation of many geological provinces it is found that the degree of inclination of the beds is changed and there are localized areas where the strata lie flat. That is a terrace such as is known to oil fields. While it may be true that after passing upward along the inclination of the beds falling away from the terraced area, and across the latter area also, the beds will again disclose the inclination noted further down the dip, and that such inclination will continue to rise until the point of action or the apex of the dip-plane is found. The fact remains that the terrace is present, and that oil will not continue to pass along under a level stratum or move through one, though it may accumulate in it after it is driven from lower levels in the dip-plane because of the greater specific gravity of water.

The Dip-plane Structure is that area of change of degree of inclination of the dipping beds, and may be present at any point along the dip of the strata. Oil will move upward through a porous stratum as water passes to the low levels, but will not have the freedom of action at places where the pitch exhibits any considerable change of degree. This type of structure is not as favorable as the terrace, though it differs from it only in the fact of being somewhat removed from an actual horizontal position of the permeable material in which the oil may be contained.

THE FAULT STRUCTURE: Properly speaking, we do not refer to the faulted conditions found in nearly every region where the evidences of disturbances are present as a structure; though a sealed fault into one or the other plane of which oil may have found access and be impounded, is a form of structure. Since some of the very important producing areas are delivering their values from structures of this type, it will be well to explain the condition under which the petroleum may gather and remain in them. (See cut No. 4, page 38.)

In the first place, a fault is a breaking of the formations in a more or less nearly vertical manner, and a lifting of the strata on one or the other side, possibly upon both sides, but usually with one plane lifted higher than the other. The plane of higher elevation is called the up-throw side, in event it is known that the lower side was not in fact an actual down-throw, leaving the other side in place at the time of movement. Now, observe that if the up-throw plane of a fault were to lift with its movement a porous stratum of material containing oil so that its edge rested against the broken edge of a massive body of limestone, or a clay stratum, or some other impervious material, the oil content of the porous body would be sealed in and would stay in that higher portion of the formation. If there were water on top and oil on the bottom of the formation so uplifted, the position the bed would occupy after being elevated would drain the oil to the higher part of the formation as the water settled to the lower part. The present disclosures upon the surface in some of the fields now producing from sealed fault planes indicate that the oil-bearing member was uplifted from a position in the earth so deep that it could not have been reached by the drill; possibly also leaving the other portion of the elevated formation at the original great depth from which recovery would be impracticable if not impossible.

It may be said that there are other forms of structure known which are uncommon, and doubtless yet others exist the type or form of which we do not know; but the foregoing gives a fairly good idea of the most prevalent types met with in various of the great producing fields. Something about the natural processes of oil movement in the ground so that it gathers into catchment reservoirs will be of interest.

CHAPTER VI

OIL ACCUMULATION AREAS, HOW DETERMINED

Some Instances

Petroleum as it is found in the ground in local accumulations represents the results of gathering processes which are operative by reason of certain laws of Nature which are pretty well understood. It is believed that the great amount found in the many fields of the world were at first in very small particles or drops in the formations which bore the antecedent possibilities of oil making; also that such formations may or may not have occupied a level position then, and that water was also in the formations at that time or was later admitted to them. It is known that petroleum migrates to elevated positions above water whether it be on the surface of the ground or in sub-surface levels. It is also true that nearly all strata have been shifted and tilted out of a horizontal position, and that such position offers the condition which provides for separation of water and oil by natural activities known to have been present in the earth throughout its past, and not absent in this age.

LOCATIONS IN NEW REGIONS

Upon the foregoing knowledge and its application to the earth picture of an area every location for a drill in a new region should be based. It is needless to say that a great many test wells are drilled without regard to the existence of such information, and that possibly one out of every two or three hundred of them find oil in profitable quantity. The percentage of successful wells drilled in new areas selected by experienced and capable geologists after they have determined that petroleum-bearing formations are present in the area is relatively very large; probably out of every one hundred such wells drilled, ninety of them find oil in commercially profitable amount. Statistics of oil discoveries of late years appear to fully bear out that statement. During 1920 it is reported that 21 new oil fields were discovered in the United States, and that 20 of them were drilled in areas and at locations selected by geologists. It may be well to make a brief statement of some of the more important considerations which must be remembered if one would safely locate areas in which petroleum may exist in commercial quantities, and would properly select the site for the drilling of the first wells in that area.

1. Determine if the area is underlain with oil-making formations, and if so, if such formations are in contact with or so located in the sub-surface area as to allow the migration of any petroleum content to porous formations which may act as reservoirs for the accumulation and retention of it.

Develop a knowledge of the foregoing conditions by a careful examination of all exposures of the formations which indicate that they are present under the area. Learn if such formations are actually productive of oil in any area in the geological province which includes it. Examine the identities, similarities and differences of the formations exposed as to their lime, sand or shale character, their looseness, porosity, density, etc., as compared to the same formations from which oil is being taken out of profitable wells in all related areas.

2. Determine as far as possible if any area in the province shows arching, doming or terracing of the strata which include the petroleum-making and the petroleum-bearing formations which the investigation outlined above has identified.

3. Measure the degree of dip, the direction of the inclination, the thickness of the various sandstone, lime and shale formations, and determine definitely if there actually be a folding of the rocks, or a possible elevated condition of the sub-surface strata indicated; and if so, if there be adequate thickness of the oil-producing and porosity of the oil-bearing members to warrant the conclusion that the possible output may be in profitable amount.

4. Note on a map of the area the corners of sections and other sub-divisions of the land, and with relation thereto mark the places of outcrop, what rocks are exposed, what their inclination may be as to degree of dip and direction and to what extent disclosed. Use pencils of different colored lead for the different formations.

5. Proper use of the Aneroid Barometer will give elevations, which should be noted on the map as the formations are spotted, so that the level of any given formation will be seen at a glance throughout an area the size of a small ranch or as extensive as a county.

6. One must be assured by sufficient examination to decide if any possible arch or dome might have been caused by the presence of some mineral in the sub-surface levels, such as beds of salt or gypsum, which increase in size while crystallizing and

produce effects in overlying formations similar to such effects caused by folding and buckling of the deeper formations. Also, the possibility of ancient landslides having left effects which may be similar to the change of pitch found in terrace and dip-plane structures, or the reversal of dip as found in anticlinal or domal structures must be carefully noted. But such superficial displacements of the strata are usually easy and certain of determination, though they must not be neglected.

7. Examine the area along the apex of the anticline and at either extremity of it to determine if it is closed, so that any accumulation which may ever have drained into it is still present.

This may usually be definitely ascertained by noting if the inclined beds again resume their normal dip after the uplifted areas have been passed; or by a fault zone which has formations exposed in one or the other of its planes which are of an impermeable character; or if the inclination of the rocks is away from the apex of the fold at the ends; or if sealed non-conformable contacts are present, thus cutting off the possibility of escape of the oil.

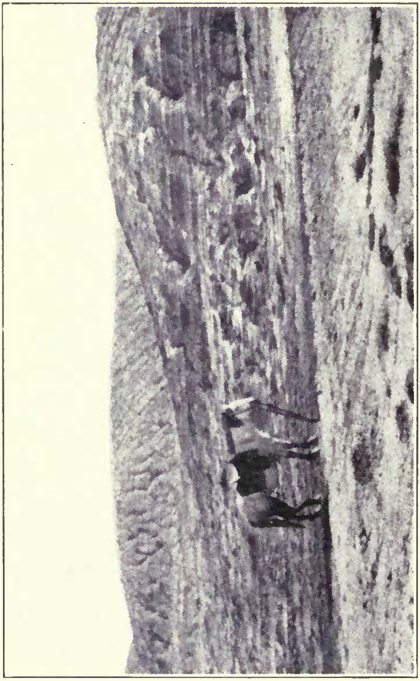
Terrace and dip-plane structures will in almost all cases be naturally closed to prevent the wastage of the oil content to the surface by reason of the peculiar forms of such structures. To learn if a fault be sealed so that the one or the other plane of it will hold oil if any were in it or has drained into it, is a matter of the most careful field investigation, and the methods are so complex and the usual earth forms are so broken up and distorted that it is impracticable to undertake to describe conditions upon which a conclusion might be based as to whether the fault actually does seal the structure or leave it open. Upon that point, however, the field examination must proceed to a degree of definite satisfaction.

The type of structure will be determined in most cases at the first glance over a region, if any be present; but its character and exact form, and the various disclosures shown on the surface denoting the extent of the inequalities and displacements of the underground picture, must be examined with the utmost care, and exactly mapped.

It is now seen that every type of oil structure confirms the following assumptions and appears to provide for the operation of the laws of gravity, though with respect to the latter there will be found many qualifying conditions and determining factors involved.

Let us state the matter in short sentences:

1. The beds must incline from a horizontal position.
2. There must be beds present in which petroleum originates.
3. The possible gathering area must be extensive.
4. The generating formations must be in some manner in contact with the porous formations which act as catchment reservoirs.
5. Impermeable formations must in some manner enclose the latter.
6. Adequate thickness must exist in the oil-making formations.
7. Matters of feasibility and practicability of access to the world are important.
8. Petroleum in many instances is found impounded by water in a syncline (a relatively low area with reference to adjacent strata).
9. Oil may be driven by water into a trap formed by a fault wall or a non-conformable deposit which is impervious.



Cut No. 5—Unconformable Formations

In cut No. 5 one limb of an anticline is shown. In the bank of the stream at the right of the horse the inclination of the beds is well developed. In the extreme background at the left of the horse, in the side of the hill, the level-lying formations are well pictured. Evidently the tilting strata of the anticline pass under the latter formations, but the level strata do not dip conformably with the formations in the limb of the fold at the right.

In nearly all cases similar to the earth picture shown in the cut it will be found that there is an unconformity in the top formations. That is to say, after the forces were expended and the anticline was formed, later sedimentation occurred and beds were put down in a horizontal position, the ends of which lie in that level manner against the formations which define the tilting beds of the anticline. In all such cases it is of moment to determine to what depth such non-conformable formations reach, and what rock stages are embraced in the unconformity. Usually the line of unconformity may be readily determined, and from the facts it will not be difficult to decide if accumulation areas for oil might have been provided along such line.

10. Like all other fluidic substances in or upon the ground, oil will seek the lowest accessible level, and if water be absent, it will settle in time into any trough (syncline) formed by the strata.

With respect to paragraph 4, it may be explained that the originating formation may lie very distant indeed from the formation in which we find the oil when we drill; but the fact of accessibility is not thereby absent. The travel or migration of oil through a formation may have covered a short or a very great distance before being impounded in some character of natural trap in the earth. (See cut No. 6).

There is a very interesting theory to account for the presence of petroleum accumulations which has lately been advanced by Marcel Daly. It is known as the "Diastrophic" theory, and may be presented with some clearness by illustration. If we squeeze a mass of sugar saturated with water, the latter will be forced out; as when we wring a water-soaked cloth, the water leaves it.

As has been said, the earth is not solid, but is made up as to its crust by alternating harder and softer formations of varying characteristics; some are very thin and massive, others are thick and porous, and still others are modifications of the qualities of one or the other. When the tremendous forces are exerted in Nature's vast power stations which are adequate to the disturbance of extensive areas of the surface and sub-surface strata, it appears possible that any petroleum in the formations affected might be squeezed or wrung out. It would not follow that it would be forced to the surface or wasted, but it might well be driven into areas of the formations adjacent, over, at one side, or upon the sides, or possibly under the formations, which felt the force of the action. Even so, the petroleum could conceivably be retained in formations within the axis of action, but in less space as compared to its scattered condition before the earth movement.

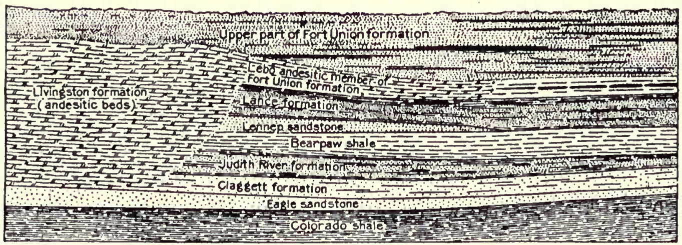
Examination of the illustrations throughout the book will convey a good idea of the appearance of a large number of areas near oil fields and elsewhere throughout the United States. In the first picture, on page 16, the topography is well shown. In the second the diagram indicates the place occupied by each formation with relation to underlying and overlying strata. Also, in the second the outcropping beds could be examined as to character, thickness and relative position, as to inclination and direction of dip, as we walked up the side of the elevation shown in the middle of the top of the picture, if we were going toward the east. If we were going toward the west from the base of the hill shown at the right-hand side of the picture, we would walk upon the Mancos shale to the summit of the hill unaware as to what beds might lie under it, or indeed as to what position they might occupy, and could not have knowledge as to their character. Oil accumulation in an area like this could have been caused by Diastrophic action.

Now, assume that the Dakota sandstone outcrop near the summit of the hill shown in the middle of the top of the picture could be followed along the surface for ten or a hundred miles as the case might be, somewhat as its upturned edges have been traced by the writer about the slopes of the Black Hills of South Dakota and Wyoming for a greater distance than the maximum stated; suppose also that in a nearby area oil was being taken in profitable quantities from wells which found the saturated horizons in the Dakota sandstone, and that it had been found that the productive area occupied a place where the sandstone had been uplifted above its normal position, and that the overlying strata was of an impervious character, and that the last named formation was exposed lying over the sandstone farther up the hill; it would be known that the sandstone with the massive material overlying it would occupy relative positions throughout the general region; now, suppose that we are at position A, and the imaginary oil field mentioned is 40 miles southeast of us at position B, and that 30 miles northwest of us at C, or some 60 miles north of B, there is a defined anticline or dome, the inference would be strong that an oil field could also be opened at C. Then the examination would proceed to the determination of every factor involved in the strata and their character and relative position in the entire region, before decision could be made as to the probabilities of finding oil in paying quantity in the new area. However, new oil fields are located with much greater assurance in the manner stated than in any other way. It will be found that nearly all of the problems which will be involved in arriving at dependable conclusions with reference to the probabilities of profitable oil accumulation in new areas have now been touched upon.

CHAPTER VII

SUMMARY, PROBABLE NEW FIELDS.

In the illustration shown in cut No. 5, the inclinations of the beds are plainly seen in the hillside in the right background from the horse. When following such strata throughout an extensive region it is always well to select certain beds as *horizon markers.* By that we mean to say, certain members which are distinctive by reason of color, size of grains and all other features which render them certain of identification, in order that we may be assured that the same formation and an identical part of that formation is being followed. It is possible to secure the exact levels above or below some selected datum line of any part of a designated formation throughout every part of a region if the formation is exposed at intervals, even if covered in places by hills or removed at other places by erosional processes.



Cut No. 6—Unconformities of the Formations

The diagram showing an excellent vertical section of nonconformable strata, pictured in cut No. 6, is selected from U. S. Geol. Sur. Bulletin 647, and represents one of the best illustrations of that form of earth picture available to the writer. Indeed, all of the pictures reproduced in this booklet, except cut No. 7, first appeared in Government publications.

It will be seen that the position of the beds lying against the andesite of the Livingston formation could not be known except by drilling at many places, or because of their exposures at many localities in the related geological areas.

Various local areas in Texas, such as the productive district adjacent to Desdamona, in the Electra area, in the developing areas along the Marathon Fold in the west-central portion of the State, Mitchell County, etc., first investigated and mapped by the present writer in 1919, are expressive of many unconformities. It has been essential to such knowledge to compare drill cuttings from many wells, though the general fact was determined by geological investigation. In and around the great Healdton oil field in Oklahoma the drills have provided accurate information of lines of unconformity, though at the time of the first examination of the area, when the writer made the location upon which the discovery well was drilled about twelve years ago, many lines of unconformity were indicated in the report upon the region.

Formations lying upon rocks of older or younger stages express such interrupted age position to good advantage where several beds are exposed in deep depressions, and along hillsides which embrace considerable areas in their slopes.

The diagram shown in cut No. 6, clearly sets out the position of the beds underground in an area familiar to the writer. At points many miles distant in different directions some of these strata are exposed. At other places others of them are exposed, and at still other places others are upturned to the surface. It is by noting such conditions with relation to other stratigraphic and lithologic facts that we are able to determine with a reasonable degree of certainty what beds were to some extent wasted away before later beds were put down over them, causing what is termed an unconformity. That determination is in some regions impossible, though there are yet other methods involving many complex and baffling problems which may be employed in arriving at working conclusions. They are too intricate to admit of treatment here.

The diagram shown in cut No. 7, is a vertical chart of the formations embraced in a structure of the anticlinal type investigated by the writer recently for a California oil company. The area lies in the geological province which includes the productive district of Coalinga, and in the main embodies identical formations with the last named oil fields.

Disclosed by the exposures of the uplifted Tejon sandstone formation of the Eocene deposits, the first sedimentation of the Tertiary period, the anticline passes southeastward from near the middle of Section 3, Township 6 South, Range 7 East, in the foothills west of Patterson, Stanislaus County, California, in a definite arc to a final southwesterly direction, ending in the southward tilting beds along the south line of Sections 35 and 36 of the township and range named. It underlies approximately 9,000 to 11,000 acres. The Moreno shales, the last deposit of the Upper Cretaceous formations in that region, underlie the sandstone mentioned. It is known to be a petroleum-making formation and to be delivering oil in profitable amount from wells in the Coalinga district.

The last named formation is principally shale, though sand lenses exist in it. The first formation named is principally a sandstone body, though shale members of varying thickness are found in it.

It is noted that these formations lie in proper relative position for the gathering of petroleum into the upper out of the lower strata. The Moreno is known to be organic and is equally known to produce oil. The Tejon is of a porous character, as all sands are to a greater or less degree. The beds lie in a series of inclined strata which dip towards the east away from the apex of the Coast Range, it being possible to follow their upturned edges from the Coalinga district to the area of the structure west of Patterson as described.

Lying towards the east is the San Joaquin Valley, under which the beds lie, as has been determined by reason of their exposed edges on the east side of the valley where they have been uplifted along the slopes of the Sierra Nevada Mountains.

The extent of the formations throughout the region from which petroleum may have been gathered by drainage into the structure is very great, being possibly as much as 150 square miles in areal dimension at their sub-surface level. The thickness of the Moreno, which is the oil-making member, is somewhat near a possible average of 800 feet; hence the possibilities of the anticline containing oil in profitable amount appear very well founded indeed.

In San Joaquin Valley towards its eastern border, a considerable distance from Bakersfield, the writer has investigated a structure which it is thought contains an accumulation of oil, and which will in time no doubt be exploited by test drilling.

South of Devil's Den, west of the Lost Hills field, another structure has been examined which should contain oil in profitable amount. It now has a drill located upon it at a point which it is thought will prove its possible value. A considerable distance southeast of the anticline described west of Patterson, in Township 6 South, Range 7 West, which was called the Salado Anticline by members of the United States Geological Survey in Bulletin No. 603, there are evidences pointing to a very extensive anticlinal fold, which, if actually present, is ideally located to have gathered an accumulation of oil of large proportions.

The writer believes that there are oil fields in California, as well as in the mid-western States, which have not been opened, basing that opinion upon many more or less critical investigations made during the past 20 years. As to California, it appears that there might be profit resulting from more detailed and careful investigation of various areas in and along the borders of Sacramento Valley, where the formations are in many places similar and in some places identical with formations in the south valley. There are areas where structural conditions warrant the opinion that oil accumulations exist, and such regions constitute an integral portion of the varied and wonderfully rich domain known and loved by us as California. In Texas, Louisiana, Oklahoma, Kansas and New Mexico, including areas in Illinois where critical examinations have been made, the writer knows of localities where new fields will probably be opened.

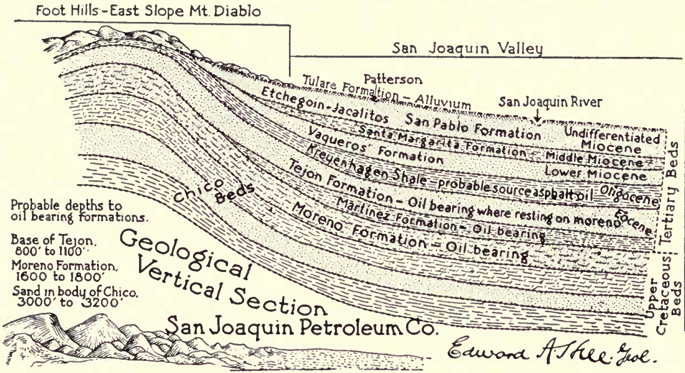
With the constantly increasing number of avenues into which the refined products of crude petroleum are poured, and the ever-widening and extending necessities of expanding industries essential to the prosperity of the race, there appears to be an equal broadening of the opportunities for great wealth held ready for the intelligent, capable and straightforward oil field promoter.

Falling within the experiences of the present writer throughout an active professional life extending to all of the oil-producing regions of the United States, he has seen very few men indeed who failed of success in the oil fields if their purposes were clean and logical, if their good names were kept good, if they were counseled by scientific advisers of experience and ability, and if they followed with determination the rapidly opening fields of this great industry.

While it appears true that the known sources of great oil production are being rapidly depleted throughout the country, it is equally true that there are a very large number of regions in many of the States where the present writer has in times past made critical and extensive investigations, some of which will quite surely be opened to production and which will deliver quantities of oil for the enlarging needs of the world, and will in equal measure make and break promoters in about the established ratio of the past. He that drills at random will in many cases lose, while he that drills upon proper counsel will in most cases win.

The United States may be kept at the fore for many years in oil production among the nations of the world. California may be kept in the lead for many years in oil production among the States of the Union.

Pacific shore lands will be the most active portion of the world throughout the next century or longer. California is on Pacific waters.



Cut No. 7—Salado Anticline

The diagram shown by cut No. 7 was prepared by the present writer for a California oil company, and is representative of a general vertical section of San Joaquin Valley and the foothills of the Coast Range along the western border of the valley.

It will be understood that no possible knowledge available in advance of drilling would be adequate to the exact determination of the precise line where any given underlying formation is cut out, though sufficiently dependable information of such probable line would be obtainable by examination of the whole area lying along the western border of the valley.

Referring to the diagram, it may be said that the formations grouped near the surface, beginning with the bottom of the Kreyenhagen shale and inclusive of the overlying Vaqueros, Santa Margarita and Etchegoin (horizon), are unmistakably absent at a point in the picture which may be pointed out as the top of the oval hill shown under the word "East." The diagram was intended to predicate the general position of the formations along the western border of the valley, but with direct reference to the location and character of Salado Anticline west of Patterson. The Tejon formation is known to be disposed on the surface in some places along the apex of the anticline, though in many places it is hidden by a thin covering of the San Pablo. Exposures of the edges of the inclined beds immediately west of the anticline are proof of the absence or presence of certain of the otherwise sequent deposits embraced in the fold. Such upturned edges when followed southward to the productive fields indicate with equal assurance the recurrent lines of unconformity indicated in the cut.

CHAPTER VIII

NOTES ON OIL COMPANY PROMOTION AND RELATED SUBJECTS

THE lure of quick returns and great riches appears to be the compelling attraction which turns the efforts of many promoters in the direction of oil company promotions. The drilling of oil wells throughout the United States and elsewhere in the world has been made into a history of spectacular delight to the shrewd men whose energies are given to the enterprise.

The Bulletins of the United States Survey, and the Professional Papers, Reports and Statistical Reviews published by the Department, together with the annals of the oil fields everywhere, have supplied documentary evidence in quantities amounting to actual proof of the tremendous riches hidden in the oil industry—when such documents are subjected to the winnowing processes employed by men whose wish is to uncover the promises and neglect the snares that inhabit the business.

It will be admitted that if a statistician is actuated by a desire to establish the very high percentage of paying wells to the whole number of wells drilled in any good paying field, the facts extant upon the subject provide the necessary material to amass the proofs needed. If such array of established facts relative to some special field be applied to the fields in general throughout the country it will be found that the ratio of paying wells is rated entirely too high. If, again, such ascertained facts be applied to the possible fields throughout the country and to regions where oil is possible of occurrence in profitable quantity but has not yet been discovered, the hypothetical inference will bear no relation to the real facts.

This is equivalent to saying: If we assume that there were a total of 5,657 wells drilled in the old Glenn Pool in Creek County, Oklahoma, and of that number it is found that 95 per cent of them were paying wells, and that by reason of that established fact we may expect 95 per cent of the wells to be drilled within the area of any oil-producing State will be paying wells, it will be found that our estimates are very much awry.

If we further assume that a vast lot of wildcat drilling is being done in a region, say for illustration, in the State of Texas, and we are possessed of the knowledge that that State has about 40 fields where oil in commercially profitable amount is being produced, and is generally known to be a region favorable for oil, it does not of necessity follow that the same percentage of paying wells will be found in the wildcat areas to the whole number of wells drilled that will be found in the more nearly proved districts.

Suppose that there are 4,000 wells actually under the drill at any given time in the entire country, but that of the whole number stated four-fifths of them are drilling in partially proved and proved areas, the others are drilling in unproved regions. This would mean that about 3,200 of the drills are at work in areas where oil should be found, while 800 of them are in areas where the possible oil-bearing formations are so far untested. Actual facts heretofore proved by drilling in a vast number of districts throughout the United States appear to have shown that of the 3,200 wells somewhat near 90 per cent of them may expect oil in paying quantity; the 800 in unknown regions may expect a possible 8 wells out of the entire lot. Now, it will be noted that the percentages of dry holes to paying wells out of the whole number drilling would be but little changed, though nearly all of the profitable wells would actually be found in the areas where oil is a most reasonable expectation because of its known presence in the geological complex.

The tremendous excitement which attends the bringing in of a big field in a new area has the effect of immediately setting the promoters busy in acquiring leases and starting the drill in many impossible regions, of some relation in some cases to the known facts of the productive area, and in other cases of no known relation to them whatsoever. It is admitted that sometimes new fields are really opened by such indiscriminate drilling, but in proportion to the whole number of such untoward attempts the successes are very rare.

In arriving at a dependable opinion relative to the ratio of profitable wells to the whole number of wells drilling in any given State it is essential to ascertain how many such tests are being put down in regions where oil has not yet been proven, usually distant from present oil production, as distinct from the tests that may be drilling in proved and partially proved areas.

An experienced scientist will usually be equipped with the knowledge necessary to determine if good opportunity to discover oil exists in an untried region though it may be distant from present oil output; but such information would be too much to expect of any man whose training and information do not include expert knowledge of geological formations and structures which are adequate to the making and impounding of oil.

Wholly aside from the aspect of the geologist's profession as an economic asset to the oil-producing industry, there exists an ethical side to the matter. Such subjects are often treated by learned men in the journals and other publications of a scientific character devoted to the professions, but it is not often that we see the matter mentioned in mediums of general circulation.

Except by a few world-renowned geologists it was not thought that the science of geology could have any relation to the knowledge of oil well drilling and oil production, until long after the output of oil in America became very great. The first well drilled for oil in the United States was at Titusville, Pennsylvania, in 1859. Thereafter during a period of 15 to 20 years the industry was feeble, undergoing the formative stages through which nearly all new things of an economic character pass. Extensive fault planes partly determined the direction and width of the oil accumulation areas in the first great Pennsylvanian fields, and as the drilling progressed along the plane in which the oil was impounded it was found that profitable wells were opened. If the drilling diverged from that line there were dry holes. That fact gave rise to what the drillers called "Oil Lines." Wells were located in new areas by the simple process of placing a ruler upon the map of a region so that its edge passed through the productive areas, the proposed wells being spotted on ahead of known production along the line mentioned. Geologists were derided—the old Pennsylvania driller had small use for the profession; his father found oil without science and what his father did was good enough for the son.

During the early years of the Kansas fields many locations were made with the *rule and map.* Drilling near Independence, Coffeyville and Caney had to some noticeable extent developed along a given line, indicating that even in the West as in the East the "oil lines" held good. An operator of note in the pioneer days of Kansas, a man by the name of Bloom, of Pennsylvanian experience, electrified his credulous auditors by announcing that he would ship an outfit over to Cleveland, Oklahoma, and drill a well. He proved to all listeners that the oil line passed near Cleveland as it plunged its way southward out of Kansas. He did move over to the new location some fifty miles southward, and did actually get a producing well. Time and drilling have long since developed the knowledge that it was by the merest good luck that the new location happened to be on a good anticline, and that it was local to the Cleveland area, though embracing oil-making and oil-bearing formations of great regional extent.

Little by little throughout the years, developing in the many oil-producing regions throughout the world, information accumulated and experiences multiplied to the point of convincing oil operators that a scientific knowledge of the character of rocks and their relative position in the earth bear a most intimate relation to the possible presence or absence of oil in a locality. The great oil-producing companies first employed geologists to determine favorable regions where test drilling should be done. Later such advice was sought also in making new locations in a known productive field, since it soon became known that not all locations upon a well-defined oil structure possessed equal opportunity of returning large quantity oil output.

Since about the year 1900 no serious undertaking in the control of men of noteworthy achievement in the oil business has been launched without the counsel of geologists. At this time if one were to institute measures looking to the drilling for oil in an unknown region, and did not include an exhaustive examination of the ground to determine its oil-bearing possibilities, the men of successful experience in the industry would refuse to impute intelligence or honesty to the undertaking.

Even with the facts stated being constantly before us, it appears of statistical record in the documents of the United States Geological Survey, the Geological Surveys and Mining Bureaus of various of the States, and in the private reports of various of the great oil-producing companies, that in excess of 400 test wells are drilled every year throughout the country at locations which have not had the benefit of intelligent investigation by scientists whose opinions are worthy of confidence. It follows quite naturally that an excessively small percentage of such tests result in discovering oil.

It is facts of the character stated which have to no inappreciable extent surrounded the oil-producing industry with a general mental complex which embraces every conceivable hazard. It is generally thought that nothing can represent a danger of loss equal to the peril of oil drilling. The records mentioned bear out the opinion, though in the main it is wrong.

After a region has been critically examined by scientific investigators, and its oil-bearing possibilites passed upon favorably, test drilling carried on at the indicated locations under the direction of competent managers and experienced oil drillers, has been found to result in discovering oil in upward of 90 per cent of the tests. When such test drilling is done at random, without the benefit of a favorable report from competent advisers, the percentage of failures is probably greater than 90 per cent.

Oil promotions which have been rife throughout the country for a period of twenty years induced the enactment here and there, and with commendable rapidity in logically located legislative bodies, of various statutes looking to the protection of the legitimate and the discouragement of the irresponsible company promoter. While it appears that there are heard from time to time certain criticisms directed at laws of the character mentioned, it is the experience of the writer that almost inestimable good has been achieved by the efforts to curb useless and unwarranted promotions, especially as applied to the oil industry.

It will be seen that there would grow up around the conditions which would evolve from the laws referred to, commonly called "Blue-Sky Laws"; the industry of oil drilling; and the province of the geologist as an economic factor in the business; a situation which would include the State Department charged with the administration of the law, the driller, promoter, and the geologist, as parties to any new oil promotion. These conditions have enforced a further necessity which has been taken in hand by various organizations of professional geologists, notably in the direction of formulating certain categorical requirements antecedent to accepted professional standing. The *American Association of Petroleum Geologists* is one of the organizations of national standing; the *International Geological Society* is another; the *Southwestern Association of Petroleum Geologists*, largely devoted to interests lying within the Mid-Continent, Gulf Coastal and Louisiana-Arkansas fields, is another of local note. At this time a movement is under way to organize the *International Pacific Geological Society* in California, which should quite fully provide for adequate representation of professional men of standing in the lands of all Pacific Ocean shores.

Many of the State Universities have added teachers to their Geological departments, and have greatly widened and extended the scope of the scholastic work, making special provision for classes in oil field examination.

It is by such processes that enterprise joins with learning in developing sanely the leading economic resources of the country, and in doing so conforms to a liberal and intelligent application of the laws governing the identification of funds for the purpose. The results which have been accomplished by the administrators of the restrictive statutes defining honest and practicable promotions are as excellent as could be rightly expected from efforts undertaken during the formative stages of such activities. Millions of dollars have been saved to speculators by reason of such laws; and millions in addition have been saved and will be saved to them when it is generally known that geologists of standing and reputation work in harmony with such State officers.

It appears practicable to suggest that amendments to the laws mentioned in many of the States might be enacted to include a complete and readily verifiable statement of the entire purposes of the promoters, not only, but a copy also of a geological report upon the area proposed for drilling made by a geologist of standing, all to be supplied to the administrative department having charge of the province of the law. This simple addition to the laws would in many cases operate to prohibit drilling in new and untried regions where competent knowledge of the formations and structure would perforce advise against it. In addition, it would have the beneficial effect of serving favorably the proper interests of legitimate and honest efforts in opening new fields.

Quite often the very interesting question recurs that geologists might refuse to make investigations in regions known to them to be wholly unfavorable for oil. Also, that they might well withhold their professional services from men or companies that cannot make a proper showing of intention and record. Neither would be practicable or in good practice. The surgeon asks no questions with respect to the causes of injury before operating, unless he knows that penal laws have been violated; even then he operates and discloses the facts to the authorities afterward. The lawyer asks no questions relative to the standing of his client if the proper fee and a right issue are offered, except that he really has knowledge of law violation. The subject is one of an ethical character, and must be answered by the geologist as it is answered by men of other professions; that is, Is the thing offered honorable and of good report? The surgeon's knife has at times uncovered the seat of trouble where it was not suspected, as the geologist has found adequate evidences of oil accumulation in areas which he had previously supposed to be unfavorable.

However, the fact must not be lost sight of that there is no man of greater value to a community than a capable, conscientious promoter. It is during the period only before success has followed his efforts that his methods are questioned, or his objects and purposes are adversely scrutinized. After the initial success, and after there develops from his activities profit-paying, stable enterprises resulting in general good, is he admitted to the inner circles of *solid business.* One should not quarrel with that fact; it is a situation no amount of discussion will change. There may be cases where the restrictions of the laws and the regulations of commissions appear to render more difficult the speedy accomplishment of a worthy promotion; but it should be borne in mind that such conditions also operate to remove from the field many who would take advantage of the absence of such restrictions and such regulations.

During the past few years the writer has observed that there is a rapidly growing sentiment among promoters everywhere to more fully and definitely trim their activities to the strict ethics of speculation, and to so order their promotions as to actually give the people who supply the funds a *square deal* and a *clean run for their money.* It has been noted further that few will complain of having lost their money if they realize that they have been treated fairly, and have had to contend only with the hazards nearly always present in any enterprise which offers the possibilities of very big profits in a comparatively short time. It is when a stockholder believes he has not had an honest chance that he will complain, and very justly so.

The blue-sky laws are day by day making it safer and better for the honest promoter to successfully launch and complete his enterprise, and day by day more difficult for the unscrupulous promoter.

LETTER FROM DR. GEORGE H. HOOK, GEOLOGIST, REQUESTING THE AUTHOR TO INCLUDE CHAPTER IX IN THE BOOK

San Francisco, California,
February, 1922.

Dr. Edward Allison Hill,
San Francisco, California.

Dear Doctor Hill:

The writer has been afforded great pleasure by availing himself of the privilege extended by you to read the proof sheets of the entertaining and instructive matter in *GEOLOGICAL NOTES ON OIL STRUCTURES.*

While the epitome of geologic history gathered into the brief compass of an article written for the Fort Worth *Star-Telegram,* which treats in a masterly fashion the fascinating subject of successive formations for millions of years as they are found underlying Tarrant County, Texas, might not be thought cognate to the matter of the book, it would be a real loss not to incorporate that profound study as a part of your delightful analyses of earth forms and oil structures. It deserves a place in a work of permanent value, and in that form it will add to the interest of the reader while it impresses him with the knowledge that you are in full possession of the abstruse as well as the simple elements of your profession.

The writer adopts this opportunity of again expressing to you his appreciation of the honor of reading your book before its publication, and wishes to suggest that the layman will find in your work a most pleasing, direct and forceful exposition of the subjects treated. Interesting and instructive books are rarely found which cover so fully and in such every-day language any of the deeper and more technical aspects of the many departments of any economic science; your book achieves such objects in a very happy manner.

I have the honor to remain

Fraternally and sincerely,

George H. Hook,
Geologist.

GHH-S

CHAPTER IX

(Requests of many friends of the author to include the following article is complied with. It first appeared in the Fort Worth Star-Telegram, of Fort Worth, Texas, Sunday, May 8, 1921.—Ed.)

TARRANT COUNTY GEOLOGICAL HISTORY REVEALED BY DRILL

In Period of 10,000,000 Years Both Land and Sea Existed Here—Some Queer Animals

By Edward A. Hill

DEEP well drilling in Tarrant County has revealed the geological structures upon which Fort Worth's skyscrapers have been built as well as the prehistoric record of this section. Cuttings through the various formations take us back ten million years or more.

The sands, limes and shales that have been uncovered by the drill in the Burchill well in Polytechnic recount eras of hot deserts, the submerging of waters of cold and warm seas and alternating ages of arctic, tropic and temperate climates.

Cuttings from the Aledo well and from other deep borings in counties west of Tarrant supply evidence that monstrous creatures roamed or waddled awkwardly over the land or slid slimily into seas of an ancient world. These wells also tell of profuse and entangled verdure.

No species of plant or animal ever has returned after once it passed. Nature cleared the page as one erases figures from a slate when once the infinite object of life was achieved.

First were the Azoic rocks, void of organism, lying doubtless 7,000 to 10,000 feet under the pavements of the city. No drill near Tarrant has penetrated to their great depth. But we believe they are there because in other places we find them lying under formations which are here. Over Azoic are rocks called the Proterozoic formations, which contain traces of organic life.

Sea Life First

After that are other series called Paleozoic rocks, meaning ancient life formations. No hint of any land life has been found in them. Evidently living organism passed all or nearly all of its life in the waters that formed the seas of those ages.

The succeeding era was the Mesozoic, the last one before the era in which we live, the Cenozoic. Some have liked to say we live in the Quaternary. We live in the early part of the Cenozoic—probably the spring season of it.

At the opening of the Paleozoic we find the oldest known normal fossils, and we know that they are at very great depth under Fort Worth. Before that time billions of varied genera and species lived in the waters. Throughout the last named period, and in the Ordovician and Silurian, the two next succeeding periods, what we call Cystoids (stone lilies) grew in the seas and upon their bottoms in immense profusion. Their remains have in some places made great bodies of limestone. Also there were marine scorpions not unlike their stinging posterity of today, some of them attaining nine feet in length. Fossils of the latter have been found in the limestones of Travis County. In early Cambrian times nearly all of Texas was dry land. In late epochs of that period a sea covered the State and adjoining regions.

Armour Bearing Animals

In sea life the mollusks and arthropods were legion. Trilobites rolled up, unrolled and scuttled away from the bigger and more active Cephalopods, other armour-bearing marine animals. Famous slate quarries in Wales and in New York and other places are in rocks of Cambrian age.

Then came the Ordovician age (Lower Silurian), during which the nearest land surfaces to what is now Tarrant County were islands extending chainlike from Wyoming to Arizona, and in what we know as the Ozark region in Missouri and Oklahoma. A great authority has said that upward of 1,600 classified species of animals are known from the Middle Ordovician alone.

In the Upper Silurian limestones we find that Crinoids became so prolific that they formed veritable flower gardens in the seas. Horned crawfish-looking fish, some with hook-shaped beaks, were in the waters. Probably sharks of primitive type, among the first vertebrates, were also in the waters.

Strata Here Untapped

But none of the drills near Tarrant have penetrated to the depths of the foregoing forms; nor have they reached the formations made under a later and much more extensive sea, the Devonian. Yet it is probable that in the midst of that period the seas withdrew from a considerable of the land area of Texas, and that Tarrant County and large adjacent regions were dry land.

The seas of the Mesozoic era possibly came nearly to North Fort Worth. Great fishes like sea cows ground their food with a sidewise motion of the jaws, gyratory, somewhat as cud-chewing animals do now.

In the earlier period, the Mississippian, nearly all of North America was submerged by waters. Drill holes not far from Tarrant have penetrated to rocks of that age, hard, crystalline, massive.

About 140 miles northward an island was formed then by an upthrust of the strata, the upheaval releasing to the flood vast quantities of sulphurous, iron-bearing waters. The Arbuckle mountains were made at that time. But before the end of the period the waters withdrew from many localities and the exposed rocks were denuded by erosion. We know that there are hills, ridges, valleys and great tilted sub-surface areas that were the result of the wastage wrought by the elements and the buckling strata. The drills have shown this in many places.

Minerals of Mississippian

Many animals survived from the Devonian to the Mississippian, and flourished throughout the latter, multiplying and developing. Many and varied values of an economic kind are taken from rocks of that age. Much of the oil in the Eastern States and some of it in Kansas and Oklahoma come from formations of that series. Vast quantities of salt are pumped from them, and zinc and lead are found in their later members in Missouri, Kansas and Oklahoma. Great cup-like, flower-appearing corals of that age were in abundance. Ivory-like, bead-shaped embedded heads of Crinoids, beautiful sea growths of lime, are nearly the entire component of many beds of limestone of that period. Their growth must have been widespread and excessive.

Of the vertebrates, the shark shows the greatest development from Devonian times; it grew very big and was very fierce and bloodthirsty, but without anything like a living man to eat.

In the Pennsylvanian period, the great middle series of the Carboniferous age, we are nearer home as to depth, but long ages removed in time.

It is near us in depth under our streets. If we were to dig a hole fifteen times deeper than our tallest skyscraper is high, the bottom might be upon the formations of Pennsylvanian age. The waters over this region then formed great bodies of limestone, shale and sand rock, beating for hundreds of thousands of years against the walls of the Arbuckles, which were formed in an earlier age 140 miles north of Tarrant County.

Plant life was far more prolific then than in any previous period. Our present ground pines are direct lineal descendants of plants of that age. Their ancestors we call Lycopods. What are known as Equisetas, our present horsetails, growing along creeks and ditches, were also representative of Lycopodian vegetation.

Swamp of Forests

Over in the region of Bridgeport and in Palo Pinto County and Jack, and in the numerous places where we now mine coal, vegetable growth of the character mentioned must have been in bewildering swamp forests. Our coal measures are made of them and kindred plant life. What we call Cordaites grew in swamp and marsh lands in impenetrable profusion, for we find their remains in our coal bodies in vast amount. Sometimes they were 50 to 100 feet high, their diameters from two to five feet, their leaves from five to six feet long and as many inches wide. Certain of their species are called Sigillarians, meaning seal-trees, so called because their trunks bore seal-like impressions running spirally around them.

Now, at about the time of the ending of the period a vast sea of blood-red waters came to the shores where Weatherford now is. We know its place in geological history as the Permian period. The great ranch country of Texas is upon earth deposited during that period. It was made throughout a transition stage between the Paleozoic and Mesozoic eras. Plant life was more scant, which means that animal life was not so varied or so extensive as during the Pennsylvanian.

True reptiles of monstrous size and great beasts which developed out of the lesser species of earlier times, were to be seen along the shores of the red seas. The waters spread northward as far as Idaho, southward into what is now Mexico and westward to New Mexico. But it is not quite true to speak of this widespread water as a sea, as it consisted of great lakes, rivers, shallow and deeper bodies of water in its later epochs.

Heavy, Awkward Beasts

Where we now live, snake-like beasts with sharp teeth, long, cumbrous tails and short, heavy legs, waddled in the soft muds of the shore and over the semi-arid lands. Upon the bottoms of the water bodies, as well as during the following periods, the Triassic and Jurassic, great deposits of gypsum and salt and dolomite were made. We are plastering and whitening the walls of our homes with the first, sometimes building them of the last and seasoning our food and feeding our cattle with the other.

The Permian period ended with a great physical disturbance. What is called the Appalachian Revolution occurred then. By its action there were born the mountains of that name in Eastern United States, and the Ouchita Mountains of Oklahoma and Arkansas were then strung in zigzag along the horizon to define Homer and Caddo and other oil fields. The region of Tarrant County remained dry land.

Animals of Permian Age

Though the animals of the Permian were often clumsy, clinging to and bending down the branches of trees to eat the foliage; in the Triassic and Jurassic, they were huge and fierce. The nearest shores of the Triassic sea were about the vicinity of Bluffdale, and some of the blundering creatures with arm-like, nimble front legs, doubtless had habitat where now flows the Paluxi River. Mostly the land surfaces in the southwestern regions of the United States were desertlike during that period, the climatic conditions arid. Yet in Arizona, in what we call the Petrified Forests, there are tree trunks 100 feet long and ten feet in diameter, dating back to the Triassic. Such trees grew near water or during a less dry epoch. In Erath County not more than forty miles from Forth Worth there are great tree trunks, silicified, heavy, solid rock, that are part Cretaceous, but probably also part Triassic. What we know as Cycad trees grew then as they now grow in Mexico.

First Feathered Birds

The first feathered birds known to the earth came then. There had been great flesh-eating, ravenous, smooth-skinned, birdlike reptiles, reptilian-birds, in the world for long periods, but no feathered songsters. Moisture increased during the latter part of the period and the balmy air and greater dampness clothed the vast Western and Northwestern plains with verdure.

In excavations for our tall buildings, in the railway cuts, along the deep channels made here and there by Trinity River, are to be seen the layers of rocks of Cretaceous age. Towards the Gulf of Mexico these rocks are covered by formations of later periods. At Galveston, drills have shown that there are later deposits of 3,000 feet in thickness. Though our homes are built upon the solid foundation of the Cretaceous period, we are surely removed from it by something like a million years.

Throughout the period there was an extensive sea connecting what are now Gulf waters with the oceanic basins of the Arctic region. Tarrant County is about 140 miles south of its northeastern shores, which bent northwesterly and then northward toward the pole. Under that water in this area thick sand deposits were put down. We know these deposits as the Trinity, Woodbine and other sands. Afterward were earth movements which depressed the bottom of the sea and limestones of great thickness were deposited. We call that the Fredericksburg lime. Later, what we know as the Austin chalk was put down, far from shore. Its purity and freedom from wastage carried away from land masses prove that.

Cretaceous Oil

In the Cretaceous much oil and gas have been found, and without question vastly greater quantities will yet be developed. The fields at Beaumont and Corsicana, and later at Mexia, are producing from rocks of that age. Some have thought that there are very good reasons for believing that profitable fields will be found in formations of that age near Fort Worth.

What is called the Rocky Mountain Revolution occurred during the ending epochs of the Cretaceous period. The folding and the buckling of the rocks of western North America, the Isthmus and South America happened then. The turmoil traveled from Alaska to Cape Horn, in some places upturning strata 20,000 feet in thickness. Mountain chains were made with peaks sometimes as much as fifteen miles high.

Volcanic Eruptions

Far towards the northwest was a red flare of light reflected by the dust-filled air near where are now Rabbit Ear Mountains in northern New Mexico. There were volcanic eruptions near there then. The Black Mesa is there today, a lava flow formation.

At that time Tarrant County was covered with sea water, but it was not very distant from the northerly shore. The whole firmament was filled with fine, suffocating dust, blown about thousands of miles by the contrary and shifting winds. The logs of wells have disclosed such conditions.

The eruptions continued throughout the succeeding period, the Tertiary. The infusion of volcano waters and gases into the seas, and the breaking up of the solid foundations of the earth in so many places and at such widely separated localities, resulted in great changes in the existing forms of animal and vegetable life.

At first Tarrant County was some 300 miles north of the more northerly shores of the Tertiary waters. Later it was about midway between a great epicontinental sea toward the northwest some 250 to 300 miles, and another southeasterly nearly an equal distance, but the area of Fort Worth was land. To be sure it was a land of many lakes and rivers, marsh and swamp and slough and embayment, a soggy land. Also, it was a warm country. Fossils are in abundance and are satisfyingly accurate in denoting a warm climate even to the northern boundaries of the United States. Figs, palms and magnolias grew over the Great Plains.

Life Forms Change

But all life forms had undergone bewildering changes. Many forms took on grotesque shapes, struggling with the sulphurous waters and the gaseous air to adapt themselves to swiftly altering conditions.

What we now know as the Glacial periods fell athwart the hemispheres during the times named. During a part of the ice epochs we know that the ice sheets extended as far south as Texas, and irregularly to about that latitude across the continent. Across Northern Kansas and in Illinois and Indiana, where the debris is accumulated in most pronounced dunes, terraines, ridges and mounds, we easily and certainly trace the approximate southern margin of the vast ice sheets. Their melting dropped down boulders and gravels carried in the ice from Labrador and Greenland and from other far northern Laurentian rock lands.

The last glaciation was something like 35,000 years ago. It had a relaxing effect upon the meteorological conditions of Tarrant County. The climate was temperate and every variety of vegetation multiplied and increased. Probably it was earlier than the last epoch that Mastodonic tribes of great beasts, called proboscidians, roamed about in the thick wooded bottoms of the Trinity, the Brazos and the Colorado Rivers. In the Carnegie Library at Fort Worth are a pair of ivory tusks that were found in a gravel pit southwest of the city a few miles. These are but a specimen among many that are like, and very many that are different, which represent other parts of the skeleton build of these and other great animals making their homes in Texas then.