General Principles of Oil Geology As Applied to Montana

By L. W. STORM, Geologist.

SCIENCE is obliged to follow carefully before it can lead. It takes facts of any subject and tries to explain them and their relation to one another. If it can do this, it has a basis upon which to make deductions and build out toward new discoveries.

Thus, during the last 50 years, while the oil industry has been making its wonderful advance, the science of oil geology has been keeping up with it and trying hard to get ahead and lead the way to new pools and fields. It can hardly be said to have done so until very lately, for the facts of oil occurrence have seemed to be contradictory. Accidental features have masked the significant ones, and meanwhile the industry could not wait for the correct solution but must push on hit or miss, with many mistakes, using the drill to settle all arguments.

Within the last few years, however, ideas on oil geology have cleared up greatly, so that it has become a valuable guide in the use of the drill. Entirely unpromising fields are eliminated from the start and the number of test holes to prove a new field and locate the oil pools is much smaller than formerly.

In this article an outline of the now generally accepted views, which most practical geologists use as a working basis will be given. Afterwards these views will be taken up again as applied to the geology and oil possibilities of Montana.

Nature of Petroleum.

Petroleum consists of a mixture of hydrocarbons; that is of substances composed of the elements: hydrogen and carbon combined chemically in definite proportions. Hydrocarbons, mostly of very complicated molecular structure, are the chief substances forming the softer parts of plants and animals. Lime and a smaller amount of phosphorus and silica enter into the composition of bones, shells and many other parts, particularly of animals and low orders of plants, but hydrocarbons are the chief substances concerned in the chemistry of life.

The hydrocarbons of petroleum belong to a number of series of similar compounds, such as the paraffine series of which Pennsylvania oils mostly consist, and the naphthenes, ethylenes and others, which mostly compose the asphaltic oils of California, Texas gulf, Mexico, Russia and most foreign oil fields. Other American fields have a mixture of paraffine and asphaltic oils. The simple members of each series are gases and liquids and the more complex ones are solids such as the paraffine waxes and ashpalt of commerce.

Natural Gas Substances.

To show something of the nature of these hydrocarbons the paraffine series may be taken as an illustration. Its simplest member is methane, chemical formula CH_4 indicating one atom of carbon to four atoms of hydrogen in the methane molecule. This is the principal substance in all natural gas. It is formed also in swamps where it is called marsh gas and is the most prevalent gas in the fire damp of coal mines.

By adding one atom of carbon and two of hydrogen to CH_4 we obtain C_2H_6 or ethane, a less common constituent of natural gas. The addition of another CH_2 combination produces C_3H_8 or propane, another gas. Thus by the continued addition of a carbon and two hydrogen atoms successively higher and more complicated members of the series are obtained, the general chemical formula being C_nH_{2n+2} CH_4 to $C_{14}H_{30}$ are gases at ordinary temperatures. C_5H_{12} to $C_{11}H_{24}$ are included in the gasolines. $C_{12}H_{26}$ to $C_{18}H_{38}$ comprise kerosenes, distillates, etc. $C_{20}H_{42}$ to $C_{35}H_{72}$ (as high as the natural series is known to go) are the solid waxes.

Other series with their chemical formulas are the naphthenes and olefines, having the same chemical formula C_nH_{2n} but a different internal arrangement of the atoms in the molecules and therefore different properties; the acetylene series C_nH_{2n-2} of which only some of the higher members occur in petroleum; C_nH_{2n-4} some of whose members are present occasionally, and aromatic or benzine hydrocarbons C_nH_{2n-6}—present in various petroleums and in coal gases and the liquids obtained in distillation or coal.

Coal and Petroleum.

The relationship of petroleum and coal, the only other important hydrocarbon occuring in the rocks, is shown by the similarity to petroleum hydrocarbons of some of the oils obtained by distillation of coal, especially at low temperatures. The thin liquid known as "pitch" which is one of the chief products of such low temperature distillation consists chiefly of oils and asphalt-like substances similar to or identical with those of petroleum.

Oil shales seem to be an intermediate substance. These usually show little or no oil in their natural state nor can more than a trace of oil be dissolved from them by chloroform or any of the solvents of petroleum. Yet such shales when gradually heated often yield as much as 60 gallons of true petroleum to the ton of shale. It seems to require the heat to complete the oil forming process. Cannel coals on distillation, act in a manner very similar to oil shales.

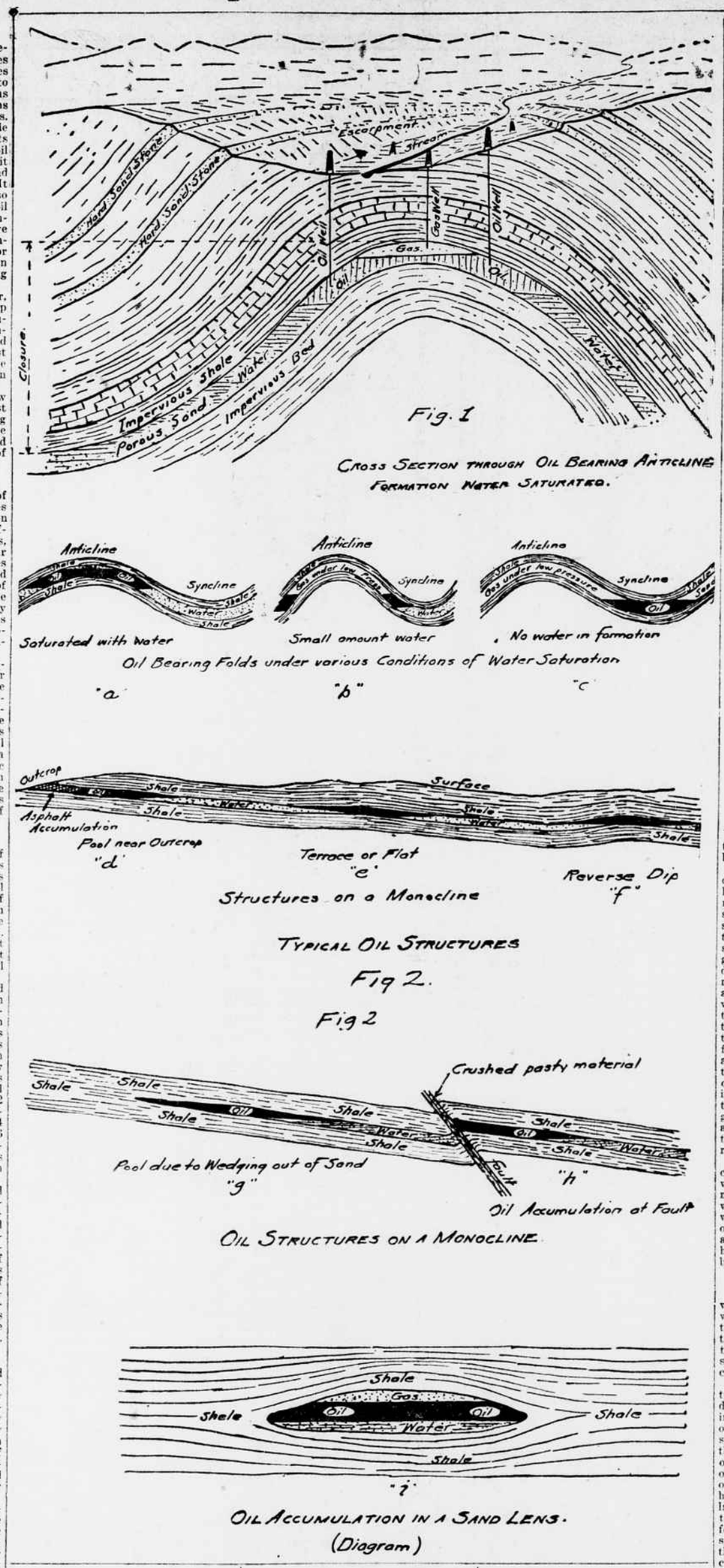
Origin of Oil.

As might be anticipated coal and oil seem to have had a similar origin from organic material. The evidence is very plain that coal was formed by the accumulation of vegetable matter, mostly of woody character in fresh or slightly salty water swamps on land and oil appears to have been formed from accumulations of the remains of sea life in the mud of the sea bottom, including animal and vegetable remains of all sorts from the highest to the lowest forms.

That the amount of such life is ample to account for any known oil accumulation is shown by the existence of beds hundreds of feet thick, composed largely of shells, cases, bones and other hard parts of such organism.

The slow change or decomposition of the softer parts of such animals or plants is thought to have produced oil. Decomposition of all sorts in the air or under water is now believed to be the work of bacteria and many investigators hold that the particular sort of decomposition whose final product is petroleum is effected by certain special bacteria present in the mud of the sea bottom.

It has been held that petroleum is or can be formed without the intervention of life. Those who believe this attribute its origin to the action of certain gases from the interior of the earth upon particular minerals or rocks near the earth's surface. Laboratory experiments indicate that this is possible, but few geologists now believe that such processes have acted on a large scale in nature.



Accumulation of Oilbearing Formations

Of the sediment washed down by streams into the sea, the coarser or heavier part, that is the sand, is not carried out very far from shore. It is deposited near the mouths of the streams or distributed by short currents up and down the shore in irregular beaches and bars. The finer particles and silt which are later compacted into shales are carried further out.

Where the land is rising and the sea therefore retreating, the sand deposits of the shore advance out over the muds deposited a short time previously and then perhaps the conditions are reversed and with the land subsiding and the sea advancing over it, mud covers sand again. Thus beds of sand are often formed over large areas and with many reversals of this sort alternating beds of sand and shale are formed. But the shale nearly always predominates and the deposits of sand tend to be irregular and to thicken and become coarser toward the shore, while in the other direction they tend to thin out or gradually to change into shale. This has an important bearing on the subject for oil tends to accumulate in the sands.

Oil in Shales.

The oil forming material and the oil itself to begin with are mostly in the mud or shales, as the sands are too much disturbed while forming and accumulate too fast for the proportion of organic material in them to be high. However, the spaces in a heavily compacted shale are very fine while sands on the other hand have comparatively large pore spaces between the grains.

Such space averages 5 to 10 per cent and sometimes amounts to as much as 30 per cent of the total volume of the sand. It so happens that the force of capillary attraction, which draws a liquid strongly into small spaces, is considerably greater for water than it is for oil. Thus as the muds are compacted and the water and oil squeezed out, water tends to remain in the shales rather than oil and as more oil is formed in the shale by heat or further decomposition, water tends to displace it also and drive it into the larger spaces.

For this reason commercial oil deposits are mostly in sands, and the irregularity of sand deposits is one of the reasons for the erratic distribution of oil fields and of the oil within a field.

Limestone, the only other marine formation of importance, may act as an oil container or under other conditions as a formation impervious to oil. It is composed of shells, coral derbis, cases of microscopic animals, etc. At a distance from the shore it may be nearly pure, but nearer shore it is mixed with mud and sand. It is often strongly petroleum bearing and is sometimes crushed or rendered porous in some other manner so that important accumulations of oil occur in it.

Formations of Oil Structures.

The muds and sands accumulate often to great thickness and are hardened by their own pressure into shales and sandstones. Then, perhaps, earth movements on a large scale begin to affect these formations Pressure from the sides due to earth shrinkage may tend to buckle the beds into a wavy structure. It may be only gently wavy or strongly folded and broken and the region may or may not be elevated out of the sea. No doubt there are oil fields, structures and all, covered by the sea and unavailable for the present. But more often than not, such folding is accompanied by elevation of the beds out of the sea.

This folding is one way of forming mountains. Another way is more in the nature of a direct uplift. But in either case there is generally parallel to the main mountain range a belt in which the rocks are more gently folded than they are in the mountains proper. Such folding decreases as you leave the mountains and at last virtually dies out in the plains.

The various sorts of structures favorable to oil accumulation are mostly found in such moderately folded regions and thus the principal oil fields of the world lie on the flanks of mountain ranges or are associated with an uplift of some sort. For example, there is the Pennsylvania and West Virginia field adjacent to the west slope of the Appalachian mountains, and the California fields on the flanks of the coast range. All around the Ozark uplift are oil fields in Kansas, Arkansas and Oklahoma. Smaller uplifts account for the oil in Ohio, Indiana and Illinois and for the Texas fields. Finally we have the Rocky mountain fields of which Montana is a part.

The central part of a mountain range is usually of some massive rock like granite that has been pushed up from below and from which the original cover of sedimentary rock has been mostly eroded away.

Oil Seldom Found in Mountains.

What sedimentary formation remains near the granite has usually been subjected to so much heat and pressure and so badly broken that any oil once present has been either driven off or allowed to escape through the breaks.

Oil is, therefore, seldom found in the mountains themselves or even in the foothills, but in the wide belt between the foothills and the undisturbed beds.

Fig. 3

Table of Geological Eras and Periods with Principal American Oil Fields

Era	Period		Known Oil Regions
Cenozoic	Recent	Present	
		Pleistocene	Beaumont, Tex. Jennings La
	Tertiary	Pliocene	Lost Hills, California
		Miocene	Coalinga, Sunset, Los Ang. Cal. Porkfield Cal.
		Oligocene	Sespe, Santa Clara
		Eocene	Coalinga Santa Susana Cal.
Mesozoic	Cretaceous	Upper Cretaceous	Coalinga Cal. Colorado. Lander Alberta (Gas) Corsicana Texas Spring Val. Big Horn Salt Cr. Wyo.
		Lower "	Caddo, Louisiana. Cat Cr. Mont.
		Jurassic	Medill, Oklahoma " " " North East Wyoming.
		Triassic	Chugwater formation Wyoming
Paleozoic	Carboniferous	Permian	Lander. Wyo. Bluff. Utah
		Pennsylvanian	West Va. Pennsylvania Ohio. Ill Kansas. Oklahoma, Devils Riv. Texas
		Mississippian	Penn. W. Va. Ohio. Kentucky
		Devonian	Penn. W. Va. New York, Ontario
		Silurian	New York, Ontario, Ohio.
		Ordovician	Ohio, Ind, Kentucky N.Y. Ontario
		Cambrian	N.Y. Ga. Ala. Ont. Newfoundland
Proterozoic	Keweenawan		No known oil or gas fields
	Unconformity		
	Animikian		
	Unconformity		
	Huronian		
Archeozoic	Archean Complex of schists and granitoid rocks		

In order for a valuable pool to exist, conditions must be such that oil from a large area of sand can gather or segregate into a comparatively small space. The first way perhaps that suggests itself for this to happen is for the oil to run down and collect in some sort of a tight basin in the underground formation and this it frequently does when water is not present, but more often the operation is reversed as the formation is usually saturated with water and this being heavier than the oil seeks the low places and tends to float the oil to the surface, or if there is a tight shale or other tight formation above the oil sand, the oil and gas is driven to any high places that may exist due to folds or other causes and confined in such places. Thus in an oil pool, gas is usually found at the highest point with oil below the gas and resting on water. This is usually salt water and is believed to be the original sea water remaining in the rocks.

To demonstrate this method of accumulation the following experiments were made at the University of Minnesota: Glass tubes of various shapes were filled with a mixture of sand, water, oil and gas and left standing in one position for some time. The oil and gas gradually accumulated at the higher places in the tubes with water below.

Anticline Theory.

The traps where oil gathers are of various shapes and originate in many ways but the commonest place for oil to accumulate is where a tight formation arches over a porous one at the top of a fold or anticline for which reason this theory of accumulation is called the anticline theory.

In Pennsylvania where this explanation was first applied it met with many difficulties due to the very gentle folding and the attendant difficulty of recognizing structures. Irregularity of sands was also confusing and some of the sands were not fully saturated with oil and water, so that the water could only float the oil part way up the sides of the folds. In some cases where oil had migrated to dry sands formed on land, water was entirely lacking and the oil had settled to the bottoms of the folds or synclines. The very detailed study which has since been given to those old fields has explained these discrepancies and virtually established the theory. Its application to each new field tends to confirm it.

The principal oil structures are anticlines and domes, synclines and basins, sand lenses surrounded by tight shales, and the various structures which consist of interruptions or obstructions in sand formations having a general dip in one direction. Such a formation is called a monocline. These types will be briefly described.

Dome Is Like Inverted Bowl.

A dome is a short anticline, the rocks dipping away in all directions, though hardly ever with the same dip in all directions. A structure, roughly like a bowl or bathtub upside down, would be called a dome. If its dimensions were more like those of an inverted canoe it would probably be called an anticline. Sometimes a long anticline has a number of bumps, bulges or domes along its crest separated by saddles. Usually in such cases there is not more than enough oil to fill the domes and the saddles may be unproductive. If an anticline pitches and the formation is saturated with water, the oil works up along the crest of the fold and if not stopped by some obstruction may run out as a seepage at the outcrop.

Synclines and structural basins are the opposites of anticlines and domes. The condition of a formation free from water, such that oil accumulates in synclines is exceptional.

A monocline is usually defined as a structure having a dip in one direction. In such a structure, oil in a sand confined between two impervious layers of shale and in a water saturated formation, tends to work up the slope as in a pitching anticline until stopped by some obstruction. Such an obstruction may be:

A fault;

A local dip opposite to the general one forming a sort of anticline;

A flat place or so-called terrace;

A wedging out of the oil sand or its becoming impervious on account of its pore space being filled with cement or fine material;

An accumulation of asphalt or paraffine at the outcrop by partial evaporation of the oil or by oxidation.

Oil Escapes Through Faults.

A fault exists where a crack or break (usually of considerable extent) has occurred in the formation and movement has taken place along the break so that the two rock surfaces have slipped and rubbed against each other. Faults, more often than not, cause breaks that allow oil and gas to escape, but the slipping usually produces considerable crushed rock, part of which when water is present has been ground to a thick paste. This paste may stop the flow of oil or the formation may be so displaced that shale has been brought opposite the oil sand and the flow blocked in this way.

The other oil structures mentioned will probably be explained sufficiently by the diagrams, figures 1 and 2.

There is a great variety of exceptional structures which need not be described here as the same principles of oil accumulation apply to all of them. A few, however, of exceptional interest may serve as illustrations. For this purpose we may choose:

The oil structure due to unconformity.

The volcanic uplift structure.

The salt domes of the Texas coast.

Some Special Structures.

An unconformity exists where a formation has been raised above the sea and partly eroded, then submerged again and a new formation laid down on the uneven surface of the old one. If the first formation was tilted as well as eroded, the unconformity is called an angular unconformity.

In such an angular unconformity the edge of an oil sand may be overlain by some tight formation which holds any oil that may accumulate after the second set of beds begins to be laid down.

A volcanic neck or an intrusion of molten rock, in pushing its way up through a series of beds may tilt them so that they slope away in all directions. Oil in a sand, beneath some tight formation will have a tendency to work up the slope toward the intrusive mass and if the contact is a tight one the oil will accumulate there. Some pools of this sort exist in Mexico.

Regarding the Texas coast salt domes, no satisfactory explanations of the occurrence has been worked out. But immense masses of salt have formed in some manner and in so doing appear to have heaved up the oil bearing sedimentary formations. Oil has accumulated in many cases around these domes though possibly a hole drilled directly on the top may penetrate salt without finding any oil.

Closure.

The closure of a structure is the vertical distance from the top of the oil trap down to the highest place at which the oil can run out and escape The amount of oil that a structure can contain is limited by the amount of closure but very often there is closure to spare, the structure not being full.

The Gathering Area.

The term gathering or drainage area means the area of sand in which any oil that may be present will tend to move up into the oil structure. On a monocline, the oil moving up the dip will be stopped at the first obstruction. If there is oil to spare, after filling the first trap it will move on to the next. If not, the second structure will have only the gathering area up the dip from the first one. This is a point that should receive consideration in a new field.

The amount of slope which appears to be necessary to cause oil to migrate and collect in a suitable structure is not the same in all oil fields. In most American fields a dip of 20 to 50 feet to the mile seems to be enough. But the productive structures in the California and Rocky mountain fields are steep sided on one side at least. This factor probably depends upon the viscosity of the oil, that is, whether it is thin or thick, the water conditions, the richness of the original oil bearing formations, the porosity of the sands, the amount of time elapsed, and probably also upon whether true petroleum is present in the sands, or simply bituminous shales exist from which oil can be distilled by heat. In the latter case, the heat developed in forming a steep-sided, well pronounced fold might distill some oil out of the shales where the slight heat produced in gentle folding would leave the shale unaltered.

In closing this section on structure we may mention the case of an isolated patch of porus sand, entirely surrounded by oil bearing shale. Even in flat formation, pressure and capillary action of water may force oil out of the shales into the sand and thus form an oil pool. There is virtually no clue to the location of such a pool.

Geologic Formations and Ages.

A description of the geologic formations of Montana had probably best be prefaced by a few words about formations the world over.

The surface of the earth as present consists of about one quarter land and three quarters ocean. Beside the land there is a considerable area of shallow water surrounding the continents and connecting them in northern latitudes. The rest of the ocean is many times deeper and may be regarded as the real ocean basins.

It seems that in a general way the positions of the ocean basins and of the areas where there is either shallow water or none, have remained about the same as far back as the geological record goes.

Sinking of the ocean basins or elevation of the land areas as a whole or the reverse process has resulted in a greater or less proportion of the land being exposed, and differential movements have raised or submerged first one part and then another of the continents, so that the map of the world has changed greatly from time to time. A given area may have been submerged at several different periods, and between times has been above water and part of the formations previously deposited may be washed back into the sea ar redistributed over the land.

Series of Rock Formations.

The formations present and their arrangement, therefore, are not exactly the same in any two parts of the world, but by correlating the rocks exposed all over the world, a series of geologic ages has been worked out and a series of rock formations corresponding to them. This has been done largely by means of fossils, which are the remains of animal and plant life forming a progressive series from the beginning of geologic time.

The diagram, figure 3, shows the ages and periods as worked out for North America, also some of the principal oil fields in the corresponding formations.

The region now occupied by the Great Plains and the Rocky mountain system has been submerged and reelevated wholly or in part a number of times. Twice at least, a sea has extended over the entire region from the Gulf of Mexico to the Arctic ocean. This condition existed during the carboniferous and later in the cretaceous period.

The diagram, figure 4, of the stratigraphic column in southern and northern Montana shows the other marine formations as well as those deposited in the lakes or on land.

The map, figure 5, shows the approximate greatest extent of the cretaceous sea in this region. The carboniferous sea extended further west but not so far east in Montana.

After the cretaceous period, the sea gradually receded and this region was elevated, the Rocky mountains beginning to form at the same time. The history of the region during and since the tertiary has been one of elevation and erosion with deposition of some sediments on land. The glacial drift is one of the latter as it was carried by ice sheets moving from the north, and was scattered over the country in comparitively recent time.

Oil Districts in Montana.

The proven oil fields of Montana and the most promising districts under investigation lie in the moderately folded region east of the mountains. That part of the state west of this belt is occupied either by the mountains themselves or is beyond the area of marine cretaceous rocks. East of this belt the oil possibilities become poorer for several reasons, i. e., the oil bearing beds as you go east, dip down beyond the reach of the drill, being covered by non-oil bearing land formations. The sands fade out as you leave the old shore and the folding decreases so that "structures" are few or entirely wanting. These conditions change again of course, as you approach the Black Hills Uplift.

Irregularities in the front range and outlying mountains to the east complicate the structure and give the eastern edge of the disturbed area a scalloped outline. Some of the eastward projections are faintly traceable well out into the plains toward and possibly by the Black Hills. The map of Montana compiled from a number of sources believed to be reliable, shows the relation of oil districts to mountain uplifts.

Four areas in Montana may be classed as productive. These are: The Elk Basin and Crow Reservation fields in the south; the Devil's Basin and Cat Creek fields in central Montana.

Elk Basin and Crow Reservation.

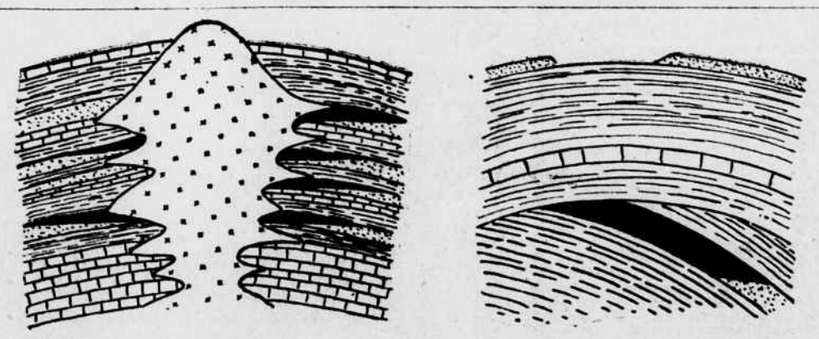
The Elk Basin pool projects over a little from Wyoming into Montana, only about one third of it being in the latter state. The structure is a typical steep-sided Rocky mountain region oil dome. It lies between the two uplifts of the Beartooth and the Big Horn mountains. Production is from the Peay and Torchlight sands which occur in the Frontier formation in the lower part of the Colorado shale. The oil is of a good grade.

The Crow Reservation field is better known as the Soap Creek district. It lies on the northeast flank of the Big Horn uplift. The Soap Creek structure in T 65-R 32 E is a steep-sided dome with about 350 feet of closure, dimensions at the bottom of closure being about three miles east and west and six miles north and south. There is a large gathering area to the east. The Western States company has more than 2000 acres on the top of the dome and has brought in two wells, capped at present on account of no transportation facilities but capable of producing 250 and 2400 barrels a day respectively. Other companies with acreage a little off the top of the structure are preparing to drill. The Tensleep (carboniferous) is the producing sand, reached in the first hole at 1650 feet. The oil is heavy and black and is said on good authority to carry 8 per cent gasoline and 12 per cent kerosene, remainder being fuel oil and lubricants, the latter in considerable amount.

Other neighboring domes are the Rotten Grass, on which Western States company is now drilling, Toluca, Woody and Beauvais structures all more or less promising.

Cat Creek Field.

The Cat Creek anticline is a fold with a series of domes, extending east



Oil around Volcanic Neck in Mexico — Oil Pool at an Unconformity.

After Dorsey Hager.