THE OIL POSSIBILITIES OF ARIZONA

By

D. A. HOLM, GEOLOGIST

STATE LAND DEPARTMENT
STATE OF ARIZONA
Phoenix, Arizona

December 1, 1938

The Honorable Wm. Alberts
State Land Commissioner
State Land Department
Phoenix, Arizona

Dear Sir:

I have the honor of submitting to you my report on "The Geology and Oil Possibilities of Arizona".

This report is a brief summary of the geology of Arizona, based upon field reconnaissance surveys which have been supplemented by a careful study of the available geological literature.

The field work was done between April 1, and December 1, 1938, as part of the combined State and Federal Project, W. P. A. #890, Classification of State Lands. The basic purpose of the survey was to classify state lands in the category of "Potential Oil Lands" or "Non-potential Oil Lands". The detailed description of such lands is not included in this report but is given in the Report on Classification of State Lands which is filed in the permanent records of the State Land Department.

The classification of certain lands as "Potential Oil Lands" was based upon a broad application of the fundamental criteria for the occurrence of oil and is inclusive of lands which lie within a probable petroliferous province.

Considerable place in this report is given to the seepages of petroleum which occur in the Salt River Valley and in southeastern Arizona. The importance of these seepages as evidence of potential petroleum reservoirs can not be too highly emphasized.

It gives me great pleasure to report that the indications for petroleum are favorable in extensive areas within the State of Arizona. In particular, we may consider a large part of northeastern Arizona, the "Strip" of northwestern Arizona, large areas in southeastern and southwestern Arizona, and a portion of the central area; namely, the Salt River Valley, as favorable to the occurrence of petroleum.

Respectfully submitted,

D. A. HOLM, Geologist
State Land Department

DAH/bb

S T A T E L A N D D E P A R T M E N T

STATE OF ARIZONA

Phoenix, Arizona

R E P O R T

On

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D. A. HOLM, Geologist
State Land Department

Compiled under the Direction of

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and
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December 1, 1938

REPORT ON THE OIL POSSIBILITIES OF ARIZONA

I. INTRODUCTION

The State of Arizona, for the purposes of petroleum exploration, may be divided into three geological provinces:

1. The plateau province
2. The central mountain belt
3. The desert range and basin province

These divisions are physiographic and geologic provinces with facies of rocks, topography and geologic history distinct in each.

THE PLATEAU PROVINCE

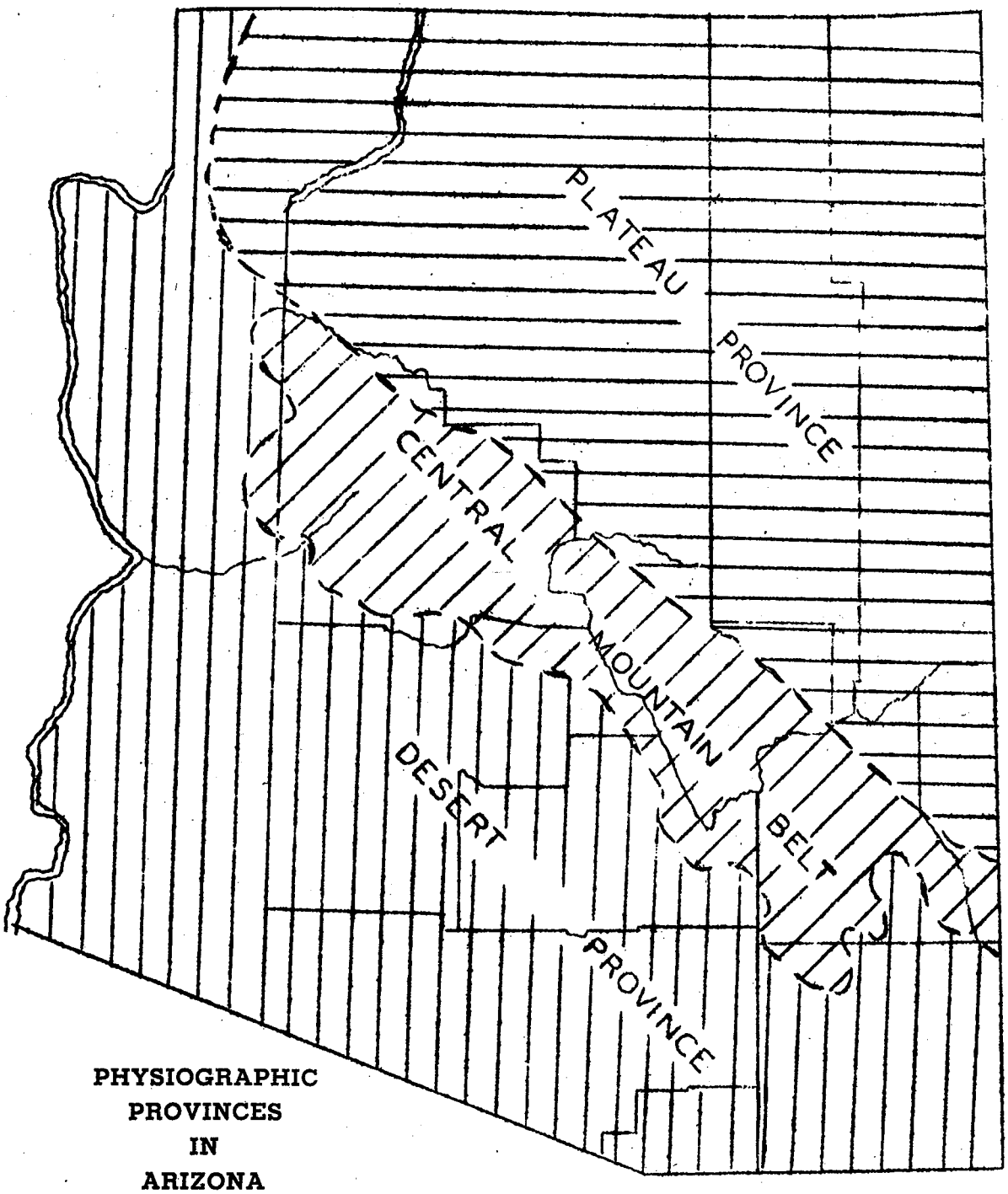
The plateau province includes the larger part of the northern half of Arizona, particularly those portions north of the Mogollon Rim and northeast of the Aubrey Cliffs. The province extends northward beyond the boundaries of Arizona into the plateau region of Utah and Colorado and is a part of the great Colorado Plateau. In this province the rock formations are largely sedimentary, including both marine and continental facies of deposition. In general the older rocks from the Cambrian through the Permian may be regarded as marine, and the younger rocks from the Triassic through the Cretaceous may be regarded as terrestrial. In exception to this classification, the Coconino sandstone of Permian is terrestrial and the Mancos Shale (Cretaceous) is marine.

The formations in the plateau province are more or less horizontal, the exceptions being on the several uplifts which border the plateau where the strata are folded and faulted and in a few minor flexures within the plateau where the beds lie at low angles of dip.

The oil possibilities of the plateau province are considered to be favorable in character. In the marine sequence of formations occur limestones and organic shales which provide a source of petroliferous material. Sandstones are interbedded with these organic formations and provide reservoir conditions for the accumulation of petroleum. The strata are deformed in mild flexures to form a number of anticlinal structures in which petroleum may be trapped.

THE CENTRAL MOUNTAIN BELT

A belt of rugged mountainous terrain extends across the central part of the state from southeast to northwest, lying immediately southwest of the rim of the plateau. This is the central mountain belt. It is composed of numerous mountain ranges, the bulk of which are long and narrow. Some extend in a north-south direction but the majority have axes parallel to the trend of the belt. The ranges are composed of metamorphic and igneous rocks of Pre-Cambrian complex with sedimentary rocks of age ranging from late Proterozoic to Tertiary folded and faulted in patterns varying from simple to complex. Igneous intrusions and effusions have occurred from Pre-Cambrian time to recent with much activity concentrated in Mesozoic



PHYSIOGRAPHIC PROVINCES IN ARIZONA

and Tertiary. The central mountain belt is a highly mineralized region. It has been studied mainly by the mining engineer and mining geologist with emphasis on the mineral deposits. Stratigraphy, structure, geological history and paleogeography have not received much attention. As a result, some misconceptions are current in geologic thought. Among these is the hypothesis that the mountain belt remained as a positive element of the continent during a large part of the Paleozoic time. There is evidence to support the hypothesis that the belt was a negative element at intervals from early Proterozoic to the end of Mesozoic.

Rugged topography and high relief characterize the mountain belt. Peaks rise from 1,000 to 6,000 feet above the valleys. Streams follow steep canyons and have high gradients.

The mountain belt varies in width from ten to fifty miles. The southwest border grades so gradually into the desert basin and range province that the two provinces are difficult to distinguish where they merge.

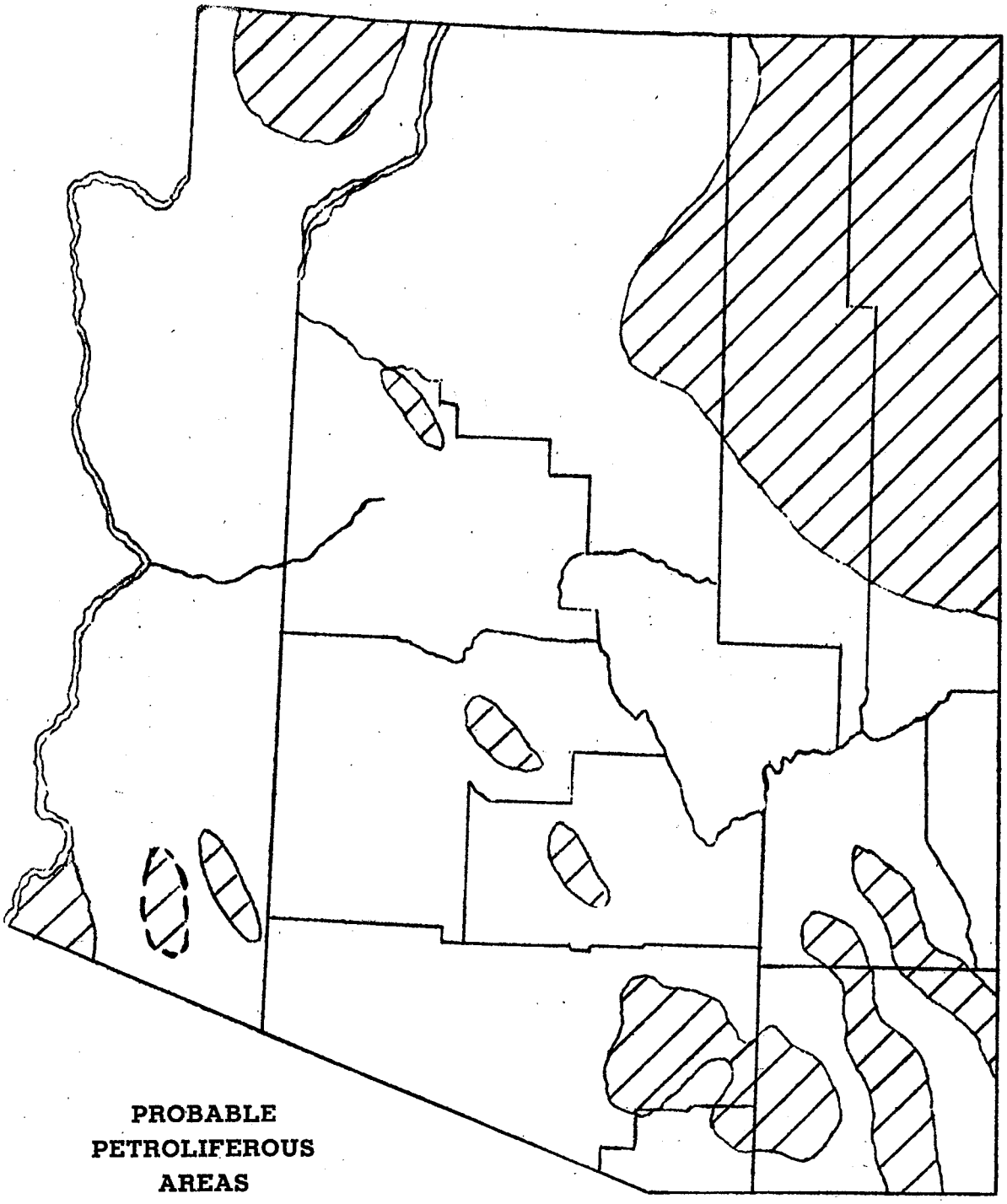
Petroleum possibilities within the central mountain belt are regarded as negative. Folding, faulting, igneous intrusion and volcanic extrusion have occurred to such a degree that little or no petroliferous matter could be preserved in the rocks.

THE DESERT BASIN AND RANGE PROVINCE

The southwest third of the state is a desert plain sloping gradually toward the Gulf of California. Its regularity is broken at intervals by elongate mountain ranges projecting out of the plain. The trend of the ranges is mainly to the northwest with the exception of several ranges which trend to the northeast, i. e., the Harquahala and Harcuva ranges in Yuma County and the Salt River Mountains near Phoenix. Broad, level valleys lie between the ranges. Some are enclosed basins like the Hualpai or Red Lake Basin north of Kingman and the Willcox playa in northern Cochise County. Many intermontane valleys are drained by old rivers, such as the Salt and Gila Rivers and their tributaries. The valleys are filled to considerable depth by deposits of alluvium, either lacustrine or fluvial.

The ranges are composed of crystalline rocks of the basement complex. Igneous and metamorphic rocks predominate. Sedimentary rocks ranging in age from Proterozoic to Tertiary occu rin some of the ranges. Volcanic extrusions of Tertiary age are associated with the ranges and sometimes overlap the adjacent valleys.

G. K. Gilbert's theory of basin and range structure dominates geological thought on this problem. Gilbert visualized the ranges as fault blocks, tilted or rotated to elevate one side of the block. Intermontane areas were basins at first, filling with alluvium from adjacent elevated blocks. Base level was reached eventually and streams cut through the margin of the basins, beginning to cut new valleys in the fill. This stage may have been repeated more than once culminating in the existing broad, level desert plains out of which the ranges appear to rise abruptly. The valleys are thought to be floored



PROBABLE PETROLIFEROUS AREAS

with rock similar to that of the ranges with valley fill a comparatively shallow veneer over the basement rock. Until wells were drilled in the intermontane basins, this theory was tenable. A deep well, to be described later in detail, has been drilled below 6,400 feet near the village of San Simon in the center of the San Simon Valley. Valley fill was penetrated at about 1,500 feet and the next 4,900 feet were drilled in sedimentary rocks which are thought to be marine, at least in part. Oil shows were frequent in occurrence from 1,730 feet down. No volcanic rocks have been recognized. The lower 640 feet is in calcareous conglomerate containing abundant showings of oil and gas. The neighboring mountain ranges, namely Dos Cabezos, Chiricahua and Peloncillos, contain great thicknesses of sedimentary rocks from Proterozoic to Tertiary. It is not unlikely that similar rocks are preserved in the down-dropped block of the San Simon Valley and may eventually be recognized in the strata penetrated by the drill. Another deep well near Bowie had a total depth of 4,110 feet with a valley fill about 1,000 feet thick and a section of probable marine sediments underlying it.

With such data before him, the geologist must reconsider theories of basin and range structure and history. The greater part of the desert province has long been considered to be a positive element. Schuchert located the ancient continent "Ensenada" on the southwestern part and McKee extended the land mass as a peninsula northeast to include the Mazatzal range in central Arizona. Holm has examined the mountains in parts of the central mountain belt and the desert province looking for outcrops of marine sediments. The Paleozoic formations which remain in place today maintain an outline and thickness which suggests that a large part of the so-called positive element in Arizona was covered by Paleozoic seas. The southeastern part of the element was also covered in Mesozoic time by Cretaceous seas. Much of the sedimentary sequence once present in the basin ranges has been removed by erosion after uplift. It is suggested here that the intermontane valleys are down-thrown blocks with sedimentary formations preserved below the valley fill.

The importance of Holm's suggestion to the occurrence of oil in the desert province is obvious. Working on this theory the geologist may expect to find marine sediments in the intermontane valleys below the valley fill and may expect such sediments to be folded and faulted into structures which provide the desired structural traps for petroleum. Exploration of the desert valleys will be arduous and expensive, necessitating exploratory drilling with "slim-hole" portable rotary equipment and geophysical surveys utilizing measurements of magnetic intensity, the force of gravity, or seismic velocities. Other methods such as measuring electrical resistivity of shallow formations may be effective, and the recently developed technique of soil analysis may prove valuable in locating the presence of oil and gas.

II. GEOLOGY AND STRUCTURE OF THE ARIZONA PLATEAU PROVINCE

The eastern half of the plateau, designated here as the Navajo country, forms a broad, more or less circular, shallow, structural basin with beds gently dipping toward a common center and bordered by uplifts on all sides. The basin is bordered on the east by the Zuni-Defiance uplifts, on the north by the Monument uplift, on the west by the Kaibab uplift, and on the south by the so-called Apache uplift which is a part of the central mountain belt.

The Defiance uptlift is an elongate and broad uplift extending from the Rio Puerco on the south nearly to the Utah line, a distance of about 100 miles. It has a width of ten to forty miles. The core of the uplift appears to be a granitic and quartzitic fault block of Pre-Cambrian age, which has been a positive element during and since Carboniferous time. The Pennsylvanian beds of the San Juan Canyon in southeast Utah appear to overlap the flanks of the uplift but do not go over it. Permian and Triassic beds cover the uplift. In Bonito Canyon west of Fort Defiance, Permian redbeds of probable Cutler age lie in contact with a quartzite considered to be Pre-Cambrian, probably equivalent to some of the Proterozoic quartzites of the Mazatzal mountains or perhaps to some of the Proterozoic quartzites of the Grand Canyon region such as occur in the Unkar group. At the entrance to Black Creek Canyon, where Black Creek cuts through the Defiance monocline, Holm measured a section which included at least 600 feet of redbeds of Cutler age at the base. In the Hogback Oil Company well in section 24, Township 23 North, Range 30 East, several miles south of the canyon, Cutler redbeds below the de Chelly sandstone are at least 900 feet thick. Below the redbeds in the Hogback well are about 200 feet of limestones and sandstones which rest directly on decayed granite, 75 feet thick, which in turn rests on fresh gray granite. The sedimentary beds on this part of the uplift are a little more than 1,400 feet thick. In the area of Canyon de Chelly the sedimentary section is probably 600 to 1,000 feet thick, according to the record of a well drilled at Nazlini which penterated to granite at about 600 feet.

The Defiance uplift is probably barren of any oil bearing strata and is considered as unfavorable territory for oil exploration.

The Monument uplift is a broad uplift crossed by the San Juan River which has cut its deep canyon through the highest part of the uplift. The uplift is not a simple upwarp but is crossed by several north-south folds which are described in detail by A. A. Baker in U. S. Geological Survey Bulletin 865 on the Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah. Some of these folds extend southward into Arizona from Utah and may have oil possibilities. Several wells have been drilled on the folds near the San Juan River in Utah and a small production of oil obtained. The country is rugged and inaccessible and presents rather poor prospects for petroleum exploration at the present time. The struc-

tures lie within the Navajo Reservation and come under the control of the Department of the Interior.

The Monument uplift is bounded on the south by the Comb Ridge monocline which extends from Kayenta northeast across the Utah line to the San Juan River. The formations present on the uplift range from Pennsylvanian (Hermosa formation) to Upper Jurassic (Morrison formation) in age.

The Kaibab uplift lies largely west of the Marble Canyon of the Colorado River, which is cut through the east flank of the monocline from Lee's Ferry to the mouth of the Little Colorado River. At its south end, the Kaibab uplift plunges to the south just north of San Francisco Peaks.

The rocks present on the Kaibab uplift are all well exposed in the walls of the Grand Canyon and are described in detail in reports of the U. S. Geological Survey on the Grand Canyon region, particularly those of L. F. Noble. Oil possibilities on the Kaibab uplift are poor due to the exposure of possible petroliferous beds in the Grand Canyon and to the probable absence of Pennsylvanian formations from the uplift.

The southern rim of the plateau is marked by the high cliffs of the Mogollon Rim, from the edge of which the strata present dip with uniformity toward the center of the basin. South of the rim lies the remnants of a great uplift called "The Apache Uplift" by Dorsey Hager because of its location in and near the Apache Indian Reservation. The term is in disuse. Central Mountain Belt seems to be more appropriate as the uplift includes several mountain ranges and is not restricted to simple vertical movement in an individual uplift.

The term "uplift" may seem a misnomer to the layman who stands upon the high rim of the Mogollon plateau and looks down on the uplift. The term is used here strictly in the geological sense inferring that the geological structure is that of a once greatly uplifted region. The geologist, aided by imagination and a sound background of geological observation, can reconstruct the appearance of the central mountain uplift as it must have looked before erosion stripped it to its present state of dissection.

Between the rim of the Mogollon plateau and the Salt River north of Globe, the geologist will find laid out before his eye most of the formations which underlie the plateau between the Mogollon Rim and the Little Colorado River at Holbrook. The key to the stratigraphy and oil possibilities of the plateau region lies here. Any program of petroleum exploration of the plateau which does not include a detailed study of the region exposed south of the Mogollon Rim is, at best, incomplete and inadequate.

It is extremely doubtful that oil will be discovered in commercial quantities in the central mountain belt for the reasons already given under the introductory discussion of that province.

VOLCANIC ROCKS OF THE NAVAJO COUNTRY

A large area of volcanic rocks lies in the Hopi Buttes region about twenty miles north of Holbrook. It consists of broad mesas and buttes capped by basalt of probable Miocene age partly dissected by erosion into an area of strong relief and rugged topography. Some forty or more volcanic necks or plugs are described from this region and these probably represent the outlets through which the basaltic lavas flowed out upon the surface. The sedimentary rocks underlying the Hopi Buttes are relatively undisturbed. Where dikes or necks have been observed, the distortion of the sediments is scarcely noticeable. The Hopi Buttes area does not appear to contain any anticlines or other structures which might be suitable for petroleum production and the abundance of volcanic outlets makes the area rather unfavorable for the production of petroleum.

A few isolated plugs of considerable size occur on the southeast edge of the Monument uplift near Kayenta. These represent the core of former volcanoes which erupted with explosive violence in contrast to the probable quiet effusion of lavas from the Hopi Buttes volcanoes. Several similar plugs occur on the Defiance uplift not far from Canyon de Chelly.

The largest volcanic field of the Arizona plateau is the San Francisco Peaks volcanic field near Flagstaff. Robinson described this region in detail in U. S. Geological Survey Professional Paper 76, 1913. Several hundred volcanic cones have been mapped. The type of extrusive rocks exuded vary from rhyolites to andesites and basalts. The region was active until recent times. Sunset Crater northeast of Flagstaff, having been the most recent cone, was last active in 880 A.D. Great flows of basalt spread out upon the plateau from the centers of extrusion. The San Francisco volcanic field is decidedly unfavorable as potential oil land, but the marginal areas have possibilities that must be examined in detail before receiving condemnation.

THE WHITE MOUNTAINS

Southeast of the Navajo country in southern Apache County lie the White Mountains which are volcanic in origin. The flows radiate from this volcanic center and extend northward lapping over some of the anticlines in the St. Johns region. No volcanic necks or plugs are known to be connected with these flows save at their source close to the mountains. The oil prospects of the lava-covered anticlines are not necessarily lessened by the presence of lava on the surface. A group of cinder cones lie on the north flank of the mountains about ten miles south of St. Johns representing the most recent volcanic activity in the region.

Basalt flows remain on the southern edge of the plateau between the White Mountains and San Francisco Peaks. The centers of origin are not known, but the flows probably originated south of the plateau in a terrain now obscured by thick lava flows.

Laccolithic intrusions occur on the northern part of the plateau. Navajo Mountain, thirty-five miles east of the Glen Canyon on the

Colorado River, lies on the Utah-Arizona boundary. According to Baker it is a laccolith with lavas intruded into the lower Triassic shales, doming the beds above. Carrizo Mountain in the northeast corner of Arizona is said by Gregory to be a laccolith. These two examples are probably genetically related to laccolithic mountains in southern Utah, such as the La Sal Mountains and the Henry Mountains. The structure of a laccolith is domical or ovoid. The beds are bowed up by the intrusive force of rising lavas which spread out when reaching a zone of weakness. The dome structure is apparent at the surface but is not deep-seated. Because of this and the high temperature of the lavas, laccolithic domes cannot be regarded as favorable to accumulation of oil.

STRATIGRAPHY OF THE ARIZONA PLATEAU

The Arizona plateau is underlain by a Pre-Cambrian complex of granite, schist, gneiss, quartzite and other metamorphic rocks. The best exposures of the complex are in the walls of the Grand Canyon. These have been studied in reconnaissance by L. F. Noble of the U. S. Geological Survey and reported on in bulletins of that survey. A more recent study, still in progress, is being carried on by Doctors Maxson and Hinds of the University of California under the auspices of the Carnegie Institution of Washington, D. C. Some preliminary reports are available in the Yearbooks of the Carnegie Institution for 1933-34-35-36-37, and the final monograph will undoubtedly be published in the near future.

The oldest Pre-Cambrian is known as the Archean or Archeozoic. It is composed of the oldest rocks known on the surface of the earth. The Archeozoic is usually so thoroughly altered by the processes of intrusion, folding, faulting, uplift and hydrothermal action that the original character of the rocks is completely destroyed. The Archeozoic represents an immensely long period of geologic time. Age estimates based on the disintegration of uranium or radium bearing minerals give the Archeozoic a history extending back to 1,350,000,000 years ago and lasting perhaps 350,000,000 years. What remains of the Archeozoic today is interpreted by geologists as representing the roots of very ancient mountains long since eroded away. The upper service of the Archeozoic is a peneplain representing a long period of weathering and erosion. On this peneplain were deposited rocks of later age.

Lying on the planed surface of the Archeozoic in some parts of the Grand Canyon are found great thicknesses of sedimentary and igneous rocks, partly metamorphosed, which belong to the Proterozoic age. In various parts of Arizona, such as Bonito Canyon near Fort Defiance, a quartzite of Proterozoic age outcrops, and in central Arizona there are massive quartzite and other rocks which are believed to be Proterozoic as, for example, the Mazatzal quartzite in the Mazatzal Mountains. Measured sections of Proterozoic rocks in the Grand Canyon give a total of about 12,000 feet of sediments including limestones, sandstones, conglomerates, shales, siltstones, and

some intruded igneous rocks such as diabase or basalt. These rocks are preserved in fault blocks in the Grand Canyon, the remaining parts of the series having been eroded away in a great period of erosion at the end of the Proterozoic time. It is likely that there may be other such fault blocks buried beneath the sedimentary rocks of the plateau in which thick sections of Proterozoic rocks will be preserved, but, unless these are discovered by the drill, knowledge of their existence will be lacking. Age of the Proterozoic is estimated at from 1,000,000,000 to 650,000,000 years ago.

The Pre-Cambrian rocks as a whole do not possess characteristics favorable for the origin and accumulation of petroleum because these rocks have undergone great chemical and physical alteration as the result of frequently repeated geological revolutions.

GEOLOGICAL FORMATIONS ON THE ARIZONA PLATEAU PRE-CAMBRIAN AND PALEOZOIC

Formations	**Grand Canyon**	**Monument Uplift**	**Mogollon Rim**
Permian	Kaibab Limestone	Cutler Formation	Kaibab Limestone
	Coconino Sandstone	Hoskinini Tongue	Coconino Sandstone
	Hermit Shale	de Chelly Sandstone	Supai Formation
	Supai Formation	Organ Rock Tongue	(?)
		Cedar Mesa Sandstone	Rico Formation (?)
		Halgaito Tongue	
		Rico Formation	
Pennsylvanian	Absent	Hermosa Formation	Hermosa Formation (?)
		Paradox Formation	
Mississippian	Redwall Limestone	Not Exposed	Redwall Limestone
Devonian	Temple Butte Limestone	Not Exposed	Jerome Formation
Silurian	Absent	Not Exposed	Absent
Ordovician	Absent	Not Exposed	Absent
Cambrian	Muav Limestone	Not Exposed	Tapeats Sandstone
	Bright Angel Shale	Not Exposed	or Troy Sandstone
	Tapeats Sandstone	Not Exposed	
	GREAT UNCONFORMITY		
Pre-Cambrian	Proterozoic	Not Exposed	Proterozoic
	Grand Canyon Series		Apache Group
	Chuar Group		Mescal Limestone
	Unkar Group		Dripping Spring Quartzite
			Barnes Conglomerate
			Pioneer Shale
			Scanlon Conglomerate
	Archeozoic		Archeozoic
	Vishnu Schist	Granite, etc. (?)	Pinal Schist, etc.
	Granite, etc.		Granite

PALEOZOIC FORMATIONS

Succeeding the Pre-Cambrian rocks on the plateau are a series of sedimentary rocks belonging to the Paleozoic era. The Paleozoic rocks were laid down on the truncated edges of the Pre-Cambrian rocks and are much younger in age. According to the radium estimates of the age of the earth, the Paleozoic extends from about 650,000,000 to 300,000,000 years ago. The best exposures of the Paleozoic are found in the walls of the Grand Canyon where all the formations from the Cambrian through the Permian are exposed.

Cambrian System: The Cambrian formations of the Grand Canyon lie more or less horizontally on the peneplaned surface of the Pre-Cambrian. The base of the system is formed by the Tapeats sandstone which varies in thickness from 165 to 328 feet. It is massive, unfossiliferous and grades upward into the Bright Angel Shale.

The Bright Angel shale is a green to drab shale with some limestone beds fossiliferous in part, carrying fossils which have been determined as of Upper Cambrian in age. The thickness varies from 325 to 402 feet.

The Muav limestone rests on the Bright Angel shale and is composed of massive, bedded limestone, carrying Upper Cambrian fossils. The upper surface is an erosion surface. Thickness ranges between 238 and 685 feet, being thickest to the northwest.

The Cambrian section is thickest in the west and thins eastward, probably wedging out under the plateau toward the eastern part of Arizona. Both the Bright Angel shale and the Muav limestone disappear to the southeast, but the Tapeats sandstone appears to extend to the vicinity of Jerome, and equivalents of it found southeast of Globe are described as the Troy sandstone which may correlate in the Bisbee region with the Bolsa quartzite.

The top of the Cambrian is marked by a large unconformity which, in the Grand Canyon region, includes both Ordovician and Silurian systems. Neither are known to be present anywhere in the Arizona plateau.

Devonian System: Resting on the Cambrian lies the Devonian system. In the eastern part of the Grand Canyon the Devonian is represented by scattered outliers of the Temple Butte limestone with a maximum thicknss of about 100 feet. To the west, McKee has described greater thicknesses of Devonian: 359 feet at Diamond Creek, 1156 feet at Quartermaster Canyon, and 1340 feet at Iceberg Canyon. Eastward the Devonian may extend as a thin series, wedging out under the plateau before reaching the Defiance uplift, but extending northeast toward the San Juan Mountains of southwestern Colorado where it is present as the Ouray formation, 74 feet thick, and the Elbert formation, 131 feet thick. Southeastward the Devonian increases in thickness to 505 feet at Jerome and is present as an important member of the Paleozoic section in the

Globe region and in southeastern Arizona. It may underlie the plateau south of the Little Colorado River in the Holbrook region but, as far as known, no definite correlation of Devonian has been made for any of the deeper wells in that region.

Mississippian System: An unconformity separates the Devonian and Mississippian in the Grand Canyon region, in some places having removed all of the Devonian so that the Mississippian rests directly on the Cambrian. The Mississippian of the Grand Canyon is largely dense, massive limestone, known as the Redwall limestone, which varies in thickness from 500 feet in the eastern part of the canyon to 700 feet or more at Kanab Creek. Part of the great thicknesses of so-called Redwall in western Arizona may belong to other systems, namely the Devonian and Pennsylvanian. Some sections of 1,100 feet have been reported but no attempt was made to differentiate Devonian, Mississippian or Pennsylvanian. The Redwall extends to Chino Valley and thins out under the Mogollon Rim east of Pine. The Mississippian southwards from here is thin and may be absent in many places. Under the plateau the Redwall probably thins eastward, disappearing before reaching Defiance uplift. It has not been definitely recognized in any wells in the Holbrook region.

Pennsylvanian System: Early reports on the Grand Canyon placed all the Paleozoic above the Redwall in the Pennsylvanian. Later studies by Noble, White and others showed that the Pennsylvanian was probably absent in the eastern part of the canyon and that the series above the Redwall was all Permian. McKee has found a thick Pennsylvanian section in the western part of the canyon region. In the Muddy Mountains of Nevada, the Callville limestone of Pennsylvanian age is at least 2,000 feet thick. Further west in Goodsprings Quadrangle, Nevada, it is 2,500 feet thick, and in the Inyo Range of California, a thickness of 7,750 feet is reported. Pennsylvanian occurs in southeast Utah about 2,000 feet thick as the Hermosa formation, and it is underlain within the Paradox basin by 2,000-4,000 feet of black shales and salt of the Paradox formation, also referred to the Pennsylvanian. The Pennsylvanian is found under the Mogollon Rim in a comparatively thin section of about 250-400 feet, carrying fossils which correlate with those of the Hermosa formation in southeastern Utah. The Pennsylvanian is absent on the Defiance uplift but in all probability remains in an elongate basin west of the Defiance uplift extending north and south between the San Juan basin and the Central Arizona basin. It is believed to be present in the Taylor-Fuller well near Holbrook and in the Adamana well twenty miles south of Holbrook. At Superior Pennsylvanian limestones may be at least 1,000 feet thick.

The extent and thickness of the Pennsylvanian is important from the standpoint of petroleum exploration because it is abundantly fossiliferous and contains much organic shale, limestone and some sandstones which may serve as reservoir rocks. Detailed exploration of the plateau will not be complete before subsurface data re-

vealing the character and thickness of Pennsylvanian sediments are obtained. This will require exploratory drilling to depths of about 4,000-5,000 feet. If the presence of a Pennsylvanian shoreline across the Holbrook-St. Johns region northward to the San Juan basin can be established, there is reason to expect discovery of a good oil pool will follow, provided suitable structures exist within the limits of that shoreline.

Permian System: Overlying all the older rocks is a prominent series of limestones, red shales, and buff sandstones which make up the Permian of the plateau region. The Permian is best known in the Grand Canyon region from the detailed studies of L. F. Noble at the Bass trail and subsequent studies by McKee on the Coconino sandstone and Kaibab limestone. The work of A. A. Baker in the San Juan region of southeastern Utah is the guide to the Permian in that part of the plateau. No direct correlation between the Grand Canyon section and the San Juan section of Baker can be made, the facies of deposition of the two series being greatly different.

COMPARISON OF GRAND CANYON AND SAN JUAN REGION PERMIAN SECTIONS

Grand Canyon Bass Trail	**San Juan Canyon Monument Uplift**
Kaibab limestone	Cutler formation:
Coconino sandstone	Hoskinini tongue—red shales
Hermit shales—red	de Chelly sandstone
Supai formation—red shale & sandstone	Organ Rock tongue—red shale & sandstone
	Cedar Mesa sandstone—light
	Halgaito tongue—red shales
	Rico formation—alternating redbeds & limestones

It is quite likely that the Supai will be correlative in part with the Rico formation and the Halgaito and Organ Rock tongues of the Cutler formation. The Hermit shale thins out to the southeast, being absent at Jerome. Its relationships to the northeast are in doubt. The Coconino sandstone covers the greater part of the Arizona plateau, having its thickest section at Pine on the Mogollon Rim and thinning gradually in all directions toward the eastern, northern and western borders of the State. At Bass Trail the Coconino is 330 feet thick; at the mouth of the Little Colorado it is 600 feet thick, and at Pine it is 1,000 feet thick. It is present on the south end of the Defiance uplift in Black Creek Canyon but disappears to the north in Canyon de Chelly. From Pine eastward along the Mogollon Rim, it thins to about 100 feet at the west margin of the White Mountains. At Winslow it is about 900 feet thick according to the log of a water well drilled by the Santa Fe Railroad. It does not appear in the San Juan region at all. It overlies the de Chelly sandstone in Black Creek Canyon near Lupton and appears to wedge out as the de Chelly thickens northward. The de Chelly sandstone is thickest at the Canyon de Chelly, being 850 feet according to McKee. It thins in all directions, being 500 feet at Comb Ridge on

the Arizona-Utah boundary, and disappears north of the San Juan River. At the mouth of Nokai Canyon on the San Juan River, it is 92 feet thick, disapearing to the northwest. At Lee's Ferry it is absent. At Fort Defiance the thickness is given as 263 feet, and at the extreme entrance to Black Creek Canyon it is about 100 feet thick, thinning southward. Some red, massive sandstones are reported in wells south of Holbrook and Winslow below the Coconino sandstone and may be the southwest extension of the de Chelly sandstone. The Kiabab limestone is thickest in northwestern Arizona and thins to the east and southeast from that corner, but appears to have had greater thicknesses southwest of Pine and Jerome than exist there now, for the thickness along the Mogollon Rim is 400 feet north of Pine and thins regularly toward a line between Winslow and Snowflake. Northeast of this line no Kaibab is known. The marine conditions under which Kaibab was deposited may have originated to the west, southwest and southeast as there are great Permian limestones in the Cochise County region which are correlative with Kaibab. Similar formations occur in Nevada.

The Cedar Mesa sandstone has its greatest extent in southeastern Utah and probably does not extend very far into Arizona. The Organ Rock tongue of redbeds underlies the de Chelly sandstone in the San Juan region and a similar series underlies it in the Defiance uplift from Canyon de Chelly south to Black Creek where the Permian disappears under younger rocks. The relationships of the Halgaito tongue are not clear outside of the San Juan Canyon but it probably merges with the Organ Rock tongue where the Cedar Mesa is absent. The Rico formation is marine in part and contains Permian fossils. It probably underlies much of the plateau and correlates with the lower part of the Supai of the Grand Canyon.

The Supai formation averages 900 to 1,000 feet thick in Grand Canyon, thickening slightly to the west. The formation may be traced eastward along the rim of the plateau from the Aubrey Cliffs at Seligman to the west margin of the White Mountains. It is everywhere present under the Mogollon Rim and makes a broad outcrop between Oak Creek, east of Young, and the White River. The bright red of the Supai under the light buff of the Coconino contributes no small part to the colorful scenery of the Grand Canyon and the Mogollon Rim. In several wells near Holbrook, showings of oil and gas were recorded from the Supai. In no place on its outcrop have salt beds been found but south of Holbrook the thickness of the formation increases to 2,400 feet due to the presence of salt and gypsum beds, according to well records.

As the Permian beds form the surface of a large part of the outer margins of the plateau, they are of particular importance in oil exploration as datum beds for detailed and reconnaissance surveys. The Kaibab-Moenkopi contact is a good datum plane in the regions surrounding the Grand Canyon. Where the Kaibab plays out, the Coconino-Moenkopi contact makes a good marker. The Coconino sandstone is cross-bedded, very massive and has no datum planes

that can be recognized on the surface or in the well log. One may use the top or the base, but no datum planes or surfaces exist, as far as is known, within the formation. Where the Supai formation is exposed south of the Mogollon Rim, it has several distinct limestones. These are fossiliferous and regular in thickness, persistent in character for many miles. Where the Kaibab is present and exposed in canyons, there are probably markers within the formation that could be used.

The lower part of the Permian has favorable indications of petroleum. Wells near Holbrook had showings in the Supai. Supai limestones under the Mogollon Rim give off an odor of petroleum on fresh fracture. There are some beds in the Kaibab which give off an odor of petroleum on fresh fracture. The Rico formation of the San Juan region produced oil in commercial quantities. The Coconino sandstone would make a very fine reservoir rock under suitable geologic conditions. It may make a good reservoir rock under some structures within the central plateau where it is deeply buried.

GEOLOGICAL FORMATIONS OF THE ARIZONA PLATEAU

MESOZOIC FORMATIONS — NAVAJO COUNTRY

Cretaceous	Mesa Verde Sandstone
	Mancos Shale
	Dakota (?) Sandstone
Jurassic	Morrison Formation
	San Rafael Group
	Entrada Sandstone
	Carmel Formation
	Glen Canyon Group
	Navajo Sandstone
	Kayenta Formation
	Wingate Sandstone
Triassic	Chinle Formation
	Shinarump Conglomerate
	Moenkopi Formation

The Mesozoic formations are well exposed in the Arizona plateau. The saucer-shaped structure of the plateau, combined with the marked physiographic relief, forms more or less circular bands of outcrops with long continuity. Formations may be traced across the plateau for many miles. The abundance of deep canyons, walled by vertical cliffs, provides many excellent exposures for study. The synclinal nature of the plateau has preserved the youngest formations in the center with the older rocks exposed successively in great arcuate bands toward the margins. Formations which are hard make narrow outcrops such as, for example, the Wingate sandstone or Shinarump conglomerate. Softer formations, such as the Chinle formation, composed largely of clays, shales and marls, make outcrops that are broad. A contributing factor is, of course, the rate of dip of the beds which is low, being

about 2° or less. The Triassic and Jurassic rocks are highly colored and contribute in no small degree to the scenic beauty of the Navajo Country. The Painted Desert in particular is noted for the brilliant variety of its colors and the almost total absence of vegetation on its barren surface. The Painted Desert is part of the broad outcrop band of the Chinle formation.

Triassic System: **Chinle Formation**
Shinarump Conglomerate
Moenkopi Formation

The Triassic system is represented on the Arizona plateau by the formations given above. They are exposed in great arcuate bands around the margin of the Navajo Country from Lee's Ferry on the Colorado River to Desert View, then up the Little Colorado River and its confluent the Rio Puerco. The band continues up the east side of the Navajo Country from the Petrified Forest to Ganado and Chinle and then continues down the Chinle Valley to the San Juan River region in southeastern Utah.

Moenkopi Formation: The lower Triassic is represented by a wedge of dark maroon to reddish-brown or chocolate-colored shales, siltstones, sandstones and conglomerates which were deposited on the litterol margin of a marine basin. The Moenkopi is thought to grade westward into a thick marine series carrying a Lower Triassic marine fauna. The wedge of the Moenkopi thins to the east disappearing on the Defiance uplift in the Canyon de Chelly. The following table shows the thickness and distribution of the formation:

THICKNESS OF MOENKOPI FORMATION IN NORTHERN ARIZONA AND UTAH

Locality	Thickness	Source of Data
Chinle, Arizona	0	Darton
Hunter's Point, Arizona	40	Darton
East side T. 23N., R. 30E., Arizona	132	Holm
Same, 2 miles south	150-175	Holm
Petrified Forest National Monument HQ Well	295	Walker
Holbrook, Arizona 2 miles east	244 plus	Holm
Sec. 32, T. 13N., R. 23E., Arizona	258 plus	Holm
Sec. 2, T. 15N., R. 22E., Arizona	220 plus	Holm
Water well, Adamana, Arizona	305	Walker
Joseph City, Arizona (estimated)	300	Holm
5 miles below Tanner's Crossing, Arizona	389	Gregory
Cedar Mountain, Arizona	491	Noble
Comb Ridge, Arizona-Utah line	80	Baker
Sec. 22, T. 43S., R. 16E., Utah	130	Baker
Sec. 17, T. 43S., R. 14E., Utah	167	Baker
East end Oljeto Mesa, T. 43S., R. 15E., Utah	180	Baker
Sec. 11, T. 43S., R. 12E., Utah	247	Baker

Locality	Thickness	Source of Data
Sec. 9, T. 42S., R. 13E., Utah	254	Baker
Monitor Butte, Utah	340	Baker
Sec. 28, T. 41S., R. 12E., Utah	325	Baker
Lee's Ferry, Arizona	390 plus	Gregory
West side Circle Cliffs, Utah	490 plus	Moore
Kaibab Gulch, Utah	514	Gregory
Virgin City, Utah	1,775	Reeside & Bassler
Muddy Mountains, Nevada	1,200-1,600	Longwell
8 miles west of Virgin City, Utah	2,035	Reeside & Bassler
Cedar City, Utah	2,650	Lee

The table shows clearly that the formation thickens to the west and northwest and thins out on the Defiance uplift, being absent at Canyon de Chelly (Chinle). Darton has reported a thickness of 600 feet plus or minus from Bluewater, New Mexico, some forty miles east of the Arizona-New Mexico boundary.

The lower part of the Moenkopi in the Little Colorado River valley is composed of dark maroon thin-bedded shales, siltstones and sandstones. The middle part is similar with some gypsum beds and other dessication products. The upper part of the formation in this valley is composed of massive coarse grey to red gritty sandstones and conglomerates alternating with red shales or siltstones. The sandstones of the upper part are lenticular and irregularly deposited and appear to have had their origin somewhere to the south, as the material is seen to become coarses in that direction. Westward and northwestward from Holbrook these upper sediments either disappear, lens out, or are laterally changed to redbeds like those of the lower part. In northwestern Arizona marine limestones are reported in the formation and a lateral gradation of the redbeds into marine shales occurs.

The Moenkopi is very sparsely fossiliferous where the red facies is predominant. Dr. C. L. Camp of the University of California has recently collected some fragmentary vertebrate fossils and plant fossils, associated with footprints of vertebrate animals, from the base of the Moenkopi near Meteor Crater, Arizona. These are said to be the first vertebrate remains of Lower Triassic age collected from the Triassic of the United States.

The writer has seen plant remains, poorly preserved, in several localities; one being the upper beds of the Moenkopi a few miles southeast of Holbrook in the canyon of the Little Colorado River, and the other about two miles southwest of the bridge crossing the Little Colorado River on U. S. Highway 260 about ten or twelve miles northwest of Concho. Correlation of Moenkopi with the Lower Triassic is based upon invertebrate fossils collected from the formation in northwestern Arizona and southwestern Utah where the marine facies occurs. Correlation of the barren facies of the Little Colorado River Valley is based upon tracing outcrops from northwestern Arizona into those of the Little Colorado River Valley.

Oil possibilities of the Moenkopi are indicated by showings re-

ported from the formation in wells drilled in Utah. Where the formation is exposed on the surface, as in the Little Colorado River Valley, conditions are unfavorable. Under the central part of the Navajo Country, where the formation is buried deeply under the Cretaceous of the Black Mesa, showings are possible but not probable until explored by drill.

The lower contact of the Moenkopi is one of unconformity with the upper surface of the Permian. The formation rests successively, from west to east across northern Arizona, on the Kaibab limestone, the Coconino sandstone, and the de Chelly sandstone. The upper contact is also one of unconformity but is only apparent in a few exposures where the overlying Shinarump conglomerate lies on the eroded surface of the Moenkopi.

Shinarump Conglomerate: Overlying the Moenkopi formation is a persistent and uniform conglomerate which has wide distribution over the Colorado plateau. It varies in thickness from a few feet to a little more than 200 feet but averages about 40 feet. It is composed of a sand matrix with an abundance of well-rounded pebbles, cobbles and small boulders which have been derived from older rocks ranging in age from Archeozoic to Triassic. The pebbles and cobbles show gradation in size, southwest from the Little Colorado River Valley, that indicates their origin was somewhere south of the plateau, coarser materials being found on the south. On the Defiance uplift the Shinarump is difficult to distinguish from the enclosing sandstones as the pebbles are very small and infrequent, but the presence of pebbles is considered diagnostic. Fragments of vertebrate animals and abundant petrified wood have been found in the Shinarump. Their age has been determined as Upper Triassic. Thus it is clear that the unconformity between Lower Triassic Moenkopi and Upper Triassic Shinarump for the plateau region is equivalent in time to the Middle Triassic. No sediments of Middle Triassic age have been recognized in the plateau region.

Th Shinarump conglomerate is a good aquifer in some localities and in southern Utah showings of oil have been reported from it. Under proper conditions of structure and hydrostatics, the formation is a potential reservoir rock and should be tested for oil in exploration drilling within the limits of the plateau.

Chinle Formation: Overlying the Shinarump and forming a broad outcrop band is the Chinle formation, a thick sequence of continental deposits exhibiting a wide range of coloration. The sediments range from conglomerates to fine shales, sandstones, marls, thin gypsums, to thick unbedded clays containing bentonite. The lower part probably is gradational with the Shinarump. North of Holbrook a series of conglomerates occur in the lower Chinle which are difficult to distinguish from the Shinarump. The conglomerates and sandstones of the Chinle are lenticular, irregular, extremely variable, and alternate with shales, clays and marls of variable thickness. Colors range from dull gray and brown to brilliant reds, purples, blues, yellows and creams. It is this formation which makes up the Painted Desert,

so famed for its beautiful coloration. The Chinle outcrops from Echo Cliffs east of the Marble Canyon of the Colorado River in a great arcuate band about twenty miles wide around the south end of the Navajo Country to the Petrified Forest whence it swings north again to the beautiful expanse of highly colored badlands south of Chinle, called Beautiful Valley. The formation was named from its fine exposures near Chinle. Here a thickness of 1,182 feet was measured by Gregory. The thickness is greater in a depositional basin near the Petrified Forest, being at least 1,200 to 1,400 feet thick. In southern Utah the thickness is about 900 feet and southward from the Little Colorado River Valley it is similar. The formation probably continues eastward across New Mexico to the Pan Handle of Texas and correlates with the Dockum beds of that region.

The Petrified Forest National Monument is but one of many such forests. Petrified wood occurs throughout the Chinle but is most abundant in the lower third. It occurs as logs up to 150 feet in length and in scattered fragments largely in sandstones and conglomerate lenses. Travelers through the Navajo Country will see petrified forests north of Cameron along the highway to Lee's Ferry, at the Petrified Forest National Monument near Holbrook and at various places near Chinle. Many isolated segregations of petrified wood occur in small patches elsewhere. Associated with the wood may be remains of vertebrate animals, such as the Phytosaurs which were common in Upper Triassic time. Many plant fossils are now being obtained from the Chinle, including a wide variety of ferns, conifers, ginkos and other early floras. Some fossil fish have been found as well.

The Chinle formation is considered to have been deposited in flood plains or lagunal bodies of water near the margins of the Triassic continental land mass. The formation offers very poor opportunity for origin or accumulation of oil and is not considered favorably in this report.

Jurassic System:

Morrison Formation
San Rafael Group
  Entrada Sandstone
  Carmel Formation
Glen Canyon Group
  Navajo Sandstone
  Kayenta Formation
  Wingate Sandstone

The Jurassic system of the Colorado plateau has its largest development in southern Utah and is prominently exposed in the mesas and canyons of the Navajo Country. For a complete discussion of the Jurassic rocks of this region, reference is made to a report of A. A. Baker, C. H. Dane and J. B. Reeside, Jr.: "The Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico and Colorado, U. S. Geological Survey Professional Paper 183, 1936".

The Jurassic rocks of the plateau are predominantly sandstones, probably aeolian in origin, as suggested by the presence of cross-

bedding and uniformity in grain size. Bedding is massive and great thicknesses occur.

Early reports on the Jurassic of the plateau confused several formations such as Navajo sandstone, Wingate sandstone and Morrison formation. The Morrison was described originally by Gregory as the "McElmo formation", a term now in disuse. The Wingate and Morrison formations, lowest and uppermost formations respectively, are the most extensive. Their outlines are practically the same for northern Arizona and the thickness of both formations is comparatively uniform. To the northwest the two formations diverge and are separated by the lens-shaped formations of the intervening Jurassic formations. The latter formations wedge out in northeastern Arizona and are absent in the easternmost exposures of the Jurassic system.

Glen Canyon Group: This group is composed, somewhat arbitrarily, of the Navajo sandstone, Kayenta formation and Wingate sandstone. Each formation in this group possesses a distinct basin of deposition quite unrelated to those of the other two formations. Source of materials, environments of deposition and character of sediments are different for each formation. The name of the group is taken from Glen Canyon of the Colorado River where the formations are well exposed in the vertical walls of the Canyon.

(a) Wingate Sandstone: Underlying the Black Mesa of the Navajo Country and extending in a narrow outcrop beyond its borders is a massive, cross-bedded, red sandstone of aeolian deposition named the Wingate sandstone from its type locality near Wingate, New Mexico. The formation lies more or less conformably on the Chinle formation. On the west side of Black Mesa near Tuba City, the two formations are separated with difficulty, appearing to grade into each other. The Wingate forms vertical cliffs and often weathers into picturesque erosional forms. It is well exposed in Glen Canyon of the Colorado, in Echo Cliffs, in a narrow band around Black Mesa, and in parts of the Monument uplift. It is also well exposed in the scarp forming the east flank of the Defiance uplift and extends eastward into New Mexico around the margins of the San Juan Basin. The thickness ranges from nothing to a maximum of 470 feet in northwestern New Mexico. The formation would form a good oil reservoir if properly buried and located on a structure. It is unlikely that the formation will contain petroleum because it is not associated with good source rocks and is terrestrial rather than marine in origin.

(b) Kayenta Formation: Overlying the Wingate in the Glen Canyon is the Kayenta formation, a comparatively thin lens of shale and sandy shale of probable marine origin. It is best developed in southeastern Utah but extends into northeastern Arizona about as far as Kayenta where it thins out. The thickness ranges from nothing to a maximum of 270 feet, the latter occurring in Utah. The Kayenta formation is not considered to be a good prospect for petroleum.

(c) Navajo Sandstone: The Navajo sandstone is the upper mem-

ber of the Glen Canyon group and is well exposed in southern Utah and northern Arizona. It is a huge wedge with great thickness far to the west in Nevada and thinning out eastward near the eastern border of Arizona and Utah. A thickness of 2,100 feet was measured near the Muddy Mountains, Nevada, and in southwestern Utah. The southern limits are unknown due to erosion of the formation from the southern part of the Arizona plateau. The Navajo sandstone is massive, cross-bedded, uniformly, fine-grained, and ranges in color from light to dark red, sometimes in bands of alternating light and dark red. Origin was somewhere to the west in Nevada. Because of its color, thickness, and massive character, where it is exposed in the plateau, it usually forms striking topographic features with colorful cliffs and canyons or impassable, hummocky topography of high relief. Rainbow Bridge near Navajo Mountain south of the San Juan River in southern Utah is formed from the Navajo sandstone. The formation is probably a good reservoir rock, but it is doubtful that it occurs in satisfactory relation to structure or has sufficient depth in northern Arizona to be petroliferous.

San Rafael Group: This group is best exposed in Utah but extends in thin remnants southward into Arizona, thinning out near Kayenta. It is named from exposures in the San Rafael Swell, Utah. Only the Carmel and Entrada members of this group occur in Arizona.

(a) Carmel Formation: The Arizona portion of the Carmel formation overlies the Navajo sandstone with practically the same limits. It is a red earthy sediment, composed of red sandstones and shales which, to the northwest in Utah, grade into marine formations such as shales and limestones bearing Upper Jurassic fossils. The formation is of practically no importance in Arizona.

(b) Entrada Sandstone: Overlying the Carmel formation is a massive, red, cross-bedded sandstone similar to the Navajo and Wingate sandstones which has its best development in Utah but extends, like the Carmel, into northern Arizona near Kayenta. It is relatively unimportant in Arizona.

Morrison Formation: Overlying the older Jurassic formations in the Colorado plateau is the Morrison formation. In northern Arizona it is largely sandstone of variegated color, massive, sometimes cross-bedded and comparatively uniform in grain size It outcrops around the margin of Black Mesa and forms several prominent outliers, among which are White Mesa and Square Butte on the Kaibito Plateau east of Tuba City. It also occurs prominently on the east side of the Defiance uplift and extends eastward into New Mexico for many miles. To the northeast in Colorado, the Morrison is more typically shale and marl. In Utah at Dinosaur National Monument, it contains remains of the great dinosaurs. Thickness ranges in Arizona from nothing on the southwest margin of Black Mesa to nearly 700 feet in the northeast corner of the state. The formation is not important as a possible petroliferuos horizon in Arizona.

Cretaceous System: Mesa Verde Sandstone
Mancos Shale
Dakota (?) Sandstone

The Cretaceous system in northern Arizona is well exposed in Black Mesa and is of Upper Cretaceous age. It forms the higt vertical-walled mesas on which the Hopi villages are built. The formations are similar to those in the San Juan Basin north of Gallup. The Dakota (?) and Mesa Verde represent continental deposition while the Mancos shale is marine. Strata of Lower Cretaceous age are absent.

Dakota (?) Sandstone: For the purpose of this report, the Dakota will be discussed as such although its correlation with the typical Dakota of the Great Plains is not definitely established. It is buff, massive sandstone, sometimes conglomeratic, often coarse and irregularly bedded, and containing some thin seams of coal. In northwestern New Mexico it produces oil in commercial quantities, being the main producing horizon in the Rattlesnake Field. It forms the cap of broad mesas or plateaus east of Tuba City but is very thin here being seldom more than 40 feet thick. Under the Black Mesa it thickens to the north, being 295 feet thick at Lolomai Point near Kayenta. On the east side of the mesa it thins southward to 40 feet at Steamboat Wash. It lies unconformably on the Morrison formation, the contact near Tuba City being very sharply defined by the contrast between the variegated Morrison and the buff to drab Dakota. The Dakota is a possible oil producing horizon in Arizona, and if encountered by drill on structure within the limits of Black Mesa, may be expected to produce oil in commercial quantities. The Dakota is Upper Cretaceous in age.

Mancos Shale: Overlying the Dakota and having a broad outcrop because of its softness is a section of black or drab shale, fine-bedded and fossiliferous, occasionally containing limestones. The fossils are marine of Upper Cretaceous age and correlative with the Niobrara and Pierre formations of Colorado. Thickness is variable under Black Mesa, being greatest at Lolomai Point southwest of Kayenta. Here it is 610 feet, thinning to 130 feet at Padilla Mesa southwest of Oraibi. At the Hopi villages the thickness is about 250 to 300 feet, thickening to nearly 500 feet at Salahkai Mesa on the east and 490 feet at Blue Canyon on the northwest. The Mancos shale is a good source rock for petroleum and under suitable conditions may be considered as a favorable source for the occurrence of petroleum in northern Arizona. It does not occur on the plateau south of Black Mesa but is preserved in the synclinal basin of the Gallup region in New Mexico and to the north in southwestern Colorado.

Mesa Verde Sandstone: Overlying the Mancos shale is a series of buff to brown sandstones, massive, cliff-forming, lenticular, conglomeratic to course-grained, and sometimes interbedded with shales and coals. The coal is mined at Keams Canyon and east of Tuba City for use in the Indian Schools at those points. The sandstone outcrops in Black Mesa, being well exposed by the numerous, deep-

steep-walled canyons which cross the mesa from the northeast rim to the southwest. The Hopi villages are built on the top of mesas formed by this sandstone and the high vertical cliffs of the east and north faces of the Black Mesa are also formed from this sandstone. The thickness is greatest at Yale Point, being nearly 900 feet, but at other places on the Mesa erosion has removed unknown amounts and thickness cannot be determined. The Mesa Verde sandstone is exposed so completely on the mesa that it is not favorably situated to become a reservoir for petroleum and is not considered here as a potential oil sand.

Tertiary Systems:

Deposits in the Arizona plateau younger than Cretaceous are of Tertiary age and occur largely associated with the volcanic extrusions of the Hopi Buttes and White Mountains. South of the Rio Puerce in Apache County, a thick section of Tertiary beds forms a high mesa. These sediments are largely volcanic ash beds and debris deposited in lakes or as river sediments. The Tertiary of northern Arizona has not been studied in detail and, as it is of no importance as far as petroleum is concerned, is not discussed in this report.

STRUCTURES OF THE PLATEAU PROVINCE

In this report the discussion of structures of the plateau province will be confined to the Navajo Country and the section of the plateau stretching southward to the Mogollon Rim.

The Navajo Country has been likened to a saucer as it is a broad, shallow basin, more or less circular in shape, with uplifts forming the margins. These uplifts are major structural features of regional importance. The tectonic forces which formed the uplifts and folded belts on the margins extended their influence to the crust underlying the Navajo Country and the Mogollon plateau. Where competent rocks were present, the strata were folded into anticlines and synclines. In part of the region normal faults of small displacement are common. The greater part of the plateau is crossed in northeast-southwest direction by long shear zones which are not clearly evident to the observer on the surface of the ground but become remarkably distinct when seen from high altitude or on the aerial photographic mosaic.

The anticlinal structures are of several types. In southern Apache County near St. Johns, the rocks are folded into ovoid domes or elongated anticlines with dips on the flanks which approach a maximum of about 10°. These folds are narrow, seldom a mile in width, and usually not more than six or eight miles in length. In the Holbrook region the structures are less evident to the casual observer but are present as broad, elongated swells with dips on the flanks which are seldom as high as 1°, usually being of the magnitude of ½° or less. The trend of the structures in Apache County is roughly parallel to that of the Zuni Mountain uplift to the east, or N30°W. The trend of the Holbrook structures varies from N30°W to N15°E, all of them being aligned more or less radially with regard to the

center of the basin. The Holbrook structures plunge gently to the north.

Structures in the Navajo Country are found in more or less close association with the bordering uplifts. In the northern part of the state a series of elongated, assymetrical anticlines extend in a north-south direction from the San Juan River canyon down into the south flank of the Monument uplift. These folds are steep-sided on the east flank and slope gently on the west flank. Their axes are more or less sinuous, rather than simple, straight lines. The structures have been mapped by the U. S. Geological Survey in the Utah portion of the Navajo Country but have not been defined except in reconnaissance surveys on the Arizona side of the line. In the western part of the Navajo Country are several elongate trends which have not been completely defined as to extent, location, or degree of folding. The trends are roughly parallel to that of the Kaibab uplift, or about N30° W.

South of the Navajo Country in the Rio Puerco Valley, several broad swells are indicated by reversals in dip. These are intermediate in type between the sharp folds of Apache County and the broad, flat arches of the Holbrook region.

Southeast of Flagstaff in the portion of the plateau where the Kaibab limestone forms the surface rock, normal faults of moderate displacement occur having strike parallel to the usual trend N30°W. or, in one or two cases, N15°E. Length of these faults varies from a few hundred yards to several miles and the displacement from a few feet to about 100 feet.

About 20 miles south of Holbrook, the rocks of the plateau are displaced in a zone extending northwest from Snowflake some thirty miles to a point beyond Richards Lake. South of the scarp is a synclinal valley forming a drainage basin without outlet. Bordering the north margin of the synclinal region are scattered areas of sink holes which, from the aerial view, resemble pockmarks on the surface of the earth. The scarp is sinuous and appears to possess an irregularity that is difficult to interpret. After careful examination Holm decided the scarp was a fault scarp with a displacement that reaches a maximum of 400 feet. The fault is not a continuous fault but is probably a fault zone with a series of en echelon faults which are staggreed in position. The fault scarp is crossed at right angles by several obscure anticlinal trends which appear to jut southward beyond the scarp, increasing the irregularity of the fault scarp. The fault zone is considered to be one of normal faulting although it would appear at first glance that the sinuous line of the scarp should indicate thrusting.

The explanation of the fault zone is simple. The surface rocks are sandstones, limestones and shales, dipping with regularity on both sides of the scarp to the north. Under the Coconino sandstone, which is about 600 feet thick here, lies the Supai formation composed of red sandstones, shales, siltstones, gypsums, salts and marls. The salt beds are quite thick and form a large part of the subsurface section.

At some time during the geological history of the plateau, probably after the major folding and uplift of the late Cretaceous Laramide revolution, the stresses applied to the crust at this line caused fracturing and slipping or, in other words, a fault zone with the rocks upthrown on the north side developed. The displacement was sufficent to place the salt beds in the Supai in the upthrown side in juxtaposition to the water-bearing Coconino sandstone on the downthrown side. The water, moving northward under the force of gravity, entered the salt beds and slowly dissolved away large amounts of salt. In time caverns were formed which collapsed by the weight of the overburden and the resulting slump of the rocks at the south edge of the upthrown strata formed the escalloped fault zone scarp which exists today.

This fault zone is designated here as the Richards Lake-Snowflake fault zone. The importance of this interpretation of the scarp becomes evident when it is recalled that Darton and Hager, in their exploration of the Holbrook region, described the structure as the Holbrook Dome and recommended it as a suitable site for the drilling of oil wells.

Careful examination of the structure by Holm failed to find any consistent signs of true folding, anticlinal structure, or doming. The result of Holm's work is the interpretation of the fault zone just given above. The Holbrook Dome of Hager and Darton was described as an elongated dome trending northwest for some twenty-five miles between Snowflake and Richards Lake. Darton contoured the so-called structure using the base of the Kaibab limestone as a datum plane and showed it with steep south side and gentle north slope. Several attempts to drill for oil on this so-called structure were made between 1918 and 1928 with little success. Both Darton and Hager failed to recognize the presence of the flat, broad, anticlinal folds which cross the trend of the fault scarp at right angles. None of the wells drilled were located on any of these anticlinal structures.

Nineteen anticlinal structures have been observed by Holm in the Navajo Country and the plateau south of the reservation. Eight anticlines are known from geological work of several oil companies in Apache County. Six structures, which are faults, have been observed by Holm between Snowflake and Flagstaff. Most, if not all, of the anticlinal structures listed are considered from the structural point of view to be satisfactory for the accumulation of petroleum. It remains to be seen whether the fault structures are suitable for petroleum accumulation.

OIL POSSIBILITIES OF THE PLATEAU PROVINCE

The preceding section lists the portions of the plateau which have structures favorable to the accumulation of oil. Structural prospects are not sufficient. The petroleum geologist must determine the presence of satisfactory source rocks as well as reservoir rocks under the surface of the structures.

Geologic conditions under which oil may form and accumulate appear to be best exemplified in rocks which are sedimentary in origin. Of the sedimentary rocks, the petroleum geologist finds that those deposited under marine conditions are most favorable for the occurrence of petroleum. Marine bodies of water usually teem with organic life which, after death, provides an abundance of organic matter. Under proper conditions of burial and decay, bacteria act upon organic matter and form various hydrocarbons which may ultimately yield the complex mixture known as petroleum. Sedimentary rocks seldom rest through geologic time without being subjected to great stress. Compression and tension, resulting from tectonic forces involved in mountain building, fracture and bend the rocks of the earth's crust. Even the most impervious rocks, such as dense shales, may become fractured and petroleum may work its way through the fine maze of cracks into more porous and pervious layers. Sandstones are composed of sand grains of varying degrees of roundness, packed together and cemented. The sandstones may have continuous pore space which provides the desired porosity and permeability. Water is often imprisoned in sandstones at the time of deposition. As the petroleum trickles into a permeable sand, it does not mix with water but, being lighter, rises to the upper part of the fluid level in the sand and may migrate horizontally through the sand until trapped:

(1) By an anticlinal structure
(2) By change in porosity
(3) By pinching out of the sand
(4) By any feature which prevents further migration of the fluids.

Surface and subsurface conditions may indicate to the competent geologist the site of such traps. It is in such places that the geologist recommends the drilling of wells for oil.

In the plateau province the older rocks, classed in the section on stratigraphy under Paleozoic System, provide the most favorable conditions for petroleum formation and accumulation. Of the Paleozoic rocks, it is here considered that the Pennsylvanian and Lower Permian formations present the most satisfactory conditions.

The Grand Canyon section, as exposed at Bass Trail, does not contain any rocks of Pennsylvanian age. The eastern part of the Grand Canyon region in all probability is barren of the Pennsylvanian rocks. Structures which border the Grand Canyon region closely, in particular the Kaibab uplift, are lacking in good source and reservoir rocks and are also so close to the canyon that the formations are all exposed and hydrocarbons would have full freedom to escape into the atmosphere. East of the Grand Canyon region toward the Navajo Country, knowledge is lacking at present of the occurrence of Pennsylvanian rocks although it is considered as a possibility which can be proven only by the drill.

North of the Navajo Country, Pennsylvanian rocks of good thick-

ness occur in the San Juan region of southeastern Utah and southwestern Colorado. South of the plateau under the Mogollon Rim, Pennsylvanian rocks bearing marine fossils occur extensively. Fossils from Carrizo Creek in the Apache Indian Reservation bear close resemblance to fossils from the Pennsylvanian Hermosa formation of the San Juan region. It is postulated here that these two areas of Pennsylvanian rocks are connected under the Navajo Country by a series of Pennsylvanian rocks buried, of course, under younger rocks. The connection will probably lie west of the Defiance uplift and east of the Coconino-Navajo County line. The western margin of this connecting Pennsylvanian basin is not definitely known or located, pending discovery by drill, but is predicated by virtue of paleogeographic data available to any observant and imaginative geologist. It is suggested that the western shoreline will probably lap some of the structures in western Navajo and eastern Coconino Counties. If true, the prospects for discovering oil are good for those structures at least.

Structures in the Holbrook region are believed to lie well within the limits of the Pennsylvanian basin. Showings of oil reported from the Adamana well and the Taylor-Fuller well south of Holbrook indicate that conditions for origin and accumulation of petroleum have been favorable. If prospecting wells are properly located upon the anticlinal structure, the expectation of discovering oil is good.

III. GEOLOGY AND OIL POSSIBILITIES OF THE DESERT PROVINCE

The desert province has been described as a great plain sloping gently toward the Gulf of California and punctuated by numerous mountain ranges which rise abruptly from the surface of the plain. The ranges are aligned in northwest-southeast trends with the exception of several which trend northeast-southwest. The latter are the Harquahala and Harcuva Mountains in Yuma County and the Salt River Mountains near Phoenix. The desert ranges are composed largely of igneous and metamorphic rocks with some sedimentary rocks present in a number of the mountains. Ranges in the southeastern part of Arizona have a larger proportion of sedimentary rocks, and a few ranges in the western part have comparatively small volumes of sediments infolded. The metamorphic rocks are, in many cases, part of the Pre-Cambrian basement complex, but in others may be altered rocks of Paleozoic or later age. The igneous rocks are, in part, Pre-Cambrian in age and may be intrusive or extrusive. It is probable that intrusions occurred in Mesozoic time and many extrusions are known to have occurred in Tertiary time. The age of the sediments ranges from Pre-Cambrian to Recent with the geological column best represented in the southeastern part of the province. In the western part, Carboniferous rocks and probable Cretaceous clastics have been observed in a few ranges. Between the ranges are intermontane valleys comprising the surface of the great desert plain. Their surface rocks are varying volumes of Recent or Quaternary alluvium. Under the alluvium may lie unknown amounts of older sedimentary rocks.

STRATIGRAPHY OF THE DESERT PROVINCE

Pre-Cambrian Systems: The oldest rocks of the province are those on which all other rocks repose. They form the basement complex, generally Pre-Cambrian in age, and are composed of igneous and metamorphic rocks. The oldest of these are generally referred to the Archeozoic system and comprise the most highly altered chists, gneisses and other rocks which may have been originally either sedimentary or igneous but have been changed so completely their original condition is indeterminate. Many of the desert ranges have as foundation or cores rocks of Archeozoic age. In central and southeastern Arizona the basement rocks are schists named Pinal Schist by Ransome. This schist is intruded by granites in places. Schists are also found in the western part of the province but have not been given much detailed study. It is possible that some of the western schists are not Pre-Cambrian but may be altered Paleozoic rocks.

Proterozoic System: In central and southeastern Arizona a group of rocks of sedimentary origin lies uncomformably on the older Archeozoic rocks. Ransome described them originally from the Globe district as the Apache group. Included therein are conglomerates, sandstones or quartzites, shales, limestones, and intruded sills of diabase or basalt. Ransome referred the Apache group doubtfully to the Cambrian but later work by Darton and Stoyanow suggests the advisability of referring the greater part of the group to the Algonkian (late Proterozoic). The group has been found extensively in the central mountain belt and in a number of exposures in the central part of the desert province. In the following table are listed the formations of the Apache group with general description and thickness:

Apache Group (Late Proterozoic)

Mescal Limestone—Limestone	225-300 feet
Dripping Spring Quartzite	450-700 feet
Barnes Conglomerate	5-50 feet
Pioneer Shale—Red Shales, etc.	150-250 feet
Scanlon Conglomerate	0-30 feet

Parts of the Apache group have been recognized in the Slate and Vekol Mountains and in the Santa Catalina Mountains. The Troy sandstone was originally included in the Apache group but has been shown by Darton and Stoyanow to rest unconformably on the Mescal limestone or other members of the Apache group. and has been referred to the Cambrian. The Apache group is generally metamorphosd slightly and is not considred to be suitable for petroleum origin or accumulation.

Paleozoic System: Rocks of Paleozoic age, or "Oldest Life," rest unconformably on Pre-Cambrian rocks. In the southeastern part of the province the Paleozoic section is thick, beginning with Cambrian sandstones which are overlain by thick limestones and shales of Upper Cambrian age. Beds of Ordovician age overlie the Cambrian but are present only in a few places in Arizona; namely the Morenci

district, the Dos Cabezos Mountains, and possibly the Vekol Mountains. Silurian rocks are absent altogether. Overlying the older rocks is a section of limestones and shales, usually fossiliferous in the upper part, which is referred to the Upper Devonian. This is overlain by rocks of Mississippian age, largely limestones. In the southeastern part a thick limestone section including rocks of Pennsylvanian and Permian age forms the upper part of the Paleozoic section and is known as the Naco limestone, notably exposed near Bisbee. West of the central part of the desert province few Paleozoic rocks have been recognized, except for several small patchs of Carboniferous limestone infolded with metamorphic rocks in northern Yuma County.

TABLE OF PALEOZOIC FORMATIONS IN DESERT PROVINCE

Western	**Vekol Mountains**	**Bisbee**	**Clifton-Morenci**
Carboniferous	Permian	Naco—Upper	? ? ? ? ?
	Pennsylvanian	Naco—Lower	Tule Springs Limestone
Absent	Mississippian	Escabrosa Limestone	Modoc Limestone
Absent	Permian	Martin Limestone	Morenci Shale
Absent	Ordovocian ??	Absent	Longfellow Limestone
Absent	Cambrian-Quartzite	Abrigo Limestone	
		Cochise Formation	
		Santa Catalina Formation	
		Bolsa Quartzite	Coronado Quartzite
		UNCONFORMITY	
Pre-Cambrian	Schist	Schist or Granite	Granite

Cambrian System: Where the Cambrian rocks have been observed, the base is usually a sandstoen or quartzite, sometime conglomeratic. In southeastern Arizona it is known as the Bolsa quartzite, in the Clifton-Morenci district as the Coronado quartzite, and in central Arizona as the Troy sandstone or quartzite. All have been correlated with the Tapeats sandstone of the Grand Canyon region but this is based on stratigraphic position and Lithological resemblance rather than fossil content. Overlying the sandstone are usually limestones or shales, some of which contain fossils of Upper Cambrian age. In Cochise and Pima Counties, Stoyanow has named several new formations, notably the Santa Catalina and Cochise formations, which lie upon the Bolsa or Troy sandstone. Overlying these formations is the Abrigo limestone, a thick, massive limestone of wide extent. Thicknesses of Cambrian formations, as given by Stoyanow, are listed below:

Bisbee	Ft.	**Whetstone Mts .**	Ft.	**Saonta Catalina Mts**	Ft.
Copper QueenLs....	82	Rincon Ls.	42	Peppersauce Ss.	21
Abrigo Fm.	770	Abrigo Fm.	770?	Abrigo Fm.	288
		Cochise Fm.	311	Southern Bell Qtz't..	26
Pima Ss.	4	Pima Ss.	4	Santa Catalina Fm..	415
Bolsa Qtz't.	430	Bolsa Qtz't.	160	Troy Qtz't.	350
	1284		1287		1100

Most exposures of Cambrian formations are found in mountain ranges where they have been subjected to the stresses resulting from igneous intrusion and mountain uplift and are subsequently more or less metamorphosed. Under some of the intermontane valleys, it is not unlikely that Cambrian formations will be found by the drill in unaltered condition. It is to be expected that the organic matter present in the fossiliferous sections will be a satisfactory source of petroleum.

Ordovician System: Lindgren described a limestone in the Clifton-Morenci district containing Ordovician fossils and named it Longfellow limestone. The lower part may be partly Cambrian. Darton observed Ordovician fossils near Dos Cabezos and also in the Vekol Mountains. No other occurrences have been reported in Arizona. It is probable that the Ordovician sea lapped over a part of southeastern Arizona with the main body of the sea far to the southeast in the El Paso region.

Silurian System: Rocks of Silurian age are not represented in Arizona.

Devonian System: The Devonian seas covered most of southeastern Arizona and extended to the northwest, as already mentioned in this report, covering parts of the plateau region. Darton observed Devonian fossils in the Vekol Mountains but no occurrences west of there have been reported. The thickness of Devonian in the southeastern part of Arizona was not great, being about 100-400 feet. The Martin limestone, first described and named by Ransome at Bisbee, is found in many places southeast of Tucson. Fossils found are usually Upper Devonian in age.

Mississippian System: In the Bisbee district the Mississippian is represented by the Escabrosa limestone which has a thickness of 700 feet. At Tombstone the same limestone has a thickness of 500 feet. In the Clifton-Morenci district the Mississippian is represented by the Modoc limestone of Lower Mississippian age, 170 feet thick, and by the lower part of the Tule Spring limestone which is about 200 feet thick. Rocks of Mississippian age probably occur in many of the mountains of southeastern Arizona but have not been studied in detail. They have not been recognized in the western part of the province.

Pennsylvanian System: The Pennsylvanian rocks are well represented in southeastern Arizona and have been recognized in various mountains in the central and western parts of the desert province. At Bisbee the Naco limestone, with a thickness estimated as ranging from 3,000-5,000 feet or more, lies more or less comformably on the Escabrosa limestone. The lower part of the Naco is Pennsylvanian and the upper part Permian. When originally described, it was regarded as wholly Pennsylvanian. Later work has shown the presence of Permian fossils in the upper portions. The Naco occurs in most of the mountains in southeastern Arizona and has been observed in the Dos Cabezos region, Winchester Mountains, and in the vicinity of Tucson. Limestones of Pennsylvanian age have been

studied in the Galiuro Mountains and have been recognized in the Silver Bell Mountains, Vekol and Slate Mountains, Waterman Mountains, and also in the Sierra Blanca, Twin Buttes and Growler Mountains, and near Ajo. In Yuma County Pennsylvanian rocks were observed by Darton in the Harquahala and Harcuva Mountains.

The Pennsylvanian seas covered the southeastern part of Arizona and extended northward into the central part of the state, probably connecting for a part of the period with the San Juan basin in southeastern Utah. West of the Grand Canyon region a thick Pennsylvanian sequence is known in the Muddy Mountains of Nevada, and it is not unlikely that the sea deposited some Pennsylvanian limestones and shales in the western part of the province. The presence of abundant fossils and other organic material makes the Pennsylvanian rocks a good source of petroleum and, in such regions as are underlain by Pennsylvanian rocks, the prospects for occurrence of petroleum are generally favorable.

No Pennsylvanian rocks have been recognized in the region around Phoenix, but it is not unlikely that the Pennsylvanian seas once covered that region, at least in part, as the present margin of the Pennsylvanian outcrop lies within a radius of fifty miles of Phoenix. Erosion and mountain building have destroyed the former continuity of the outcrop but it is entirely within the realm of probability that, in some of the downthrown fault blocks underlying present intermontane valleys, rocks of Pennsylvanian age containing organic matter may be discovered by the drill.

The great intermontane valleys of southeastern Arizona are in all probability underlain in part by Pennsylvania rocks. The thicknesses may range from 3,000 to 6,000 feet. Organic material is abundant and there are potential reservoir rocks in the form of limestones (which may have developed porosity wherever exposed to weathering) sandstones, fractured shales, etc.

Permian System: The Permian, which has only recently been recognized in southern Arizona, is represented by the upper portion of the Naco limestones and by the Snyder Hills formation exposed west of Tucson. The latter correlates with the Kaibab limestone of the plateau province. Northwest and west of Tucson, shales and limestones carrying Permian fossils have been recognized, and it is probable that the Permian sea covered a large area of southeastern Arizona; its deposits merging or grading laterally into the Permian redbeds and clastics of the Plateau region to the north. The Supai formation in the Mogollon Rim near White River contains several marine, fossiliferous limestones which increase in thickness to the southeast. The Kaibab limestone on the southern margin of the plateau province thins to the northeast, suggesting that it may have been present in greater thickness to the south. Little evidence of is presence south of the rim remains as the region is part of the rugged mountain belt, much distorted and eroded since late Mesozoic time.

Valleys underlain by Permian sediments in southeastern Arizona

are considered in this report as potentially favorable to the origin and accumulation of petroleum.

Mesozoic Systems: The Mesozoic system, comprising Triassic, Jurassic and Cretaceous formations, is represented in the desert province only by the upperost division; namely, the Cretaceous. In the Bisbee district clastic sediments composed largely of sandstones, shales and conglomerates, with limestones playing a minor role, form the Bisbee group of lower Cretaceous age. The group has a thickness at Tombstone of 3,115 feet according to B. S. Butler and others. A greater thickness is stated to occur at Bisbee. The group is unconformable on the Paleozoic formations. The sediments were laid down presumably in brackish waters and were probably closely related to the shoreline of the advancing Cretaceous sea. Deposits of lower Cretaceous age are found in abundance to the southeast in Mxico and south of El Paso and were probably deposited within the same basin as those in the Bisbee district. It is not unlikely that the Cretaceous sea covered much of southern Arizona for at least some part of the Cretaceous period.

Cretaceous rocks in the Bisbee district were described by Ransome as divided into our formations:

Cintura Formation	Redbeds, etc.	1,800	ft.
Mural Limestone	Limestone	650	ft.
Morita Formation	Redbeds, etc.	1,800-2,000	ft.
Glance Conglomerate	Basal Conglomerate	0-1,000	ft.

The Bisbee group, subdivided above, has not been studied in detail outside of the Tombstone-Bisbee area, but similar rocks are found in most of the ranges bordering the Sulphur Springs Valley and the ranges south of Tucson; namely, Santa Rita, Empire, Whetstone, etc. The Glance conglomerate is made up largely of local materials and is variable in thickness. The Morita formation is reddish at the base, and the red shales are hard with numerous calcareous nodules. The upper part is more sandy and the sandstones are cross-bedded and sometimes quartzitic. There appears to be no unconformity between the Morita formation and the Glance conglomerate, nor between the Morita and the overlying Mural limestone. The Mural limestone is composd of two members; the lower one a limestone 300 feet thick composed of impure, thin-bedded limestones, capped at the top by a 25 foot bed of buff sandstone; the upper member 350 feet thick made up of thick-bedded, pure white limestones. The Cintura formation is similar to the Morita formation. It has a thickness east of Bisbee of 1,800 feet, but the top is eroded. It is composed of:

Red, nodular shale	600	ft.
Flaggy, cross-bedded gray to buff sandstones	300	ft.
Red, nodular shales	700-800	ft.
Red shale, thin-bedded sandstones, and impure limestones	100-150	ft.
Buff quartzite	10-15	ft.

In the Empire and Patagonia Mountains a section of red shales, sandstones and conglomerates grading upwards into gray or green beds occurs with a thickness said to be about 6,000 feet. These are referred to Lower Cretaceous by Darton but were regarded earlier by Schrader as including rocks from Triassic to Tertiary in age. When this section has been thoroughly examined for fossils or other correlative criteria, there will probably be available some definite data on which to base a correlation.

Most of the fossils found so far occur in the Mural limestone and have been referred to the Comanchean or Lower Cretaceous.

Rocks of Upper Cretaceous age occur at Clifton and were named the Pinkard formation by Lindgren. Not far west in the Deer Creek Basin are clastic and volcanic rocks also referred to Upper Cretaceous. These sediments may be related to the Upper Cretacous sediments of the plateau province.

North of Elgin in the Cienega Basin between the Whetstone and Santa Rita Mountains, a thick succession of clastic sediments measuring 10,000 feet or more are exposed. At the base of the section are some thin fossiliferous limestones which are said to contain Upper Cretaceous fossils. Above the limestones are alternating dark black or drab shales and buff to brown sandstones with sandstones predominating in the section. Several sills of rhyolite have been intruded in this part of the section with localized contact metamorphism. About 3,200 feet from the top of the section is a black shale section which is highly bituminous. Above it lies a sequence of alternating red shales and sandstones, the latter cross-bedded and lenticular and sometimes conglomeratic. The upper part of this series may be either Upper Cretaceous or Tertiary as no fossils have been collected from it as far as is known.

The Cretaceous rocks found in southeastern Arizona probably represent a sedimentary environment in part litterol and in part marine. The upper portion may represent brackish water deposition. It is thought that the environment was favorable to the development of abundant organic life which may have been buried to form a source of petroliferous matter. The abundance of sandstones and lenticular bodies should provide good reservoir conditions and, if suitable structures exist such as the Klene anticline in southeastern Pima County, good traps for petroleum may be found. In this report the valleys of southeastern Arizona, which are underlain by Cretaceous sediments, are regarded as potential oil lands.

In the western part of the desert province, Cretaceous rocks have been observed and reported at Twin Buttes, Sierrita Mountains, Tumacacori Mountains, Oro Blanco Mountains, Baboquivari Mountains, Quijota Mountains, and Plomosa Mountains. Other areas having exposures of red shales and sandstones have been referred to either Cretaceous or Tertiary on basis of lithological similarity to the Bisbee group or the Tertiary of the Benson area, but these rocks may as well be referred to the Triassic or Permian. Until definite studies have been completed on such sections, correlations are at

best merely an expression of the personal opinion of the observer.

The significance of such deposits, regardless of age, to the petroleum prospects of the desert province lies in the fact that each area of sedimentary rocks discovered adds to the potential area in which exploration for petroleum may be advantageously pursued.

Tertiary System: Rocks of Tertiary age, or the "Age of Mammals," are found widely distributed in the desert province. The standard classification on the Tertiary groups is as follows:

Pliocene
Miocene
Oligocene
Eocene

Tertiary rocks in Arizona have not been studied in sufficient detail to be distinguished as members of the groups listed above except in one or two isolated instances where vertebrate fossils have been found on which to base a correlation.

The events of Tertiary time, as tabulated by Kirk Bryan in his studies of the Papago Country, may be used as a summary of the geological history as it is known today.

At the end of the Cretaceous period, the Rocky Mountains were formed and a large area to the west was folded and uplifted. The central mountain belt of Arizona was formed at this time and many of the axes of mountain structure in the desert province developed as longitudinal folds or arches.

In Eocene time the region of the desert province was subjected to uplift and general erosion, resulting in formation of coalescing pediments surmounted by small mountains and deposition of alluvium in the valleys.

In Oligocene time, not mentioned by Bryan, the record is obscure. To the west in California, this period was one of redbed formation, particularly in the Los Angeles basin. Some of the Tertiary redbeds found in the desert province may be of this age although to date there is no evidence, fossil or otherwise, to form the basis of such correlation.

In Miocene time the region developed great volcanic activity. There were extrusions of lavas which were preceded by the deposition of stream laid conglomerates and fine grained red sandstones and shales which may be referred in part to the Oligocene or Eocene. In some instances lava flows are intercalated with the sediments. Bryan considers these sediments to be fresh water deposits, either stream-laid or lacustrine, but there is a possibility that some of the redbeds were deposited on the landward margins of marine basins.

Following the period of Miocene volcanism came the Pliocene period which was a period of uplift and block-faulting followed by erosion of the mountains. The best known Pliocene deposits are in the San Pedro valley near Benson where vertebrate fossils of Pliocene age have been recovered. This valley was filled to some depth by gravels and other alluvian from the bordering mountains and has

since been dissected to badland topography exposing the Pliocene beds.

Schrader thought that rocks of early Tertiary age might underlie parts of the region adjoining the Santa Rita, Empire and Patagonia Mountains. He found an exposure in Adobe Canyon, five miles east-southeast of Old Baldy, having about 640 feet of conglomerates, shales, grits and sandstones lying on rocks of supposed Cretaceous age. Fossils from this exposure were thought to be fresh water forms of probable Eocene age.

Bryan found outcrops of sediments of supposed Tertiary age at various points, notably south of Ajo, near Tule Well, near Cabeza Prieta, at Antelope Hill, south of Baker Peak, north of Table Top, and at Comobabi. These were composed largely of coarse, poorly sorted, arkosic beds, in part conglomeratic. They range in thickness from 50 to more than 1,000 feet and are classed as Tertiary because of their intimate association with the volcanic rocks of that period.

Bryan also mentioned the thick, red arkosic conglomerates of the Papago Hills just east of Phoenix and classed them as Tertiary. Holm has examined these red arkoses and found them widely distributed in the Salt and Gila River valleys. In the Phoenix region a series of red arkosic conglomerates and sandstones occurs on the west end of Camelback Mountain bearing a marked resemblance to those in the Papago Hills. There are three members on Camelback; the lower being a dark, maroon arkose, lying unconformably on older granite with a thickness of about 100 feet. The middle member is lighter in color, composed of coarser material, with great angular boulders of granite and other basement rocks. It has a thickness of about 200-300 feet. Overlying the middle member is a dark, red arkose, in part conglomeratic, with a sand matrix, showing some well defined bedding and ripple-marks, containing angular fragments of the underlying rocks, both sedimentary and crystalline. The thickness is at least 200 feet, and the top is eroded. Holm has proposed the name Camelback Formation for this series. It is the same as occurs in the Papago Hills and is found in the southeast extension of these hills just north of Tempe. In Tempe Butte, just at the north edge of the town of Tempe, occurs about 250 feet or more of thin-bedded, red sandstones, siltstones and shales, displaying regular bedding, ripple-marks and other evidences of having been deposited in an extensive body of water. The beds have the same dip as the coarses arkosic beds to the north and are assumed to be younger members of the same series, in other words, part of the Camelback formation. The upper part of the exposure in Tempe Butte is in contact with a gray felsite, a volcanic rock of probable extrusive origin, which Holm interprets as lying on the eroded surface of the Tempe Butte beds. Other observers have called this volcanic rock intrusive, which may be true. In this case it is a sill.

About thirty miles east of Phoenix just north of Granite Reef Dam across the Salt River, about 1,000 feet of red arkoses form the greater part of the butte-like McDowell Mountain. They are similar

to the Camelback formation in appearance and are correlated with that formation by Holm. In the upper part of the section two small sills of felsite or basalt have been intruded between bedding planes. The conglomerate lies unconformably on crystalline rocks which may be Pre-Cambrian in age. To the west and northwest of McDowell Mountain remnants of the basal part of the conglomerate are found lying on the basal complex.

Under the thick basalts and tuffs of the country north of Cave Creek, some thirty miles north of Phoenix, Holm found about 450 feet of red arkose and conglomerate showing fairly definite bedding and lying unconformably on the Pre-Cambrian (?) diorite and containing fragments of the latter as well as other crystalline rocks from the vicinity. It bears some points of resemblance to the Camelback formation and is tentatively correlated with the latter.

In Yuma County just north of the McPhaul bridge across the Gila River near the Antelope Hills, Holm found some dark, red arkoses and conglomerates under basalts, tilted and eroded previous to the effusion of the lavas. In appearance and material these arkoses bore great resemblance to the Camelback formation. Bryan and Wilson have mentioned several probable Tertiary sections in nearby hills or mountains. The Antelope Hills are composed of light-colored sandstones and conglomerates derived largely from the decomposition and erosion of nearby igneous rocks and are probably younger than the arkoses mentioned above. In the Baker Peaks south of the Antelope Hills more than 1,000 feet of tilted, faulted, reddish-brown to gray conglomerates, arkosic sandstones and shales are exposed. They also occur in the Mohawk Mountains and Antelope Hills. The age is probably Tertiary.

These red, arkosic sediments lying in the Salt and Gila River valleys have not been found to contain fossils, but it is not improbable that a careful search will uncover either plant or vertebrate fossils and possibly some fresh or brackish water fossils. The age is indefinite at present but may be given as pre-volcanic or in part contemporaneous with the volcanism which, if Bryan's assignment of the early volcanic activity to Miocene be accepted, places these redbeds in or previous to Miocene beds. At Camelback Mountain, Tempe Butte, Papago Hills, McDowell Mountain, and in Yuma County the redbeds have been tilted and in some cases faulted, definitely establishing their age as older than the tilting and faulting movements. For lack of better information, the Camelback formation is tentatively regarded as Tertiary but may just as well be Lower Cretaceous, Triassic or Permian. As already mentioned, volcanic rocks have been intruded as sills or dikes into some of these redbeds, and in others lava flows are interbedded with the redbeds. The amount and extent of this volcanic activity is not known at present as the area of exposures of the rocks involved is small in comparison to the total area of those rocks.

Pleistocene System: The Pleistocene in other regions, such as the northern part of the continent and some high mountain ranges,

is composed of glacial deposits. The age is commonly known as the "Ice Age". In Arizona the period is one of erosion and fluvial deposition, the earlier part being represented by the thick gravels and conglomerates described in the upper Gila Valley by Ransome as Gila conglomerate. Later deposits may be represented by the so-called "valley fill" of the present day valley floors and by underlying stream and lake deposits. Volcanic activity during the period is evidenced by extensive basalt flows. The activity lasted until recent times as evidenced by remains of cinder cones such as those near Douglas.

Pleistocene deposits are probably of no great importance as potential petroleum prospects.

OIL POSSIBILITIES OF THE DESERT PROVINCE

The desert province of Arizona has often been condemned by conservative geologists as unfavorable to the origin and accumulation of petroleum because the mountain ranges are composed of large masses of igneous and metamorphic rocks. They have assumed that the intermontane valleys are merely down-thrown blocks of the same nature as the mountains and covered with a thin veneer of alluvium.

The presence of numerous seepages of high gravity oil in the desert province from the Salt River Valley to southeastern Arizona, as well as the records of several deep wells, has thrown this conservative opinion into disrepute.

The State Land Department has investigated the occurrence and geology of as many seepages as possible. The geology of regions in which deep well records are available has also been investigated. The results lead us to the firm belief that petroleum prospects in the desert province of Arizona are favorable. The regions which offer the best possibilities are:

1. Intermontane valleys in southeastern Arizona
2. The Salt River Valley near Phoenix
3. Intermontane valleys free from volcanism in southern Yuma County
4. The Yuma Valley near Somerton
5. Deep, intermontane valleys free from volcanism between Tucson and Casa Grande.

Exploration of these regions will involve:

1. Extensive drilling campaigns by wildcat operators
2. Geophysical prospecting:
   (a) Magnetic surveys
   (b) Gravity surveys
   (c) Seismic surveys
   (d) Electric resistivity surveys
3. Geochemical exploration:
   (a) Soil Analysis surveys

4. Geological mapping:
   (a) Surface reconnaissance and detailed mapping
   (b) Core drilling
   (c) "Slim-hole" exploratory drilling
   (d) Regional stratigraphic and structural studies
5. Aerial Photographic surveys

ESSENTIAL CRITERIA FOR THE RECOGNITION OF PETROLIFEROUS PROVINCES

Geologists divide the continental areas into three categories:

1. The impossible areas for petrolierous rocks
2. Possible petroliferous areas
3. Petroliferous (favorable) areas

According to Schuchert, these categories are elaborated as follows:

1. The impossible areas for petroliferous rocks:
   (a) The more extensive areas of igneous rocks and especially those of the ancient Pre-Cambrian shields; excepting the smaller dikes.
   (b) All Pre-Cambrian rocks.
   (c) All decidedly folded mountainous tracts older than Cretaceous; excepting domes and block-faulted mountains.
   (d) All regionally metamorphosed strata.
   (e) Practically all continental or fresh-water deposits; however, relic seas, so long as they are salty, and saline lakes are excluded from this classification.
   (f) Practically all marine formations which are thick and uniform in rock character and that are devoid of interbedded dark shales, thin-bedded dark impure limestones, dark marls or thin-bedded limy and fossiliferous sandstones.
   (g) Practically all oceanic abyssal deposits; these, however, are but rarely present on the continents.
2. Possible petroliferous areas:
   (a) Highly folded marine and brackish water strata younger than Jurassic and, more especially, those of Tertiary time.
   (b) Cambrian and Ordovician gently folded strata.
   (c) Lake deposits formed under arid climates that cause the waters to become saline. It appears that only in salty water (not over 4%?) are the bituminous materials made and preserved in the form of kerogen, the source of petroleum. Some of the Green River (Eocene) continental deposits (the oil shales of Utah and Colorado) may be of saline lakes.
3. Petroliferous (favorable) areas:
   (a) All marine and brackish water strata younger than the Cambrian and but slightly warped, faulted or folded. Here are included also the marine and brackish water deposits of relic seas like the Caspian, formed during the later Cenozoic. The more certain oil-bearing strata are the

porous, thin-bedded sandstones, limestones and dolomites that are interbedded with black, brown, blue, or green shales. Coal-bearing strata of fresh water origin are excluded. Series of strata with disconformities may also be petroliferous, because beneath former erosional surfaces the top strata have induced porosity and are therefore possible reservoir rocks.

(b) All marine strata that are, roughly, within 100 miles of former land masses. Here are apt to occur the alternating series of thin and thick-bedded sandstones and limestones interbedded with shale zones.

According to this classification, under "impossible areas for petroliferous rocks" would fall:

1. Most of the mountain ranges in the desert province.
2. The pediments surrounding desert ranges.
3. Mineralized regions.
4. Areas where volcanic rocks predominate.

Possible petroliferous areas are:

1. Intermontane basins and valleys.
2. Old lake basins such as the Willcox playa and the Hualpai playa.
3. Downthrown fault blocks including sedimentary rocks.

Petroliferous (favorable) areas are:

1. Intermontane valleys in southeastern Arizona containing:
   (a) Slightly folded marine and brackish water strata younger than Cambrian.
   (b) Folded and faulted Cretaceous or Tertiary marine or brackish water strata.
2. Marine or brackish water shoreline deposits as probably occur in the lower Yuma Valley under the recent alluvium.

Having recognized the favorable and possible petroliferous areas in the desert province, there are additional criteria the geologist may use to narrow the search to more restricted limits. These are:

1. Existence of surface indications (see pages, etc.).
2. Sedimentary origin of the rocks.
3. Similarity in age of strata with those prevailing in some known oil and gas field.
4. Existence of possible source origin.
5. Existence of porous beds or reservoirs in which oil may be held in commercial quantities.
6. Existence of sufficient caprock above reservoir to prevent escape to surface of oil and gas.
7. Metamorphism of strata must be sufficiently slight so that oil and gas have not been driven away.

8. Existence of geologic structure suitable for concentrating oil and gas in commercial quantity.
9. Existence of hydrostatic conditions favorable to the accumulation of oil in pools.

If the majority of these factors are represented for a prospective area, an oil field may be safely predicted. Taking the factors one by one and applying them to the possible and favorable areas in the desert province, we find that the province has a large area of potential oil lands.

SURFACE INDICATIONS OF PETROLEUM

The occurrence of petroleum seepages is easily recognized and may be significant as a surface indication of the presence of petroleum within a given district. Seepages may occur in water wells, springs or pools of water and may also occur as surface seepages such as the Rancha La Brea tar pits near Los Angeles or the vast asphalt lakes in Trinidad.

Seepages in wells have been observed in parts of southern Arizona, particularly in the Salt River Valley and the Willcox district. A list of such seepages is given in the appendix to this report.

SEEPAGES OF PETROLEUM IN THE SALT RIVER VALLEY NEAR PHOENIX

The irrigated lands around Phoenix contain many water wells used by the Salt River Valley Water Users' Association to keep the level of ground water down below the surface in order to prevent concentration of alkali materials in the irrigated soils. Many of those wells show small amounts of light oil.

The best known seepage of this nature is in a Water Users' well at the corner of Chicago Avenue and Thomas Road a few miles northeast of Phoenix. This well is 172 feet deep and is pumped by an electrically driven centrifugal pump. The volume of water has been estimated at about 500,000 gallons daily. The water flows out of the discharge pipe into an open concrete ditch which has a weir at the lower end. Between the discharge pipe and weir a board has been placed across the surface of the ditch which serves to lessen the agitation of the water on the weir-side of the board. In this portion of the ditch a strong film of high gravity oil may be observed on the surface of the water, sometimes thick enough so that it can be skimmed off readily. The odor of kerosene or gasoline is strong. Samples of this oil have been collected and sent to the U. S. Bureau of Mines, Petroleum Experiment Station, Bartlesville, Oklahoma, for analysis. The results are extremely interesting.

ANALYSIS OF OIL SEEPAGE AT CHICAGO AVENUE AND THOMAS ROAD

Speciifc gravity 0.808	API Gravity .....43.6°
Percent Sulphur less than....0.1	Color lighter than NPA No. 1.

Saybolt Universal Viscosity at 100° F., 32 Sec.

Distillation, Bureau of Mines, Hempel Method

Dry Distillation Barometer 749 mm. First Drop: 246° F.

Temperature (Degrees F)	Percent cut	Sp. Gr. of cut	API Gr. of cut	
257-302	3.3	0.756	55.7	NOTE: This oil is a light distillate composed of the lighter paraffinic fractions.
302-347	14.0	.782	49.5	
347-392	35.8	.803	44.7	
392-437	36.7	.819	41.3	
*437-455	6.8	.830	39.0	

*End point 455° F.

Carbon residue of residuum 0.3%.

Carbon residue of crude less than 0.1%.

Approximate Summary

Light Gasoline	Percent	Sp. Gr.	API°	Viscosity
Total Gasoline and Naptha	53.1	0.795	46.5	
Kerosene distillate	36.7	.819	41.3	
Gas oil	6.8	.830	39.0	
Nonviscous lubricating distillate	.....	.....	.....	50-100
Medium lubricating distillate	.....	.....	.....	100-200
Viscous lubricating distillate	.....	.....	.....	above 200
Residuum	2.8	0.852	34.6	
Distillation loss	.06	.....	.....	

Analysis by (Signed) E. L. Garton. March 1, 1938.

This oil is classified by the Bureau of Mines as a crude mineral oil of parrafin base and is definitely not a vegetable oil.

This well has been showing signs of oil for at least five years. Estimates of the quantity of oil being produced daily vary from twenty gallons to five barrels. It is the opinion of Holm, after careful check and frequent observation, that the oil is natural and coming from rocks at some unknown depth below the surface of the ground.

During the past summer (1938) the well evidenced some production of casinghead gas. When the pump was shut down, gas collected under pressure in the casinghead and when led off to the air by a small pipe and ignited, it burned readily with a yellow flame, having length varying from four to ten feet. A match thrown carelessly near the pump head at almost any time would ignite gas mixed with air and explode with startling unexpectedness.

A well to test the possible source of this oil was drilled during the summer of 1938 by L. P. Newcom of Phoenix, at a location sixty feet north of the Water Users' well. When last reported, depth was about 1,000 feet. The drill cuttings between 550 and 1,000 feet contain mostly fine-grained, red or gray sand, somewhat angular, oc-

casionally rounded. Dumpings from the bailer showed small amounts of gas and small, black, greasy globules of oil accumulated on the surface of the barrel in which the bailer was dumped. These globules were greasy to the touch and probably represent particles of residual oil from the sands penetrated. It is the opinion of Holm that the rocks underlying the well are part of the Camelback formation, dip strongly to the west or southwest, and their upper edges have been truncated by the erosion which formed the floor of the Salt River Valley. A thin veneer of valley fill covers these dipping rocks. Ground water of probable meteoric (meteoric-rainwater) origin may have washed through the beds and removed oil once present there in probable quantity. If a suitable structural trap occurs somewhere in the vicinity of the well, an oil pool may be eventually discovered.

The Chicago Avenue and Thomas Road well seep is one of the best to be observed near Phoenix, but it is by no means the only one. A recent check by the Land Department discovered 37 seepages in 65 wells examined. The seeps and their locations are listed in the appendix. The seepages are distributed in a band about two miles wide extending northwest through Tempe, south of Papago Hills and north of Phoenix, and lying there between the Arizona and Grand Canals. This trend is parallel and strikingly similar to the strike of the Camelback formation just northeast of the seepages and indicates to the geologist location and apparent width of a saturated zone of oil sands.

SEEPAGES IN THE WILLCOX AREA

Several seepages indicating presence of oil in the Willcox area are known. The most familiar is undoubtedly that which occurs in the Southern Pacific water well at Willcox Station. The well is 650 feet deep and was used until a few years ago. The seep of oil was noticed in about 1928, when a light oil collected on the surface of water in the water tank in considerable quantity. Between 1928 and 1938, it has been reported that the pumper sold this oil to ranchers for 10c per gallon and estimates of the amount vary from 2,500 gallons to as much as several hundred barrels. It is said that the oil could be placed in automobile fuel tanks and used to run the cars. A representative of the State Land Department collected samples from this well in December, 1937, and sent them to the U. S. Bureau of Mines at Bartlesville, Oklahoma, for analysis. The results are as interesting as those from the Chicago Avenue seepage at Phoenix.

ANALYSIS OF OIL FROM SOUTHERN PACIFIC WATER WELL AT WILLCOX

Specific Gravity	0.814	API Gravity	42.3°
Percent Sulphur	0.11	Color lighter than NPA No. 1	

Saybolt Universal viscosity at 100°F., 32 Sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Dry Distillation Barometer 749 mm. First Drop: 235°F.

Temperature (Degrees F)	Percent cut	Sp. Gr. of cut	API Gr. of cut	
257-302	9.5	0.744	51.3	NOTE: This oil is light distillate composed of the lighter paraffinic fractions.
302-347	27.7	.793	46.9	
347-392	30.0	.814	42.3	
392-437	19.7	.832	38.6	
437-482	7.3	.847	35.6	
*482-493	2.2	.860	33.0	

*End Point 493°F.
Carbon residue of residuum 0.4%.
Carbon residue of crude less than 0.1%.

Approximate Summary

Light Gasoline	Percent	Sp. Gr.	API°	Viscosity
Total gasoline and naptha	67.2	0.800	45.4	
Kerosene distillate	.....	.....	.....	
Gas oil	29.2	0.838	37.4	
Nonviscous lubricating distillate	.....	.....	.....	50-100
Medium lubricating distillate	.....	.....	.....	100-200
Viscous lubricating distillate	.....	.....	.....	Above 200
Residuum	2.9	0.887	28.0	
Distillation loss	0.7	.....	.....	

Analysis by (signed) E. L. Garton. March 1, 1938.

This seepage has a high content of gasoline and naptha; kerosene distillate is absent, and the greater part of the balance of the sample is composed of gas oil. The oil, like that from the Chicago Avenue well, is considered by the U. S. Bureau of Mines as a natural crude petroleum.

Other seepages are known from shallow water wells in the town of Willcox and nearby farms. Judge C. O. Anderson has in his possession a sample of brown oil taken from a water well 250 feet deep, drilled in 1925 on a farm which he formerly owned. The oil burned freely. The State Land Department has in its files an analysis of a sample of oil taken in 1925 from a fourteen foot posthole in Willcox. The sample contained 84% gasoline, 16% kerosene, a very little sulphur and had a gravity of 44°.

Other seepages in the desert province are listed in the appendix.

Specimens of asphalt have been found recently over a wide area in the White Water Draw north of Douglas. The source of these asphalt "balls" is not known, but according to the report of a rancher in the vicinity, there is exposed an outcrop of rock which may be either sandstone or limestone in which streaks of asphalt occur. There has been no opportunity to check this report but it is mentioned here in the fond hope that some individual with insatiable curiosity will locate the outcrop in the eastern edge of Sulphur

Springs Valley, somewhere north and east of Elfrida and obtain a good sample for the State Land Department.

Seepages of petroleum have been found in many petroleum producing regions before any production of oil occurred and may have been the only clue existing to lead the wildcatting driller to a suitable location. The presence of oil seeps in the Pennsylvania hills was known long before Drake drilled the historic well at Titusville. Petroleum exploration in South America included, in its early stages, the search for and the examination of oil seeps. The presence of seeps may indicate that petroliferous matter exists in the rocks of the region in which the seep occurs but does not necessarily restrict the occurrence of the source of that oil to the immediate vicinity of the seep. If the rocks are dipping at an angle to the horizontal, it is possible that the oil may have migrated through the strata for considerable distance.

SEDIMENTARY ORIGIN OF THE ROCKS

The section on stratigraphy has given the age and distribution of the sedimentary rocks of the desert province and has suggested that such rocks may have greater distribution than is generally conceded by conservative geologists. The age of such sediments has a range comparable with that of rocks in regions producing petroleum. There is abundant source rock in which petroleum may originate, particularly in southeastern Arizona and the Salt River Valley. There are porous beds suitable as reservoirs, not only in the Paleozoic rocks and the thick Cretaceous sediments of southeastern Arizona, but in the so-called Tertiary sediments of the Salt River Valley. The existence of suitable caprocks over reservoir beds is a matter of determination for individual petroleum prospects.

Metamorphism of sedimentary strata in potential petroliferous regions is considered in this report to be comparatively slight. Regions in which metamorphism is due to the intrusive action of igneous magmas and to hydrothermal activity are thought to be restricted to the areas associated intimately with mountain building. In other words, the metamorphic belts for the purposes of this report are regarded as being limited to the mountain blocks, and the intermontane blocks, now evidenced on the Earth's surface as valleys, are regarded as only slightly metamorphosed. Holm has observed outcrops of Cretaceous clasites in Cochise County which show little or no metamorphism though not far from neighboring mountain ranges. Upper Cretaceous or possible early Tertiary clastics in southeastern Pima County (Klene Anticline), which have been intruded by several thin rhyolite sills, show remarkably little metamorphism, the alteration on the outcrop being restricted to a few feet of section adjacent to the sills. Members of the Camelback formation outcropping on McDowell Mountain thirty miles east of Phoenix, likewise intruded by thin sills of fine-grained volcanic rock, show practically no metamorphism. These observations suggest the interesting possibility of slight metamorphism of the intermontane sediments. With metamorphism slight it is unlikely that any petroliferous matter present in

the strata will have been driven off. Several geologic structures have been observed on the surface of Pima and Cochise Counties. Others may presumably lie buried under the veneer of valley fill. Discovery of the hidden structures will be accomplished by systematic geophysical exploration or accidentally by wildcat drilling. Hydrostatic conditions, where deep wells have been drilled in the desert province, indicate abundance of water in sands both shallow and deep. A well near Pima encountered salt water. The deep well at San Simon had fresh water down to 6,450 feet but recently reported salt below that depth. There is sufficient water in the sedimentary strata to aid in the migration of petroliferous matter through the reservoir rocks.

Individual areas in the desert province which possess a majority of criteria which are deemed favorable to the occurrence of oil are abundant. The search for petroleum in this province can be limited to definite areas small enough for efficient detailed exploration. The methods which may be used will include plane-table mapping, core-drilling, geophysical surveys, and exploratory drilling to depths of at least 5,000 feet. The search for petroleum in this province will not be an easy one. It will require expenditure of large amounts of capital. It is not a simple matter of forming a block of acreage and drilling a well in the center of the block. One must know where to select the block. The common procedure of forming a company composed of local business men who contribute sums for drilling from their personal funds does not provide sufficient capital for modern methods of petroleum exploration. The implication of this statement may be bitter to some, but the flavor of its truth may be sweeter if not realized too late.

CONCLUSIONS

It has been fashionable among certain authorities in the past to remark that oil possibilities in Arizona do not exist. The evidence submitted in this report is sufficient to make the accuracy of that opinion questionable.

Geological conditions under which oil may form and accumulate are best exemplified in sedimentary rocks of marine origin. The portions of Arizona where such marine formations occur have been described. It is in these areas that exploration for petroleum will be most successful.

In the plateau province, the areas which are favorable for petroleum exploration include a large part of the Navajo Country, various anticlines on the Monument uplit, the Little Colorado River Valley from Cameron to St. Johns, the Rio Puerco Valley between Holbrook and Sanders, the so-called "Strip" in northwestern Arizona, and Chino Valley.

In Southeastern Arizona are included the intermontane valleys of Cochise County such as the San Simon and Sulphur Springs Valley, the Cienega Basin in southeastern Pima County, the Gila Valley near Safford, and some intermontane basins in the vicinity of Tucson.

The Salt River Valley near Phoenix is considered highly favorable for petroleum exploration on the basis of being an intermontane basin containing abundant probable marine sediments, numerous seepages of high gravity oil, and probable structural traps underlying the valley fill resulting from folding and faulting.

In southwestern Arizona the Yuma Valley south of Yuma is considered favorable as probably containing sediments of a relic sea (The Gulf of California), and some of the intermontane valleys in southern Yuma County, such as the Mohawk Valley, may contain suitable marine Mesozoic and Tertiary formations.

Other intermontane basins in the desert province may be possible petroliferous areas, such as those between Tempe and Tucson.

The geology of Arizona is still an unknown quantity. South of the plateau province geological studies are few and sketchy. What work has been done was restricted to mineral deposits except in some rather broad reconnaissance surveys which outline the stratigraphy briefly.

No regional studies of Arizona geology have been published except in the northern part and these are at best incomplete. No regional studies of geological structural problems have been published. No regional stratigraphic studies are available. There is not enough geological data available to compile satisfactory paleogeographic maps of Arizona showing distribution of sedimentary rocks, shorelines, land masses, etc., for any particular geological period. The desert province is indeed very poorly known both geographically and geologically.

Much geological exploration remains to be done in all of Arizona. If the State of Arizona becomes awake to the pressing need for such geological work and makes provision for adequate geological surveys of the more favorable petroliferous areas, the search for petroleum will be materially aided.

Scientific and industrial progress are based today upon accurate and adequate research studies. This is particularly true with regard to the undeveloped natural resources of Arizona.

Petroleum exploration in all probability will be done by expenditure of private capital. Drilling campaigns will be most successful if based upon accurate geological and geophysical surveys.

It is recommended that provision be made by the Arizona Legislature for the preservation of the records of drilling wells and that such records include a complete set of samples of drill cuttings; such samples to be taken at regular intervals and in continuous sequence. The records should be filed in the office of the State Land Department and provision made for the geological examination of those samples.

The value to Arizona of an adequate geological survey cannot be measured in dollars and cents. However, the increased revenues which result from development of newly discovered resources is evidence that anyone can understand.

Arizona annually consumes enough petroleum products to represent a daily crude oil production of about 12,000 barrels. At present Arizona purchases all the petroleum products it consumes outside the state. When Arizona's potential oil resources are developed, the income from the production and processing of petroleum consumed will flow, not into the coffers of out-of-state capital, but into the pockets of Arizona's citizens. City, County and State government will benefit by increased tax revenue. State institutions will derive greater income from the revenues from state lands. It behooves every Arizonan to put his shoulder to the wheel and boost:

"ARIZONA OIL"

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OIL AND GAS SEEPS IN THE SALT RIVER VALLEY

Description of Land Descr.	Se.	Tp.	Rg.	Water Users' Description	Location of Seep	Data on Oil Seep
SW¼SW¼	9	1N	1E	2E—4N	Buckeye Road & Lateral 23 Northeast corner	Well not running date of check (11/12/38) Rainbows on water? Lubricated.
NE¼SE¼SE¼	1	1N	3E	18E—5N	40th Street & Van Buren near Asylum farm	Light film oil—good rainbows. Lubricated.
SE¼SE¼	20	1N	4E	20E—2N	Broadway	Film of oil—rainbows. Lubricated.
SE¼SE¼	28	1N	4E	21E—1N	Southern Avenue	Not running date of check (11/15/38) Rainbows in water? Lubricated.
NE¼NW¼NW¼	30	1N	5E	24½E—2N	Broadway & Tempe Canal	Rainbows? Lubricated.
S¼ corner	30	1N	5E	24½E—1N	Southern Avenue & Tempe Canal	Bubbles breaking in water with rainbows. Pump lubricated.
SW¼	32	1N	5E	26E—0N	Baseline Road	Light oil film and rainbows. Lubricated.
SE¼SE¼	2	2N	1E	5E—11N	Glendale Avenue & Lateral 20 Northwest corner	Good film oil, emulsion, rainbows, oil on ditch bank. Pump lubricated.
SE¼SE¼	17	2N	1E	2E—9N	Cameblack Road & Lateral 23 Northwest corner	Well not running on date of check (11/10/38). Baffle board shows signs of oil. Pump lubricated.
SE¼SE¼	20	2N	1E	2E—8N	Indian School Road & Lateral 23 Northwest corner	Well not running on date of check (11/10/38). Some oil on baffle boards and banks of ditch. Pump lubricated.
NE¼NE¼	21	2N	1E	3E—9N	Camelback Road & Lateral 22 Southwest corner	Light film oil. Lubricated.

OIL AND GAS SEEPS IN THE SALT RIVER VALLEY—(Continued)

Description of Land Descr.	Se.	Tp.	Rg.	Water Users' Description	Location of Seep	Data on Oil Seep
SE¼SE¼	29	2N	1E	2E—7N	Thomas Road & Lateral 23 Northwest corner	Well not running on date of check (11/12/38). Rainbows in water? Lubricated.
SW¼SE¼	13	2N	2E	11½E—9N	Camelback Road North side of road	Light film oil and rainbows. Lubricated.
NE¼ SE¼	10	2N	2E	10E—10½N	Lateral 15 East side of road	Globules or bubbles breaking in water form small rainbows. Lubricated.
NW¼SW¼	14	2N	2E	10E—9½N	Lateral 15	Rainbows. Lubricated. Fifty feet to water, depth 280 feet. Pump uses 27 gravity oil under pressure. Rainbow may be from lubrication.
NE¼NE¼	24	2N	2E	12E—9N	19th Avenue & Camelback Road Southwest corner	Light film oil and small rainbows. Lubricated.
SE¼SE¼	16	2N	3E	15E—9N	Camelback Road & 16th St. Northwest corner	Light film oil and good rainbows. Lubricated.
NW¼NW¼	17	2N	3E	13E—10N	7th Ave. & Bethany Home Road Southeast corner	Light film oil and small rainbows. Lubricated.
SE¼SE¼	17	2N	3E	14E—9N	7th Street & Camelback Road	Good film light oil and small rainbows; bubbles of air or gas break with force. Concrete walls of ditch coated with oil and dust caught by oil; emulsion of oil, water and gas forms on wooden frames, has light cream color, feels greasy, gives off odor of oil or gasoline.

OIL AND GAS SEEPS IN THE SALT RIVER VALLEY—(Continued)

Description of Land Descr.	Se.	Tp.	Rg.	Water Users' Description	Location of Seep	Data on Oil Seep
SE¼NE¼	17	2N	3E	14E—9½N	7th Street West side of road	Good film light oil, rainbows. Lubricated.
NW¼SW¼	19	2N	3E	12E—8½N	19th Avenue & Grand Canal	Good film oil (light) and small rainbows. Lubricated.
NW¼NW¼	25	2N	3E	17E—8N	Indian School Road & 32nd Street Southeast corner	Light film of oil and occasional rainbow. Lubricated.
SE¼NE¼	25	2N	3E	18E—7½N	Osborn Road & 40th Street Northwest corner	Light film oil and rainbows. Lubricated.
SE¼SW¼	25	2N	3E	17½E—7N	Thomas Road & 36th Street Northeast corner	Light film oil and rainbows. Lubricated.
NE¼SE¼	26	2N	3E	17E—7½N	32nd Street West side of road	Light film and rainbows. Oil on ditch bank. Lubricated.
NE¼NE¼	27	2N	3E	16E—8N	Indian School Road & Biltmore Drive	Light film oil and rainbows. Lubricated.
NE¼SE¼	35	2N	3E	J. A. Aldrich Farm Well	One-fourth mile north of McDowell Road on 32nd Street	Well 84 feet deep; cased 60 feet; pump cylinder set at 50 feet; water level 35 feet. Has shown small rainbows 1937-38 and has smell of oil.
NE corner	36	2N	3E	18E—7N	Corner 40th Street & Thomas Road	Swimming pool. Reported to have shown oil on weir in past but not showing in 1938.
West quar. cor. of	29	2N	4E	Gas Seep	In bottom of old cross-cut canal under bridge — Osborn Road at 48th Street	Bubbles of gas rise out of small holes in bottom of ditch at several places. Said to be inflammable by Zanjero Cluff.

OIL AND GAS SEEPS IN THE SALT RIVER VALLEY—(Continued)

Description of Land Descr.	Se.	Tp.	Rg.	Water Users' Description	Location of Seep 444	Data on Oil Seep
SE¼SW¼	30	2N	4E	18½E—7N	Thomas Road & Chicago Avenue	Well 172 feet deep. Pumped for five years by electric-centrifugal, packed in rubber. Showed light film oil continuously except for short periods after well shut down. Estimated 20 gallons to 3-5 barrels oil daily. Sample oil analysed by U. S. Bureau of Mines, Bartlesville, Oklahoma. 43.6° API gravity; 53.1% gasoline and naphtha; 36.7% kerosene distillate.
NW¼NE¼NE¼	30	2N	4E	18¾E—8N	Indian School Road South side of road	Light film oil and rainbows. Lubricated.
SW¼SW¼	27	3N	1E	3E—13N	Olive Avenue & Lateral 22 Northeast corner	Light film oil and rainbows. Baffle boards coated with oil and dust caught by oil. Lubricated.
SE¼SE¼	33	3N	1E	3E—12N	Northern Avenue & Lateral 22 Northwest corner	Good film oil and rainbows. Baffle boards and banks of ditch coated with oil. Lubricated.
SW¼SW¼	36	3N	1E	5E—12N	Northern Avenue & Lateral 20 Northwest corner	Good film oil and rainbows. Lubricated.
SE¼SE¼	30	3N	2E	7E—13N	Olive Avenue & Lateral 18 Northwest corner	Light or small rainbows. Lubricated.
SW¼SW¼	30	3N	2E	6E—13N	Olive Avenue & Lateral 19 Northeast corner	Light film oil and small rainbows. Baffle boards coated with oil, dust caught by oil, greasy to touch. Lubricated. Slight smell of oil.

OTHER SEEPAGES IN SOUTHERN ARIZONA

Gila Crossing Indian School NW¼NW¼ Sec. 9, Twp. 2S., Rge. 2E.

Water well drilled in 1936, 925 feet deep, cased near to bottom, pumped by diesel-driven centrifugal set at 150 feet, lubricated by oil. Odor and taste of oil noticed by Mr. and Mrs. Whiteman, teachers at the school, early in 1938. Scum forms on neck of water bottles in icebox. Amount of oil is probably small. Well is not run continuously, hence oil show may be expected to be small.

Schmitt Ranch Well SE¼SE¼ Sec. 11, Twp. 10S., Rge. 10E.

Near Marana. Old water well deepened in 1930 from 150 to 250 feet, pumped oil with water for several months. Sample tested by a laboratory in Los Angeles showed: Gravity Baume 37.2°. J. J. MacNeill, Pima Mercantile Company, Marana, has sample in possession, brown in color like lubricating oil. Said to have burned freely at the time it was collected.

Southern Pacific Railroad In NE¼ Sec. 6, Twp. 14S., Rge. 25E.

Water well at Willcox Station. During 1928-30 this well pumped large quantities of light oil with water, oil collecting on water in tank. Pumper sold amounts of this oil estimated from 2,500 gallons to 800 barrels at 10c per gallon. The well is no longer in use but when pumped shows same oil. Sample taken late in 1937, analysed by U. S. Bureau of Mines, Bartlesville, Oklahoma. 67.2% Gasoline and naphtha; Gas oil 29.2%; API Gravity 42.3°.

C. O. Anderson Farm In Sec. 24, Twp. 14S., Rge. 25E.

Water well drilled in 1925, depth 250 feet, water level 30 feet, heavy brown oil appeared sometime after farm was sold by Mr. Anderson. The well has been unused for some time. Oil burned readily, according to Mr. Anderson, who possesses a sample in his office at Willcox. No analysis.

Klene Anticline In Township 19 South, Range 18 East

Located in Southeastern Pima County. Black shale seep in monocline north of Klene Anticline; very carbonaceous; tested with chloroform and gave a positive ring of petroleum. Outcrop is in beds of Upper Cretaceous or later age. The same bed underlies the Klene Anticline at a depth of about 3,200 feet.

Hunsaker Ranch In Township 21 South, Range 28 East.

Walnut Spring in north slope of hills on south side of Leslie Canyon; said by William Hunsaker to have seeped oily material about four years ago when spring was fresh. Spring located in outcrop of Cretaceous sandstone N60°W, dipping 55°SW.

PARTIAL LIST OF WELLS DRILLED IN ARIZONA

APACHE COUNTY

1. **Hogback Oil Company No. 1** **Sec. 24, T. 23N., R. 30E.**
   340 ft. from north line, 300 ft. from west line of NW¼NW¼
   Drilling commenced November 15, 1926.
   Drilling completed May 7, 1927.
   Total depth 1510 feet in gray granite.
   No shows recorded.
   Log on file and plotted.
   Located on upthrown fault block in south end of Defiance uplift.

2. **U. S. Indian Service Water Well**
   At east junction of roads south of Window Rock and two miles east of St. Michaels.
   Total depth 1,795 feet.
   Surface dips 15-25° E., in Chinle formation.
   Hole bottomed in Cutler formation.
   No shows of oil or gas.
   Log on file.
   Located on east flank of Defiance uplift.

3. **Zuni Oil Company, No. 1** **Sec. 6, T. 19N., R. 24E.**
   Total depth about 1,000 feet.
   Start in Chinle and bottomed in Lower Chinle.
   No shows of oil and gas on our records.
   No log on file.
   Located on the northeast flank of the so-called Carrizo Anticline.

COCHISE COUNTY

1. **Arzberger No. 1** **SE¼ Sec. 19, T. 15S., R. 26E.**
   Commenced drilling April 3, 1931.
   Completed drilling October 28, 1931.
   Total depth 3298 feet.
   No shows recorded on log.
   Temperature at 3225-3235 feet, 110°F.
   Log on file and plotted.

2. **Bowie Oil Leasing Syndicate No. 1**
   Commenced . . . ? **SE¼NW¼ Sec. 16, T. 13S., R. 28E.**
   Completed drilling February 1, 1925.
   Total depth 4,110 feet.
   Shows:
   1925-1935—slight show oil.
   2100-2300—sandy shale, slight show oil.
   2670-2700—sandy shale, slight show oil and gas.
   2958-2962—sand, slight show oil and gas.
   3580 —shale, slight show oil and gas.
   3815-4110—shows oil when tested with chloroform; also shows H_2S.
   Log on file and plotted.

3. Funk Benevolent Corp., No. 1 Fee
SE¼NE¼ Sec. 27, T. 13S., R. 30E.

Commenced drilling 1929.
Completed . . . ? Still drilling December 1, 1938.
Depth on above date, 6,466 feet.
Temperature at 2,430 feet—165°F.
Temperature at 6,400 feet—274°F.
Shows of oil and gas numerous beginning at 1,730 feet and occuring at frequent intervals to bottom.
Hole full of water; operators attempting shut-off and swab test.
No correlation of formations available but suggestion is offered that the conglomerate in the lower 500 feet of hole may be basal Cretaceous.
Log on file to 6,400 feet.

4. Southern Pacific Railroad Water Well, Willcox

Seepage active 1928-1930.
Total depth 650 feet.
Produced light oil, kerosene and gasoline; pumper sold 2,800 gallons to local ranchers at 10c per gallon.
Well not used since 1930.
Log on file and plotted.

GRAHAM COUNTY

1. Underwriters Syndicate of N. Y. Mary Mack No. 1
NE¼ Sec. 13, T. 6S., R. 24E.

Total depth 3,767 feet.
Shows:
1450-1451—oil sand.
3104-3108—oil sand.

MARICOPA COUNTY

1. Camelback No. 1 **NE¼NW¼ Sec. 30, T. 2N., R. 4E.**

Drilled 1907.
Total depth 2,818 feet.
Shows numerous between 618 feet and 2,400 feet.
Log on file and plotted.
Located on flank of Camelback uplift.

2. Tannehill No. 1, Beardsley **SE¼NE¼ Sec. 25, T. 4N., R. 2W.**

Total depth 3,350 feet.
Shows:
2,540 feet— light oil.
3,280 feet—black shale saturated with oil, some gas.
Log on file.

3. L. P. Newcom No. 1, Langley SE¼SW¼ Sec. 30, T. 2N., R. 4E.

Located on Chicago Avenue & Thomas Road, Phoenix.

Drilling commenced 1938.

Total depth 1,050 feet.

Shows:

240 feet.

550-1050 feet—Gas; globules of black oil.

NAVAJO COUNTY

1. Adamana Oil and Land Company No. 1 Sec. 4, T. 14N, R. 20E.

Total depth 3,387 feet.

Shows:

1740-1750 feet—shale; oil.

1940-1950 feet—shale; oil and gas.

2250-2300 feet—sand; oil.

2480-2495 feet—sand; oil.

3380 ? feet—sandy limestone; oil.

Hole lost after fishing for tools. Bottom show never tested.

Log on file.

Located two miles north of Richards Lake-Snowflake fault and two miles east of anticline.

2. Black Canyon No. 1 Sec. 20, T. 16N., R. 17E.

Total depth about 510 feet.

Core drill rig took 7 inch cores of Coconino sandstone which lie on ground near rig.

No shows of record.

No log on file.

Surface—Coconino sandstone.

Located north of Richards Lake-Snowflake fault on west flank of anticline.

3. Great Basin Oil Company No. 1. Fuller (E. S. Taylor) Sec. 21, T. 17N., R. 20E.

Total depth 4,675 feet.

Shows:

1925-1935 feet—sand, salt water, gas.

3590-3596 feet—limestone, oil.

3685-3870 feet—arkosic sandstone, oil on tools, water.

Correlations vague but bottom hole may be Cambrian.

Log on file and plotted.

Supposedly located on structure by Dorsey Hager, but proved to be off structure.

4. **Holbrook Oil Company No. 1** **Sec. 23, T. 15N., R. 18E.**
   Total depth 2,400 feet in 1922.
   Deepened as Jerome-Navajo Drilling Company to 3,775 feet in 1925.
   Show gas?
   No log on file.
   Located on structure? Doubtful.

5. **Hopi Oil Company No. 1** **Sec. 21, T. 15N., R. 19E.**
   Total depth 2,500 feet.
   No log on file.

YAVAPAI COUNTY

1. **Arizona-Verde Oil Company** **NW¼NW¼ Sec. 14, T. 13N., R. 5E.**
   Total depth 1,625 feet.
   Bottomed in igneous rock.
   Correlation: 0-250 feet: Redwall limestone?
   Log on file.

2. **Arizona Verde Oil Company** **NW¼NW¼ Sec. 9, T. 13N., R. 5E.**
   Total depth 1,225 feet.
   Bottomed in igneous rock.
   Log on file.

3. **Chino Valley Oil Development Company No. 1 (State)**
   Sec. 20, T. 18N., R. 2W.
   Drilling 700 feet December 1, 1938.

4. **Chino Valley Oil & Mining Company No. 1**
   Sec. 27, T. 18N., R. 2W.
   Drilled in 1913.
   Total depth 1,800 feet with slight show of oil.
   No log on file.
   Surface: Redwall limestone.
   Located on northwest trending anticline in Redwall limestone.

5. **Aricopa Drilling & Mining Company No. 1 (Puntenney)**
   Sec. 27, T. 18N., R. 2W.
   Drilling commenced December 1, 1938.

YUMA COUNTY

1. **J. R. Loftus No. 1 (Stovall)** **NW¼ Sec. 4, T. 8S., R. 13W.**
   Total depth 2,360 feet.
   Temperatures:
   2,405-2,445 feet—110°
   2,500 feet—120°
   2,545 feet—140°
   Shows: black mud at 2,545-2,550 feet, methane gas.
   Log on file and plotted. No correlations.