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OKLAHOMA AND TEXAS

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OKLAHOMA AND TEXAS

Prepared under the direction of
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OKLAHOMA AND TEXAS

Prepared under the direction of W. E. Wrather

INTRODUCTION

By W. E. Wrather

Excursion A–6 is designed primarily for those who are interested in the geology and technology of oil and gas. (See pl. 1.) Although it is confined to two States, the trip will cover a distance of about 650 miles (1,046 kilometers) between Tulsa, Oklahoma, and Houston, Texas, or approximately the equivalent of the railroad journey from Paris to Vienna. These two States and California constitute the major oil-producing districts of the United States. Their estimated production in 1931 was approximately: Texas, 333,000,000 barrels (52,943,000,000 liters); Oklahoma, 181,000,000 barrels (28,777,000,000 liters); California, 188,000,000 barrels (29,890,000,000 liters)—in all, about 82 per cent of the total production of the United States for that year, which is a fair example of their relative importance in the industry throughout recent years.

This guidebook is the result of the cooperative endeavor of several geologists, without whose cordial assistance the task of compilation would have been both difficult and time-consuming. To all who have contributed separate chapters, sincere appreciation and thanks are expressed. The same may be said of the much larger group, too numerous to mention individually, who aided no less materially when called upon for particular information.

THE ITINERARY

Typical oil fields will be visited along the route, including Cushing and Oklahoma City, which obtain their oil from the Paleozoic; Van and East Texas, which produce from the Upper Cretaceous; and Sugarland, which is a typical salt dome, deriving its production from the Tertiary. The Boling salt dome, near Sugarland, is included in the itinerary, and here visitors will have an opportunity to see the most important sulphur-producing project in the United States.

Along the route opportunity will be provided to study the interesting stratigraphic problems with which the oil geologist has been obliged to contend. Highly tilted older Paleozoic strata, which supply the oil in the deeper producing sands of Oklahoma, will be crossed in the Arbuckle Mountains. Ardmore, on the south side of the Arbuckle Mountains, is situated over a deep though small basin, filled with later Paleozoic sediments. In the Criner Hills, on the south side of this basin, occur some of the most interesting examples of structure in Paleozoic strata to be found anywhere in the United States. Here also are excellent fossil-collecting localities.

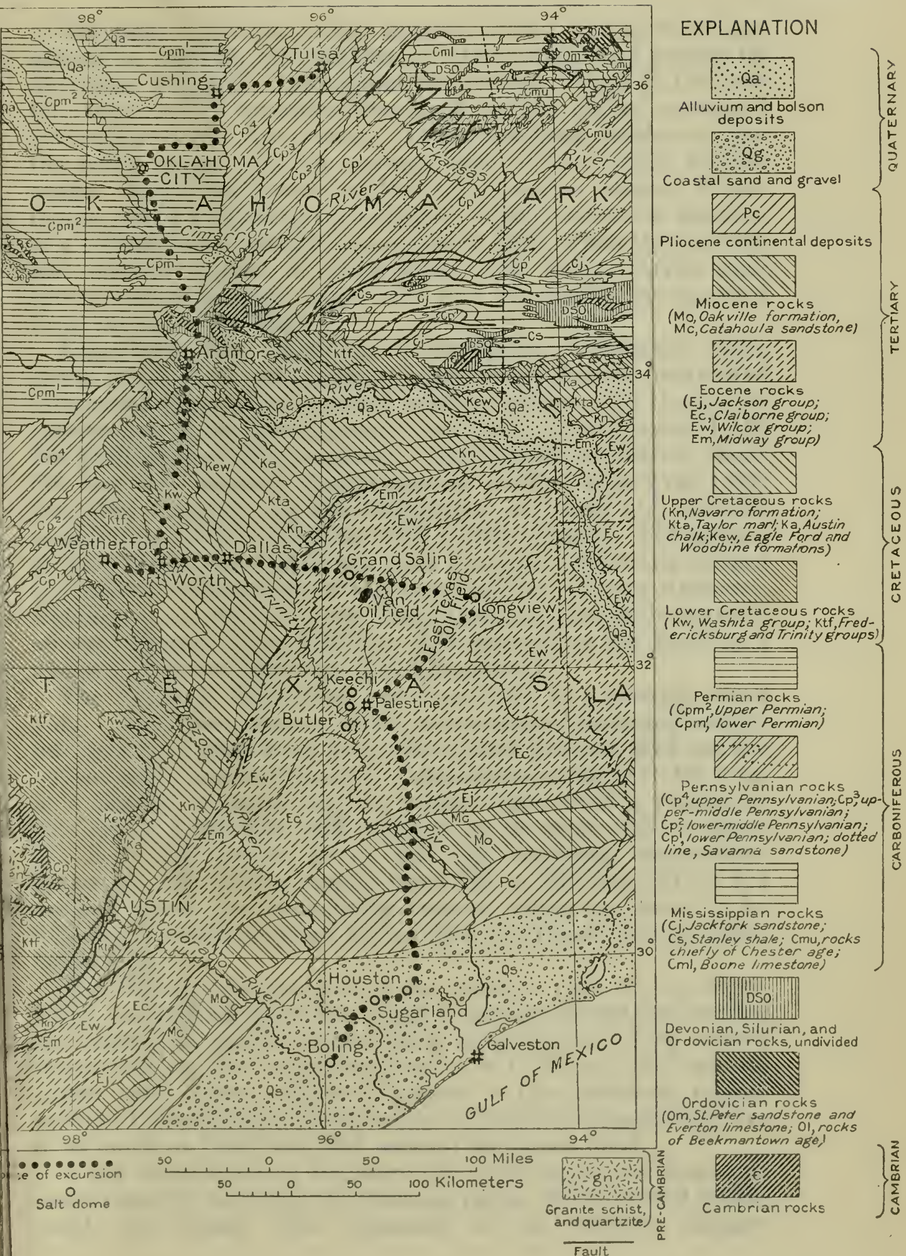
The optional trip from Weatherford to Grand Saline, Texas, should prove attractive to stratigraphers who are interested in a comparison of the European Cretaceous with that of America. This trip traverses the uninterrupted sequence of Upper and Lower Cretaceous strata of the Gulf region across their tilted and beveled edges. Included in this sequence is the outcrop of the Woodbine sand (basal Upper Cretaceous), which is the most productive oil-bearing bed of East Texas.

Near Palestine, Texas, the several East Texas "interior" salt domes to be visited will give opportunity for studying the surface phenomena associated with these unique structural features. Here ruptured and upturned Cretaceous rocks appear around the flanks of the salt, in the midst of the regional cover of Tertiary strata. At the surface around many of the interior domes can be seen structural details which around coastal domes are found only at considerable depth and are known only through a study of drill records. The interior of a salt stock may be seen in the underground workings of the Grand Saline salt mine.

GEOGRAPHIC FEATURES OF OKLAHOMA

Tulsa is situated on the banks of the Arkansas River in the midst of a belt of "scrub," or dwarfed oak timber. The timber covers the outcrop of the more sandy Pennsylvanian strata. The trip westward to Cushing will pass principally through timber of this nature. The scattered interspersed glades of prairie cling primarily to shale outcrops. Very little of this timber is of any commercial importance. Country of this sort is typical of the areas of the southwestern United States in which rocks of Pennsylvanian age are the surface formations.

Between Cushing and Oklahoma City the timbered belts become fewer as the sandy Pennsylvanian strata are left behind, and the route leads across the "Red Beds" of lower Permian age. The Permian section is here composed primarily of red clay shale that weathers to a compact soil practically devoid of trees, on which the native growth is the curly buffalo mesquite grass. This grass covers the ground in small, closely spaced tufts from 2 to 3 inches (5 to 8 centimeters) in height and is one



INDEX MAP SHOWING ROUTE OF EXCURSION A-6

From Geologic map of the United States, compiled by G. W. Stose.

130184—33. (Face p. 2.)

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of the most nutritious range grasses known. It dries on the ground in the hot, dry weather of late summer and retains its nutritious properties throughout the winter. Upon it the buffalo subsisted in countless thousands on the plains, westward toward the Rocky Mountains. Before reaching Oklahoma City the route passes into the eastern edge of the former buffalo range. It will add interest to the trip to read in advance Washington Irving's "Tour of the prairies," which records the exploits of a buffalo hunt through this region in 1832, when the country was scarcely known to white men. The buffalo herds were exterminated for their hides and had practically disappeared from the plains by 1883.

Topographically, Oklahoma is essentially a dissected plain, across which the several larger southeastward-flowing rivers have intrenched themselves in broad, shallow valleys. In the northeastern part of the State the surface altitudes do not exceed 1,150 feet (350 meters) above sea level. The altitude of Tulsa is about 600 feet (183 meters), though near-by points rise to over 1,000 feet (305 meters). In the Oklahoma City field the altitude ranges from 1,175 to 1,340 feet (358 to 408 meters). The surface of both Texas and Oklahoma rises gradually westward toward the eastern escarpment of the Great Plains. From Ardmore, Oklahoma, southward across Texas there is a gentle decrease in average altitude from 850 feet (259 meters) to sea level in a distance of about 340 miles (547 kilometers).

The Arbuckle Mountains are mountains in a geologic sense only. They were once no doubt mountains of imposing height, but they have been worn away throughout geologic ages and are now merely the eroded stumps of mountains, reduced to the level of a slightly elevated plateau, which slopes from a maximum altitude of 1,340 feet (408 meters) at its west end to about 750 feet (229 meters) at its east and southeast extremities. Although this plateau stands from 300 to 400 feet (91 to 122 meters) above the surrounding country along the route to be followed, its summit is no higher than the region around Oklahoma City.

The Wichita Mountains, in the western part of the State, which are geologic relatives of the Arbuckle Mountains, are for the most part granite peaks rising abruptly out of an almost featureless plain to maximum heights of 1,500 feet (457 meters) above their bases. Isolated points in the Ouachita region, another Paleozoic area in southeastern Oklahoma, reach altitudes of as much as 2,800 feet (853 meters) above sea level.

A few miles south of Ardmore the route leaves the Paleozoic and passes out on Lower Cretaceous rocks, which extend southward into Texas. The character of the country changes abruptly to an open, treeless prairie. Before reaching the Red River, however, the familiar scrub-oak timber will be reentered. This timber belt, bordered on each side by open prairie, marks the outcrop of the Woodbine sand.

HISTORY OF OKLAHOMA

While the southwestern country was yet a wilderness, this region was set aside by the United States Government as an Indian reservation. This step was taken as a result of the discovery of gold in 1828–29 at Dahlonega, Georgia, within the ancestral lands occupied by the Cherokee tribe. The influx of white prospectors and adventurers led to friction between the Indians and the whites, who raised so riotous a clamor for the removal of the Indians that the Federal Government conducted negotiations with the tribe and persuaded them to accept and move to other unoccupied lands in the unsettled region west of the Mississippi River. Oklahoma, or, as it was then called, "Indian Territory," was set apart for this purpose, and the Cherokee tribe was conducted thither under military escort in the winter of 1838–39. During succeeding decades several of the larger tribes occupying areas in the Southeastern States were allotted lands within the present confines of Oklahoma and were moved thither. In 1867 the Comanches were moved from Texas; and by the treaty of 1870 the Osages were awarded title to their present territory, northwest of Tulsa, after having been crowded out of their aboriginal home in Missouri.

In later years the fertile lands of Oklahoma occupied by the Indians were once again coveted by westward-migrating whites, and again pressure was brought by them on the Federal Government to dislodge the native tribes. Various treaties and purchases were accordingly made which permitted white settlement. Finally the tribes that had made the greatest progress in the acceptance of the ways of the white man were admitted to citizenship and awarded title to individual tracts of land, whereupon their tribal government and community ownership of land ceased. Certain of the tribes in Oklahoma, notably the Osages, still retain their original status as wards of the Federal Government. Much of their land proved to be very rich oil territory. It was leased to oil operators on their behalf by the United States Government, and to the end of 1930 the tribe had received in royalties and bonuses more than $238,000,000.

In 1907 the State of Oklahoma was admitted to the Union. The Indians are still here, but they have so far accepted modern civilization that the casual visitor is scarcely aware of their presence. "Blanket Indians," as those who are only semicivilized are usually called, may yet be found in certain parts of the State but will hardly be noticed along the route of this excursion. Indian ownership of deeded land, however, is to be met with on every side. Thousands of leases on such lands are held by oil operators, from whom many Indian landlords have received handsome returns in royalties.

GEOGRAPHIC FEATURES OF TEXAS

South of the Red River, the boundary between Oklahoma and Texas, the outcrop of the Woodbine sand bends southward and extends for many miles across Texas to the Brazos River, where, because of its timbered cover, it is known as the "Eastern Cross Timbers." Some 40 miles (64 kilometers) to the west occurs a similar belt of scrub oak, known as the "Western Cross Timbers," which follows the outcrop of the Trinity sand, at the base of the Lower Cretaceous. Westward beyond this last belt of timber extends the Pennsylvanian area of Texas, succeeded by the unbroken prairies of the Permian.

The Red River marks the approximate northward range of the mesquite tree, which covers the prairies in increasing abundance southward. This tree belongs to the mimosa family, which is represented sparsely in North America. It branches near the ground, seldom exceeds 20 feet (6 meters) in height, bears pods and thorns, and has lacy, pendent foliage, through which the sunlight filters with such facility that the growth of native grasses is not impeded by its shade. It has an enormous root growth, an adaptation to regions of irregular rainfall, which has given rise to the expression that "more of a mesquite occurs below ground than above."

Within the memory of many men now living prairies that are now so thickly covered with mesquite that they appear to be forested were entirely devoid of any tree growth. Before the country was settled, Indians and later white hunters periodically burned off the dry grass of the prairies, which kept the seedlings of the mesquite from getting a start and thus greatly restricted its spread. When cattlemen fenced the open range and conserved the grass for forage, the mesquite spread rapidly over the prairie country, and even to-day it is spreading farther afield, as may be frequently seen in the advance guard of young seedlings stretching headward up the shallow valleys of streams. It is supposed that the mesquite was native in the edge of the forested areas of Texas and merely awaited the cessation of prairie fires to spread out to a more congenial environment. Mesquite pods are very nutritious and contain enough sugar to be pleasant to the taste. They are frequently ground and used by the Mexicans for food and were formerly an article of diet of the Indians. They are so fattening to horses and cattle that ranchmen seldom object to the spread of the tree over the grass land.

The prairies of Texas are blanketed in spring with a profuse growth of many-hued wild flowers, giving a glorious riot of color to the landscape.

The Red River marks also the approximate northward range of the live oak, which in Texas is confined principally to the limy soils of the Cretaceous and to the Coastal Plain. In the timbered region of eastern Texas, which occupies the area of Tertiary outcrop, the lowland yellow pine and the magnolia put in their appearance; and along the stream valleys are to be found a species of birch and the "flat bark" elm (*Ulmus alata?*). Along valley bottoms in the open prairies occurs the "cedar" elm (*Ulmus crassifolia*). Over the eastern half of Texas and much of Oklahoma the pecan flourishes in alluvial soils of both timbered and prairie regions. On the coastal plain "Spanish moss" (*Dendropogon* (*Tillandsia*) *usneoides*), a parasitic growth deriving its subsistence primarily from the air, hangs in festoons from the trees and gives a characteristic touch to the scenery.

HISTORY OF TEXAS

The political history of Texas has been varied and interesting. It began in 1528, when Cabeza de Vaca and three companions, shipwrecked members of a Spanish exploring expedition, landed on Galveston Island, south of Houston, and started seven years' wandering over inland deserts which brought them eventually to Spanish outposts in western Mexico. The tales carried back to the Viceroy of Mexico by these adventurers incited Spanish explorers to penetrate the Southwestern States, and thus the first authentic information on this region was brought to light.

A hundred and fifty years later the French explorer LaSalle landed on the Texas coast and established a short-lived colony, under the mistaken impression that he was taking possession of the mouth of the Mississippi. The Spanish immediately sent out expeditions from Mexico to dislodge the French. One such expedition, in 1690, penetrated eastern Texas, where, under the leadership of Father Manzanet, several missions were founded in the region immediately south of the East Texas oil field. These establishments were built of wood, and all vestiges of them have disappeared, though Spanish missions of this same epoch, built of stone, are yet interesting landmarks in and around San Antonio.

The Sabine River, the eastern boundary of Texas, was the line of contact during the seventeenth and eighteenth centuries for contending Spanish and French forces. Nacogdoches, near the center of the eastern boundary, remained a military outpost as long as the region was under Spanish and Mexican rule. It was situated on the "old Spanish trail," a road leading westward into Texas from the head of navigation on the Red River in Louisiana. Over this road passed most of the overland travel between French and Spanish possessions; and later it was the route followed by a considerable portion of the American emigration into Texas.

Texas when first settled by Americans was Mexican territory. Mexico had become independent of Spain, and Texas was administered as a part of the State of Coahuila. In 1821 Stephen Austin obtained permission from the Mexican Government to colonize an area lying west of Houston, but the settlers were to be subject to Mexican laws and were expected to become Mexican citizens. Numerous other colonies were organized, and Anglo-American settlement proceeded rapidly. Friction soon arose over differences of laws and religion, and rebellion ensued. In 1836 Texas won its independence at the battle of San Jacinto, fought in a grove of live oaks a few miles south of Houston. Thereafter for a period of almost 10 years Texas was an independent republic among the governments of the world, but in 1845 it was annexed to the United States.

Spanish influence is yet visible through parts of Texas, more particularly in the portions adjacent to the Mexican border. There is a considerable Mexican population in most of the larger towns and cities of Texas, and many geographic names, especially in southern Texas, are Spanish. There is an unseen Spanish influence present in Texas which is more effective than the visible. Texas jurisprudence has a decided Spanish cast; Texas titles to land often emanate from original Spanish grantees; Spanish land measurements are met with on all sides. The vara (1 vara = 2.78 feet = 0.85 meter) was the unit of measure in all early land surveying in Texas.

AGRICULTURE OF THE REGION

Cattle ranching will undoubtedly be associated by many with the region through which the route passes. The itinerary does not include any important ranching country, with the possible exception of the Arbuckle Mountain section. Ranching on a large scale was principally a temporary industry, filling the gap between the disappearance of the buffalo and the predatory wild Indian and the coming of the farmer. It has been learned that much land formerly considered too dry for farming is admirably adapted to crops. Cultivation of the soil results in greater conservation of moisture and apparently increases rainfall. The tendency of recent years has been to break up large ranch holdings into farms and convert the land more and more to agriculture.

The plains of Oklahoma and northern Texas are adapted to wheat. Corn is successfully raised over the eastern portion of the two States, though it does not produce so abundantly as in the upper Mississippi Valley. Central Oklahoma is about the north limit of cotton culture, and Texas is par excellence the great cotton State of the Union. Large-scale cattle and sheep ranching are still important industries, but they have moved farther west, to drier regions on the Great Plains or to areas which are too rough to be adapted to cultivation.

PETROLEUM GEOLOGY

Visitors will probably be impressed with the detailed and complete knowledge of subsurface structure and stratigraphy in the oil fields of this region, especially after they have seen some of these fields and have noted the meager geologic information available at the surface. The major portion of the geologic data used in oil-field work to-day are obtained from a specialized and minute study of well cuttings. Especial attention is given to lithology, micropaleontology, and a study of heavy minerals. It will be apparent after a visit to the several fields that subsurface geology is of infinitely greater importance than surface geology in correctly solving the geologic problems involved. Cushing, though now a depleted oil field, was purposely chosen as the first to be visited, as it is possible to see there enough surface structure to indicate correctly the probable presence and extent of the oil field.

Many productive American oil fields owe their discovery to subsurface studies, aided and checked by core drilling, geophysical prospecting, and even airplane mapping. The structure controlling the oil accumulation in many fields is almost wholly undecipherable in the geology visible at the surface.

Petroleum geology and technology have found their place in the oil industry within the last 20 years. In this period there has been more improvement in oil finding and oil production than in the entire period since the discovery of the Drake well in Pennsylvania, which launched the oil industry in this country in 1859.

Geology was first employed in a search for surface evidences of structure. During this period plane-table mapping was extensively used, and much attention was devoted to a study of areal geology. After a time it became evident that in regions of poor outcrop other means must be devised to obtain geologic data. Then followed lithologic studies of soils, investigations of the relation of plant growth to geologic outcrops, core drilling, and finally complete sampling and study of drill cuttings.

Geophysical prospecting was the latest effective improvement in geologic technique to be introduced, and it has developed rapidly from the crude beginnings of 10 years ago. The seismograph and torsion balance remain the principal reliance of the geophysicist searching for oil. Extensive experimentation with electric potential and electric resistivity has not led to important results. The magnetometer, which is relatively much cheaper to use than other geophysical instruments, seems to give fairly accurate results in certain districts and is very misleading in others. It is therefore to-day considered of questionable value in oil work.

Great strides have been made in improving the sensitiveness and portability of the seismograph and in adapting its use to general geologic problems. Refraction shooting was originally used almost exclusively, and its application was confined primarily to the location of salt domes. Reflection shooting is now used throughout the midcontinent region and is giving invaluable information relative to subsurface structure.

Studies of temperature (geothermal gradients) have been in progress for the past few years, and it has been learned that in many fields lines of equal temperature (isothermal lines) closely follow the contouring of the surface of the oil sand. The taking of accurate temperature readings is expensive, and critical data therefore accumulate slowly. It will require more comprehensive data than are now available before the importance of temperature in problems of petroleum geology and technology can be evaluated.

PETROLEUM TECHNOLOGY

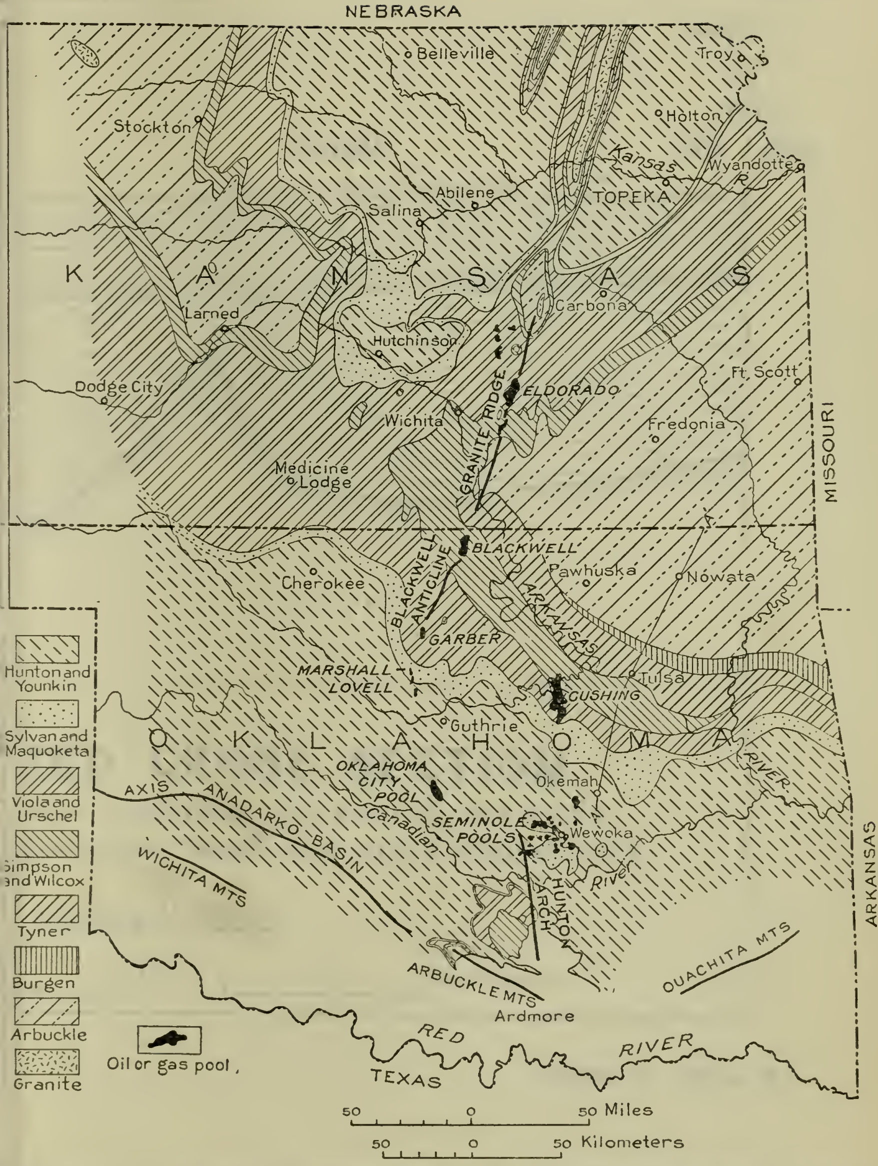
Within this period has grown up the specialized profession of petroleum technology, devoted to the more economical and efficient extraction and utilization of oil and gas. A scientific study of the problems of oil production has led to revolutionary changes in practice. Formerly oil wells were allowed to flow their maximum output until the depleted gas pressure was no longer sufficient to raise the oil to the surface; they were then placed on the pump and were so operated as long as the sale value of the oil was more than the cost of production. It was commonly supposed that the principal value of the gas was to raise the oil to the surface as rapidly as circumstances permitted, and once it had escaped from the well, huge volumes were allowed to go to waste in the air.

The true value of the expulsive force of gas as a source of energy is now recognized. Wells are forced to flow through an aperture of reduced size, known as a "choke" or a "flow bean," which tends to check the escape of the gas from the sand, thus forcing it to lift the maximum amount of oil to the surface. In some places the gas is returned under pressure to the oil sand to do additional duty. Such an operation will be seen at Sugarland. A realization of the valuable function performed by gas has more than anything else brought about the clamor for unit operation of oil pools, which is more fully described in the section on the Van field (pp. 61–66).

It is almost universal practice now to regulate carefully the amount of gas a well is allowed to produce. The gas is taken from the well and delivered to a plant where its content of gasoline is removed, after which the dry gas is either recycled (returned to the sand) or sold to gas lines which convey it to the cities for both industrial and home consumption as fuel. The piping and sale of gas for fuel has in late years become a widespread and important industry. Gasoline recovered from natural gas, known as "casing-head" or "natural" gasoline was practically unknown prior to the World War. It is now an important part of our total gasoline supply.

At the present time a study of bottom-hole pressures is being conducted widely throughout the Mid-Continent region. A recording pressure gage is run to the bottom of a producing well, and pressures are taken either when the well is flowing or when it is shut in. Accurate information is thus obtained on the permeability of the sand and the rate at which the oil and gas are depleted. It would seem that closed-in pressures taken at the casing head—that is, at the surface of the ground—should give this information, but in practice this is found not to be true. The reasons for the unreliability of casing-head pressures are not fully understood, and it would require more elaboration than space here permits to present the subject adequately. Attention is merely called to the problem in order that visitors who are particularly interested may make individual investigations while in the field.

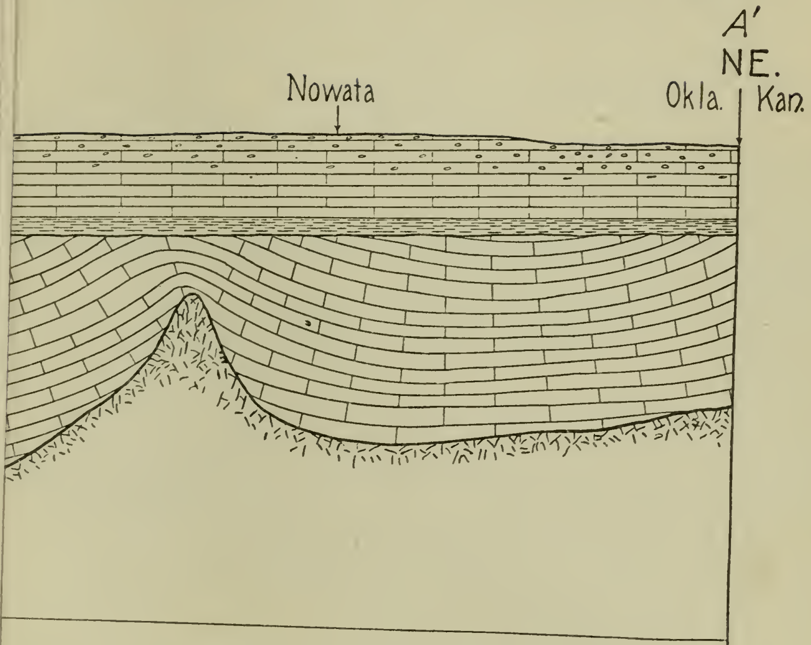
The work of the petroleum technologist is rapidly demonstrating that controlled water drive (the encroachment of edge water into the producing sand) is a most important factor in insuring the maximum recovery of oil. Until recently water in an oil sand has been considered the oil producer's worst enemy. Its beneficent aspects are now beginning to be appreciated. To be most effective the level surface of the encroaching water should be disturbed as little as possible; it should advance into the oil sand slowly and uniformly and take the place of the oil as



SHOWING SUBSURFACE DISTRIBUTION OF PRE-MISSISSIPPIAN ROCKS DIRECTLY BENEATH THE CHEROKEE SHALE IN KANSAS AND OKLAHOMA, WITH SOME OF THE PRINCIPAL STRUCTURAL TRENDS AND OIL AND GAS FIELDS

Compiled from maps by McClellan (13, fig. 2) and Charles (3, fig. 1).

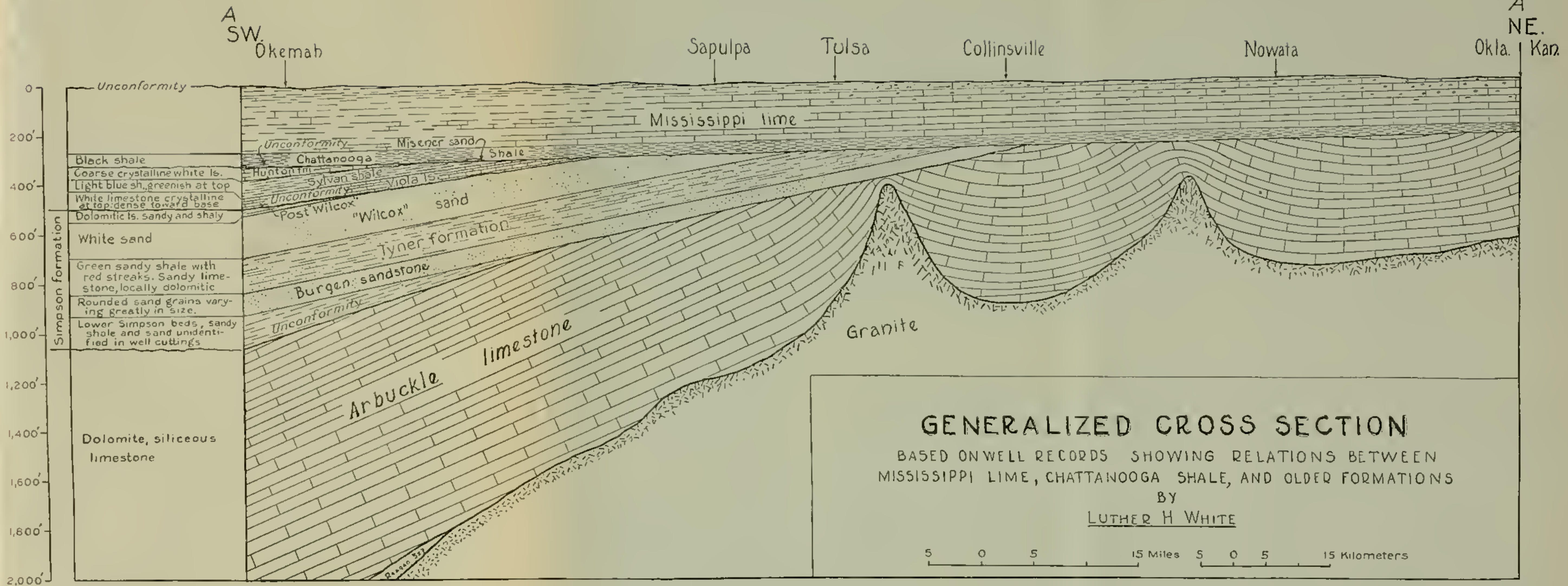
PLATE 3



ZED CROSS SECTION

RDS SHOWING RELATIONS BETWEEN
TTANOOGA SHALE, AND OLDER FORMATIONS
BY
LUTHER H. WHITE

15 Miles 5 0 5 15 Kilometers



GEOLOGIC CROSS SECTION OF OKLAHOMA

From Oklahoma Geol. Survey Bull. 40, pl. 1.

it is extracted. This can best be accomplished by watching bottom-hole pressures and allowing wells to produce only so much oil as will maintain a uniform pressure in the sand throughout the field.

It has been discovered only in recent years that wells may deviate widely from the vertical in the course of drilling, and thus has arisen the "crooked hole" problem. Crooked holes are of particular interest to the geologist. They may frustrate his efforts to contour the surface of a producing sand, as was demonstrated repeatedly during the development of the Seminole pool. Crooked holes lead to added wear and tear on pumping equipment and tend greatly to increase costs of production. Methods have been devised for detecting the degree of deflection of a well, and now that the importance of the problem is understood, methods of drilling have been perfected which tend to keep the hole vertical.

GENERAL GEOLOGY

Pre-Mississippian geology of Oklahoma.—Succeeding sections, written by different individuals, describe in some detail the geology of the several localities to be visited; but a slight elaboration of some of the general geologic features of the region will aid in a clearer understanding of the significance of the more localized descriptions.

At first sight the geology of the Pennsylvanian area in central Oklahoma appears to be simple—merely a succession of very slightly deformed strata, dipping westward, away from the Ozark Mountain uplift (in northern Arkansas and southern Missouri), at a rate of 30 to 50 feet to the mile (5.6 to 9.4 meters to the kilometer). In fact, practically all the oil found in sands of Pennsylvanian age could be satisfactorily accounted for in conformity with this relatively simple surface structure. Deeper drilling led to the discovery of oil in beds below the Pennsylvanian, though, as will be seen by reference to the account of the Cushing field, the true age of these deeper sands was not at first known. A suspicion arose that they were of Ordovician age, which of course raised the question as to what had become of the beds of intermediate age that normally fill the gap. A correlation, based on the study of cuttings from numerous deep wells scattered over the eastern half of both Oklahoma and Kansas, revealed the situation illustrated in Plates 2 and 3.

It is necessary to assume here that all Pennsylvanian strata have been stripped away from the surface. Plate 2 shows the areal distribution of strata directly beneath the Pennsylvanian. It is evident that at the end of Mississippian time this entire region was subjected to deformation, which produced local folds;

that the entire region was then extensively uplifted, a new cycle of erosion being thus begun. At the end of this period of erosion the outcrops of pre-Mississippian formations were left arranged in belts roughly concentric around the margins of the Ozark Mountains. All these formations dip outward, away from the center of the Ozarks. Later, perhaps in early Pennsylvanian time, the region was submerged and marine sedimentation was resumed, resulting in the deposition of the strata that now crop out at the surface.

Geologic history of Arbuckle Mountains (19).[1]—In the Arbuckle Mountains the sequence of geologic events followed the same general course, but there it is possible to read in the record a somewhat greater amount of detail. From earliest Cambrian to the end of Mississippian time the formations remained in approximately a flat position. The character of the rocks in the section changes abruptly from limestones in the lower part to sands and shales in the upper part, but the bedding is essentially parallel, indicating that oscillations of the sea bottom were of broad extent, and that if there was any erosion it occurred over relatively flat-lying areas.

In early Pennsylvanian time the rocks of the Arbuckle region were folded and faulted, and the western portion was elevated into land, probably into mountains. The formations involved in this uplift are from 8,000 to 10,000 feet (2,400 to 3,000 meters) in thickness and are principally massive limestones. In the succeeding period of erosion all the section down to the Cambrian was removed from the west end of the Arbuckle Mountains. Resubmergence followed, and large deposits of Carboniferous conglomerate were spread across the truncated edges of the older folded and faulted strata. Later in Carboniferous time the sediments were again folded and elevated into land, the recently formed conglomerates as well as all the rocks previously deposited being involved in the folding. Near the end of Carboniferous time subsidence again occurred, and the "Red Beds" sea encroached upon the region from the west. The red sediments remaining have not suffered any appreciable deformation. Between Permian and earliest Cretaceous time the whole region was once more elevated into land. The surface was then reduced to a relatively flat plain, which was later submerged and received the Cretaceous sediments. After Cretaceous time the region was again broadly uplifted, without deformation, and it has remained land to the present time. The deformation of the rocks now exposed in the Arbuckle Mountains therefore commenced near the beginning of upper Carboniferous time and was completed before its end.

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[1] Numbers in parentheses refer to bibliography, pp. 90–91.

The geologic history decipherable in the Arbuckle Mountains has been of great aid in interpreting the Paleozoic record of the midcontinent region, especially that portion involving formations older than Pennsylvanian.

Buried granite hills.—Drilling has demonstrated that many of the oil-bearing structural features of central Oklahoma and central Kansas have granite cores, flanked by relatively steeply dipping and truncated early Paleozoic rocks and overlain by more or less folded sediments of late Paleozoic age. The ancient granite floor of the midcontinent region is therefore known to exhibit in places an irregular surface. It is not altogether clear whether this irregularity is due to the deformation that produced the folds in the overlying and flanking sediments or whether these granite hills were parts of the ancient floor of the sea, over and around which the sediments were deposited. In some places there is a distinctly arkosic zone in the top of the granite, which perhaps indicates weathering; and usually there is a thickening basinward in the overlying sediments. Both of these features seem to point toward the existence of these elevated granite cores prior to and during sedimentation. They have often been described as "buried hills."

One such range of buried granite hills extends northward with a suggested continuity from Oklahoma City across Oklahoma and central Kansas into southern Nebraska. Granite has not been found in the Oklahoma City field, but subsurface conditions there indicate that it should be present at depths beyond the range of present drilling. Along this trend have been found several of the notable oil fields of the midcontinent region—Garber, El Dorado, and Augusta—together with other fields of less importance. To this range of granite hills the name "Nemaha Mountains" has been applied. This is a geologic designation only, as the hills are nowhere visible at the surface, though it seems they may well be the eroded stumps of an ancient range.

The Cretaceous.—A few miles south of Ardmore the Cretaceous overlap covers the Pennsylvanian sediments. The outcrop of Cretaceous strata extends in an east-west direction across southern Oklahoma, and the dip is southward toward the Gulf of Mexico. About 50 miles (80 kilometers) west of the point where the excursion will cross the Red River the outcrop of the Cretaceous swings rather abruptly southward across Texas, and the dip is then toward the southeast and east. Drilling has shown that Paleozoic rocks underlie the Cretaceous, though the eastward dip of the strata into the East Texas syncline soon carries the plane of unconformity too deep for it to be reached in wells of ordinary depth. Nothing is definitely known of the character of the rocks beneath the Cretaceous east of Fort Worth. The present Cretaceous border overlaps westward-dipping strata of Pennsylvanian and Permian age. About 200 miles (322 kilometers) west of this border Cretaceous rocks are found in a thin veneer over rocks of upper Permian and Triassic age and under Tertiary strata that cover the Great Plains.

Sabine uplift.—In northwestern Louisiana and northeastern Texas there occurs a regional roughly circular domelike elevation of the strata, with a diameter of approximately 75 miles (121 kilometers), known as the Sabine uplift. (See fig. 18.) Over and around this uplift occur the oil fields of northwestern Louisiana, and the subsurface geology of the region is well known from drilling. This area is covered by Tertiary rocks, which in turn are underlain by both Upper and Lower Cretaceous. Beneath the familiar Trinity horizon (basal Lower Cretaceous) occurs a considerable thickness of red and brown clays, known only in drilling cuttings. They are thought to be of lower Trinity age because of fragmentary plant remains found in them, and so far as is known no rocks older than Lower Cretaceous have been penetrated in drilling. Upper Cretaceous strata dip outward from the center of the uplift, and on the west side, at least, Lower Cretaceous beds dip likewise, though at steeper angles.

At the end of Lower Cretaceous time the Sabine uplift evidently stood slightly above sea level. The Woodbine sand (basal Upper Cretaceous) was therefore deposited no farther east than the strand line that formed the western shore of the land mass. Soon after Woodbine time a gradual subsidence of the land area started, and the Austin chalk overlapped the margins of the Woodbine. This relationship is clearly indicated in Figure 19 (12).

East Texas syncline.—Cretaceous strata dip eastward along the route from Fort Worth to Grand Saline, Texas, and dip westward away from the Sabine uplift; thus they indicate the position of the East Texas syncline. A considerable thickness of Tertiary strata completes the filling of the basin, which has a general north-south axis. The group of eastern Texas "interior" salt domes[2] (pl. 10) occupies the deepest part of the synclinal basin; and the northern Louisiana domes occur in the structural trough lying east of the Sabine uplift. The East Texas syncline shallows and narrows in a crescent shape around the nortwestern margin of the Sabine uplift; and at its south end it flares outward, and the strata merge into the normal coast-

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[2] The word "interior" is used to differentiate the salt domes of eastern Texas and northern Louisiana from those of the Coastal Plain. It has geographic significance only, as all domes are more or less similar structurally.

ward dip of the Coastal Plain. It is a major structural feature of eastern Texas. There is a strong suspicion among geologists that this syncline antedates Cretaceous time, and that in it were deposited sediments of Paleozoic age, containing stratified rock salt from which the salt cores of the salt domes were derived. This point is further elaborated in the description of the Van field.

Fault-line oil fields.—About 60 miles (97 kilometers) southwest of Van is an important group of oil fields usually referred to as the Mexia-Powell fault-line fields. (See fig. 15.) Following roughly the surface contact of Eocene and Cretaceous strata is a complexly faulted belt, known as the Mexia fault zone. The downthrow of individual faults is generally on the west side, with maximum displacement of 600 to 700 feet (183 to 213 meters). About 40 or 50 miles (64 to 80 kilometers) to the west is the parallel Balcones fault zone, with downthrow to the east, which makes a prominent escarpment from Austin southwestward to San Antonio and thence westward to the Rio Grande. The oil fields occur in structural traps on the upthrown side of faults in the Mexia fault zone.

Forty miles (64 kilometers) south of Austin is another group of fields, including Luling, Salt Flat, and Darst Creek, due to similar structural conditions and situated in the same line of faulting. These fields obtain oil from the upper sands of the Lower Cretaceous; those in the Mexia-Powell district produce from the Woodbine sand.

Lytton Springs and Thrall, two minor oil fields in the Mexia fault zone, north of the Luling-Darst Creek group, are of peculiar geologic interest in that they obtain oil from volcanic rocks. The oil at Lytton Springs is found in a porous zone in the domed upper surface of an old buried volcanic cone. The reservoir rock is in part volcanic ash and lava and in part intrusive basalt. The lava seems to have been exuded on the sea bottom through a throat which penetrated Austin chalk; and it was later covered by sediments of Taylor age. Both the chalk and the Taylor marl are of Upper Cretaceous age.

Gulf Coastal Plain.—Little need be said of the stratigraphy of the Coastal Plain. The record plainly indicates the continued building out of the land into the Gulf of Mexico throughout Tertiary time. If there was any extensive deformation of the competent basement rocks beneath the Tertiary, all evidence of it save that furnished by the salt domes has been hidden beneath the great thicknesses of soft, unconsolidated sediments which cover the region. Rocks of Cretaceous age are supposed to underlie the Tertiary, but this is conjectural only. In the Averys Island dome, west of New Orleans in Louisiana, a mass of red sand was found in the salt mine, infolded into the salt, which strongly suggests Permian, though this suggestion is founded only upon lithology. The age of the parent body of salt in which the coastal domes have their roots is therefore indefinite. It seems a fair guess that the competent basement rocks, which are too deeply buried to be reached by drilling, have been considerably deformed—in fact, such a premise seems to be required by the theory of the upward flowage of salt to form the numerous domes. But proof of this hypothesis is reserved for the future.

THE CUSHING OIL AND GAS FIELD, OKLAHOMA

By T. E. Weirich [3]

The Cushing oil and gas field occupies an area of 34 square miles (88 square kilometers) in the northwestern part of Creek County, Oklahoma. The discovery well was completed in March, 1912, and the location was later found to be on an anticline. As drilling in the field progressed, the obvious relationship of the oil and gas accumulation to the structure gave oil producers of the Mid-Continent region greater confidence in the practical utility of petroleum geology, and thenceforth the application of the science to problems of oil production was greatly stimulated. The major development of petroleum geology and technology in America has occurred since that time. The opening of this field therefore marks an important turning point in the progress of the oil industry.

PRODUCTION

The largest production of oil and gas in the Cushing field is obtained from the Layton, Wheeler, and Bartlesville sands, of Pennsylvanian age, and the "Wilcox" (Tucker) sand and Arbuckle limestone, of Ordovician and Cambrian age.[4]

The Layton sand produces throughout an area of 14 square miles. The Wheeler "sand" (a porous zone in the upper part of the Oswego "lime," and not a true sand) produces mainly on the

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[3] This section is modified from an article published by the writer in the Bulletin of the American Association of Petroleum Geologists (21).

[4] The "Wilcox" sand here includes all the closely associated sands of Ordovician age that occur beneath the plane of unconformity at the base of the Pennsylvanian and the top of the Arbuckle limestone. (See accompanying cross sections.) This use of the name "Wilcox" must not be confused with its use as the name of a group near the base of the Tertiary in the Gulf coastal region. Its use here is derived from a well drilled in the Wilcox pool about 35 miles (56 kilometers) southwest of Tulsa, Oklahoma.

west flank of the anticline over an area of approximately 11 square miles (28.5 square kilometers). The Bartlesville sand produces throughout an area of 28 square miles (72.5 square kilometers). Production of oil and gas from the "Wilcox" sand and the Arbuckle limestone is restricted to the crests of the domes. It is significant that the Arbuckle limestone produces only on the Dropright (north) dome, where the "Wilcox" sand has been removed by erosion. Other sands in the Pennsylvanian section have produced oil and gas in minor amounts.

The total production of the entire field to January 1, 1931, was approximately 290,000,000 barrels (46,106,000,000 liters) from 21,850 acres (8,842 hectares), an average yield of 13,272 barrels to the acre (5,275,230 liters to the hectare). The total recovery at Cushing until 1928 was greater than in any other field in the midcontinent area, though it had been exceeded by at least two fields in California; since that date it has been eclipsed by the Greater Seminole area, in Oklahoma. The peak of daily production of 305,000 barrels (48,491,000 liters) was reached in May, 1915, when the field was three years old. These figures are but approximate, owing to unrecorded waste of oil during early stages of development and the possible inclusion of production from near-by fields. During the period of great daily production the market of the United States was unable to absorb the flood of oil, and for several years the crude-oil market was in a most chaotic state, owing primarily to the spectacular performance of this field.

Development of the Cushing field occurred during an extraordinary period of exploitation of the Bartlesville sand in Oklahoma. The Nowata, Bartlesville, Glenn, and eastern Osage County fields gave the Bartlesville sand a distinction for productivity unexcelled by any other oil sand, and Cushing contributed added fame.

The recovery of oil from each individual sand at Cushing can not be differentiated. The total average yield from the Bartlesville sand would certainly not exceed 8,000 barrels to the acre (3,179,750 liters to the hectare). As the Bartlesville sand rests unconformably upon the "Wilcox" sand and other Ordovician beds, oil from the "Wilcox" may have migrated across the unconformable contact, lending a greater quantity of oil to the Bartlesville than was normally present.

STRATIGRAPHY

The succession of rocks occurring in the Cushing field is shown in Figures 1 and 2. The Pawhuska and Buck Creek formations, of late Pennsylvanian age, crop out within the area. Limestone

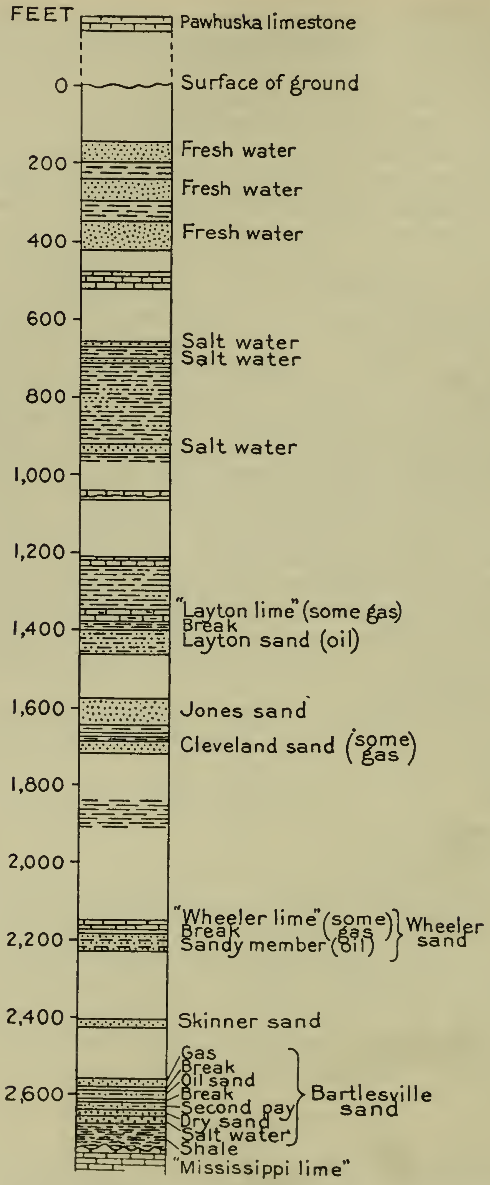

Figure 1.—Generalized columnar section of Pennsylvanian rocks penetrated by wells in the Cushing field, Oklahoma. From U. S. Geol. Survey Bull. 658, fig. 2, 1917

members of the Pawhuska formation are generally used as key horizons for surface mapping.

The underlying Pennsylvanian section is composed mainly of shales with alternating limestone and sandstone beds. At the time Cushing was drilled the geologic relations of the several producing sands were not clearly understood. It was commonly supposed that the "Wilcox" sand was of Pennsylvanian age. Some years later beds at this horizon were demonstrated to be pre-Pennsylvanian (Ordovician) in certain oil fields in Kansas, and a subsequent rechecking of data proved that in Cushing also the Ordovician sediments that had once extended across the anticline had been extensively removed from its crest by erosion prior to the deposition of the Pennsylvanian. In this field, therefore, the major thickness of the "Wilcox" (Ordovician) sand is found along the flanks of the anticline. In the north end of the Cushing field these Ordovician sands were entirely eroded and Pennsylvanian strata lie immediately upon the Arbuckle limestone. (See fig. 4.) Several wells have penetrated this limestone and entered granite, which presumably forms the deeply buried core of the anticline.

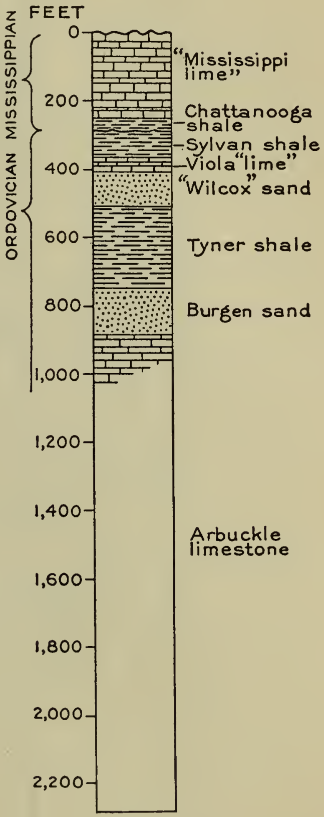

FIGURE 2.—Generalized columnar section of pre-Pennsylvanian rocks penetrated by wells in the Cushing field, Oklahoma (21, fig. 2, p. 401)

These relations between Ordovician and Pennsylvanian are common throughout the Mid-Continent area, notably in the Cleveland, Tonkawa, Garber, Thomas, Hubbard, Blackwell, Augusta, and El Dorado fields, and are a most important factor governing oil production. Both the Ordovician and the Pennsylvanian happen to be very productive of oil.

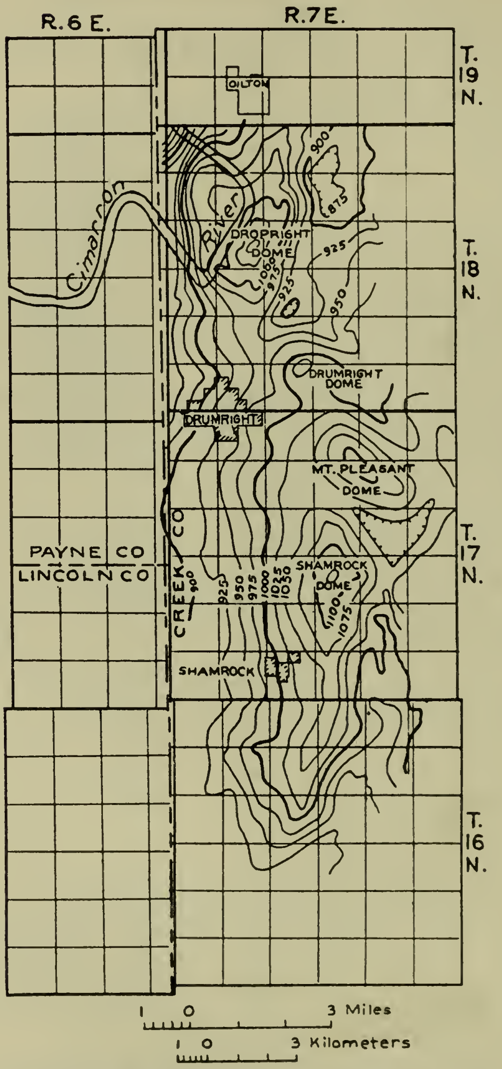

Figure 3.—Structure contour map of surface rocks in the Cushing field, Oklahoma. From U. S. Geol. Survey Bull. 658, pl. 5, 1917. Contours based on upper surface of Pawhuska limestone; contour interval 25 feet

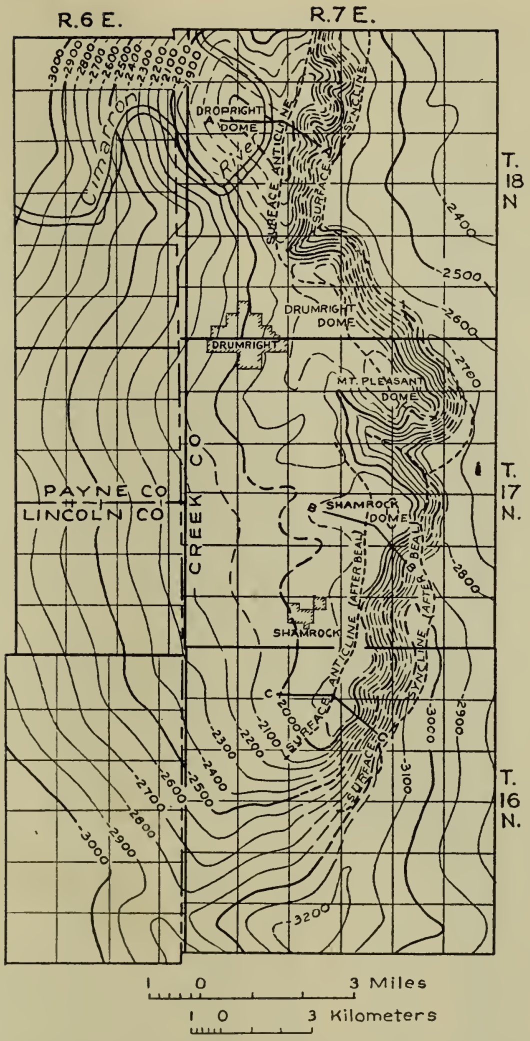

FIGURE 4.—Structure contour map of pre-Pennsylvanian rocks in the Cushing field, Oklahoma (21, fig. 3). Contours based on upper surface of "Wilcox" sand; contour interval 100 feet. Contours are inferred at crests of domes where the "Wilcox" has been removed. For sections along lines A–A′, B–B′, and C–C′ see Figures 5–7

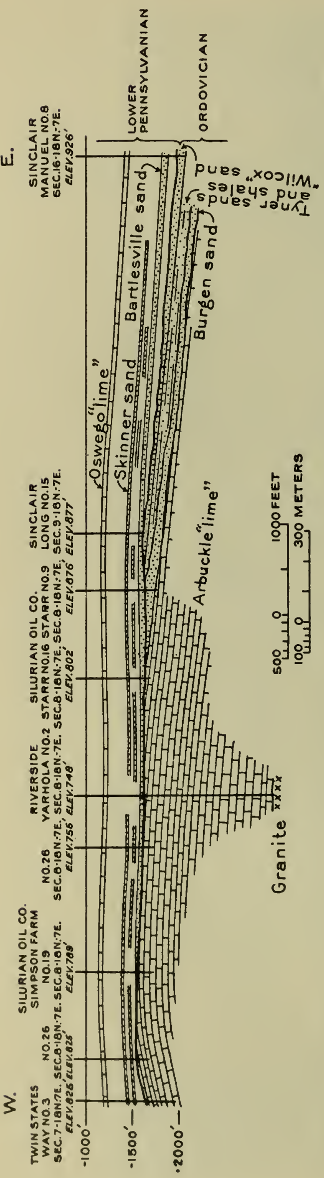

FIGURE 5.—Section along line A–A′, Figure 4 (21, fig. 4). The Bartlesville sand rests unconformably on the upper Arbuckle limestone and other Ordovician beds

STRUCTURE

The surface is characterized by an anticline with a north-south axis. (See fig. 3.) On the anticline are four distinct domes. The main axis includes the Dropright (north), Drumright (middle), and Shamrock (south) domes. The Mount Pleasant dome is a spur from the middle part of the anticline.

The underlying Pennsylvanian rocks are folded similarly except that thickening of beds away from the anticline causes greater steepening of dip with depth. These slightly incompetent beds rest unconformably on the underlying Ordovician strata within the confines of the producing field.

The pre-Pennsylvanian fold has a steep east flank, the beds being inclined 15° from the horizontal. (See figs. 4 to 7.) The west flank, on the other hand, dips gently except in the vicinity of the Dropright dome. The east limb of the anticline dips so steeply as to suggest faulting, but the logs of wells within the area of steep dip exhibit gradually shortened pre-Pennsylvanian sections as compared with those farther from the anticlinal crest. This would seem to weaken the argument for faulting. If a fault is present the section should presumably maintain its normal thickness on the downthrown

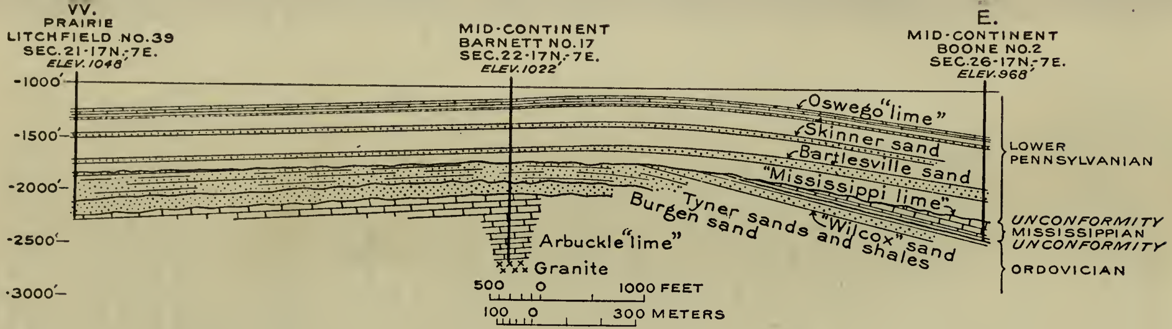

FIGURE 6.—Section along line B–B′, Figure 4 (21, fig. 5). Drill cuttings from several wells on this dome clearly established the "Tucker" sand as being "Wilcox" or its associated sands

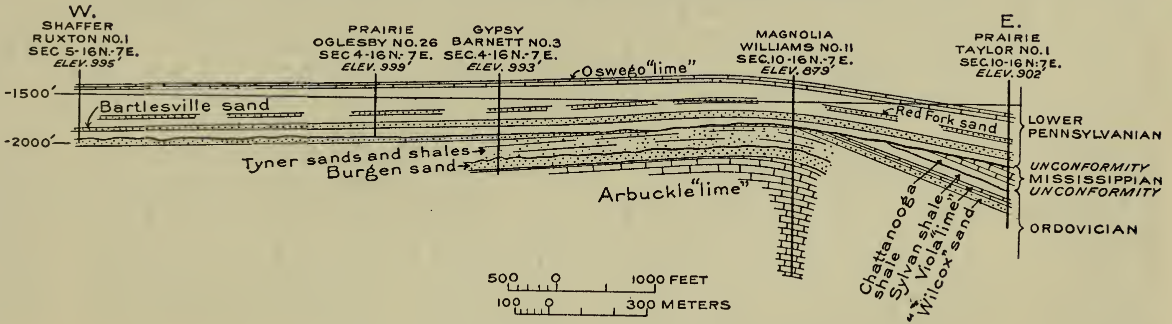

FIGURE 7.—Section along line C–C′, Figure 4 (21, fig. 6)

side. Furthermore, the area of steep dip does not follow a regular line, as might be expected if faulting had occurred. Th best evidence seems to point toward a mere sharper flexing o the east flank of the fold, though this remains a debatable point

GEOLOGIC HISTORY

Several wells in the general region have encountered pre-Cambrian granite. Arkosic débris is noticed immediately overlying the solid granite and unconformably underlying th Arbuckle limestone, of Cambrian and Ordovician age. A perio of regional erosion is known to have begun at the end of Arbuckl time. At Cushing 1,405 feet (428 meters) of Arbuckle limeston is present in a well drilled on the Dropright dome. On th Shamrock dome, which is structurally lower, only 630 feet (19 meters) is present. The latter thickness indicates either a truncated fold in the vicinity of the Shamrock dome, structurally higher than the surrounding region at the end of Arbuckle time, or a pre-Cambrian hill over which the normal thickness of Arbuckle limestone was never deposited.

Transgression of the sea during the remainder of Ordovician time resulted in the deposition of the Simpson, Viola, and Sylvan formations, with intermittent periods of erosion. The thickness of these beds in central Oklahoma (about 600 feet, or 183 meters) is slight compared with that of the same section in the Arbuckle Mountains, on the south. In the Arbuckle region the post-Arbuckle Ordovician rocks have a maximum thickness of about 3,000 feet (914 meters). The difference in thickness may be accounted for partly by erosion to the north at intervals through the section, partly by less deposition in that direction. At Cushing the Simpson section [5] is represented by a maximum thickness of approximately 475 feet (145 meters). In the Arbuckle Mountain region the Simpson section has a maximum thickness of about 2,000 feet (610 meters). From this evidence it seems probable that the floor of the Arbuckle region was being depressed, or northern Oklahoma was being elevated relatively, during the entire Ordovician period.

Events during Silurian and Devonian time are unimportant for the present purpose. Evidence indicates that an unconformity exists between the Silurian and Devonian rocks. At the end of Devonian time the rocks of northeastern Oklahoma were

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[5] The term "Simpson" is synonymous with "Wilcox" but has gradually superseded it in geologic usage. "Wilcox" has been introduced here merely to show the equivalence of the two terms, both of which occur frequently in the geologic literature pertaining to the Mid-Continent region.

further uplifted (22), acquiring a southwestern dip in the vicinity of Cushing. This apparently points toward a rejuvenation of the old uplift of the Ozark Mountains, centering in southern Missouri. Exposure of the strata around the Ozarks resulted in the erosion and truncation toward the northeast of beds progressively lower in the section. The end of this erosional period found the exposed strata forming typical belts of monoclinal structure arranged roughly in bands concentric to the Ozark uplift. (See pl. 2.) In the vicinity of Cushing the northern limit of the buried Silurian and Devonian rocks, represented by the Hunton formation, extends across northern Okfuskee County and northeastern Lincoln County, Oklahoma. The underlying Sylvan shale, dipping to the southwest, occurs in a broad belt beneath the Pennsylvanian immediately west of the Cushing field; and the Viola limestone, the succeeding lower formation, which once extended across the Cushing field, was completely eroded over a large portion of the Cushing anticline.

The submergence of the beveled strata was followed by the deposition of the Chattanooga shale and "Mississippi lime" and possibly a portion of the lowermost Pennsylvanian. The rocks at the end of this period of deposition suffered a most intense warping, and the structure of the Cushing anticline for the first time assumed a detailed form similar to that now existing.

Submergence and subsequent deposition of Pennsylvanian sediments over the eroded top of the anticline continued throughout the remainder of the Paleozoic era. Thickening of beds down the flanks, together with an arching of the unconformable contact itself, indicates a gentle but continuous uplifting of the Cushing anticline throughout the Pennsylvanian epoch.

The last major movement to affect the Cushing district tilted he strata of the entire region westward, steepening the dip of beds on the west flank and moderating the dip on the east flank f the Cushing anticline. For the present purpose it is sufficient o place the time of this uplift after the deposition of the Pawuska formation.

Thus the local history of the building of the Cushing anticline ndicates the existence of an anticline at the end of Arbuckle time verlying a pre-Cambrian granite hill; slight uplifting or cessaion of sedimentation occurred spasmodically from the beginning f the Ordovician to early Pennsylvanian time; renewed arching movements, initiated early in the Pennsylvanian, continued hroughout the remainder of the Pennsylvanian epoch.

THE OKLAHOMA CITY OIL FIELD, OKLAHOMA

By Homer H. Charles [6]

The Oklahoma City oil field (3) lies approximately in the geographic center of the State. (See pl. 2.) In the stage of development reached by June 1, 1931, it covered about 9,100 acres (3,682 hectares) in an area 6½ miles (10.4 kilometers) long and 1½ to 3 miles (2.4 to 4.8 kilometers) wide. Development has pushed the northwest side of the field into the limits of Oklahoma City. Forty miles (64 kilometers) to the southeast is the Greater Seminole oil district, and about the same distance to the north is the Lovell-Marshall district.

TOPOGRAPHY

The Oklahoma City field is in the Permian "Red Beds" area, composed of low rolling hills and wide, flat valley floors. The relief is about 165 feet (50 meters), the altitude ranging from 1,175 feet (358 meters) above sea level along the North Fork of the Canadian River to 1,340 feet (408 meters) in the south end of the field. The sandstone outcrops support scrub oaks, but the shale outcrops form rolling barren prairie land.

STRATIGRAPHY

The Permian and Pennsylvanian formations exposed at the surface and encountered in drilling are shown in Figure 8.

The Permian is the surface formation in this area. It is of the "Red Beds" type. It is represented by its basal division, the Enid group, which here includes the following formations in descending order: Hennessey shale, Garber sandstone, Wellington formation, and Stillwater formation. Only the Hennessey shale and the Garber sandstone crop out in the field. On top of the arch on which the oil field is located the Permian extends to a depth of 2,200 feet (671 meters).

The major part of the subsurface section is composed of Pennsylvanian formations with a total thickness of 3,800 to 4,000 feet (1,158 to 1,219 meters). They consist mostly of blue and gray shales but include several limestones.

The pre-Pennsylvanian rocks and their relation to the younger rocks are shown in Plate 4. Except for a few small lenses of Simpson material found at the base of the Cherokee shale, most of the material eroded from the top of the pre-Pennsylvanian anticline was removed, possibly by wave action.

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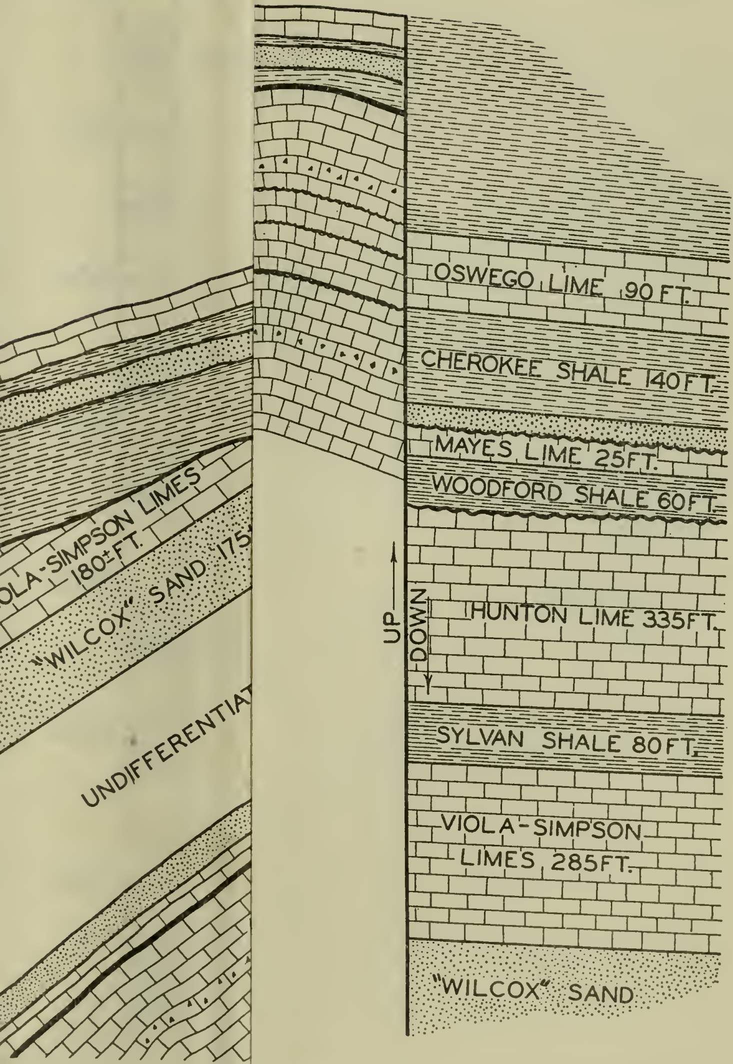
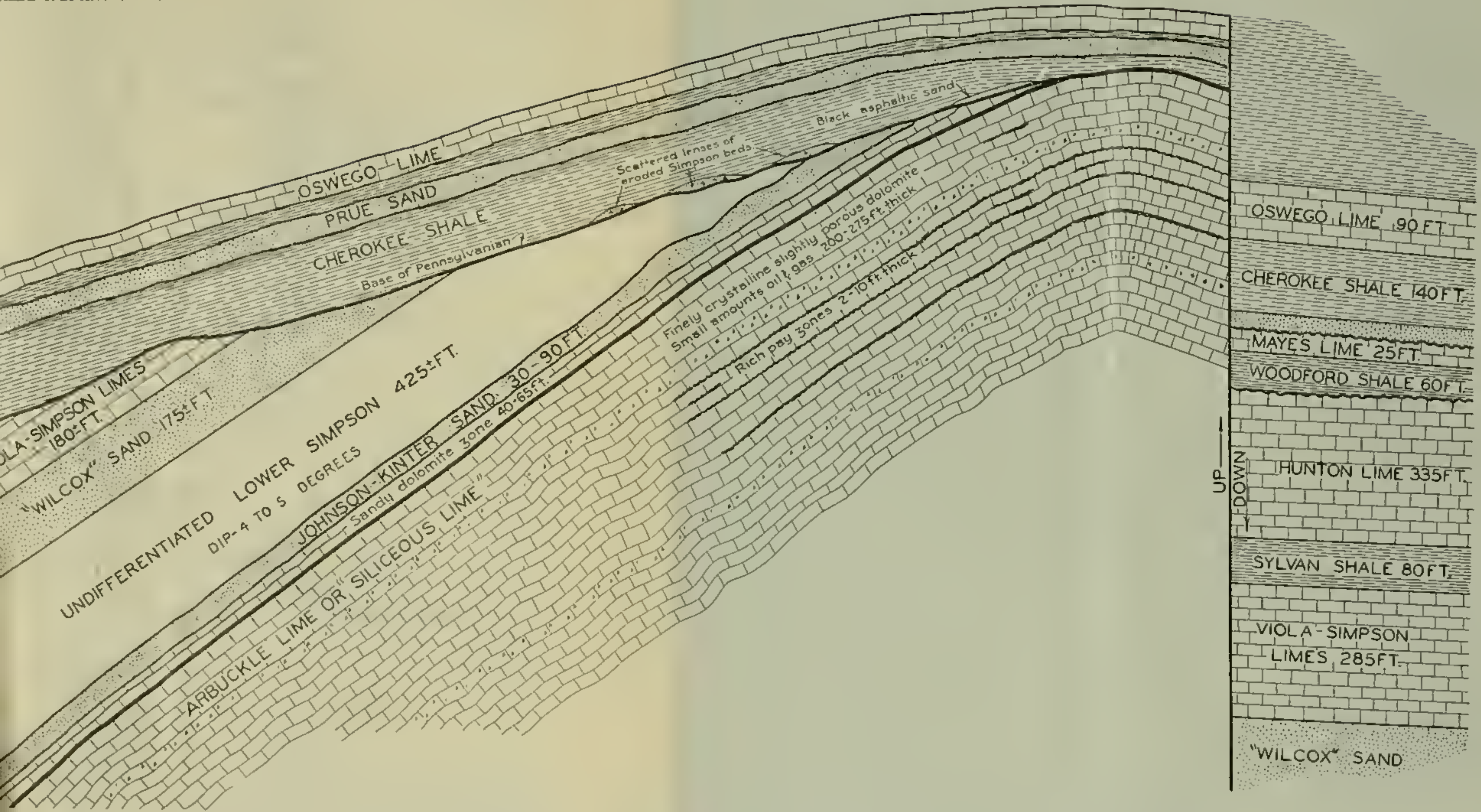
[6] Modified from an article published by the writer in the Bulletin of the American Association of Petroleum Geologists (3).



ELD, OKLAHOMA

The 3 miles (4.8 kilometers).



IDEAL CROSS SECTION SHOWING RELATIONS OF SUBSURFACE FORMATIONS IN THE OKLAHOMA CITY FIELD, OKLAHOMA

The section on the downthrown side of the fault was taken from the log of a well on the east side of the field. Length of section about 3 miles (4.8 kilometers).

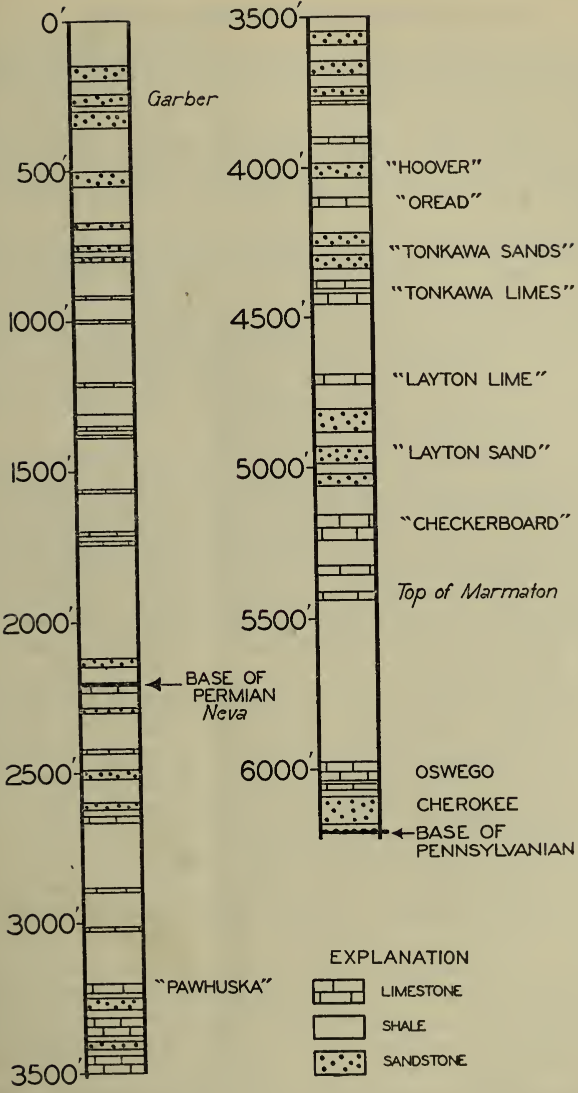


FIGURE 8.—Type section of Permian and Pennsylvanian formations in the Oklahoma City field, Oklahoma (3, fig. 2). The approximate equivalents of parts of this section with the general type section, according to Robert Roth, are shown in smaller lettering. The thickness of the Simpson formation ranges from almost nothing near the top of the structure to about 800 feet on the flanks. Other younger formations ranging from Viola limestone to Mayes limestone, inclusive, are present in the surrounding area

OIL AND GAS BEARING FORMATIONS

The sands in the Pennsylvanian have yielded mainly gas. Oil and gas have been produced from all the pre-Mississippian formations.

The "Wilcox" sand [7] has been an unusually large producer. From some wells it has yielded oil at the rate of 75,000 barrels (11,924,000 liters) a day on the basis of tests of a few hours' duration.

The undifferentiated lower Simpson contains several sands, somewhat lenticular, represented in places by slightly porous dolomitic sand or sandy dolomite. Because of their small porosity they have been less productive than other pre-Pennsylvanian sands in the field. The initial daily production of wells completed in them has varied from 1,000 to 5,000 barrels (159,000 to 795,000 liters) of oil and 1,000,000 to 40,000,000 cubic feet (28,320 to 1,132,700 cubic meters) of gas.

The lowest sand in the Simpson is the "Johnson" or "Kinter" sand, 30 to 90 feet (9 to 27 meters) thick and 40 to 65 feet (12 to 20 meters) above the Arbuckle limestone. It has yielded wells with a maximum production of 30,000 barrels (4,770,000 liters) of oil a day. Along the narrow band of its former outcrop directly beneath the Cherokee shale gas wells with an initial daily flow of 100,000,000 cubic feet (2,832,000 cubic meters) were completed. Several of these sands will be seen in crossing the Arbuckle Mountains.

The Arbuckle limestone, commonly termed the "Siliceous lime," furnished spectacular wells in the Oklahoma City field. The accumulation of oil and gas in the Arbuckle at Oklahoma City is unique in that it is found in zones as much as 500 feet (152 meters) below the top of the formation, whereas in other "Siliceous lime" pools the oil and gas were concentrated in the upper few feet, directly under the unconformable contact with the capping formations. Cores and cuttings show the Arbuckle to be a dense, coarsely crystalline gray or brown magnesian limestone. Chert is a common constituent of some beds. Bands of green shale occur in places, and local sandy beds are reported in some wells. Little progress has been made in interpreting the stratigraphy and structure of the Arbuckle. In general the upper 200 to 225 feet (61 to 69 meters) of beds beneath the Simpson is finely crystalline, and below that depth the formation has the same general appearance but is more coarsely crystalline. As indicated by differences in texture recorded in different wells, the dip in the Arbuckle on the west

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[7] See footnote 4, p. 16.

flank of the fold ranges from 4° to 5° and is practically the same as in the Simpson strata.

The largest part of the effective porosity in the "Siliceous lime" probably is confined to zones ranging from 2 to 10 feet (0.6 to 3 meters) in thickness. Results of drilling have given evidence that cavities of considerable size exist. Secondary solution is the agent most likely to have caused this porosity. The porous zones in the magnesian limestone, particularly the zone in which a chert conglomerate was found, may be the markers of stratigraphic breaks that occurred when the formation was above the sea.

Water and oil occur in the "lime" in a very irregular manner. Wells yielding both water and oil have had their oil production increased when deepened to another pay zone.

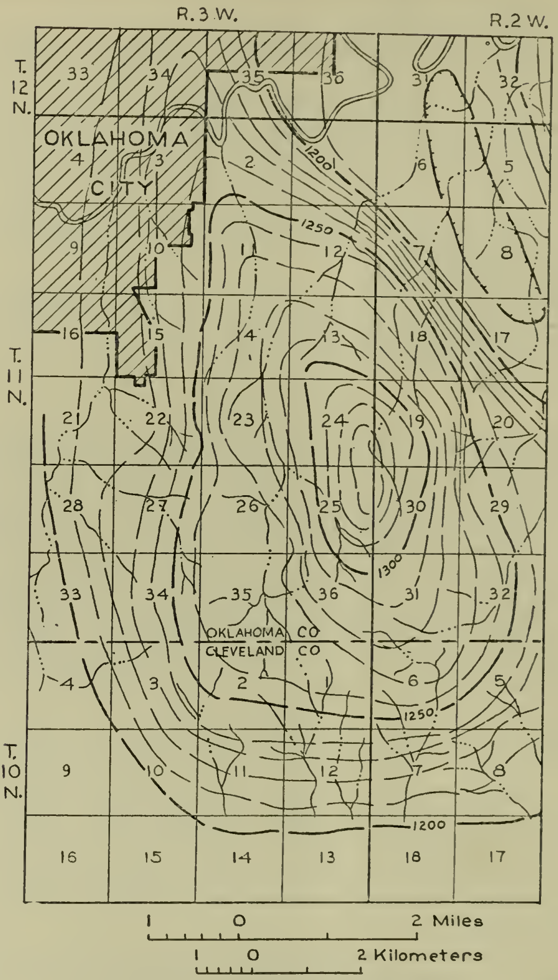
STRUCTURE

Surface structure.—In its surface structure the Oklahoma City field (fig. 9) is an anticline 9 miles (14.5 kilometers) long and 4 miles (6.4 kilometers) wide within the lowest closing contour, which is 90 feet (27 meters) below the crest. The chief feature of the surface structure is the abrupt dip, equal to 150 feet to the mile (28 meters to the kilometer), on the northeast flank, where the dip would normally be 30 feet to the mile (5.6 meters to the kilometer) in the opposite direction. (See fig. 10.) This steep dip reflects the subsurface fault known to have caused displacement of formations up to and including the Oswego "lime."

Subsurface structure.—The dips on the formations increase with their depth. (See fig. 11.) Final development may show 500 feet (152 meters) of closure on the Oswego "lime." The major axis of the anticline shifts eastward with depth, so that at a depth of 6,000 feet (1,829 meters) the highest points are approximately three-quarters of a mile (1.2 kilometers) from the highest points on the surface structure, giving the axial plane an inclination of 33°.

From the preceding description it is evident that the Oklahoma City field is developed on one of the buried anticlines in pre-Pennsylvanian rocks, which, as explained in the introduction to this guidebook, are common in the Mid-Continent region (4, pp. 159–160; 8, pp. 182–183; 20, pp. 60–64). Its position on the southward extension of the buried granite ridge known as the "Nemaha Mountains" is illustrated in Plate 2.

The fact that granite was reached in deep tests on the top of the anticlines in the Blackwell and Garber fields, which lie along this axis to the north, suggests that in the Oklahoma City field



Contours on Garber sandstone
Contour interval 10 feet

Figure 9.—Surface structure map of Oklahoma City field (3, fig. 4)

there is probably also a relatively thin section of Arbuckle limestone overlying granite in this position.

The Oklahoma City fold appears to differ from that in the Cushing field and from many other similar buried anticlines of the Mid-Continent region in that it is strongly faulted at the deeper horizons by a major fault that has a maximum displacement of about 2,200 feet (671 meters). On this fault, developed in pre-Pennsylvanian time, there was further displacement after deposition of the Pennsylvanian Oswego "lime," which, in two pairs of wells 660 feet (201 meters) apart, differs 400 feet (122 meters) in altitude. The effect of the fault is also shown by the abnormal dip in the surface rocks.

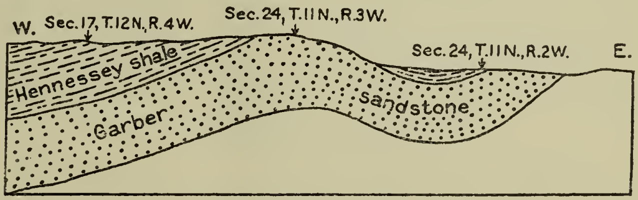


FIGURE 10.—Generalized cross section showing the arching of the Garber sandstone from east to west across the Oklahoma City field (20, fig. 63)

PRODUCTION

On June 1, 1931, there were 752 oil wells and 34 gas wells in the field. In most of the gas wells production was developed in higher sands after lower sands were depleted.

The average initial daily production of the wells in the Arbuckle "lime" was 12,000 barrels (1,908,000 liters); in the Simpson sands between the Arbuckle and "Wilcox," 7,500 barrels (1,192,000 liters); and in the "Wilcox," 35,000 barrels (5,565,000 liters).

The average total depth of the wells in the field is 6,500 feet (1,981 meters).

The gravity of the oil ranges from 37.5° to 40° A. P. I. (37.2° to 39.7° Baumé).

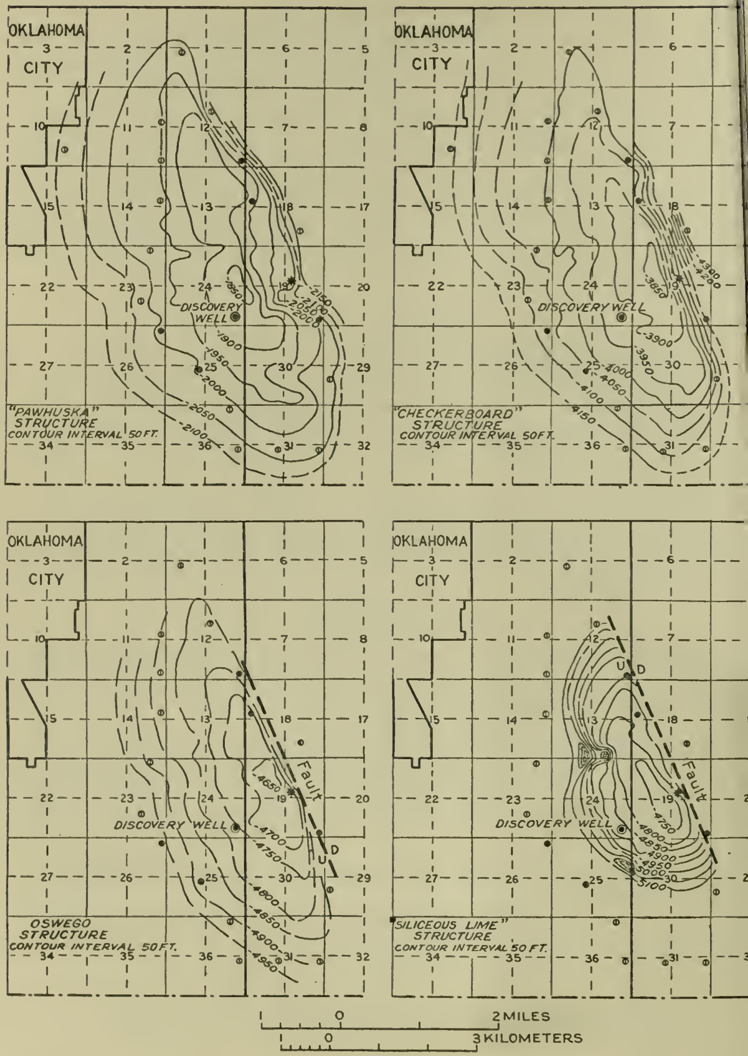


FIGURE 11.—Subsurface maps of the Oklahoma City field (3, figs. 5, 6). Co
tours on Oswego are on base of member.

THE ARBUCKLE MOUNTAINS AND ARDMORE BASIN

By C. W. Tomlinson

Although the Arbuckle Mountains and the adjoining Ardmore Basin are now reduced to very moderate relief, these areas constitute one of the most remarkable geologic exhibits in the United States. Here may be seen in a few hours a greater thickness and variety of sediments and greater complexity of structure than can be found in any equal area in the central section of North America—if, indeed, it is surpassed anywhere.

There are exposed in this district over 30,000 feet (9,000 meters) of Paleozoic sedimentary rocks, representing every period of that era with some of the richest fossil localities in the country. Here also are recorded intense mountain folding and faulting, and sharp angular unconformities, offering the key to much of the Carboniferous orogeny which stretched across this continent, accompanied by extraordinarily great erosion.

GEOLOGIC HISTORY

Early Paleozoic erosion and subsidence.—The earliest known sediments in the Arbuckle Mountain region are of Upper Cambrian age and buried a peneplain of pre-Cambrian igneous rocks. It is evident that deep and long-continued erosion characterized this region through most of Cambrian time. During Upper Cambrian and most of Ordovician time the region was part of a subsiding basin, the Ouachita geosyncline, which received an enormous thickness of calcareous sediments. The great bulk of these are included in the Arbuckle limestone, of Upper Cambrian and early Ordovician age. During part of the time the Ouachita geosyncline was continuous with the greater Appalachian syncline to the east and northeast and also with the Sonoran geosyncline to the southwest and west, producing a continuous belt of early Paleozoic sediments stretching diagonally across North America from Quebec to northwestern Mexico.

In spite of the dominance of sedimentation and subsidence, slight erosion occurred here at certain times in the Ordovician, notably just prior to the beginning of deposition of the Viola limestone.

Middle Paleozoic quiescence.—The Silurian, Devonian, and Mississippian are only fractionally represented; but although there are gaps of long duration in the sedimentary sequence for these periods, there is no proof of extensive erosion, nor even of proximity to any area of deep erosion, in southern Oklahoma during those intervals. An extraordinary feature is the difficulty of determining the boundary between the Henryhouse shale (middle Silurian) and the overlying Haragan shale (early Devonian). In spite of the long time interval between these two formations and their moderate thickness, their contact is scarcely distinguishable except by paleontologic evidence along hundreds of miles of outcrop in southern Oklahoma, and no evidence of an erosional surface between the two has ever been reported.

Gentle warping and slight erosion occurred late in Devonian time, prior to the deposition of the Woodford formation. However, there is nowhere in the region any pronounced angular unconformity of any considerable extent interrupting the essential parallelism of strata from Upper Cambrian to latest Mississippian.

Some of the Ordovician limestones are slightly bituminous. The Woodford formation (late Devonian or early Mississippian) includes some richly bituminous black shales. Beginning in late Mississippian (Caney) time, a series of black shales, including richly bituminous strata, was deposited in southern Oklahoma, attaining a thickness of over a mile (1.6 kilometers) in the Ardmore Basin. These black shales of the Woodford, Caney, and Springer formations, with minor zones of black shale higher in the Pennsylvanian section, are believed to be the chief source from which the petroleum and natural gas of this region were derived.

Pennsylvanian subsidence, orogeny, and erosion.—The Pennsylvanian epoch was the stormy interlude of geologic history for southern Oklahoma. Within its span there accumulated in this area a greater thickness of sediments than in all the rest of its history since the beginning of Upper Cambrian deposition. There was also more erosion than in all the rest of its post-Cambrian history: at least 4 miles (6.4 kilometers) of sediments were stripped off the Arbuckle Mountain area. And all or nearly all the mountain folding which this area is known to have suffered took place within the Pennsylvanian epoch—possibly beginning near the end of the Mississippian.

This orogeny was concentrated chiefly in two great movements—one near the beginning of Pennsylvanian time, the other one after the middle of the epoch. It produced a chain of mountain ranges, the Arbuckle-Wichita Mountain chain, extending west-northwest for about 1,000 miles (1,600 kilometers) across the heart of the continent, from northeastern Texas or northern Louisiana to western Colorado. (See fig. 12.) Although perhaps related causally to the Ouachita geosyncline and other basins of deposition, the peculiar trend of this mountain system does not parallel them closely, nor is it near to any known continental border. It strikes out almost at right angles

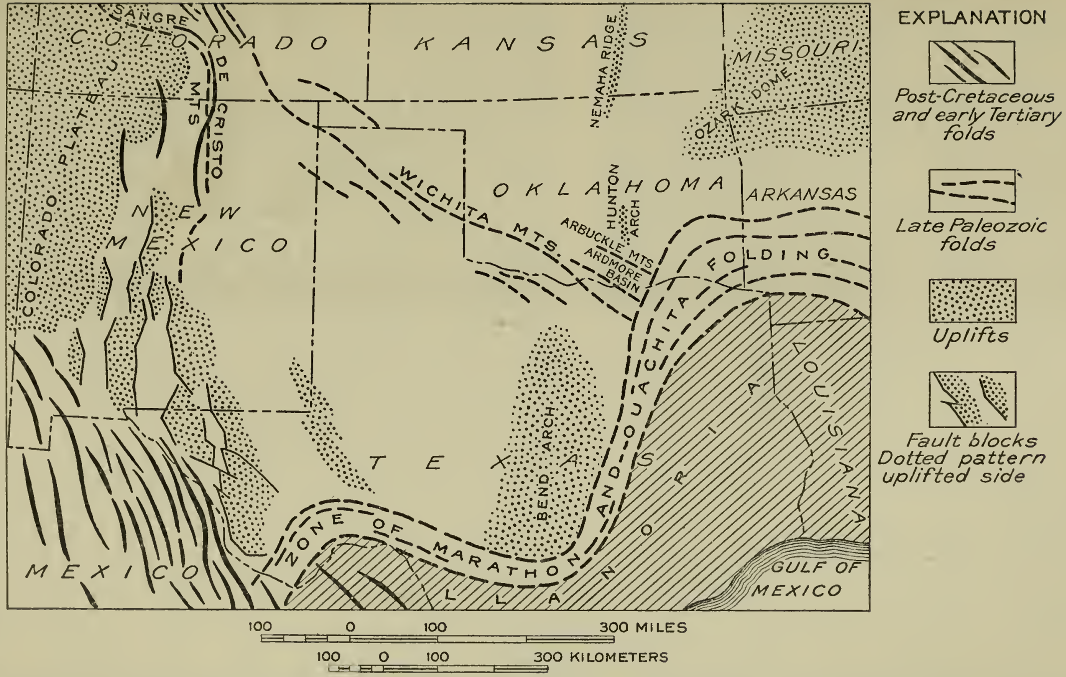


Figure 12.—Map showing general structural trends in and adjacent to Oklahoma and Texas in relation to the Arbuckle Mountains. Compiled by Philip B. King, U. S. Geological Survey

to the probable contemporary shore line of Llanoria, the old land mass in Louisiana and southern Texas, which may have been continuous then with the Appalachian continent and, like it, trended from northeast to southwest. The present southern (Pacific) coast of Mexico and Central America is approximately parallel to the Arbuckle-Wichita Mountain chain but is more than 1,000 miles (1,600 kilometers) away. The major causes controlling the anomalous direction of this intracontinental mountain system remain in doubt.

The western part of this chain in Colorado and New Mexico is now obscured by the later (post-Cretaceous) Rocky Mountain orogeny. The middle portion, across the "panhandle" of Texas (the northwestern portion of the State between Oklahoma and New Mexico), is buried beneath younger sediments, but the resulting arch constitutes the world's most extensive gas field. Many of the minor ranges in southern Oklahoma, similarly buried, are producing both oil and gas. It is here in the Ardmore district that the story of this mountain system is most clearly and fully revealed. A crustal shortening of at least 16 miles (26 kilometers) was accomplished here by the later Pennsylvanian folding alone.

This orogeny was closely related in time to the formation of the Paleozoic Alps of Europe. Although it was much earlier than the culmination of the Appalachian revolution, it may have corresponded to the earlier stages of that revolution. The chief orogeny in the Ouachita Mountains of southwestern Arkansas and southeastern Oklahoma corresponded more nearly in date to the main Appalachian folding and, like it, was accomplished in part by thrust faulting from the southeast.

Sediments of lower Pennsylvanian age attain a maximum thickness of at least 17,000 feet (5,000 meters) in the Ardmore Basin south of the Arbuckle Mountains. They consist chiefly of shale, with many sandstone and limestone members and a few conglomerates. In many parts of southern Oklahoma there is a pronounced angular unconformity between early Pennsylvanian sediments, or some part of them, and older rocks. These sediments in turn were intensely folded and are overlain unconformably by the basal "Red Beds" of late Pennsylvanian or early Permian age.

A small part of the great Pennsylvanian section is composed of clastic material derived from local island mountain ranges; but a much greater part of it carries definite proof that the source of its clastic material lay to the southeast, in the ancient land of Llanoria. Clastic sediments increase in coarseness and preponderance in that direction, and the entire section thickens rapidly southeastward.

Nearly all of the oil and gas of Oklahoma south of the Arbuckle Mountains at present is derived from Pennsylvanian rocks—chiefly from the Deese and Dornick Hills formations. Important development in older formations is a probability of the future.

Later history.—From Upper Cambrian through Mississippian time southern Oklahoma was relatively quiescent, with an average surface slightly below sea level. After its stormy Pennsylvanian history, the region again lapsed into relative stability, which has continued to the present time; but during this later history its average altitude has probably been slightly above sea level, perhaps not far from its present status. Continental sediments of the red-bed type covered most of the region in Permian time, only to be stripped off from portions of it later, reexposing the late Pennsylvanian peneplain. A thin sheet of marine Comanchean (Lower Cretaceous) sediments was spread over part of the area, but this, too, has been partly stripped back, reexposing the earlier surface to slight further dissection in recent time.

STRATIGRAPHY

The formations that occur in the portion of the Arbuckle Mountains to be traversed on this excursion are shown in the following table:

- Lower Cretaceous:
  - Goodland limestone.
  - Trinity sand.
- Permian(?): Higher "Red Beds."
- Pennsylvanian:
  - Pontotoc group—
    - Hart limestone.
    - Conglomerates.
  - Hoxbar formation.
  - Deese formation.
  - Dornick Hills formation.
  - Springer formation.
- Mississippian:
  - Caney shale.
  - Sycamore limestone.
- Devonian or Mississippian: Woodford chert.
- Devonian:
  - Hunton group—
    - Bois d'Arc limestone.
    - Haragan marl.
- Silurian:
  - Hunton group—
    - Henryhouse shale.
    - Chimneyhill limestone.

Ordovician:
  Sylvan shale.
  Viola limestone (including Fernvale limestone member).
  Simpson group—
    Bromide formation.
    Tulip Creek formation.
    McLish formation.
    Oil Creek formation.
    Joins formation.
Ordovician and Cambrian: Arbuckle limestone.
Cambrian: Reagan sandstone.
Pre-Cambrian: Colbert porphyry.

Pre-Cambrian.—The pre-Cambrian rocks that crop out in the Arbuckle Mountains include the coarse-grained pink to gray Tishomingo granite, the Colbert felsite porphyry, and small dikes of diabase. The relative age and the structural relation of the granite to the porphyry are not known, as the rocks do not crop out in contiguous areas. As neither is appreciably metamorphosed, their age is suspected to be Algonkian rather than Archean. The porphyry stands up in the highest summits of the Arbuckle Mountains.

Reagan sandstone.—The Upper Cambrian Reagan sandstone averages about 300 feet (91 meters) in thickness and grades from very coarse arkosic sandstone (locally absent) at the base to relatively fine-grained shaly calcareous sandstone near the top.

Arbuckle limestone.—The lower 2,400 feet (732 meters) of the Arbuckle limestone is chiefly dolomite, with limestones, thin shale members, and dolomitic marble. The upper 5,600 feet (1,707 meters) is chiefly thin-bedded to massive limestone with thin shaly layers and locally, near the top, substantial sandstone members. The maximum thickness is about 8,000 feet (2,438 meters). The formation occupies extensive plateau areas in the Arbuckle Mountains. It is of Upper Cambrian and Lower Ordovician age.

Simpson group.—Thin-bedded limestones and dolomites with interbedded green shales and buff massive sandstones, locally used for glass sand, make up the Simpson group, 1,000 to 2,200 feet (305 to 670 meters) thick, of Middle and Lower Ordovician age. The group is divided into five formations, each (except the bottom one) with a sandstone at the base. In order from the bottom up, they are the Joins, Oil Creek, McLish, Tulip Creek, and Bromide formations.

Viola limestone.—The Viola is a thin-bedded to massive, more or less cherty limestone exposed in the Arbuckle Mountains in a series of bare, rounded knobs lying outside the eroded Simpson valley. Its thickness is 500 to 1,000 feet (152 to 305 meters). It is mostly of Middle Ordovician age, with the Fernvale limestone member (Upper Ordovician) at the top.

Sylvan shale.—The Sylvan consists of greenish to greenish-gray shale, weathering typically into long, narrow wooded valleys. Its thickness ranges from 60 to 300 feet (18 to 91 meters) and averages 150 feet (46 meters). It is of Richmond age, which most geologists, including the United States Geological Survey, classify as Upper Ordovician, but which E. O. Ulrich and some other geologists classify as early Silurian.

Hunton group.—Very fossiliferous limestones and calcareous shales or marls make up the Hunton group, which is divided by Reeds, from bottom to top, into the Chimneyhill limestone, Henryhouse shale, Haragan shale, and Bois d'Arc limestone. The first two are of early and middle Silurian age, the last two early Devonian. The aggregate thickness of the group is 150 to 300 feet (46 to 91 meters).

Woodford chert.—The Woodford comprises an average of about 600 feet (183 meters) of chert and bituminous and siliceous shales, of late Devonian or early Mississippian age. Its outcrops usually form wooded slopes and valleys.

Sycamore limestone.—The Sycamore is a rather hard, tough blue-gray limestone, weathering yellow, as much as 400 feet (122 meters) thick, that forms the outermost ridge of the Arbuckle Mountains. It is of Mississippian age.

Caney shale.—Black shales, in part highly bituminous, with limestone lentils and ironstone layers, make up the Caney shale, which has a thickness of about 2,000 feet (610 meters) in the Ardmore Basin. Its age is uppermost Mississippian.

Springer formation.—The Springer formation includes 3,000 to 3,500 feet (914 to 1,067 meters) of black shales similar to the Caney, with four sandstone members. It is probably of earliest Pennsylvanian age.

Dornick Hills formation.—Bluish and tan shales, with six fossiliferous limestone members and a few sandstones, constitute the Dornick Hills formation, which contains also coarse limestone conglomerates near the Criner Hills. Its maximum thickness is 4,000 feet (1,219 meters), but it diminishes northwestward to 2,000 feet (610 meters) or less. It is of early Pennsylvanian age.

Deese formation.—The Deese formation comprises bluish and red shales with numerous sandstone members and two or more conglomeratic sandstones carrying chert pebbles exclusively, also two or more limestones, poorly developed except locally. The conglomerates increase in coarseness and thickness toward the southeast; the limestones thicken in the opposite direction. The maximum thickness of the formation is 7,000 feet (2,134 meters); it diminishes northwestward to 5,000 feet (1,524 meters). Its age is early Pennsylvanian (mostly Pottsville).

Hoxbar formation.—The Hoxbar consists of bluish, tan, and brown shales with five or more prominent limestone members and several sandstones; also shale-pebble conglomerate and local conglomerate of limestone and chert pebbles. It has a maximum thickness of 4,000 feet (1,219 meters) and is of lower Pennsylvanian age.

Pontotoc group.—The basal unit of the dominantly terrigenous red beds that lie unconformably across the eroded edges of all the older formations around the borders of the Ardmore Basin and the west end of the Arbuckle Mountains is the Pontotoc group. It includes local masses of coarse conglomerate of limestone and chert boulders and more extensive arkosic conglomerates. Above most of the conglomeratic section is the Hart limestone member, the oldest member definitely traceable around the west end of the Arbuckle Mountains. The Hart limestone reaches a maximum thickness of 200 feet (61 meters) but is generally much thinner. Above and below it are red shales and arkoses with beds of mottled sandstone, which are locally saturated with asphalt and have produced heavy oil in the Wheeler pool and elsewhere. The maximum thickness of the group is about 1,500 feet (457 meters).

The Pontotoc group of this region is traced northward into the uppermost portion of the marine Pennsylvanian section of Kansas and northern Oklahoma.

Higher "Red Beds."—Above the Pontotoc group there crops out in this area at least 1,000 feet (305 meters) of fairly typical red beds, including dark-red shales and brown sandstones as the dominant elements. These beds have yielded no fossils in this region except a few plant impressions and fragmentary amphibian remains, but they are believed to be of early Permian age. Some of the sandstones have yielded gas and oil.

Trinity sand.—The Trinity sand, of early Comanchean (Lower Cretaceous) age, forms the edge of the Gulf Coastal Plain lapping up onto the Ardmore district from the south. It is usually conglomeratic and quartzitic at the base but has a basal calcareous facies where it lies close to the Arbuckle limestone plateau east of Ardmore.

Goodland limestone.—The Goodland is a bluff-forming limestone about 25 feet (7.6 meters) thick, forming the southern rim of the Ardmore Basin. It is of Lower Cretaceous age.

ITINERARY, DAVIS TO ARDMORE, OKLAHOMA

The trip from Davis to Ardmore goes entirely along a paved road, United States highway 77. (See pls. 5, 6; fig. 13.) For the first 3 miles (4.8 kilometers) out of Davis the party will traverse recent alluvium in the valley of the Washita River, with the low range of the Arbuckle Mountains visible ahead. A little more than half a mile (0.8 kilometer) beyond the river bridge the party will enter the mountains. The first outcrop of bedrock at the right of the road is the Woodfort chert (late Devonian or early Mississippian), standing approximately vertical. Together with the overlying Sycamore limestone (Mississippian), this forms the outer ridge (visible at a little distance from the road, on either side) encircling the Arbuckle Mountains. The softer lower part of the Woodford usually occupies a valley.

The next conspicuous outcrop is a limestone ridge belonging to the Hunton formation (Devonian and Silurian), followed by a narrow valley of the Sylvan shale (Upper Ordovician). The lower part of the Sylvan shale is well exposed in a cut bank at the right of the road. Beyond it in the same exposure is the lower part of the Viola limestone (Ordovician), still standing nearly vertical.

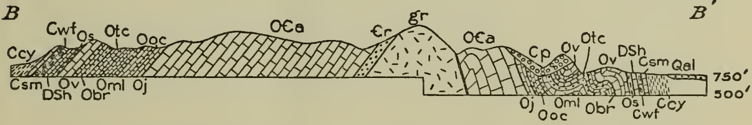


FIGURE 13.—Geologic cross section of the Arbuckle Mountains, Oklahoma, along line *B–B′*, Plate 5. For explanation of symbols see Plate 5

The Viola outcrop is widened here by a narrow anticline followed by a sharp syncline, which shows to best advantage in the left wall of the valley of Honey Creek, up which the road is climbing. The structure of the Viola is partly masked by Quaternary conglomerates resting against the valley wall near and below the level of the road. A second but inconspicuous anticlinal axis follows before the road passes into a mass of coarse conglomerates belonging to the Pontotoc group (late Pennsylvanian), which themselves occupy a synclinal basin but lie with sharp angular unconformity across the older rocks. These conglomerates are composed chiefly of limestone boulders in a reddish matrix.

The conglomerates continue nearly to the top of the steep climb, where the road leaves Honey Creek and bears to the left. At the end of the hairpin turn may be seen the contact of the conglomerates lying upon Arbuckle limestone (Ordovician and Cambrian). This contact appears again around the next turn, beyond which the road stays upon the Arbuckle limestone for 4 miles (6.4 kilometers).

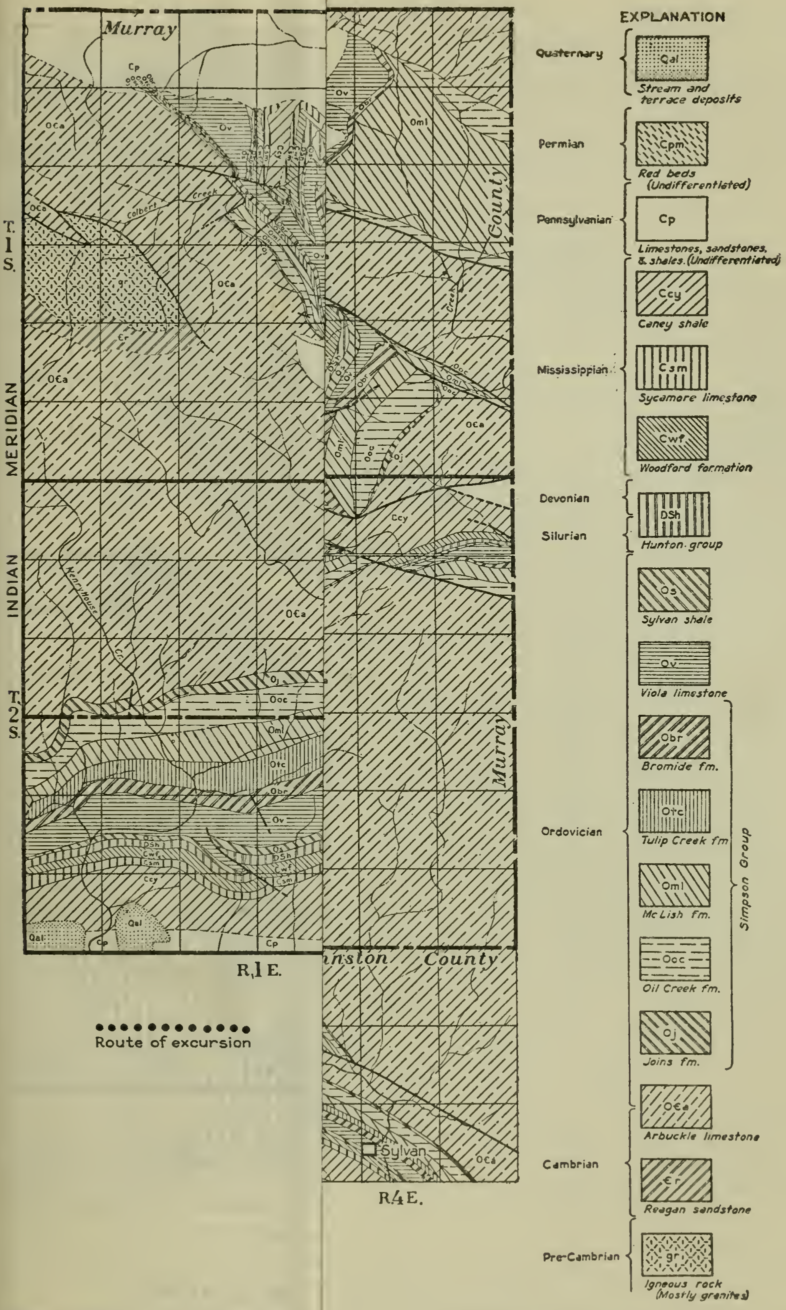
Stop 1. The cars will stop on the graveled side road at the top of the hill for a view of Turner Falls. These falls appear to have been induced originally by the greater resistance of the Colbert felsite porphyry (pre-Cambrian), which occupies the wooded hills on the sky line. The valley below the falls is cut in the Arbuckle limestone and the Pontotoc conglomerates. Large deposits of calcareous tufa surround the falls and are still being augmented by deposition of calcium carbonate from the waters of the creek, which originate in great part in very large springs emerging from the Arbuckle limestone plateau.

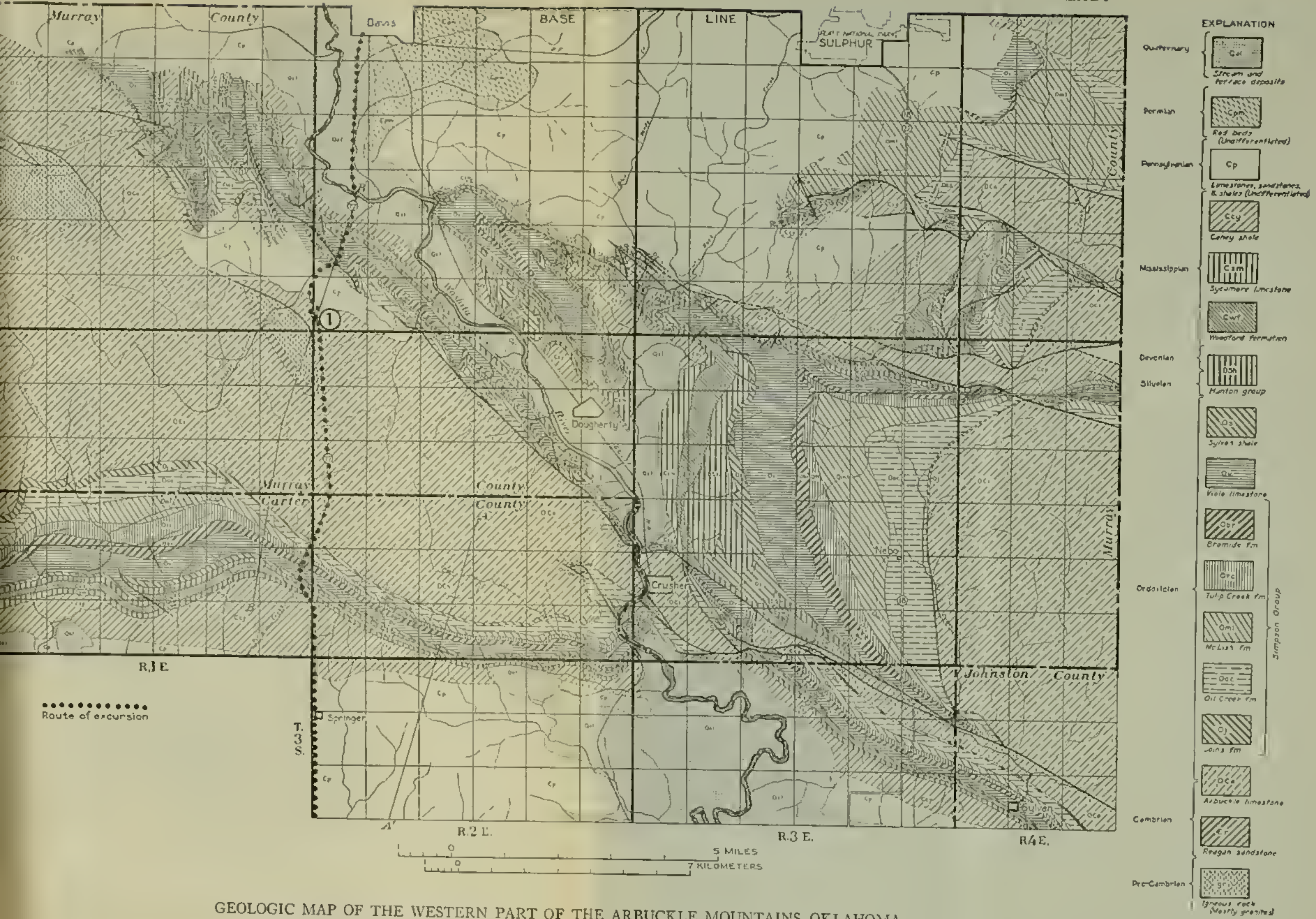
Some of the formations from this point on have been marked along the highway with roadside signs for the benefit of the traveler. For the next 4 miles (6.4 kilometers) the road crosses a plateau surface cut on the Arbuckle limestone and dolomite, which here has a total thickness of nearly 8,000 feet (2,438 meters).

The top of the Arbuckle is reached a short distance beyond the beginning of the descent on the south side of the mountains. The upper part of the formation is noteworthy for its hundreds of narrow parallel ridges of limestone, resembling plow ridges, produced by closely repeated variations in resistance to weathering of successive beds.

Along this descent can be seen a complete section of the other early Paleozoic formations (dipping less steeply than on the north side of the range) in the following order:

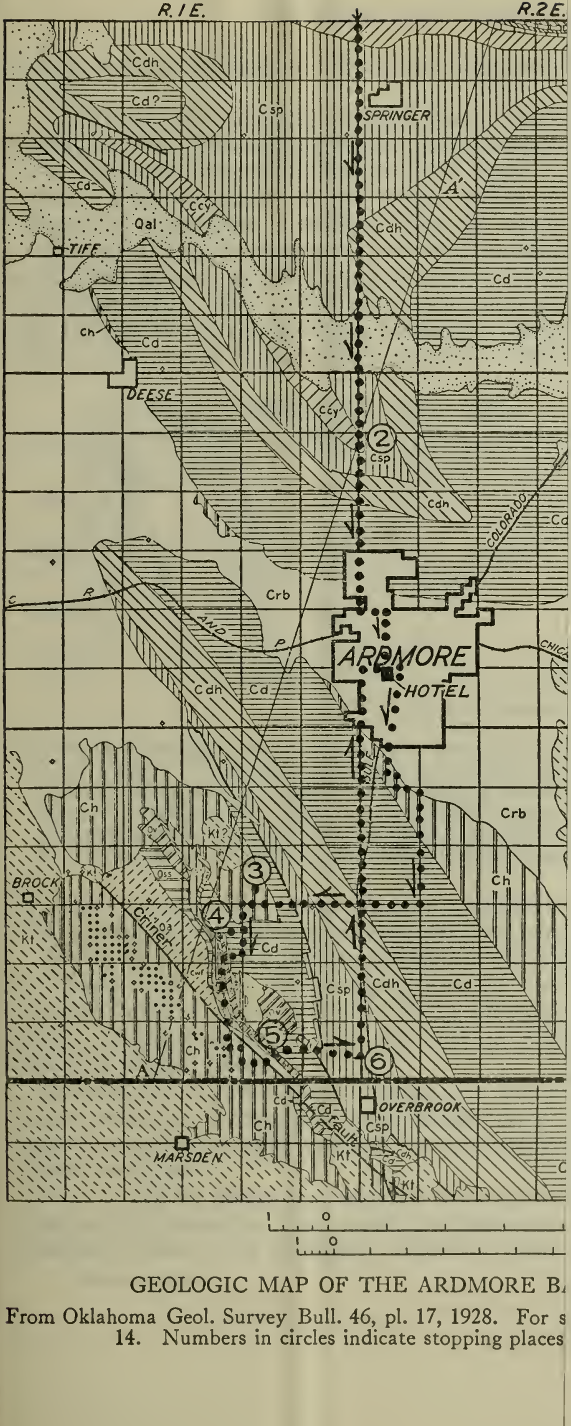
1. Simpson group (Ordovician), about 2,000 feet (610 meters) thick, including the Joins, Oil Creek, McLish, Tulip Creek, and Bromide formations. Each of these formations except the Joins has at its base a sandstone of considerable thickness, followed by interbedded limestones and green shales. The volume of limestone is greatest in the Joins and Oil Creek formations. The sand at the base of the McLish formation is called "Burgen sand" on the sign beside the road, and the one at the base of the Tulip Creek formation is labeled "Wilcox sand." Sands in the Simpson group are the most productive oil strata in Oklahoma at present.
2. Viola limestone (Ordovician), which is about 750 feet (329 meters) thick and forms a high ridge, through which the road follows a stream-cut gorge.
3. Sylvan shale, unexposed, forming a valley.
4. Hunton formation, whose lowermost unit, the Chimneyhill limestone (early Silurian), makes a low ridge, as does also the upper part of the Haragan marly limestone (Lower Devonian). The parallelism of these subdivisions of the Hunton formation over hundreds of miles of outcrop in the Arbuckle Mountain


Murray
County
Murray
Johnston County
Sylvan
T. 1 S.
T. 2 S.
INDIAN MERIDIAN
R. 1 E.
R. 4 E.
Colbert Creek
Henry House Cr.
Creek
Cp
Ov
Obr
Oml
O€a
Ooc
Oj
Otc
gr
€r
Ccy
DSh
Cwf
Csm
Os
Qal
Route of excursion
EXPLANATION
Quaternary
Qal
Stream and terrace deposits
Permian
Cpm
Red beds (Undifferentiated)
Pennsylvanian
Cp
Limestones, sandstones, & shales. (Undifferentiated)
Mississippian
Ccy
Caney shale
Csm
Sycamore limestone
Cwf
Woodford formation
Devonian
Silurian
DSh
Hunton group
Ordovician
Os
Sylvan shale
Ov
Viola limestone
Obr
Bromide fm.
Otc
Tulip Creek fm
Oml
McLish fm.
Ooc
Oil Creek fm.
Oj
Joins fm.
Simpson Group
O€a
Arbuckle limestone
Cambrian
€r
Reagan sandstone
Pre-Cambrian
gr
Igneous rock (Mostly granites)



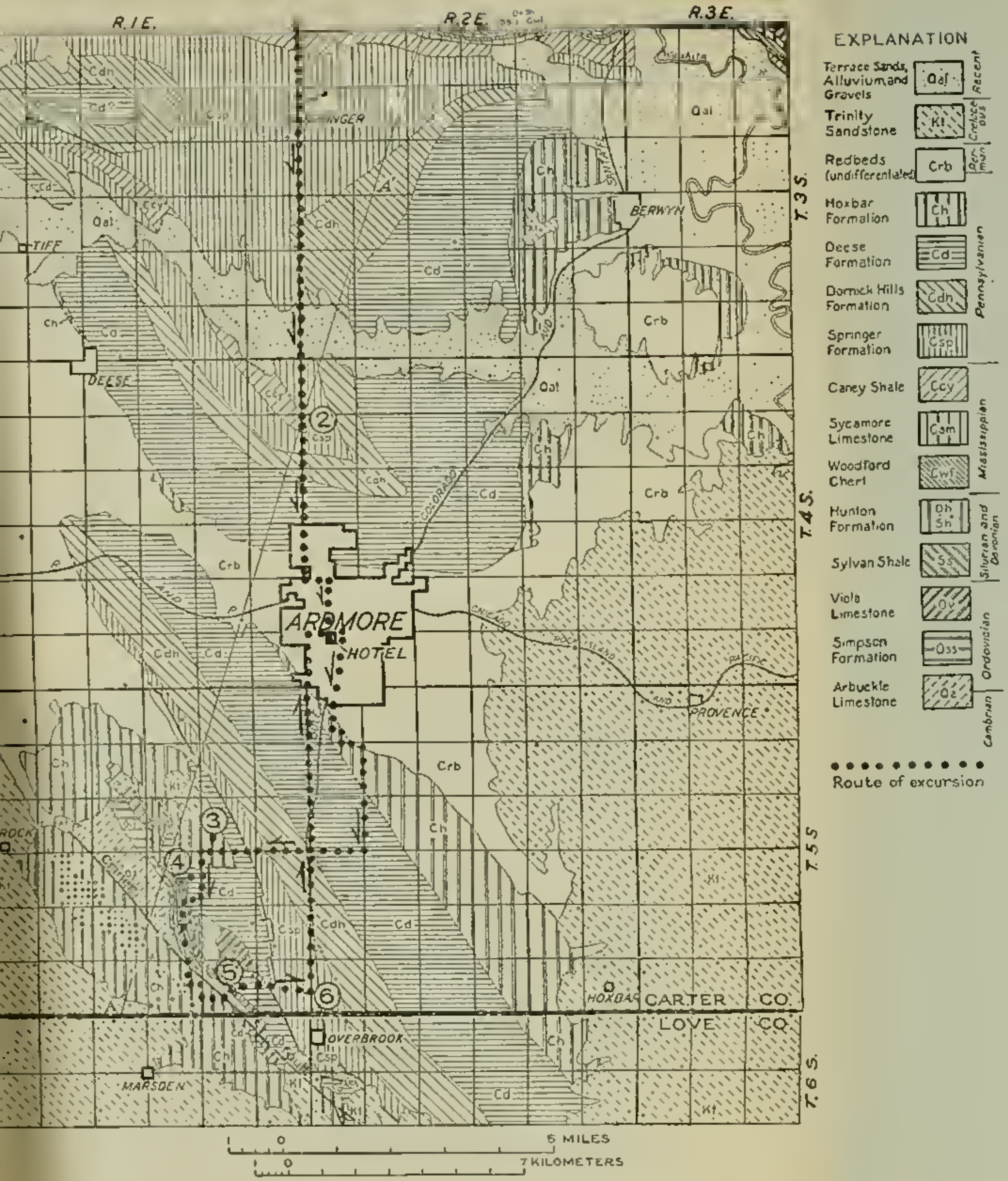
GEOLOGIC MAP OF THE WESTERN PART OF THE ARBUCKLE MOUNTAINS, OKLAHOMA

From Geologic map of the Arbuckle Mountains, by Decker, Cooper, and McGehee, 1931.



GEOLOGIC MAP OF THE ARDMORE B

From Oklahoma Geol. Survey Bull. 46, pl. 17, 1928. For s
14. Numbers in circles indicate stopping places



GEOLOGIC MAP OF THE ARDMORE BASIN, OKLAHOMA

rom Oklahoma Geol. Survey Bull. 46, pl. 17, 1928. For section along line *A–A'* see Figure 14. Numbers in circles indicate stopping places referred to in the text.

region is extraordinary in view of the long time interval between them.

5. Woodford formation, of which there is here a small exposure including both banded chert and black bituminous shale.

6. Sycamore limestone, forming the outer ridge of the mountains. The inner face of the ridge, which is occupied by the Woodford formation, is wooded; but the outer slope is bare.

Beyond the mountains the party will travel for a mile or more across low ground on the Caney shale (late Mississippian), which is not exposed. The next 3 miles (4.8 kilometers) (see pl. 6 and fig. 14) lies across the Springer formation (probably early Pennsylvanian), which is but poorly exposed. The Caney and the Springer together here comprise about 6,000 feet (1,829 meters) of black shales, with several sandstone members in the Springer.

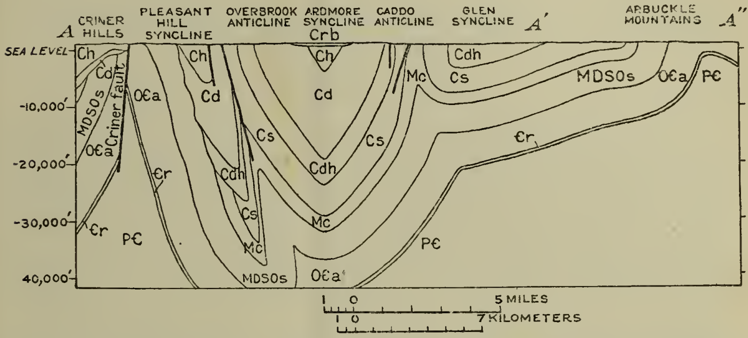


FIGURE 14.—Geologic cross section of the Ardmore Basin, Oklahoma, along line *A–A'*, Plate 6. From Oklahoma Geol. Survey Bull. 46, pl. 17, 1928. Ch, Hoxbar formation; Cd, Deese formation; Cdh, Dornick Hills formation; Cs, Springer formation; Mc, Caney shale; MDSOs, Sycamore limestone, Woodford chert, Hunton group, Viola limestone, and Simpson group; O-Ꞓa, Arbuckle limestone; Ꞓr, Reagan sandstone; P-Ꞓ, pre-Cambrian.

About 2½ miles (4 kilometers) beyond the village of Springer the party will cross the plunging axis of the Glenn syncline, exposed in limestone at the base of the Dornick Hills formation (lower Pennsylvanian). Not far beyond this is the alluvial valley of Caddo Creek.

Beyond the Caddo Creek bridge the party will cut across ridges produced by the four sand members of the Springer formation standing nearly vertical on the northeast limb of the Caddo anticline.

Stop 2 will be made just beyond the axis of the anticline, to observe the horseshoe turn made by these sandstone ridges in swinging around the plunging southeast nose of this hairpin anticlinal fold. The thrifty growth of small oak trees on the sandstone members and their absence on the intervening shale valleys are of interest.

In the next mile the party will see first the repetition of two of the sandstone members of the Springer formation (the others being cut out by strike faulting), then limestone and sandstone members of the Dornick Hills formation, followed by sandstones of the Deese formation (lower Pennsylvanian). On approaching the town of Ardmore the route passes on to a thin sheet of red beds of the Pontotoc group (late Pennsylvanian), which lie unconformably across the older Pennsylvanian rocks in the axis of the Ardmore syncline.

ITINERARY, ARDMORE TO CRINER HILLS AND SOUTHERN PART OF THE ARDMORE BASIN

[See pl. 6 and fig. 14]

The city of Ardmore lies on a shallow strip of late Pennsylvanian red beds in the axis of the Ardmore syncline. These red beds have not been materially affected by the mountain folding of this region and rarely show dips greater than 5°. The party will start out through the southeastern portion of the city. Just beyond the cemetery at the outskirts of the city the route crosses a member of the Hoxbar formation (lower middle Pennsylvanian) dipping about 48° NE. A quarter of a mile (0.4 kilometer) farther on, at a lower level, there will be visible in the ditch at the left of the road some coarse arkose belonging to the late Pennsylvanian red beds, overlying the steeply dipping Hoxbar formation.

In traveling 2 miles (3.2 kilometers) south and 2 miles west from the road corner just beyond the arkose outcrop the party will cross more than 12,000 feet (3.7 kilometers) of steeply dipping lower Pennsylvanian sediments, in order from the youngest to the oldest. First will come about 2,000 feet (610 meters) of the Hoxbar formation, including several thin limestone members, with dips averaging about 50° NE. Each hard member makes a distinct ridge extending from northwest to southeast.

This will be followed by more than 6,000 feet (1.8 kilometers) of the Deese formation, in which a large number of sandstones and two chert conglomerate members will be seen, with rarer exposures of red and lighter-colored shale.

Near the railroad crossing the party will pass from the Deese formation to the Dornick Hills formation, in which two or three thin limestones and a ridge-making limestone conglomerate can be seen. This formation consists largely of dark shales and gives rise to clay soils, supporting much less scrub-oak timber than the Deese formation.

About a mile (1.6 kilometers) beyond the railroad crossing the party will cross a valley occupying the axis of the Overbrook anticline and a concealed thrust fault having a displacement of several thousand feet.

At stop 3 the party will leave the cars and walk about an eighth of a mile (0.2 kilometer) to the right, into the pasture. There is here a remarkable exposure of some of the lower members of the Hoxbar formation, extremely distorted in the axis of the Pleasant Hills syncline, the east limb of which is overturned.

At stop 4, 1,000 feet (305 meters) west of the road, is an excellent exposure of the angular unconformity underlying the lower Pennsylvanian rocks in the Criner Hills. Coarse Pennsylvanian limestone conglomerate, probably belonging to the Dornick Hills formation, here lies almost at right angles across truncated edges of the Bromide and Viola formations dipping steeply into the hills. This unconformity represents the first great orogenic folding and erosion in the Ardmore region. It dates from early Pennsylvanian time, as contrasted with the late Pennsylvanian unconformity at the base of the red beds. Conglomerates derived from the Criner Hills area occur in abundance in the Dornick Hills formation (particularly the Bostwick member) near this area, but they dwindle and disappear along the strike away from the Criner Hills.

This unconformity is penetrated by the drill in the Brock, Hewitt, Healdton, Duncan, and Loco oil and gas fields, to the west. In all those fields the oil is obtained in the overlying Pennsylvanian formations, varying in age from Dornick Hills to Hoxbar; and below the Pennsylvanian productive series the drill passes into more steeply folded pre-Mississippian rocks, the Springer and Caney formations and in some places all the older formations down to the Arbuckle limestone being absent. In other folds near the Red River, which lies a few miles to the south, forming the southern boundary of the State, the drill passes directly from Pennsylvanian beds into pre-Cambrian granite.

The Wichita Mountains may have developed in this same epoch of orogeny.

The Pennsylvanian conglomerate at this locality has in turn been tilted to a dip of about 35° and abruptly faulted off at the east edge of the outcrop. This is one of the two great faults flanking the Criner Hills. The faulting is probably of post-Hoxbar date, corresponding to the main Arbuckle orogeny of middle or late Pennsylvanian time.

After leaving stop 4 the party will cut through the Criner Hills, made up of earlier Paleozoic rocks. The route passes first through a stream-cut gap in a ridge of Viola limestone (Ordovician), then follows a valley cut on the Sylvan shale (Upper Ordovician). After crossing the valley and traveling for a quarter of a mile (0.4 kilometer) on limestones and marls of the Hunton formation (Silurian and Devonian), it crosses the Criner fault into more open country on Pennsylvanian rocks belonging to the Hoxbar formation. Here a small portion of the Brock oil field can be seen in the valley to the right. Just before reaching stop 5 the party will reenter the Criner Hills.

Stop 5 is at the locality called Rock Crossing, on Hickory Creek. Here can be seen in order the Woodford, Hunton, Sylvan, Viola, and Bromide formations, of Mississippian, Devonian, Silurian, and Ordovician age, overlain unconformably by Pennsylvanian strata. The Viola is locally cut out by a fault. There is excellent fossil collecting in the Bromide formation, the upper unit of the Simpson group.

About a mile (1.6 kilometers) beyond stop 5 the party will pass a wooded hill at the right of the road, which is an island of Woodford chert (Devonian or Mississippian) and Sycamore (Mississippian) limestone, surrounded by Pennsylvanian rocks.

At stop 6 the party will walk 100 yards (91 meters) to the right into the pasture to see a creek bank in which is exposed the extremely sharp axis of the Overbrook anticline, in black shales of the Springer formation (earliest Pennsylvanian).

THE CRETACEOUS OF TEXAS

By Gayle Scott

INTRODUCTION

Cretaceous rocks in Texas crop out over an area of about 70,000 square miles (180,000 square kilometers) in a belt more than 600 miles (966 kilometers) long and from 50 to 200 miles (80 to 322 kilometers) wide. To the northeast the outcrop extends across southeastern Oklahoma and northwestern Louisiana, into Arkansas, where the rocks are eventually overlapped by strata of later age and by the alluvium of the Mississippi River and its tributaries. From southwestern Texas it passes into Mexico. The broad outlines of the outcrop are shown in Plate 1.

The region underlain by Cretaceous rocks in Texas borders the outer margin of the Gulf Coastal Plain. The strata dip at a low angle to the south, southeast, and east toward the Gulf of Mexico, and in that direction they are covered progressively deeper by Tertiary and later sediments of the Coastal Plain. This uniformity of dip, which results in the well-known cuesta type of topography, is interrupted appreciably only where interfered with by structure, as for instance in the vicinity of salt domes, along the Balcones and Mexia fault zones, and around the Sabine uplift.

The Cretaceous of Texas and adjoining regions lies in angular unconformity on older rocks of various ages. On the route described in this guidebook the substratum is composed of Carboniferous beds which, along their outcrop, dip at a low angle to the northwest. As a result of the low angle of dip, relatively thin units of the Cretaceous may have outcrops of considerable width and result in homogeneous geographic and topographic features of wide extent.

In his early work Hill (10), whose monograph on the Texas Cretaceous is classic, noted that the succession is divisible into two series. The lower of these he called the Comanche series, from the town of Comanche, about 100 miles (161 kilometers) southwest of Fort Worth. The upper series he called the Gulf series. Each has been considered a separate system by leading American geologists, but this characterization has not been generally accepted.

The outcrop of the Comanche series corresponds to the large geographic division known as the Grand Prairie; that of the Gulf series corresponds to the Black Prairie. At the base of the Gulf series and separating it from the Comanche series in northeastern Texas there is a succession of nonmarine and lagunal deposits (the Woodbine sand) composed largely of sand and argillaceous material, which reaches a thickness of more than 500 feet (152 meters). The outcrop of these strata results in the geographic feature long known as the Eastern or Lower Cross Timbers because of the wooded nature of the terrane. In central and southern Texas these sands are not present, and the strictly marine sediments of the Gulf series lie in trangression on the marine Comanche series. At the base of the Comanche series the broad outcrop of the basement sands results in a second wooded band known as the Western or Upper Cross Timbers.

The two series just defined were further subdivided into groups and formations by Hill. His terms are listed in the right-hand column of the accompanying table. They are arranged to show the correlation between the Texas classification of Cretaceous rocks and that commonly in use in Europe at the present time (2, 15).

	Standard section			Texas section		
Upper Cretaceous	Danian		(?)	Midway	(?)	Tertiary.
	Maestrichtian		Upper clay member Chalky marl member Nacatoch	Navarro		Gulf series.
	Campanian		*Exogyra cancellata* zone			
				Taylor (upper)		
	Santonian Coniacian			Taylor (lower) Austin chalk		
	Turonian			Eagle Ford (upper)		
Middle Cretaceous	Cenomanian			Eagle Ford (lower) Woodbine		
	Albian	Vraconnian	Buda Del Rio	Grayson	Washita group	Comanche series.
			Georgetown	Main Street Pawpaw Weno Denton Fort Worth Duck Creek		
		Gault		Kiamichi Goodland Walnut	Fredericksburg group	
Lower Cretaceous	Aptian	Gargasian		Paluxy Glen Rose Travis Peak	Trinity group	
		Bedoulian.				
	Barremian.					
	Hauterivian.					
	Valanginian.					
	Berriasian.					

The lithology and faunas of the Texas section change rapidly in vertical succession. The faunas are characterized by large numbers of Pelecypoda, Gastropoda, Echinodermata, and Foraminifera. Rudistids, brachiopods, *Orbitolina*, chalk, beds of phosphate nodules, and fish teeth are prominent features. These elements, together with the undeformed character of the beds, clearly indicate that the strata were deposited in relatively shallow (neritic and zoogene) waters of a great epicontinental sea. Sediments of the strictly bathyal facies do not exist in Texas. The Washita (Vraconnian) beds, however, with their many ammonites, preserved in pyrite, may be considered as the "mixed" type. Even in these beds strictly bathyal ammonites are not found. Complete sections and bathyal types, however, exist in the geosynclinal areas of Mexico, with which the Texas Cretaceous is continuous.

The Texas Cretaceous, faunally and otherwise, shows strong affinities with that of the Mediterranean and other regions of ancient Tethys. It readily lends itself to comparison with the Cretaceous in other regions where the section begins with the great Aptian transgression—for example, the band of neritic sediments surrounding the Fosse Vocentienne in southeastern France; the flanks of the Spanish Meseta; the borders of the Atlas in Africa; the Bulgarian Plain; India south of the Himalayas; Madagascar; and Queensland, Australia.

COMANCHE SERIES

TRINITY GROUP

The Trinity group comprises the following formations:

Paluxy sands.
Glen Rose limestone.
Travis Peak formation and basement sands.

This group represents the transgressive Aptian over the Texas region. The section is more complete and typical 200 miles (322 kilometers) south than where crossed by this excursion.

The Travis Peak beds west of Austin are the lowest strata exposed. One member contains many specimens of ammonites belonging to *Dufrenoya* (*Parahoplites*), group of *D. furcatus*. These indicate that the Cretaceous of Texas begins with the Upper Aptian or Gargasian.

The Travis Peak beds do not extend very far north of Austin but, together with the lower Glen Rose strata, grade laterally into the transgressive basement sands.

At the west end of the section crossed on this excursion about 200 feet (61 meters) of these basement sands, composed of well-rounded quartz conglomerates and sands, overlie the eroded ends of middle Carboniferous strata. These largely unconsolidated materials are spread out over considerable areas and may be seen along a line running through Bridgeport, Wise County, and Millsap and Dennis, Parker County. Except for a few Cycadeoidea, numerous silicified tree trunks, seams of lignite, and a few dinosaur bones they contain no fossils.

The sands grade upward into the alternating clays and limestones of the Glen Rose formation. The Glen Rose is about 200 feet (61 meters) thick in the area here considered but is much better developed farther south. The lithology and terrane are typical. The fauna, as well as the rapidly alternating beds of limestone, clay, and sandy clay, indicates the neritic character of the sediments. Ammonites are seldom found, but rudistids occur farther south. Large pelecypods and gastropods are abundant, but they are usually preserved in the form of internal casts. A feature of world-wide significance is the presence of a stratum composed almost entirely of *Orbitolina texana* (similar or identical to *O. lenticularis*). Other common fossils which may be collected from the Glen Rose along Sanchez Creek [1] [8] and elsewhere are *Pecten stantoni*, *Trigonia taffi*, *Cucullaea* (*Idonearca*) *terminalis*, *C. gracilis*, *C. gratiota*, *Arctica roemeri*, *Homomya* sp., *Modiola branneri*, *Pteria singleyi*, *Ostrea camelina*, *O. franklini*, *Gryphaea wardi*, *Exogyra texana*, *Loriolia texana*, and *Porocystis* sp.

The Paluxy sands follow the Glen Rose in this area. They are about 175 feet (53 meters) thick and constitute the regressive phase of the Trinity group. To the south the upper Glen Rose and the lower Paluxy beds interfinger until the Paluxy finally pinches out in central Texas. The Paluxy outcrop forms the extensive wooded areas about Weatherford. It forms scarps and the slopes of erosional hills, which are capped by the *Gryphaea* shell beds of the succeeding formation.

The Paluxy sand is generally nonfossiliferous except for silicified tree trunks, lignite seams, and a few plant fossils. The sands and lenticular bodies of sandy clay are in places varicolored, ranging from light browns and yellows to a deep purplish red [2].

The Trinity group is the approximate equivalent of the upper Aptian or Gargasian. The succeeding Fredericksburg group begins with the middle Albian and rests in transgression on the Trinity.

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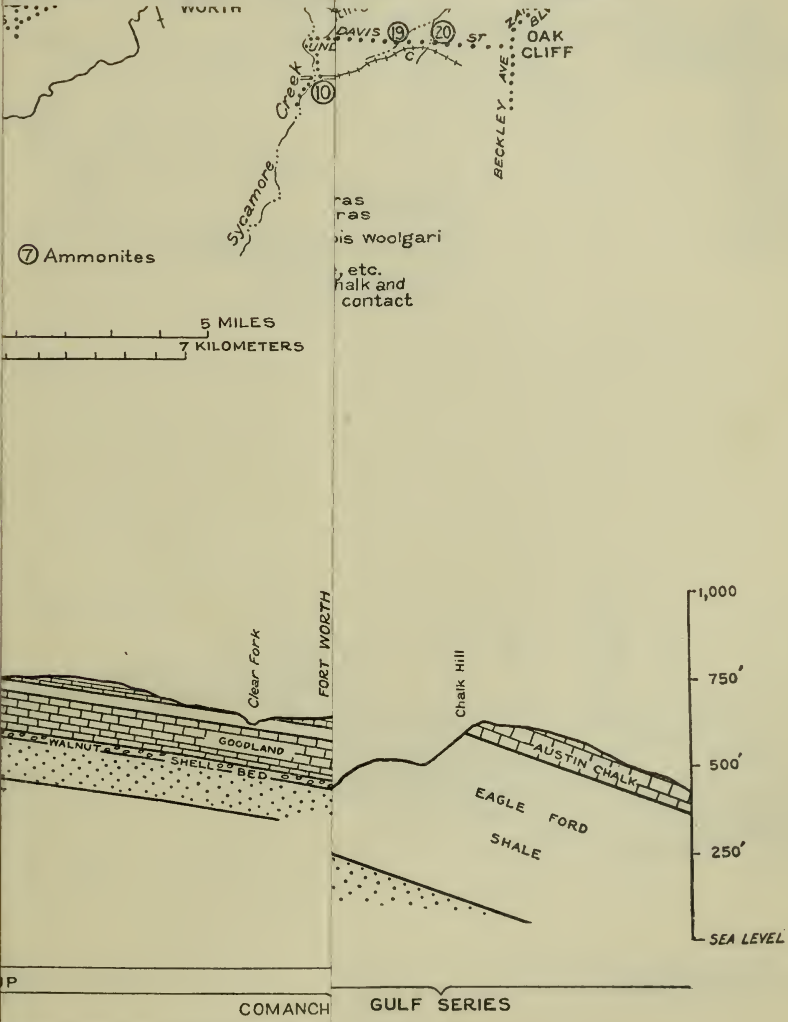
[8] Numbers in brackets refer to corresponding numbers on Plates 7 and 8.



FORMATIONS BETWEEN DE

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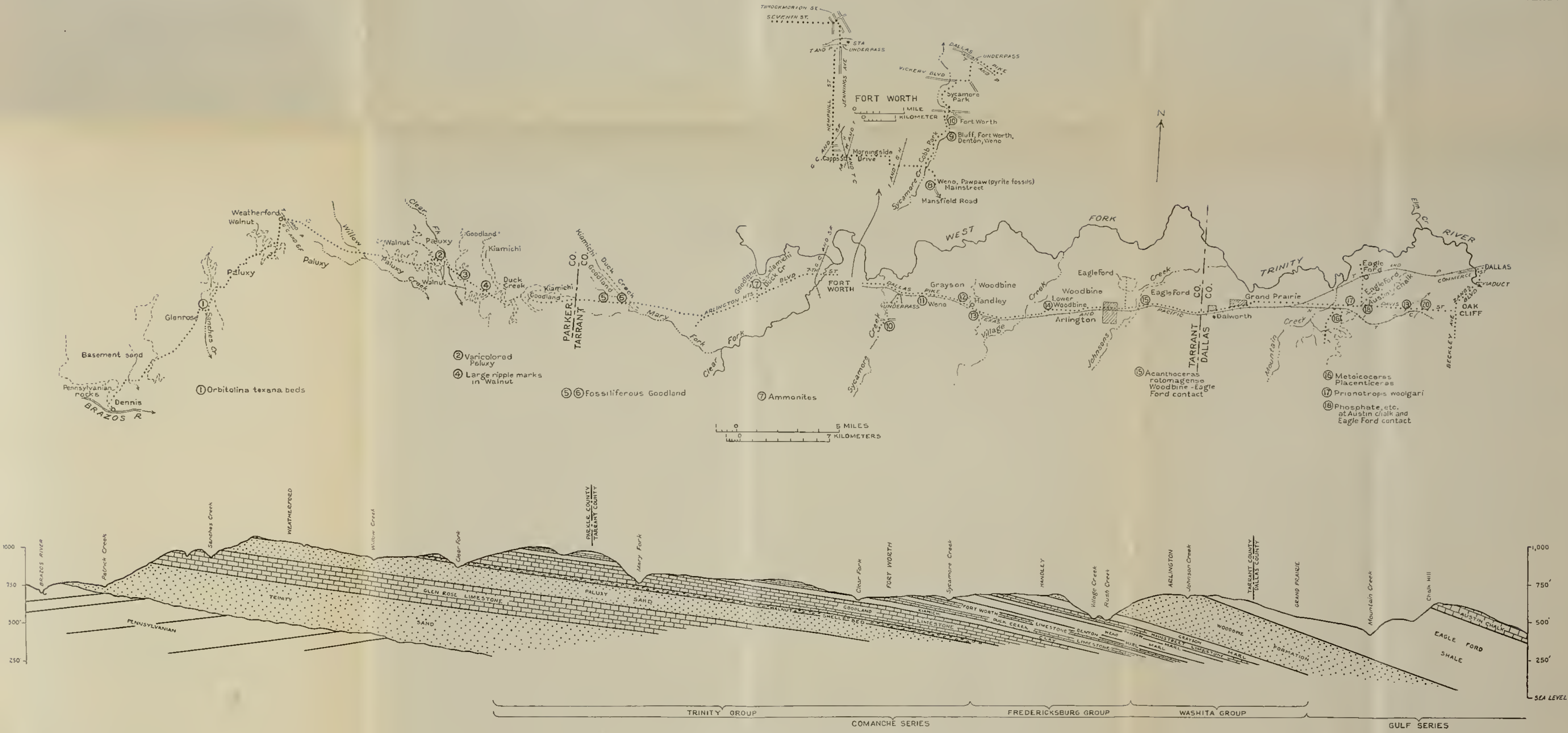
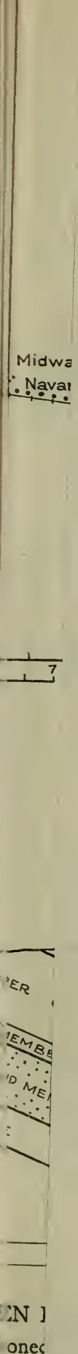


MAP SHOWING ROUTE AND GEOLOGIC FORMATIONS BETWEEN DENNIS AND DALLAS, TEXAS

Numbers in circles refer to localities mentioned in the text.



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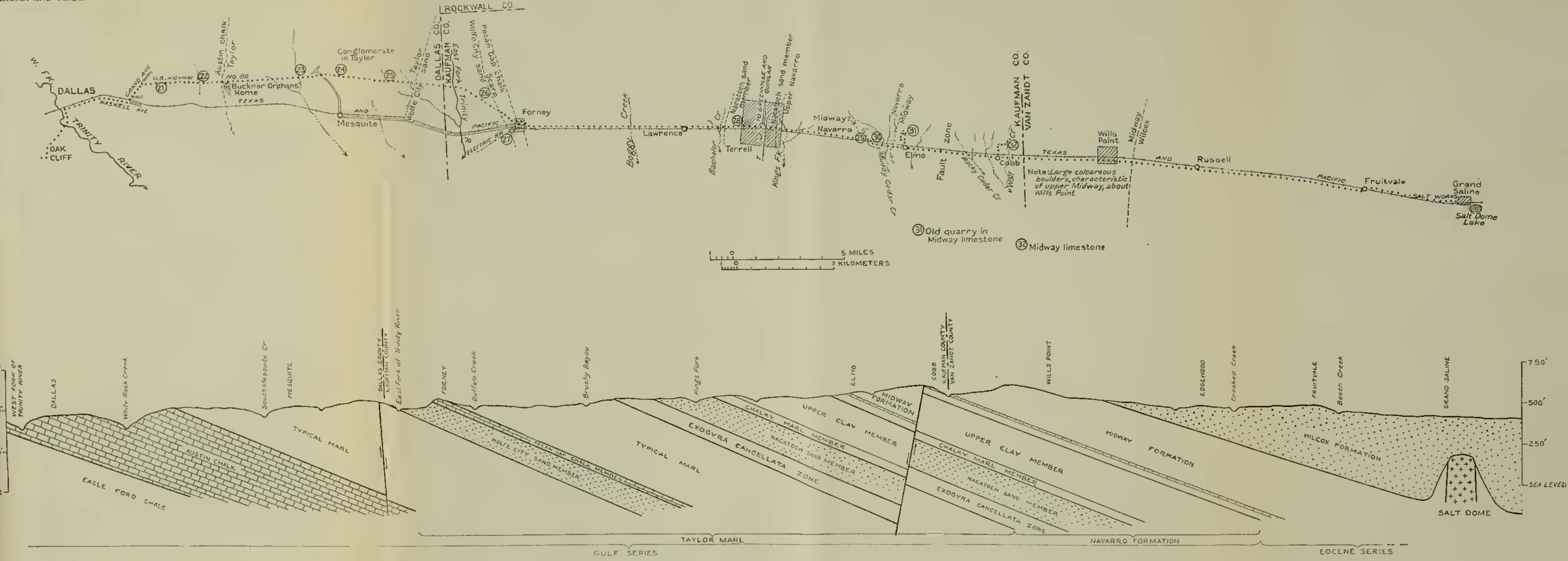

MAP SHOWING ROUTE AND GEOLOGIC FORMATIONS BETWEEN DALLAS AND GRAND SALINE, TEXAS

Numbers in circles refer to localities mentioned in the text.

FREDERICKSBURG GROUP

The Fredericksburg group includes three formations, as follows:

Kiamichi formation.
Goodland formation.
Walnut shell beds.

The Walnut shell beds lie in transgression on the nonmarine Paluxy sands. The contact is sharp and in most places clearly indicates a hiatus of considerable extent. The beds constitute the transgressive phase of the Fredericksburg.

The Walnut is a veritable bed of fossil oyster shells which averages 27½ feet (8.4 meters) in thickness over the area. The formation is well exposed all along its outcrop and caps numerous erosional outliers and scarps and forms low waterfalls in the valleys for several miles around Weatherford [2, 3, 4; note large ripple marks]. The trace of its outcrop is the most dendritic of all the Cretaceous formations in Texas.

The Walnut is an agglomerate of *Gryphaea marcoui* and *Exogyra texana*, but many other fossils may be collected from it. The species, however, are not different from those found in the Goodland and are listed in the description of that formation. The only ammonites found in the Walnut belong to the genera *Oxytropidoceras* and *Engonoceras*. *Oxytropidoceras acutocarinatum* (group of *Ammonites roissyanus*) establishes the middle Albian age of these beds and evaluates, within limits, the hiatus that exists between the Trinity and the Fredericksburg groups.

The Goodland lies immediately and conformably upon the Walnut and in Tarrant County is 100 to 115 feet (30 to 35 meters) thick. The lower 15 to 25 feet (4.5 to 7.6 meters) is composed of yellow calcareous clays, but most of the formation is made up of chalky white nodular limestones, which form the bold and in many places barren scarp faces in the area. The formation is seen in many exposures along the road on each side of the Parker-Tarrant county line and is especially well shown at the Marys Creek bridge [5, 6]. The trace of its outcrop may be seen for miles, and its contact with the overlying yellow clays of the Kiamichi formation is everywhere clearly defined.

The upper 18 or 20 feet (5.4 to 6 meters) of the Goodland is more indurated than the lower part of the formation. South of the Brazos River this member is exceedingly massive and crystalline and contains many rudistids. There it is known as the Edwards limestone (typically seen in the Lampasas cut plain of central Texas and in the Edwards Plateau region of western Texas). The lower part is known as the Comanche Peak formation, from the erosional outlier of that name just south of the Brazos River.

The Goodland, though entirely neritic, contains one of the richest and most varied fossil assemblages in the Cretaceous of Texas. Ammonites are found in considerable abundance, but they belong almost entirely to the genera *Oxytropidoceras* (group of *Ammonites roissyanus*) and *Engonoceras*. Recently a few specimens of the genus *Dipoloceras* (group of *Ammonites cristatus* and *A. cornutus*) and a *Hamites* have been found and appear to establish the middle Albian age of the beds. The absence of other ammonoids usually present in the middle Albian is explained by the extremely shallow water that prevailed over large areas during the deposition of the Goodland. Some of the more common Goodland species are *Oxytropidoceras acutocarinatum*, *O. trinitense*, *Engonoceras pedernale*, *E. gibbosum*, *E. stolleyi*, *Pinna guadalupae*, *Ostrea crenulimargo*, *Gryphaea marcoui*, *Exogyra texana*, *Trigonia concentrica*, *T. emoryi*, *Pecten irregularis*, *Pholadomya sanctisabae*, *Anatina texana*, *Protocardia texana*, *P. filosa*, *Isocardia medialis*, *Natica pedernalis*, *Tylostoma* sp., *Cerithium bosquense*, *Salenia mexicana*, *Phymosoma texanum*, *Holectypus planatus*, *Heteraster texanus*, *Macraster texanus*, *Epiaster bosei*, *E. whitei*, and *Parasmilia austinensis*. Large numbers of microscopic fossils (Foraminifera and Ostracoda) of many species may be washed from the softer materials.

The Kiamichi lies with apparent conformity on the Goodland and, in Tarrant County, is about 35 feet (10.7 meters) thick. The thickness increases to the north and decreases to the south. The formation is composed of yellow and gray calcareous clays with a few thin calcareous and sandy flagstone beds.

The outcrop usually forms gentle, grass-covered slopes. A complete section with the Goodland below and the Duck Creek above is well shown in the road cut in northwest Arlington Heights [7], Fort Worth.

Many fossil species found in the Kiamichi are identical with those which occur in the Goodland, but there are a number of diagnostic forms. The most distinctive of these are *Oxytropidoceras belknapi* and *Gryphaea navia*.

WASHITA GROUP

The Washita includes the following formations:

Grayson (75 feet, or 22.8 meters).
Main Street (35 feet or 10.7 meters).
Pawpaw (27 feet or 8.2 meters).
Weno (70 feet or 21.3 meters).
Denton (25 feet or 7.6 meters).
Fort Worth (30 feet or 9.1 meters).
Duck Creek (65 feet or 19.8 meters).

The region of Fort Worth offers one of the best areas to be found anywhere in North America for the study of the Washita (Vraconnian). Most of the formations have extensive faunas of large fossils, and microscopic fossils in abundance may be washed from the marls.

In the area considered in this guidebook the Washita beds consist mainly of limestones, marls, and limy marls, with a total thickness of about 330 feet (100 meters). This decreases to the south and increases to the north. The thicknesses of the individual formations are also variable, but the figures given in the list above are the average for Tarrant County.

In the Trinity and Fredericksburg groups ammonities are absent, rare, or of specialized neritic types (flat, thin bodies, little ornamented). The Washita, on the other hand, offers a great many ammonite zones characterized by diverse species, belonging to several genera (*Desmoceras*, *Uhligella*, *Latidorsella*, *Pervinquieria*, *Acanthoceras*, *Flickia*, *Stoliczkaia*, etc.). Thirteen zones have been recognized, but some of these are separated with difficulty (1).

There are also at least four zones of marls in which the fossils belong largely to the Cephalopoda and are preserved in pyrite. These are found in the upper Duck Creek, Denton, Pawpaw, and lower Grayson. Unfortunately, in the area convenient to this route localities with pyrite fossils are easily accessible only in the Pawpaw [8].

At the base of the Duck Creek [7] are *Hamites comanchensis*, *H. nokonis*, *Desmoceras brazoense*, *Pervinquieria trinodosa*, and other forms characteristic of the lower Vraconnian, and in the top of the Grayson is *Stoliczkaia*, group of *S. dispar*. From this fauna it appears to the writer that the Washita is the equivalent of the upper Albian or Vraconnian and in every respect invites comparison with beds of the same age in northern Africa, at St. Croix, in Madagascar, in India, and elsewhere. It is particularly interesting to compare the Washita with the bathyal and mixed facies of the Vraconnian of Mexico.

The Duck Creek is predominantly limestone in its lower half and is characterized by the Cephalopoda just named. Many of the species reach a large size. At Arlington Heights, Fort Worth, the basal contact is sharp and may be slightly nonconformable. The bedding in the lower massive limestones is irregular in places, and lower strata seem to have been trenched by ravines before the succeeding strata were deposited. The upper part of the formation is predominantly marl and, especially a little farther north, is characterized by an abundant fauna of small, dwarfed Cephalopoda, many of them uncoiled, preserved in pyrite. These faunas indicate a deep neritic zone or perhaps the upper bathyal zone of deposition for the sediments, and the Duck Creek appears to be the deepest-water Cretaceous deposit traversed by this excursion.

Unfortunately, the route does not pass near a good locality where fossils may be collected from the upper member of the Duck Creek. The following list includes common Duck Creek fossils not already named: *Kingina wacoensis*, *Macraster elegans*, *M. texanus*, *Goniophorus scotti*, *Pervinquieria* (many species), *Elobiceras* sp., *Puzosia* (*Desmoceras*) *brazoensis*, *Inoceramus comancheanus*, *Gryphaea corrugata*, *Pecten subalpinus*, and *Plicatula dentonensis*.

The Fort Worth limestone is a marly limestone composed of regular alternations of earthy limestone and thin seams of marl. The older part of the city of Fort Worth is largely built upon it, and it may be studied from the numerous road, railroad, and other excavations about the city [9, 10]. The Fort Worth is the zone of the ammonite *Pervinquieria leonensis*. Other fossils common in the formation are *Enallaster texanus*, *Holaster simplex*, *Macraster elegans*, *M. texanus*, *M. aguilerae*, *Nautilus texanus*, *Exogyra americana*, *Pecten subalpinus*, *P. wrightii*, *P. bellulus*, *Lima wacoensis*, *Pleurotomaria austinensis*, and fucoids.

The Denton formation is well shown along Sycamore Creek [9] and elsewhere about Fort Worth. It is composed of marls which farther north are rich in pyrite fossils, mostly Cephalopoda. At Fort Worth *Alectryonia* cf. *A. carinata* and a shell bed of *Gryphaea washitaensis* characterize the formation.

The Weno, composed mostly of marls but with some limestones, is well exposed on the upper reaches of Sycamore Creek [8, 9] and along the route east of Fort Worth [11]. The zone of *Ancyloceras bendirei* (rare) occurs at the base, and the zone of *Pervinquieria wintoni* near the top. Near the middle a large foraminiferan ("*Nodosaria*") is easily collected without the aid of a lens. The following list includes the common fossils: *Ancyloceras bendirei*, *Engonoceras serpentium*, *Pervinquieria wintoni*, "*Nodosaria*" *texana*, *Macraster wenoensis*, *M. subobesus*, *Pecten georgetownensis*, *Alectryonia quadriplicata*, *Corbula wenoensis*, *Nucula wenoensis*, *Trigonia clavigera*, *and Turritella worthensis*.

The Pawpaw is composed of brown and reddish marls. It is the third zone of pyrite fossils in the Washita of Texas and is particularly characterized by *Turrilites worthensis* (form strikingly like *T. bergeri*). The formation is well developed around Fort Worth, particularly along Sycamore Creek [8]. The following fossils are common: *Heteraster bravoensis*, *Macraster wenoensis*, *Washitaster riovistae*, *Arca washitaensis*, *Lima wacoensis*, *Pecten texanus*, *Remondia acuminata*, *Cardita wenoensis*, *Flickia bosei*, *Hamites tenawa*, *Scaphites hilli*, *Turrilites worthensis*, *Pervinquieria* spp., *Acanthoceras worthense* (similar to *A. martempreyi* and *A. aumalense*), *Engonoceras serpentium*, *Corbula crassicostata*, *Tapes denisonensis*, and *Tellina subaequalis*.

The Main Street is a limestone similar to the Fort Worth, but with more massive limestone ledges and thinner marl seams. At places it is extremely fossiliferous. It is the zone of the very large form *Turrilites brazoensis*. The route does not pass near any good exposures of the Main Street, but the lower beds occur along the scarp north of Sycamore Creek [8]. Some common fossils are *Pervinquieria* sp., *Turrilites brazoensis*, *Nautilus texanus*, *Kingina wacoensis*, *Holectypus limitus*, *Heteraster bravoensis*, *Exogyra arietina*, *Spondylus cragini*, *Pachymya austinensis*, *Protocardia vaughani*, and *Pholadomya shattucki*.

In central and southern Texas the formations of the Washita just described are distinguished with difficulty and are usually grouped under the name Georgetown. The Georgetown is somewhat thinner than its equivalents in northern Texas and is more calcareous.

The Grayson is well exposed in only a few places, because its outcrop of soft beds is usually obscured by wash from the loose sands of the succeeding (Woodbine) formation. The middle beds are exposed to the north of the road between Fort Worth and Handley [12] and in the deep railroad cut just east of Handley [13]. The lower beds with pyrite fossils and the upper limy strata with *Stoliczkaia* (group of *S. dispar*) can not be seen near the route. Both members, however, are excellently exposed a few miles both north and south.

In central and southern Texas the Del Rio and Buda formations occupy a stratigraphic position comparable to the Grayson. It is generally supposed that the Del Rio (with pyrite fossils) corresponds to the lower Grayson and that the Buda (a hard, crystalline, and massive limestone) corresponds to the upper calcareous member of the Grayson. Many, however, think that the Buda includes beds higher than any of the northern Texas Grayson strata.[9] In any case the zone of *Stoliczkaia*, group of *S. dispar*, at the very top of the Grayson definitely places the formation at the upper limit of the Vraconnian.

The lower Grayson is the fourth zone of pyrite fossils in the Washita and is characterized by *Turrilites bosquensis*. Other common fossils are *Engonoceras bravoensis*, *E. uddeni*, *Stoliczkaia* aff. *S. dispar*, *Scaphites* spp., *Hemiaster calvini*, *Goniophorus* sp., *Gryphaea mucronata*, and *Homomya* sp.

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[9] Burckhardt (2) has recently placed the Buda in the Cenomanian on account of an ammonite, identified as *Acanthoceras*, group of *A. laticlavium*, which has been found in it in Mexico.

GULF SERIES

WOODBINE FORMATION

The strata included in the Woodbine formation are composed almost entirely of gray, yellow to brown, and dark-colored sands, shales, and sandy shales of nonmarine (possibly deltaic) origin, but a few marine or brackish-water beds are intercalated in the formation at some localities. The thickness of the Woodbine in Tarrant County is from 300 to 400 feet (91 to 112 meters). It crops out over a broad belt which is marked by scrub-oak woodlands known as the Eastern Cross Timbers. The beds pinch out to the south in central Texas and thicken to the north.

The contact with the underlying Washita strata is everywhere obscured along the route of this excursion by the overwash of soils across the soft beds. The upper contact is easily followed along the eastern margin of the timber adjacent to the Black Prairie area, just east of Arlington, and may be studied in some detail in the stream cuts crossing the road 1 mile (1.6 kilometers) east of that town [15]. Exposures of other parts of the formation are seen on the scarp east of Village Creek and elsewhere along the road [14].

The Woodbine has been variously interpreted. Most authors consider it the transgressive phase of the Gulf series and point to an unconformable condition at its base. Some consider it in the main a regressive feature.

Fossils are rare except in the lowest and highest beds and are limited to a few plant remains, examples of which have not been found in the area as far south as Tarrant County. Fossils have been picked from the cores of wells drilled in the basal shales in the area, but most of the specimens are not determinable.

The uppermost strata of the Woodbine are composed of coarse-grained and conglomeratic, massive and consolidated brown sandstones rich in *Ostrea soleniscus*, fish teeth, bone fragments, and a few other fossils. Those who interpret the Woodbine as a regressive feature place this upper sandstone in the Eagle Ford and see it as the basal bed of the Eagle Ford (Gulf) transgression (Cenomanian). However this may be, the Woodbine is a nonmarine group of strata at the boundary between the Comanche and Gulf series. By virtue of its stratigraphic position, it is certainly Cenomanian in age. It is the source of the oil in the Mexia group of fault-line oil fields and is believed by many to be the source of the great oil production in the East Texas field.

EAGLE FORD FORMATION

The Eagle Ford shales are 500 to 600 feet (152 to 183 meters) thick in the area but thin to less than 50 feet (15 meters) at

Austin. They are composed of black shales with a few thin concretionary or flaggy limestone beds. The strata crop out in a broad flat to rolling belt across the western part of Dallas County, and the aptness of the designation of this area as a part of the Grand Prairie is at once apparent.

The Eagle Ford follows immediately above the Woodbine, and the contact may be studied in some detail in the small stream just east of Arlington [15]. Careful search at this point may yield specimens of *Acanthoceras*, group of *A. rhotomagense*. Specimens of this fossil have been collected from the basal Eagle Ford at several localities in the general area and attest to the Cenomanian age of the strata.

Except for the basal beds, the lower and middle Eagle Ford strata are not well exposed along the road. The rich black soils are characteristic of the great cotton-producing farms of the Black Prairie region.

Beds a short distance above the middle of the formation are seen in the exposures half a mile (0.8 kilometers) south of the road (side road through the underpass) east of Mountain Creek [16]. Fossils are abundant in these strata. This is the zone of *Metoicoceras whitei* and other species of the genus (forms closely related to *Mammites*) and *Placenticeras pseudoplacenta*.

Just above this zone, at the crest of the first low scarp along the road east of Mountain Creek, is a thin, flaggy argillaceous limestone ledge [17], in which are innumerable examples of *Prionotropis* aff. *P. woolgari*, a well-known middle Turonian ammonite.

From this point to Chalk Hill the upper Eagle Ford shales are well exposed along the side of the road, but large fossils are not generally very abundant in this particular locality. Interesting microfossils, however, may be washed from the soft muds. The village of Eagle Ford is about 2 miles (3.2 kilometers) north of this point on the railroad, and near-by cement plants exploit the shales and overlying chalk.

The upper Eagle Ford in places is highly fossiliferous, and an upper Turonian age for the strata is indicated.

At Chalk Hill [18] the contact of the dark Eagle Ford shales and White Austin chalk is well shown in the road cut and is a point of considerable stratigraphic interest. The contact is sharp and striking. The uppermost Eagle Ford strata contain large numbers of *Ostrea lugubris*, and the lower phosphatized ledges of the Austin chalk contain many phosphate nodules and pebbles. As the Austin chalk is not known to contain fossils older than Coniacian, the hiatus indicated by this nodule bed appears to lie at the contact of the Turonian and Coniacian stages.

Common Eagle Ford fossils are *Acanthoceras*, group of *A. rhotomagense*, *Prionotropis woolgari*, *Metoicoceras swallovi*, *M. gibbosum*, *M. whitei*, *Metengonoceras acutum*, *M. dumblei*, *Placenticeras pseudoplacenta*, *Pachydiscus* sp., *Scaphites vermiculus*, *S. septem-seriatus*, *Helicoceras pariense*, *Baculites gracilis*, *Nucula serrata*, *N. haydeni*, *Inoceramus labiatus*, *Ostrea lugubris*, and *O. alifera*.

AUSTIN CHALK

The Austin chalk is a succession of chalky limestone beds about 500 feet (152 meters) thick. The most massive beds are in the basal 150 feet (46 meters) [19, 20]. Upward the strata become less massive, and in the upper 100 feet (30 meters) shaly limestone predominates over the more chalky beds [21, 22]. The upper contact with the Taylor is sharp (16) but appears to be conformable, at least in this area. Unfortunately, the contact where it crosses the road near the Buckner Orphans' Home, east of Dallas, is badly obscured by soil.

Knowledge of the Austin chalk in this region has not advanced to a point where lithologic members or fossil zones are easily recognizable. The many streams and road cuts and other outcrops along the route and in and around Dallas afford numerous opportunities to study the formation.

Fossils, except for a few oyster shells (principally *Gryphaea aucella*) and fragmental specimens of *Inoceramus*, are relatively rare in the section, but in southern and western Texas there are many richly fossiliferous levels and localities. *Durania austinensis*, *Barroisiceras dentatocarinatus* (group of *B. haberfellneri*), and *Mortoniceras texanus* establish the Coniacian and Santonian age of the Austin chalk. The limits of these two stages, however, have not been established in the Texas section. The following list includes common Austin chalk fossils not already named: *Exogyra ponderosa*, *Inoceramus undulatoplicatus*, *Alectryonia* sp. aff. *A. diluviana*, *Baculites asper*, *Hemiaster texanus*, *Nautilus simplex*, *Exogyra laeviuscula*, and *Spondylus guadalupae*.

TAYLOR FORMATION

The Taylor formation consists primarily of marls and clays but includes also a few sands, some calcareous and chalky beds, and conglomerates. The thickness of the formation is difficult to measure along the outcrop on account of some faulting in the Mexia-Powell zone, east of Dallas (see section), but is probably more than 1,200 feet (366 meters). The outcrop spreads over a broad area from the vicinity of the Buckner Orphans' Home to a point near Lawrence. The dark soils, typical of the Black Prairie, obscure the beds over most of the route, but a few exposures are seen in the road cuts [23, 24, 25] and about Forney.

The beds exposed around Forney occur about the middle of the Taylor. Strata giving rise to the sandy soils seen on the slope on the west side of the valley of the East Fork of the Trinity River are derived from the Wolfe City sand member. This member occurs almost exactly at the center of the formation and in this section is about 125 feet (38 meters) thick. It is seen to the north of the road along the east side of the broad river valley [26].

The Wolfe City is followed by the Pecan Gap chalk. This member is well developed to the north but in this section is only a few feet thick and is really nothing more than a light-colored calcareous marl. It can be seen in the deep railroad cut about half a mile (0.8 kilometer) southwest of Forney [27]. Fossils may be collected from it, but they are not abundant.

Taylor beds above the Pecan Gap are poorly exposed everywhere along the route, and no good fossil localities are easily accessible. The upper contact with the Navarro has been variously interpreted and placed at different levels. It is usually drawn at the base of the *Exogyra cancellata* zone, the basal member of the Navarro formation. A diagrammatic representation of the relationship of these beds is given by Stephenson (17, 18).

Fossils identified by the writer as *Placenticeras*, group of *P. syrtale*, and *Scaphites hippocrepis* and other fossils in the lower part of the Taylor in certain regions of Texas lead him to believe that this part of the formation is probably of Santonian age. The Nacatoch sand (Navarro) contains fossils which he regards as basal Maestrichtian. Therefore, by virtue of its stratigraphic position as well as its fossil content, he correlates most of the Taylor, including the part of the Navarro below the Nacatoch sand member, with the Campanian. It is impossible at present, however, to indicate the Santonian-Campanian contact. Taylor fossils not already named are *Parapachydiscus streckeri*, *Ostrea plumosa*, and *Exogyra ponderosa*.

NAVARRO FORMATION

The Navarro formation in this section is composed of dark clays, marls, sands, and some limestone. Its thickness is difficult to measure along the outcrop, as the eastern contact is complicated by faulting of the Mexia-Powell fault zone (see section), but is probably around 600 or 700 feet (183 to 213 meters).

Stephenson (18, pl. 13) has divided the Navarro in ascending order into (1) the *Exogyra cancellata* zone, which is a clay marl member 150 to 200 feet (46 to 61 meters) thick; (2) the Nacatoch sand member, composed of gray marine sand with fossiliferous concretions, about 100 feet (30 meters) thick; (3) a chalky marl member, sandy at the base, probably less than 50 feet (15 meters) thick; and (4) an upper clay or shale member with some concretions and interbedded flaggy, sandy limestones, probably 300 to 400 feet (91 to 122 meters) thick.

The lowest member, the *Exogyra cancellata* zone, is characterized further by *Exogyra costata*, *Anomia tellinoides*, and in places a large undescribed *Placenticeras*. It is well exposed in a cut in the Dallas highway, in the eastward-facing slope of Brushy Creek Valley 4 miles (6.4 kilometers) west of Kaufman, Kaufman County.

The zone of sandy soils produced by the Nacatoch sand member is crossed by the route of the excursion just west of Terrell, in Kaufman County. This member has yielded a large molluscan fauna. Among the forms described are *Ostrea owenana*, *Exogyra costata*, *Dreissensia tippana*, *Veniella conradi*, *Aphrodina tippana*, *Liopistha protexta*, *Cylichna secalina*, *Turritella winchelli*, *Belemnitella americana*, *Sphenodiscus*, group of *S. lenticularis*, and *Bostrychoceras*, group of *B. polyplocum*. A notable locality from which many fossils have been collected occurs along the Dallas highway in the westward-facing slope of the King's Fork Valley just west of Kaufman, which is 12 miles (19 kilometers) south of Terrell.

The relatively thin chalky marl member, which overlies the Nacatoch sand, carries many fossils but is especially characterized by *Exogyra costata* (a variety with narrow costae) and *Crenella serica*, and at many places by a beautiful and varied fauna of Foraminifera.

The upper clay member of the Navarro formation is in general poorly exposed but produces a zone of dark rich soils, which are crossed by the route of the excursion between Terrell and Elmo. This member also carries *Exogyra costata* (variety with narrow costae), large species of *Sphenodiscus*, and many other fossils. The member is the approximate equivalent of the Escondido formation of the Rio Grande region, which carries *Sphenodiscus pleurisepta*, and of the Arkadelphia clay of Arkansas.

Before reaching Elmo the contact of the Navarro formation with the overlying Midway formation is crossed somewhere near the point where the highway intersects the railroad at an overpass about 5 miles east of Terrell [29, 30].

The Navarro formation probably corresponds approximately in age to the Maestrichtian, though the lowest member, the *Exogyra cancellata* zone, may be as old as uppermost Campanian.

MIDWAY FORMATION

The Midway formation is composed almost entirely of dark shales and clays and is about 600 feet (183 meters) thick. It is divided into two parts—the lower about 150 feet (46 meters) thick and the upper about 450 feet (137 meters) thick. At the contact of the two members thin but massive lenticular limestones are common. At other places this level is marked by shell beds or by phosphate nodules, greensand, and reworked and phosphatized fossils from lower beds.

The base of the Midway at its contact with the Navarro is characterized by a bed a few inches to a few feet thick of glauconitic sand with pebbles, phosphate nodules, and reworked fossils, indicating that the Midway lies in transgression upon the Navarro [29, 30].

This bed has generally been interpreted by American geologists as indicating a great hiatus at the contact of the Navarro and Midway, and the Midway formation has always been placed by them in the Tertiary. The Midway, however, according to the writer contains *Hercoglossa ulrichi* (closely related to or identical with *H. danica*) and *Cardita* (*Venericardia*), group of *V. beaumonti*, in considerable numbers, and its Danian age seems to him, therefore, to be indicated (15, p. 114; 6; 7; 5).

The Midway was first called the Wills Point in Texas, from the village of Wills Point, along this road, and one of the early sections was measured here. Later it was found that the Wills Point and the Midway beds of Alabama were equivalent, and the latter name took priority. Extremely fossiliferous, arenaceous Midway limestones are exposed in an old quarry half a mile (0.8 kilometer) north of Elmo [31] and at a point 1 mile (1.6 kilometers) north of Cobbs [32], but good fossil specimens are not easily recovered from the hard matrix.

TERTIARY BEDS

The nonmarine plant-bearing Wilcox beds of certain Tertiary age follow immediately upon the Midway. The formation is tremendously thick, and its outcrop extends far beyond the area here considered. No known plant-fossil localities are easily accessible along the route.

THE VAN OIL FIELD, TEXAS

By W. E. Wrather

The Van oil field is in Van Zandt County, Texas, about 60 miles (97 kilometers) east of Dallas and 40 miles (64 kilometers) west of the more recently discovered East Texas oil field. (See fig. 15.) Attention was first directed to the oil prospects of the Van locality by the detection of inconclusive geophysical anomalies, which seemed to indicate the presence of a domed area of

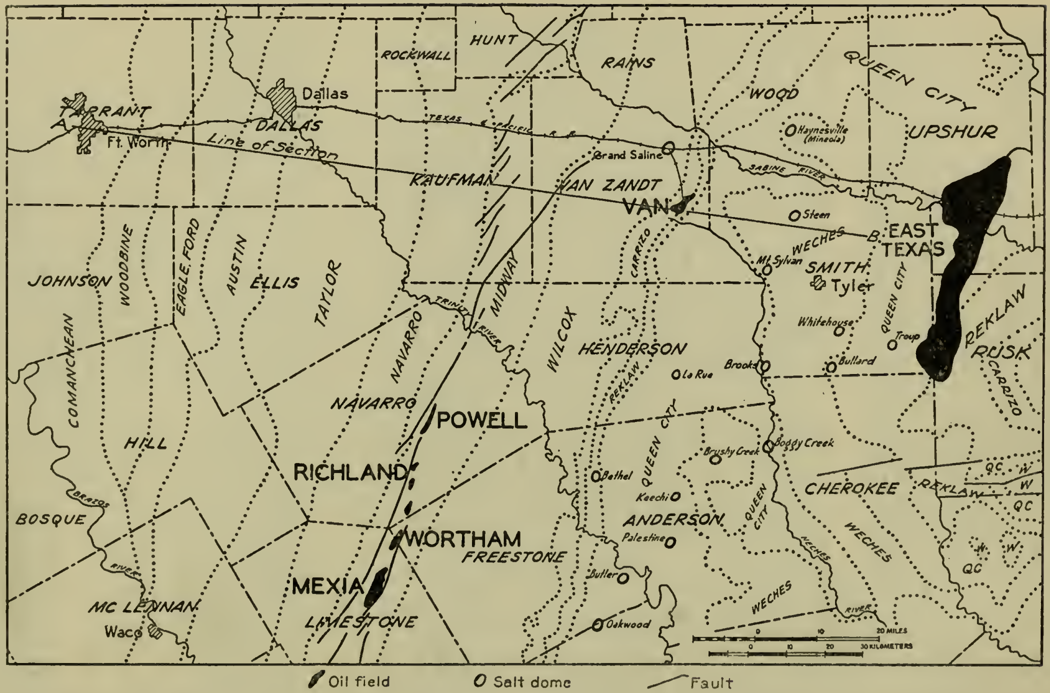

FIGURE 15.—Map of a part of eastern Texas showing location of East Texas and Van oil fields. Shows also part of the Mexia-Powell fault zone (from Stephenson's map of Texas), adapted from Wendlandt and Knebel, Lower Claiborne of east Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pt. 2, p. 1349, 1929. Map furnished by Theron Wasson, Chicago. For section along line *A–B* see Figure 16

considerable size. Detailed surface mapping was then undertaken and brought to light additional evidence of the presence of a dome. A series of core-drilled tests removed the last doubt of the existence of the dome and indicated its great size and extent. (See fig. 16.) In fact, in several of these shallow core tests some oil was discovered in the upper sands.

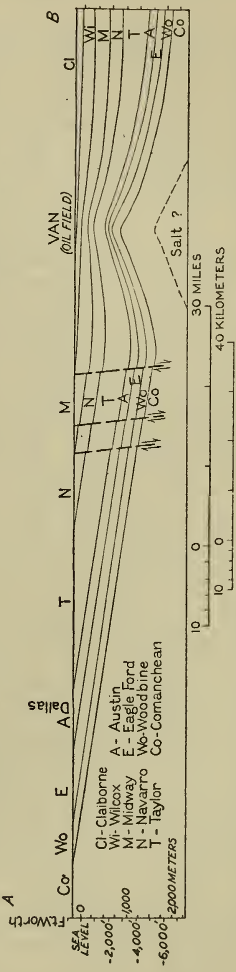

FIGURE 16.—Diagrammatic cross section along line *A–B*, Figure 15, showing relation of geologic horizons to the Van dome. Adapted from a section furnished by Theron Wasson, Chicago

The oil accumulation occurs in the Woodbine sand, which is the basal formation of the Upper Cretaceous series. This sand is one of the most productive sources of oil in Texas, yielding the oil not only at Van but also in the Mexia-Powell "fault line" fields and the near-by East Texas field. The sand reaches its greatest development in the Van area, where it is about 650 feet (198 meters) thick. Of this thickness a considerable portion consists of shale or very shaly sand, though it is estimated that in portions of the drilled area fully 50 per cent is represented by clean producing sand.

The dome is of great size. It is situated in the trough of the great East Texas syncline (see pp. 14–15) and represents a total vertical displacement of about 3,000 feet (914 meters). Subsurface data supplied by drilling indicate that an area of over 100 square miles (259 square kilometers) is involved in the deformation. The oil field, which includes about 4,200 acres (1,700 hectares), occupies the summit of this great dome and comprises not more than 6 or 7 per cent of the total area of uplift. Within the producing field there is a structural relief of approximately 700 feet (213 meters), the depth to the top of the producing sand ranging from 2,200 to 2,900 feet (671 to 884 meters) below the surface. Bottom water underlies the oil reservoir over most of the dome; in only a small area on the summit does the sand appear to be entirely free from water. Therefore, to avoid tapping the water level in the producing sand, wells located farther out from the crest of the structure are not drilled through the sand.

A rather complex fault zone cuts diagonally across the field from northeast to southwest. The displacement on the principal fault is about 500 feet (152 meters) near the summit of the dome, and it is progressively greater outward in either direction toward the margins of the drilled area. The faulting conforms to the type found in the Mexia-Powell district in that the fault plane dips 40°–45° NW. and that the downthrow is on the northwest side. Oil is here found on both sides of the faulted zone.

All Cretaceous formations above the Woodbine sand are thinner on the crest of the dome than down the flanks, indicating the existence of the dome and possibly also its slow and continued growth during the period of sedimentation.

The Van dome is located in an area in which salt domes are numerous. Although no salt has been penetrated in drilling, it is thought probable that salt occurs at great depth—perhaps beyond the reach of the drill. It is a tenable hypothesis, held by many geologists, that the structural growth represents the localizing of a large body of stratified salt, included in the deeply buried beds, which has contracted laterally while it has grown upward, and that the present structure represents a partly formed salt dome; or the core may be a lenslike salt body with an anticlinal upper surface, which sets it apart from other East Texas domes whose salt cores have broken through overlying strata and been thrust upward to levels nearer the surface.

Van is of especial interest, in that it is a unit-operated oil pool. For the benefit of visitors who may be unfamiliar with the meaning of this term, it is perhaps worth while to digress briefly and outline the background which has led to this interesting experiment in oil-field operation.

The laws of the United States provide that the owner of the fee title is the owner not only of the surface rights but also of all minerals or other valuable substances within the boundaries of his property projected downward toward the center of the earth. It has therefore been customary for the individual desiring to prospect for oil to take a lease from the landowner, allowing him to go on the property and conduct such operations as may be necessary in pursuit of his quest. For this privilege the landowner is sometimes paid a bonus, the amount of which varies according to the desirability of the land, but invariably he is guaranteed a royalty out of any oil, gas, or other minerals produced. The almost universal royalty stipulated in leases on unproved land throughout the United States is one-eighth of all the oil and gas produced and saved, entirely free from expense to the landowner. This royalty is a salable asset and may be sold by the landowner in any desired fraction of the entire one-eighth. The barter and sale of oil royalties is an established and important business.

Upon the discovery of oil, it is a matter of mutual interest to the lessor, the lessee, and the owners of the fractional royalty to have development proceed as rapidly as possible. In consequence, the law has been built up to demand continuous and prompt operation. In other words, the oil operator must diligently prosecute development, and he is denied the privilege of desisting short of the complete and adequate drilling of his lease.

Usually there are numerous landowners within the bounds of an oil pool; hence there may be many lessees, and each is placed in a competitive position with regard to all the others. The operator who first taps the oil sand obtains the advantage of the propulsive energy of the pent-up gas in the natural reservoir, and as the oil is usually driven with great force toward the early wells, oil and gas may migrate rapidly from beneath the land of one owner and become the property of the operator who reduces it to possession at the surface on the adjoining land. Until recently this procedure has been considered legal, but there has lately arisen a definite belief that one person has not the right thus to acquire possession of fugitive or migratory substances, notably oil and gas, which in their undisturbed condition in nature were originally the property of another. The gas pressure in an oil sand is a source of energy that may bring oil to the surface through wells just as effectively as pumping equipment and far more economically. As the gas in its original state is common to the entire pool, any excessive utilization of its propulsive and lifting force by one individual is unjustified. There is a growing belief also that the public, which in this age of motor transportation would be sadly handicapped without adequate fuel, has certain rights which must be safeguarded. On behalf of the consuming public it seems but fair to demand that there shall be orderly and economical withdrawal and marketing of such an indispensable national asset. In the present period of overproduction (January, 1932) prices are so low for crude oil and all its refined products that the producer, who is obliged to prosecute development regardless of the price received for his wares, faces bankruptcy and ruin.

The situation above outlined has brought about many attempts to alleviate the natural consequences of the unsound policies pursued in the past, and perhaps the most promising of these is the plan called unit operation of oil pools. Under such a plan all the landowners within a newly discovered pool combine in an effort to delimit the natural boundaries of the producing territory as early as possible and with the minimum outlay of capital. As soon as these limits are approximately defined all owners of productive territory organize a single corporation which shall manage the entire development of the pool as a unit and thus avoid the spendthrift competition involved in overhasty and unnecessary drilling. In this manner also it is possible to take full advantage of the energy of the gas as a propulsive agent without damage to any individual. It is believed that a much greater ultimate recovery may be obtained by carefully conserving the gas and controlling the influx of water. The advantages of unit operation are many, but time is required to break down the deeply ingrained individualism that has grown up in the industry and build up in its stead a willingness to cooperate for the good of all.

There are now several successfully conducted unit operations of oil pools in the United States, and enough experience has been gained to demonstrate to skeptics wherein this method is more desirable than unbridled competition. The movement seems to be rapidly gaining ground, and probably it will find favor throughout the oil industry of the Nation.

Van is a unit-operated pool; so also is Sugarland, which will be visited on this trip. At Van the Pure Oil Co. owned by far the greater percentage of the producing leases and was therefore chosen as the company to conduct operations. At Sugarland the Humble Oil & Refining Co. controlled practically the entire pool and was therefore easily able to consolidate its various leaseholds under a unified management.

Up to the present time (January, 1932) the wells at Van have been operated at partial capacity, owing to the prevailing overproduction of oil throughout the world. It is therefore impossible to do more than guess at the amount of oil the field might produce if operated at full capacity. It is obvious, however, that Van will prove to be one of the major fields of Texas.[10]

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[10] Adequate maps of the Van field can not be supplied at the time of writing. Complete information will be available when visitors reach the property.

THE EAST TEXAS OIL FIELD

By Frederic H. Lahee[11]

GENERAL FEATURES

The East Texas pool is 36 miles (58 kilometers) in length, from 3 to 7½ miles (4.8 to 12 kilometers) in width, and has an approximate area of 92,000 acres (37,600 hectares). (See fig. 17.) It is situated on the west flank of the Sabine uplift, where the normal regional dip is generally westward. (See figs. 17 and 18.) The surface rocks in the area of the pool belong to the Carrizo and Mount Selman formations, of Tertiary age. These formations, together with those encountered in drilling (see fig. 19), are listed in the following table:

- Tertiary:
  - Mount Selman.
  - Carrizo.
  - Wilcox.
  - Midway.
- Upper Cretaceous:
  - Navarro.
  - Taylor—
    - Upper Taylor.
    - Pecan Gap (Annona).
    - Brownstown.
  - Austin.
  - (Eagle Ford probably absent.)
  - Woodbine.
- Lower Cretaceous:
  - Grayson (=Buda).
  - Georgetown.

Oil is produced from sands of the Woodbine formation, which, within the field, lies between depths of 3,430 and 3,800 feet (1,045 and 1,158 meters) below the surface, or between subsea depths ranging from 3,100 to 3,150 feet (945 to 960 meters) near the east edge and from 3,315 to 3,330 feet (1,007 and 1,015 meters) on the west edge. As illustrated in Figure 20, this formation wedges out eastward between the Austin chalk and the Georgetown formation. The thin eastern edge essentially coincides with the eastern boundary of the pool. The Austin formation lies unconformably upon the Woodbine and Lower Cretaceous and probably also upon the Eagle Ford shale, which wedges out west of the west edge of the pool. (See fig. 20.) The beveled edges of separate members of the Woodbine formation—sands,

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[11] A condensed rendering of a paper read before the petroleum division, American Institute of Mining and Metallurgical Engineers, Houston meeting, Oct. 2, 1931. Printed by permission of the Institute.

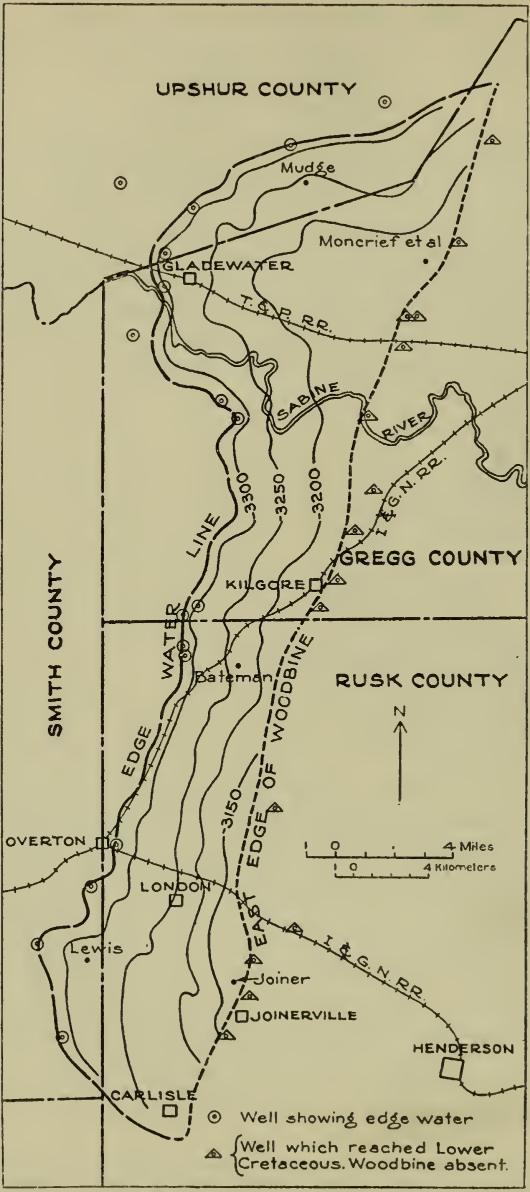

FIGURE 17.—Outline map of the East Texas pool, Texas, contoured on top of the Woodbine pay sand. The water wells shown do not include certain wells from half a mile to a mile (0.8 to 1.6 kilometers) east of the west edge of the field, southwest of the Kilgore wells, which have produced some bottom water

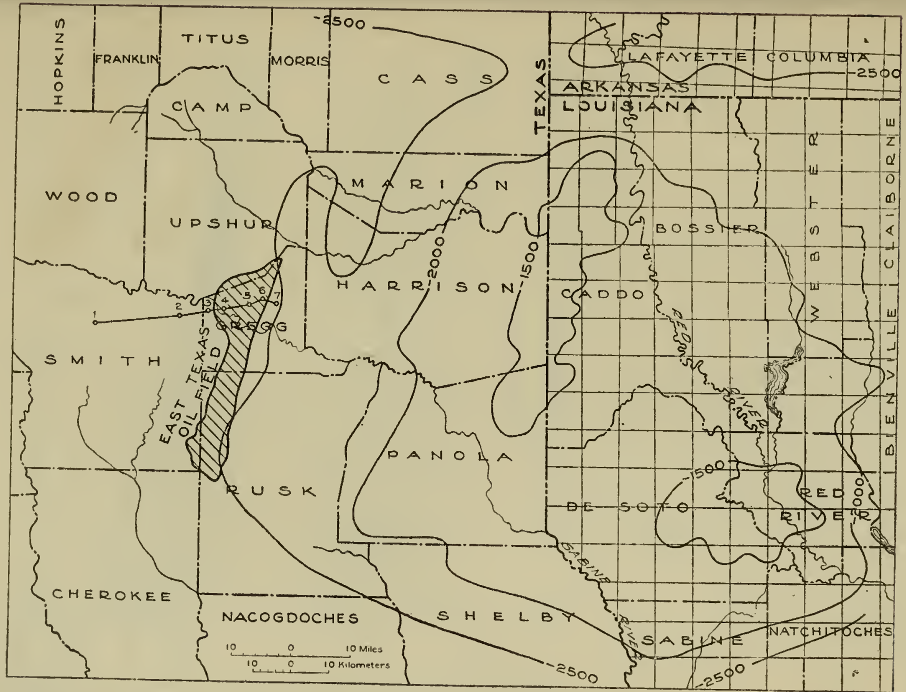

FIGURE 18.—Index map showing the position of the East Texas field on the west flank of the Sabine uplift, the general form of which is indicated by 500-foot contours on top of the Pecan Gap chalk (datum sea level). The seven numbered holes connected by a line were used in constructing Figure 20

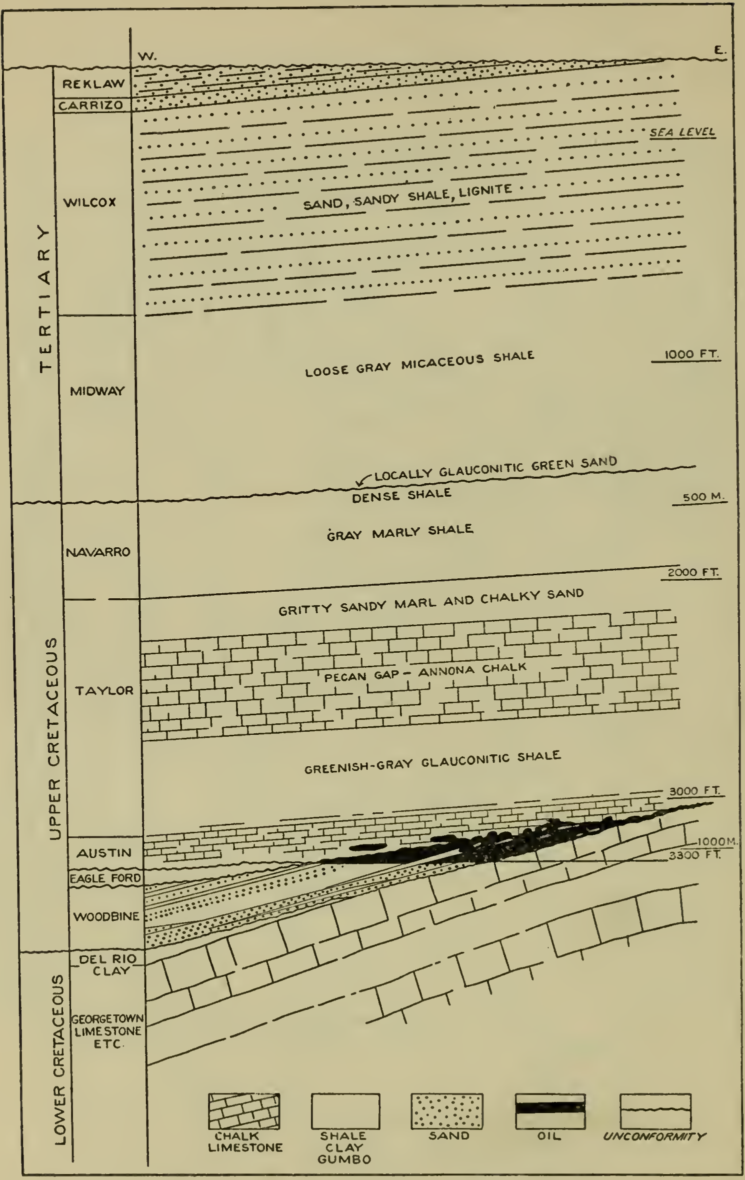

FIGURE 19.—Generalized cross section of the East Texas field, showing the formations encountered in drilling (12, p. 264). The truncation of the Woodbine formation is indicated as the reason for the thinning of the sand along the east side of the field

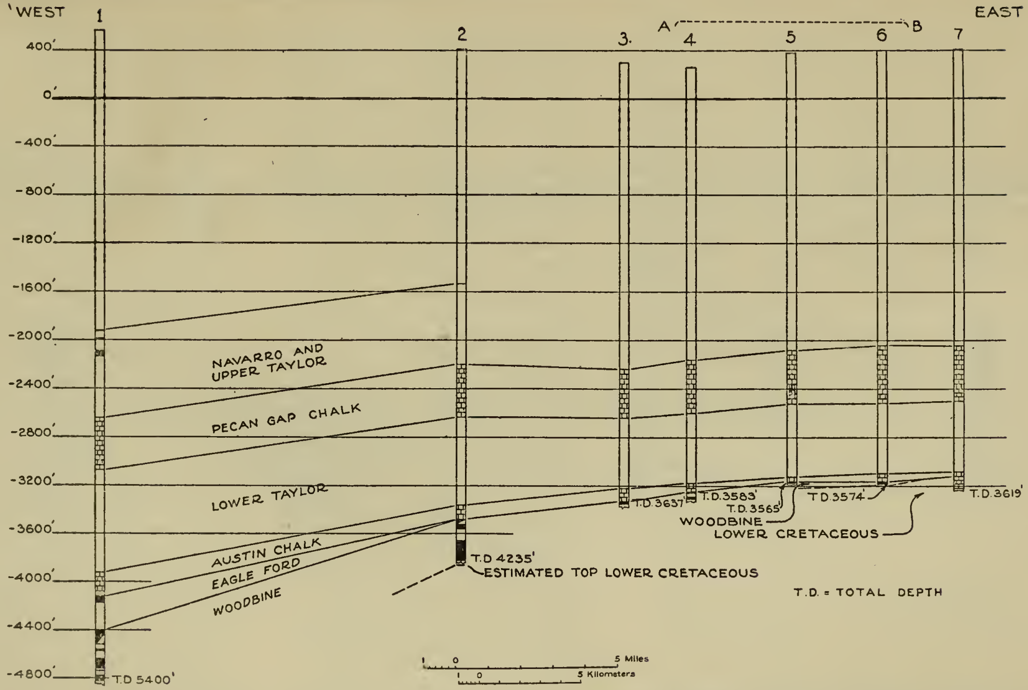

FIGURE 20.—Vertical well-log section across northern part of East Texas field, showing eastward wedging out of Eagle Ford shale and Woodbine sand. For location of wells see Figure 18. The position of the pool is indicated by the dotted line *A–B*, at the top of the diagram

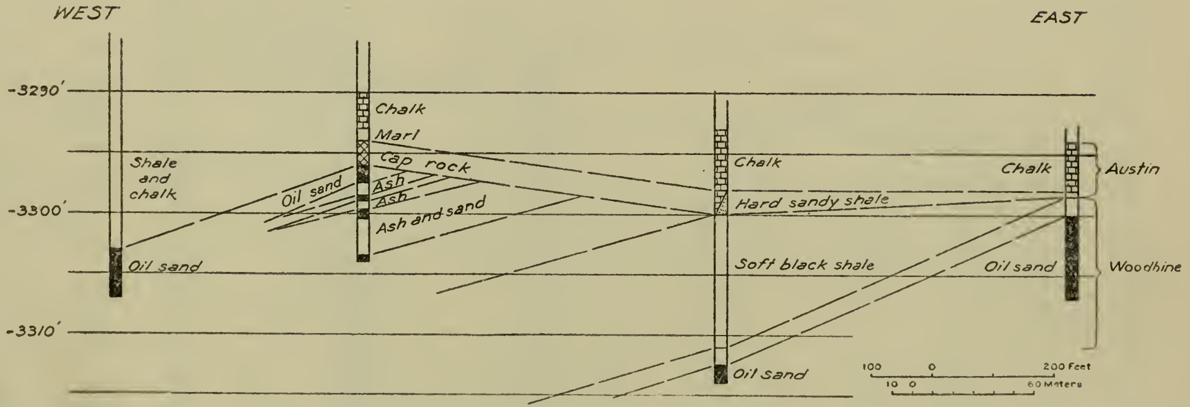

Figure 21.—Large-scale section of sand conditions in four producing wells in the southwestern part of the East Texas field, showing the Woodbine sand truncated by the overlying Austin formation. Higher sand lenses appear in the more western wells

shales, and volcanic ash—are overlain by the Austin. As a result of these relations of westward dip and truncation by unconformity, pay sands in the eastern part of the pool are somewhat older than those farther west. On a large scale this is illustrated by Figure 21, a greatly exaggerated vertical section of conditions in and just above the pay zone in four wells in southeastern Smith County. For this reason, the contouring in Figure 17, based on records of the top of the first producing sand in the various wells, shows slightly less dip than the true dip of the Woodbine formation. Some of the irregularities in detailed contouring, as in Plate 9, are undoubtedly due to this condition.

With the exception of a possible low flat closure a few miles east of Gladewater, on the Gladewater anticlinal nose, there is no true reversal of the normal westward dip. The oil has been trapped in the updip part of the porous Woodbine sand where this is unconformably overlain by impervious beds, or in some places, perhaps, where local sands lens out up the dip within the Woodbine formation.

WATER

Down the dip, within the pay-sand zone, the oil is backed by water which is under a hydrostatic head of about 1,560 to 1,600 pounds to the square inch (110 to 112 kilograms to the square centimeter). With a few local exceptions, due to special conditions, the water-oil contact ranges between 3,315 and 3,325 feet (1,010 and 1,013 meters) below sea level. (See fig. 17.) The form of this contact has not been definitely established. It is probably irregular, but, depending on sand porosity and intercalated shale lenses, undoubtedly it passes eastward beneath the oil in a strip of territory along the western edge of the pool. No water has been encountered in the Woodbine in the eastern part of the field.

SAND CONDITIONS

Studies of sand samples from the Woodbine pay zone exhibit considerable range in texture and therefore in effective porosity. In some parts of the field, particularly in the higher or younger section of the pay zone, fine volcanic ash occurs both as more or less recognizable strata and also as material distributed between the quartz grains of some of the coarser sand layers. Through material of this kind the flow of fluids is less easy than through sands of coarser texture and larger pore spaces. In a series of tests on samples taken from all parts of the field, a large percentage of the crushed sand passed through screens with openings between 0.4 and 0.2 millimeter in diameter. The porosity of these sand samples ranged from 26.5 to 31 per cent.

In spite of the fact that locally the pay zone contains some layers of relatively low effective porosity, there can be no question that this zone as a whole is relatively very porous, with freedom of communication throughout its greater part. This is demonstrated (1) by the nearly uniform character of the oil over this vast field; (2) by the consistent relations of original reservoir pressures throughout the pool; (3) by the fact, observed in numerous localities, that operations on one well may distinctly affect production and pressure values in other wells, even at distances of several hundred feet; and (4) by the rapid equalization of reservoir pressures, during the military shutdown in 1931, in many wells in which pressures had previously been very seriously disturbed by unequal withdrawals.

THE OIL

Oil from the East Texas pool is of paraffin base. Its average gravity is 39.1° A. P. I. (38.8° Baumé), with variations from 38.0° to 40.5° A. P. I. (37.7° to 40.2° Baumé). In most of the samples examined the gravity was between 39° and 40° A. P. I. (38.7° and 39.7° Baumé). Its color is dark brown, especially in the western part of the field, with a tendency toward a somewhat more greenish brown farther east.

GAS AND GAS-OIL RATIOS

Measured gas-oil ratios have shown from 100 to 600 cubic feet of gas to the barrel of oil (0.067 to 0.4 cubic meter of gas to the liter of oil) with an average of about 325 cubic feet to the barrel (0.22 cubic meter to the liter). This gas contains from 3½ to 8 gallons of gasoline to 1,000 cubic feet (471 to 1,078 liters to 1,000 cubic meters). It has a relatively low percentage of methane and a correspondingly high percentage of the heavier gases. Under the pressures existing in the pool probably some of the gas occurs as a liquid. There is no accumulation of free gas in the higher parts of the reservoir.

FLUID TEMPERATURES

Temperatures of the oil have been reported as high as 142° F. at the casing head. In one water well near the west edge of the field 162° F. was recorded at the bottom of the hole. Probably 150° to 160° F. may be regarded as average temperatures for oil and water in this pool before expansion of dissolved gas has produced cooling. These figures may be compared with temperatures of 137° F. at a depth of 2,985 feet (910 meters) recorded in a well in the Mexia field, in Limestone County, Texas, and

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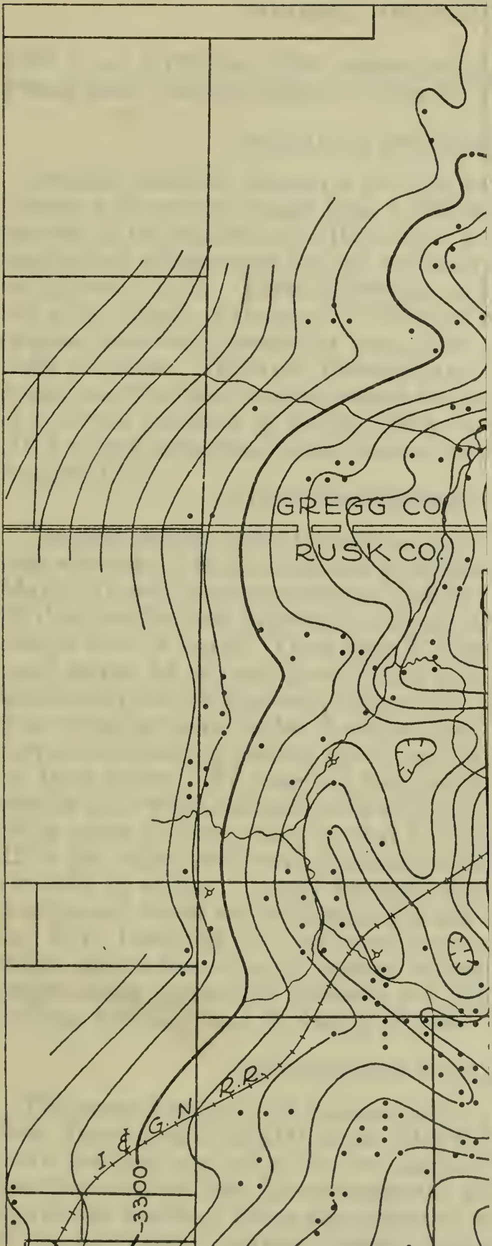
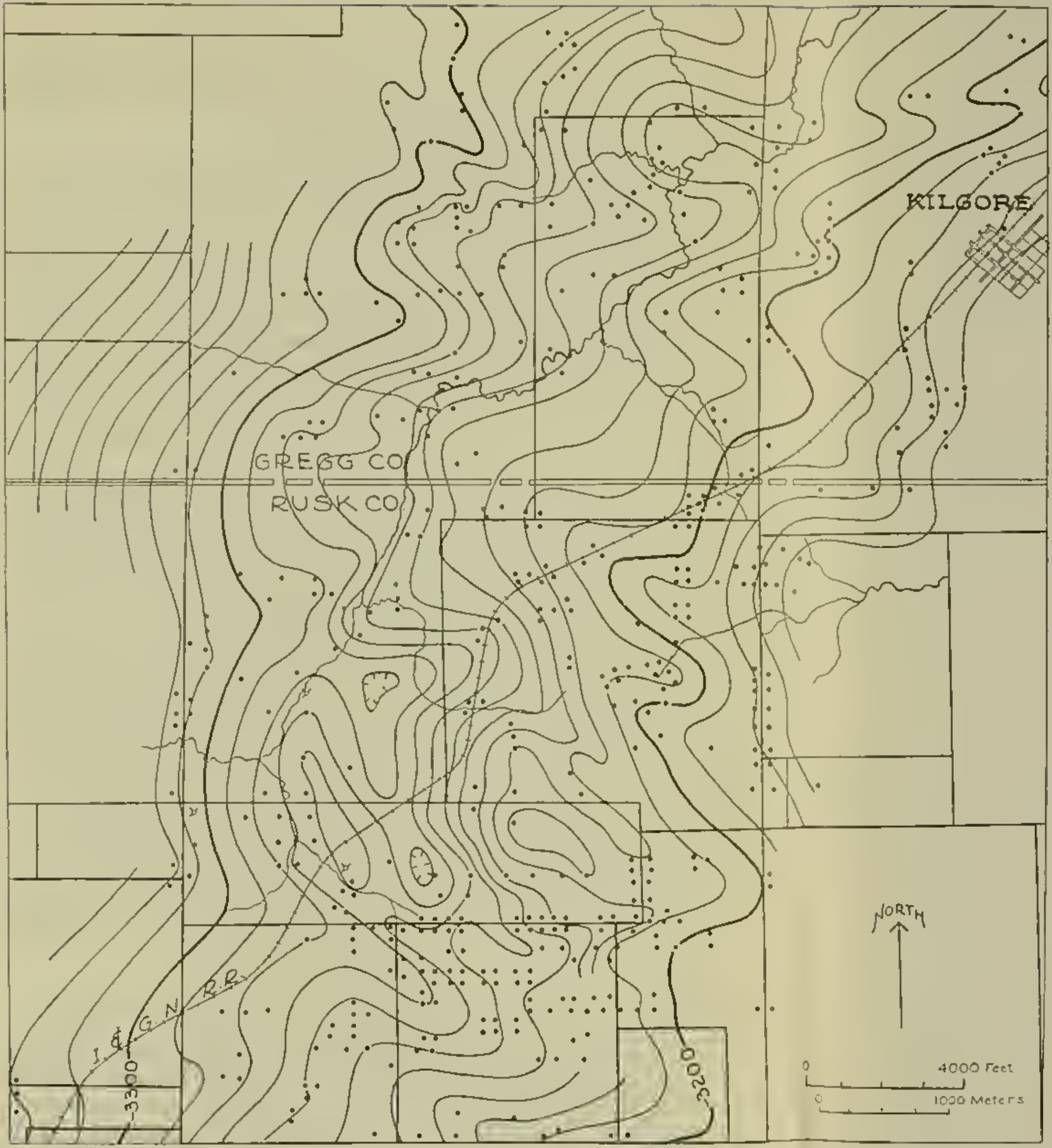


DETAILED CONTOUR MAP ON TOP OF THE

Illustrates the irregularities of the key bed



DETAILED CONTOUR MAP ON TOP OF THE PAY SAND IN THE KILGORE AREA IN THE EAST TEXAS OIL FIELD

Illustrates the irregularities of the key bed as mapped from the available data. Contour interval 10 feet.

128° F. at 2,710 feet (826 meters) recorded in a well in the Powell field, Navarro County, Texas (9, pp. 98, 99).

RESERVOIR PRESSURE

Average reservoir pressures for the field, as determined by bottom-hole records, range from 1,500 to somewhat over 1,600 pounds to the square inch (105 to 112 kilograms to the square centimeter) where there has not yet been local depletion due to withdrawal of oil. These differences are due to differences in the subsea depth of the sand. With no free gas in the pool, the original reservoir pressure at any given subsea depth is essentially the same. However, the rapid and extensive drilling campaign since the field was discovered had brought about a decline of reservoir pressure of 150 to 200 pounds to the square inch (10.5 to 14.1 kilograms to the square centimeter) by the end of August, 1931.

WATER ENCROACHMENT

The first serious water trouble occurred in two wells near the west edge of the field, southwest of Kilgore, in April, 1931. On May 7, 17 wells were reported as making some water. On July 16 this number had increased to about 30, all producing 1 per cent or more of water. On August 3 there were 32 wells making some water, 14 of them from half a mile to a mile (0.8 to 1.6 kilometers) east of the west edge of the pool. These 14 wells were yielding water either because they had been drilled too deep, or because, by flowing wide open, they had coned the water up from below. By plugging back or by choking down to a smaller daily yield, the water was very much reduced or even shut off in some of these wells, so that by September 3, 1931, only 22 in the entire pool were reported to be making more than 1 per cent of water. It may be said, then, that since the field was opened water encroachment has not been extensive. (See fig. 17.) However, the evidence is very strong that uneven water encroachment, with serious consequences, will certainly result unless systematic methods are followed in the spacing, drilling, finishing, and producing of wells.

ESTIMATES OF YIELD

The present estimate of the area which will produce oil in the East Texas pool is 92,000 acres (37,000 hectares). This estimate has been arrived at by two methods. It is considerably less than some of the figures suggested previously. Estimates of average acre-foot yields are subject to wide variation because of the differences in texture, porosity, and stratigraphy in different parts of the field, and, indeed, even from well to well. On the basis of an average thickness of 30 feet (9 meters) of producing oil sand over the entire 92,000 acres, with an average porosity of 25 per cent and an average extraction of 40 per cent, we should have a total productivity of 775.84 barrels per acre-foot,[12] or of 30×92,000×775.84 barrels=2,141,300,000 barrels (340,441,567,000 liters) for the pool. This amounts to 23,275 barrels to the acre (9,250,820 liters to the hectare). An average of 15,000 barrels to the acre would amount to 1,380,000,000 barrels (219,403,800,000 liters) for the pool.

CROOKED HOLES

Owing to the great number of leases and lease owners in this field and the frenzy of many to reach the pay sand and recover all possible oil in the least possible time, most of the drilling contracts called for speed. As a result some very fast records were made. The average drilling time to the pay sand at a depth of 3,500 feet (1,067 meters) or more was 10 days. The upper 2,500 feet (762 meters) of sand, sandy shale, and shale above the Pecan Gap chalk was drilled in some holes in three days. According to one statement a certain well was coring the Woodbine sand 2¼ days after it was spudded in. Another crew drilled 965 feet (294 meters) in 12 hours.

Naturally, crowding the drilling at rates like these caused some holes to go crooked. Possibly many are crooked. A few examples may be cited. A well drilled in the South Kilgore district should have encountered the bottom of the Austin chalk at about 3,317 feet (1,011 meters), whereas actually it reached this horizon at about 3,357 feet (1,023 meters) or 40 feet (12 meters) too low. Subsequently its offset, along the strike, reached the base of the Austin chalk at 3,317 feet (1,011 meters). A survey of the deeper hole proved that it deviated as much as 28° from the vertical, with a horizontal error in location of the bottom of the hole amounting to over 220 feet (67 meters) and a vertical error of 43 feet (13 meters).

The Universal Oil Co.'s Brown No. 1 well, in the Joiner field, was found to deviate a maximum of 20° from the vertical. In the same field the Imperator Oil Co.'s Cox No. 1, in the R. H. Penny survey, showed a deviation of 6° at 1,000 feet (305 meters) 12° at 1,500 feet (457 meters), 15° at 2,000 feet (610 meters), 52° at 2,500 feet (762 meters), and 75° at 2,781 feet (848 meters).

About 2 miles (3.2 kilometers) northwest of Kilgore a hole was actually drilled into its offset, 300 feet (91 meters) distant.

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[12] An acre-foot=43,560 cubic feet=7,758.36 barrels=1,233,487 liters.

A hole 1½ miles (2.4 kilometers) north of the Moncrief et al. Lathrop discovery well, at a recorded depth of 3,703 feet (1,129 meters), or 3,301 feet (1,006 meters) below sea level, encountered the top of the Pecan Gap chalk, normally 1,100 feet (335 meters) above the pay sand here. The hole ought to have reached the pay sand at about 3,220 feet (981 meters) below sea level, as proved by the record of the second hole drilled at the same location. The maximum angle of inclination of the first hole was found to be 45°.

THE KEECHI AND PALESTINE SALT DOMES, TEXAS (11)

By Frederic H. Lahee

The Keechi salt dome (pl. 10, No. 10) is about 7 miles (11.3 kilometers) northwest of Palestine, Anderson County, Texas. The main highway between Athens and Palestine crosses it almost centrally. (See pl. 11.)

The surface and subsurface formations in this district are as follows:

- Eocene:
  - Cockfield (formerly "Yegua").
  - Cook Mountain.
  - Mount Selman—
    - Weches.
    - Queen City.
    - Reklaw.
    - Carrizo.
  - Wilcox.
  - Midway.
- Upper Cretaceous:
  - Navarro.
  - Taylor—
    - Upper.
    - Pecan Gap.
    - Lower.
- Upper Cretaceous—Con.
  - Austin chalk.
  - Eagle Ford.
  - Woodbine.
- Lower Cretaceous:
  - Buda.
  - Del Rio.
  - Georgetown.
  - Edwards.
  - Comanche Peak.
  - Walnut.
  - Trinity.

On the Keechi dome beds of Upper Cretaceous age are exposed but not well enough to show the actual structure, for the soil cover is extensive. Surrounding the central uplifted area is a ring of Midway, which in turn is encircled by beds of Wilcox age. Normally, here the surface exposures should be of Queen City (Mount Selman) age; the top of the Midway should be at a depth of about 2,000 feet (610 meters); and the Pecan Gap chalk, 900 feet (274 meters) below the top of the Upper Cretaceous, should be about 3,650 feet (1,113 meters) below the surface.

Prior to 1926 only five wells had been drilled on the Keechi dome (14, pp. 243–253). From April, 1926, to July, 1930, eight more holes were drilled for oil. All were abandoned as dry. These eight holes were:

Humble-Navarro-Sun Greenwood No. 1 (G, fig. 1).
Humble-Navarro-Sun Greenwood No. 2 (E, fig. 1).
Humble-Navarro-Sun Greenwood No. 3 (D, fig. 1).
Humble-Navarro-Sun Greenwood No. 4 (C, fig. 1).
Humble-Navarro-Sun Barrett No. 1 (I, fig. 1).
Humble-Navarro-Sun Gardner No. 1 (F, fig. 1).
Cosden, Douglas No. 2 (A, fig. 1).
Cosden, Adams No. 1 (B, fig. 1).

Before 1926 salt had been encountered in only one well, the Producers Oil Co.'s Barrett & Greenwood No. 1 (H, pl. 11), at 2,160 feet (658 meters). Among the holes drilled since the spring of 1926 six (C, D, E, G, I, and F) encountered salt. (See figs. 22 and 23.) Greenwood 2 of the Humble, Navarro, and Sun Oil companies (E, pl. 11), reached the salt at 430 feet (131 meters). All these six wells penetrated anhydrite cap rock, from 16 to 120 feet (5 to 36 meters) thick, just above the salt.

Here, as with most other salt domes, the more drilling done and the more information obtained the more complicated does the structure appear to be. (See figs. 22 and 23.) The top of the salt with its anhydrite cap seems to be conical, yet an outcrop of Pecan Gap chalk close to well G suggests faulting, which is not indicated in the salt. Against the salt plug, formations below the base of the Taylor (top of Austin) become thinner or pinch out; but above this horizon either there seems to be no thinning or the few data available actually suggest thickening toward the dome. No attempt has been made to interpret the details. It is interesting to note that in wells A to G and I the Buda, Del Rio, Georgetown, and uppermost Edwards formations, all of Lower Cretaceous age, have been recognized on the flanks of the dome and in close proximity to the salt, yet the Woodbine is missing except in well I, where a little sand and some sandy shale, about 100 feet (30 meters) in total thickness, were determined as Woodbine. In this well the top of the Woodbine at 1,975 feet (602 meters) is roughly 3,400 feet (1,036 meters) above its normal regional position.

Small showings of heavy oil of no commercial importance were recorded in sands in several wells.

The Palestine salt dome (pl. 10, No. 13) is about 6 miles (9.6 kilometers) a little south of west of Palestine. It is easily accessible by a road that leads from Palestine to the salt works.

In the central part of the dome Upper Cretaceous strata from Navarro to Woodbine are exposed, and the Buda limestone, of Lower Cretaceous age, crops out. (See fig. 24.) Normally, on the basis of the regional dip, the Queen City sand member of

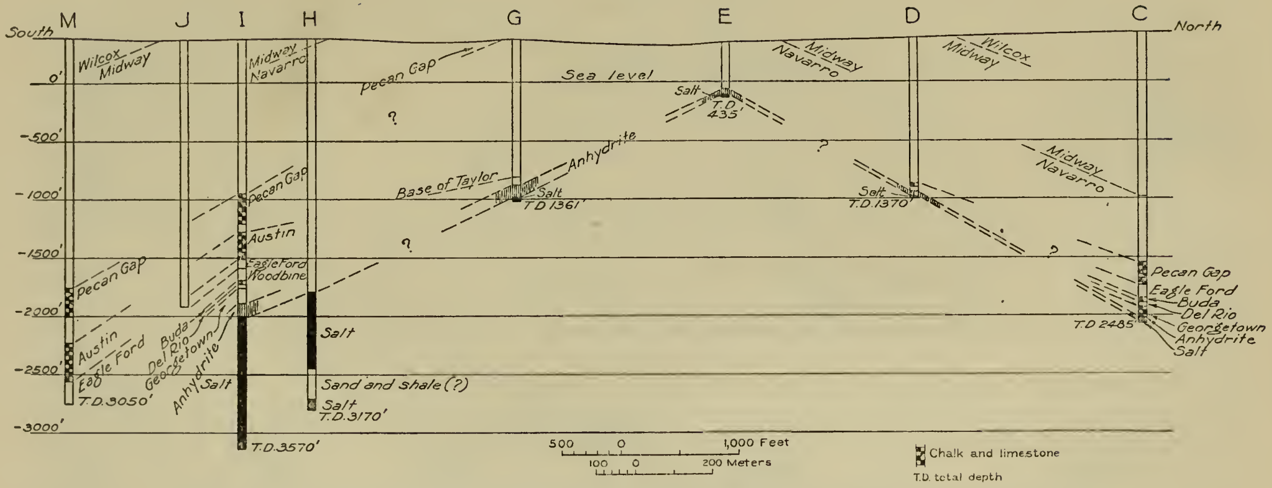

FIGURE 22.—North-south section of Keechi salt dome, Texas. (See pl. 11 for location of wells)

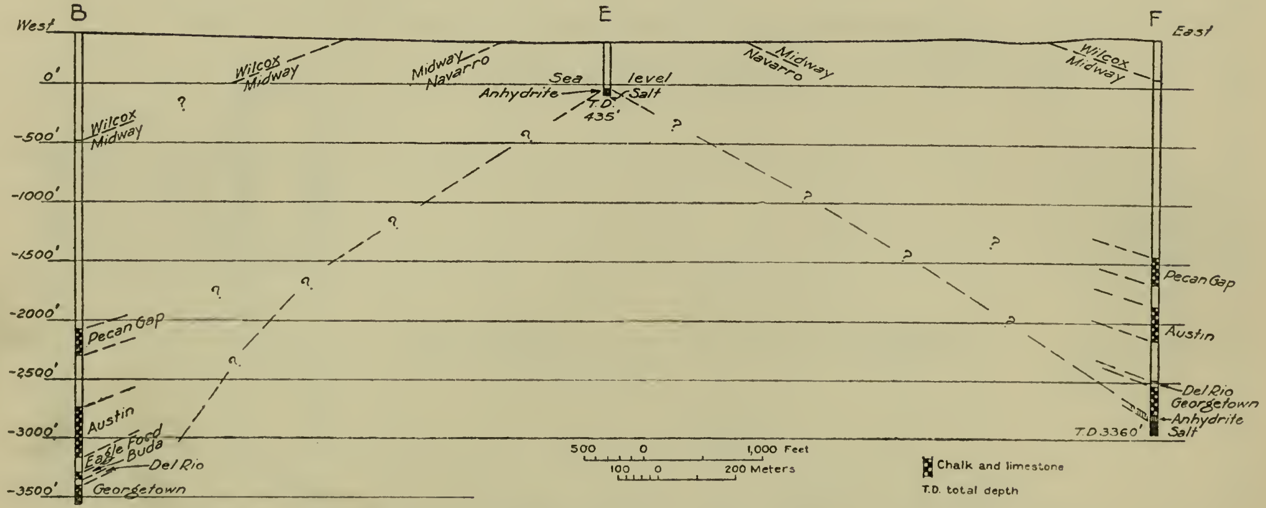

FIGURE 23.—East-west section of Keechi salt dome, Texas. (See pl. 11 for location of wells)

the Mount Selman would extend across the site of the dome, the top of the Austin would be about 5,200 feet (1,585 meters) below the surface, and the Buda would be 800 to 1,000 feet (244 to 305 meters) deeper.

Not enough deep wells have been drilled to determine the form of the Palestine dome. Numerous borings for salt show that its top is essentially flat and that locally it has thin patches of cap rock (anhydrite?). Since 1926 two holes have been drilled by the Sun Oil Co. on the south flank. The relations of these holes to the salt plug are illustrated in Plate 12. As in the Keechi dome, strata down to and including the upper part of the Edwards limestone have been penetrated by the drilling. Irregularities in the relations of the contacts in the two wells suggest faulting on the flanks. Although some Woodbine sand and lime are exposed on top of the dome (fig. 24), this formation,

FIGURE 24.—Geologic and topographic map of the Palestine salt dome, Anderson County, Texas. For section along line A–B see Plate 12

where encountered in two deep tests, was not over 30 feet (9 meters) thick.

There seems to be no doubt that in both the Keechi dome and the Palestine dome the salt actively invaded beds of Lower and Upper Cretaceous age, already deposited—in other words, that it was not intruded essentially pari passu with the Cretaceous sedimentation.

THE SUGARLAND OIL FIELD, TEXAS

By L. P. Teas

The Sugarland oil field (pl. 10, No. 42) is located on a moderately deep salt dome 25 miles (40 kilometers) southwest of Houston, in Fort Bend County, Texas, within a radius of 28 miles (45 kilometers) of 13 other domes. It is almost circular and has a diameter of slightly less than 1½ miles (2.4 kilometers). (See pl. 13.) The dome was discovered with the torsion balance in 1927 by the North American Exploration Co., working for H. C. Cockburn. A short time later a seismograph crew of the Humble Oil & Refining Co. also recognized the dome. There is nothing on the flat surface of the Brazos River bottom, under which the dome occurs, to suggest that a salt dome lies below. Even definite gas seeps or sulphur water wells are lacking.

The Sugarland dome is unusual in that the highly productive middle Oligocene sands have not been pierced by the salt, as on most of the other producing coastal domes. (See fig. 25.) These sands have therefore been left unimpaired to form a perfect blanket oil reservoir. In spite of the fact that the overlying Miocene section has likewise not been penetrated by the salt, no oil has been found in the Miocene sands. Although information is scanty as to the steepness of the sides of the salt core in this dome, and the resulting slope of the uplifted formations on the flanks of the dome, it is fairly certain that these slopes are relatively gentle for salt domes—that is, they probably do not exceed 40° or 45°.

On the highest part of this dome the usual sand, sandy clay, and clay section of Pleistocene, Pliocene, and Miocene is found to a depth of 2,800 feet (853 meters), where the first middle Oligocene is reached. The Miocene clays begin at about 1,200 feet (366 meters) and are gray, green, and red or mottled in color and usually very calcareous, with abundant reworked Cretaceous Foraminifera. The thickness of the Miocene over the Sugarland dome is only about half its normal thickness for this locality.

On the Sugarland dome the middle Oligocene has been raised 2,000 feet (610 meters) above its normal position. The middle

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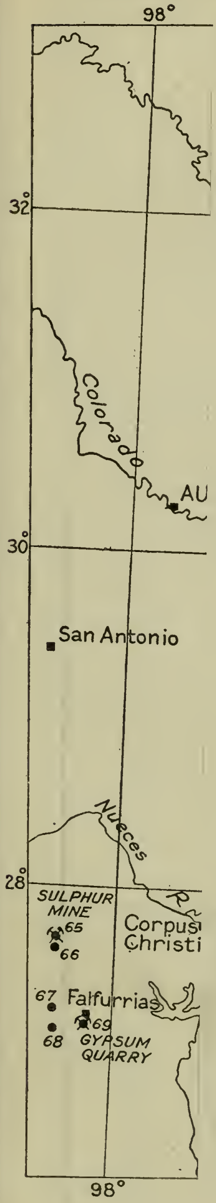
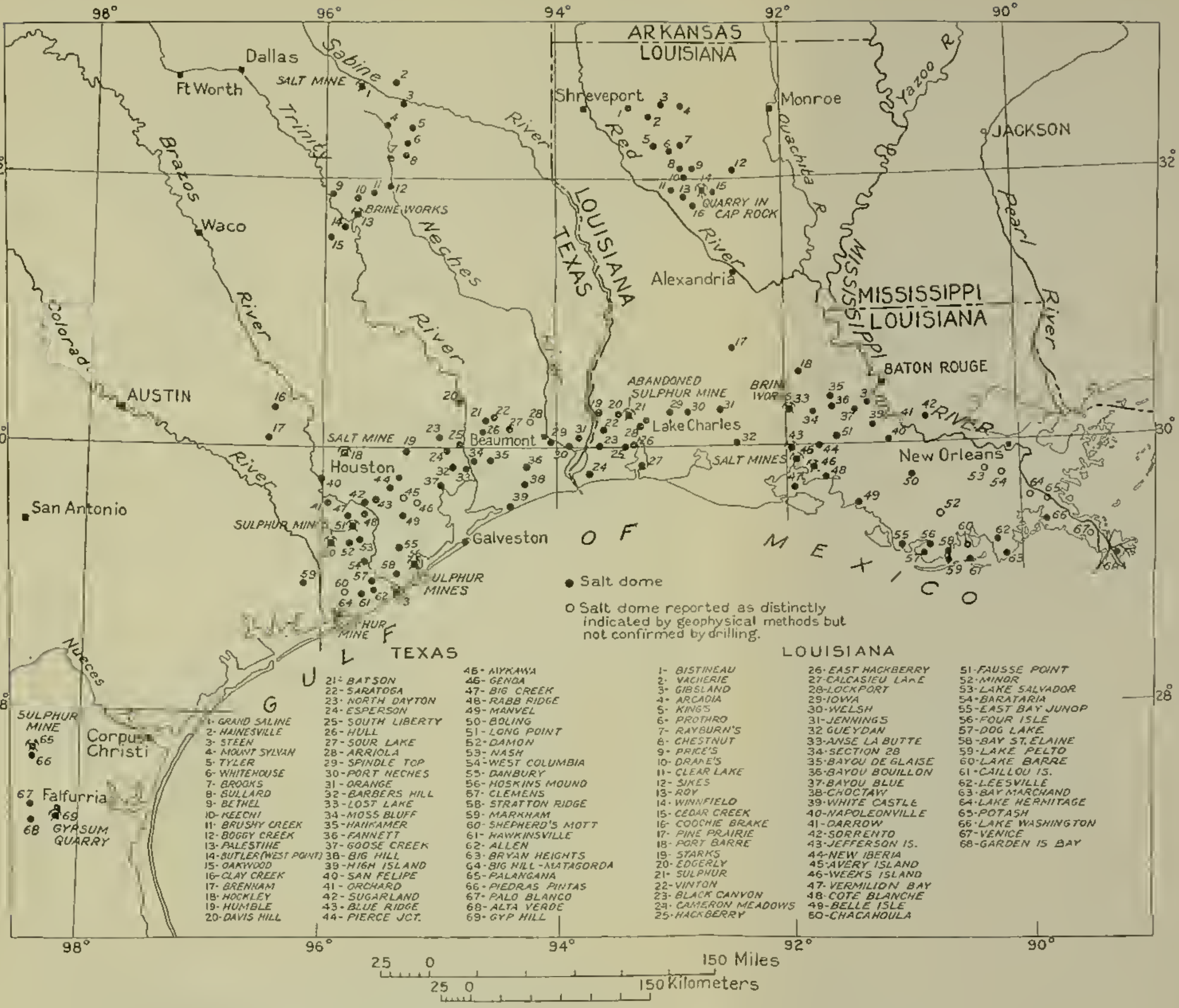
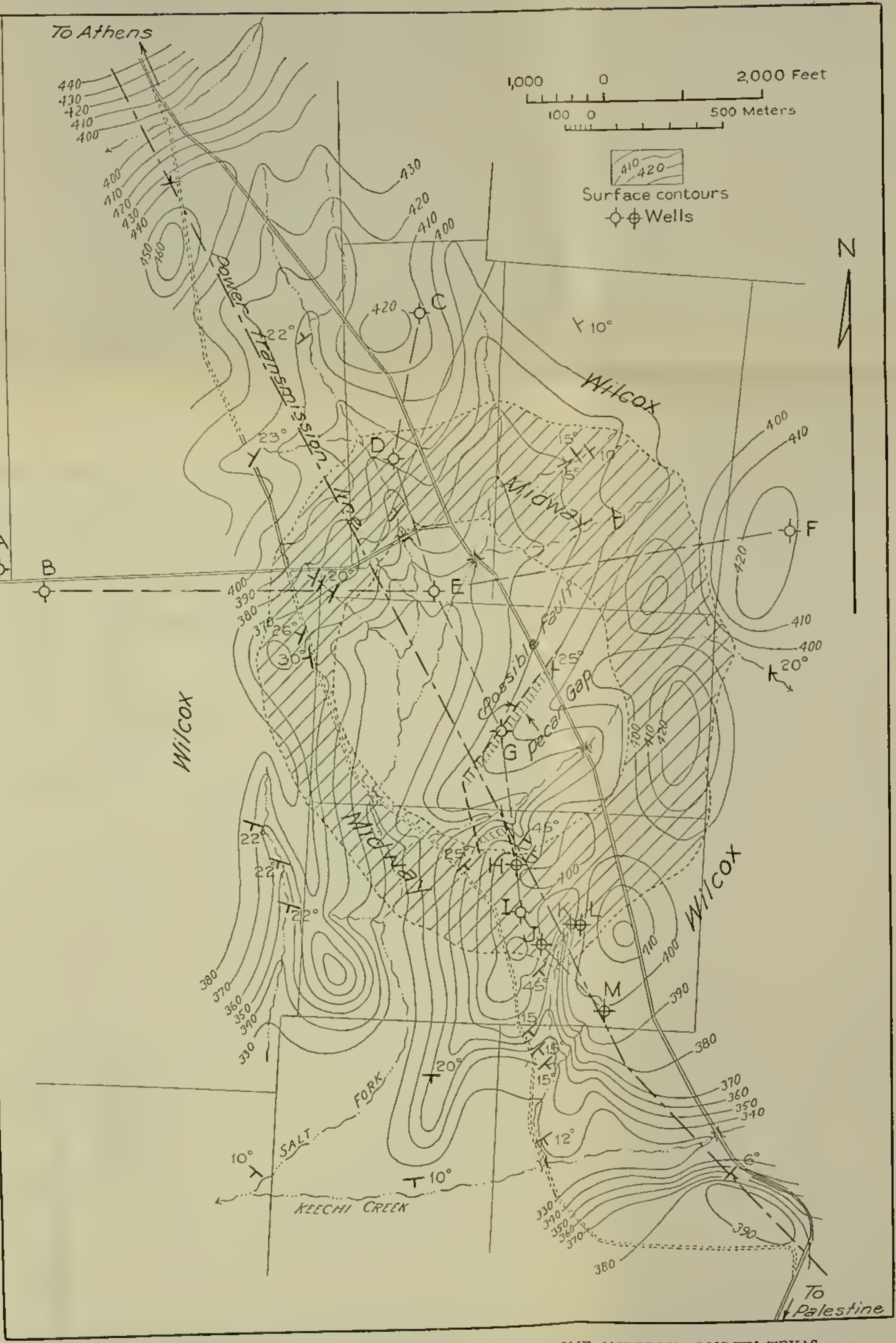




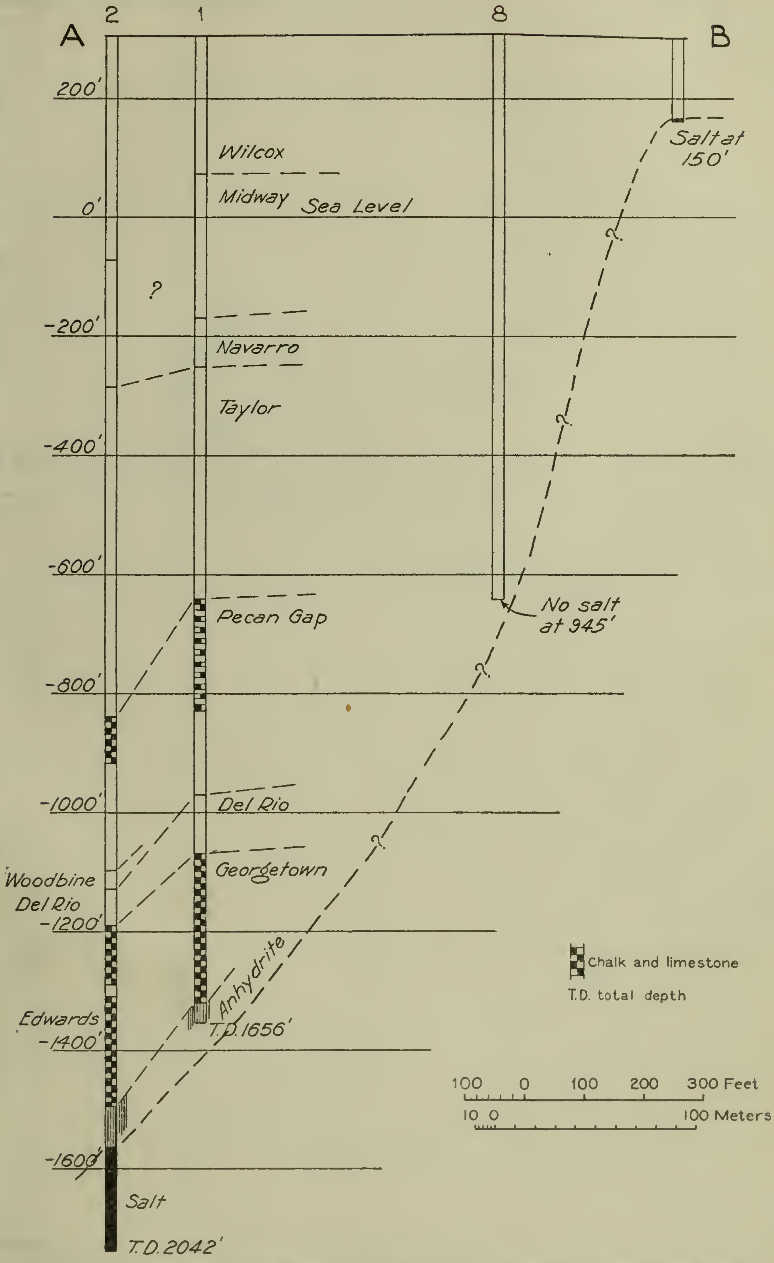
MAP SHOWING THE DISTRIBUTION OF SALT DOMES IN TEXAS AND LOUISIANA

Compiled from data furnished by Donald C. Barton, Houston, Texas.

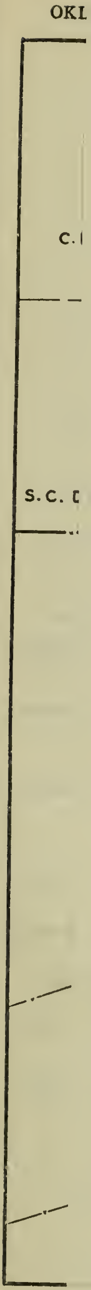
GEOLOGIC



GEOLOGIC AND TOPOGRAPHIC MAP OF THE KEECHI SALT DOME, ANDERSON COUNTY, TEXAS



GEOLOGIC CROSS SECTION ON THE SOUTH FLANK OF THE PALESTINE SALT DOME, TEXAS, ALONG LINE A–B, FIGURE 24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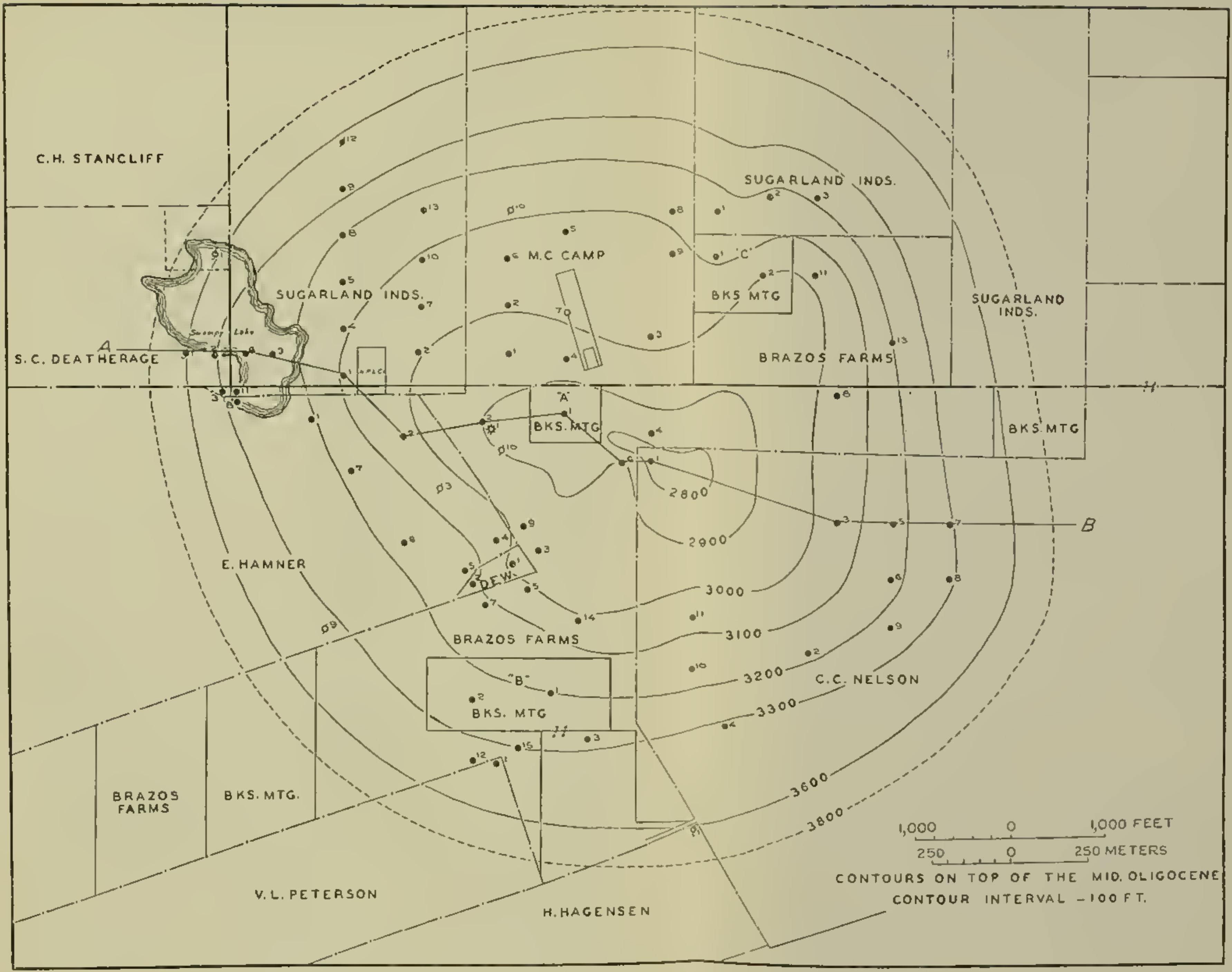

STRUCTURE CONTOUR MAP OF THE SUGARLAND SALT DOME OIL FIELD, TEXAS

For section along line *A–B* see Figure 25.

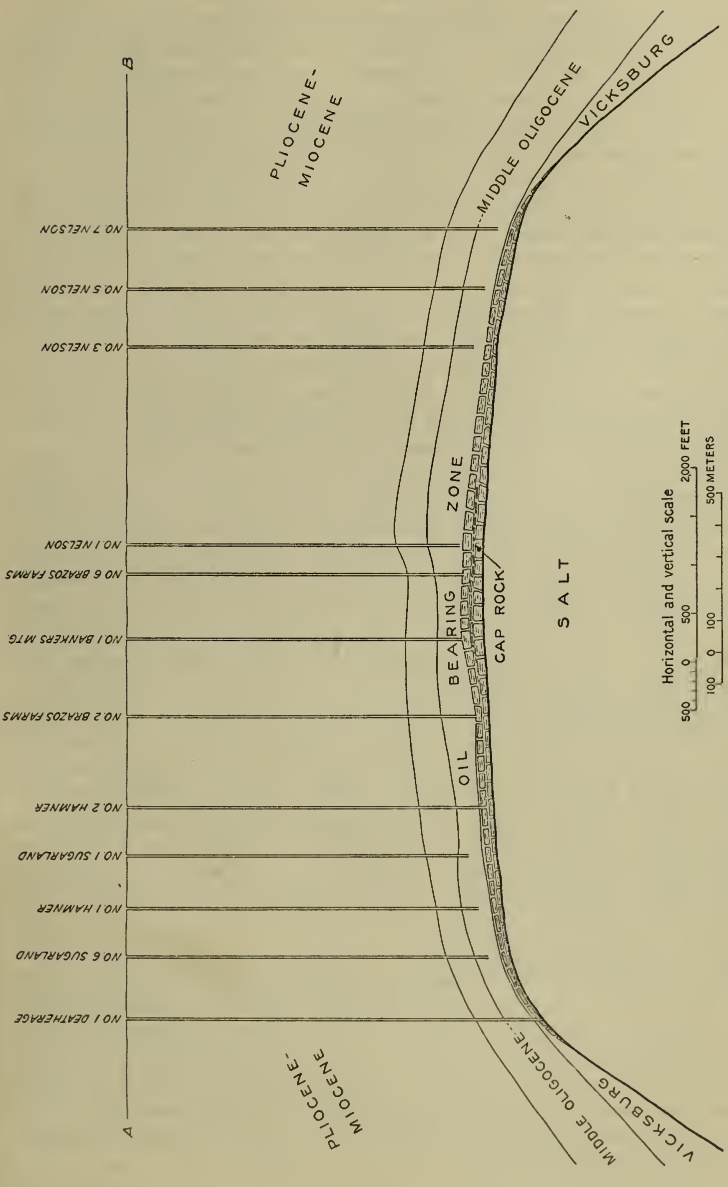

FIGURE 25.—Geologic cross section of Sugarland oil field, Texas, along line *A–B*, Plate 13

Oligocene section includes shale in the upper 235 to 375 feet (72 to 114 meters). Sands then begin which carry oil in increasing amounts until a total oil-bearing section that averages about 200 feet (61 meters) in thickness has been penetrated. The total thickness of good oil sand averages 90 feet (27 meters) for the field. The total middle Oligocene section at Sugarland ranges from 560 to 695 feet (171 to 212 meters) in thickness. Three divisions based on microfaunal differences have been recognized. On the Texas coast the upper zone is characterized by *Discorbis*; the middle zone by *Heterostegina*, which is associated on many domes with a coralline limestone as well as sand and shale, but at Sugarland the limestone is absent; and the lower zone by *Marginulina*. The producing sand at Sugarland lies almost entirely within the *Marginulina* zone.

Below the middle Oligocene there occurs a thin layer of lower Oligocene, ranging from a few inches to 60 feet (18 meters) in thickness and characterized by a distinct microfauna and some lignite and sand. Oil also occurs in this lower sand.

The depth to the calcite cap ranges from 3,441 feet (1,340 meters) near the central or highest part of the dome to 4,398 feet (1,340 meters) on the west edge, where the deepest well yet drilled (4,471 feet, or 1,368 meters) at Sugarland is located. The thickness of the cap is not known except in two west-edge wells, as no wells elsewhere have gone into the salt. These edge wells have found from 52 to 66 feet (15 to 20 meters) of anhydrite cap. The cap where reached is not porous and suggests poor possibilities for oil accumulation. No significant amounts of sulphur have been observed in the cap.

Although the Oligocene has been raised 2,000 feet (610 meters) above its normal position by the action of the salt mass, the amount of productive closure is only a little over 900 feet (274 meters). The salt-water plane varies from one part of the dome to another. It is highest on the northwest side, at a depth of 3,700 feet (1,128 meters), and lowest on the northeast side, at 3,790 feet (1,155 meters). On the south side the water occurs at 3,775 feet (1,150 meters).

The entire dome and oil field is under lease to and operated by the Humble Oil & Refining Co. The fact that only eight leaseholds exist within the area of the field somewhat simplifies the development of the property. It has been the desire of the Humble Oil & Refining Co. to develop this field with the least possible waste of gas pressure and recoverable oil and to produce the oil through the minimum number of wells consistent with maximum oil recovery and the greatest return for both operator and royalty owner alike.

The productive area has been estimated at 1,258 acres (509 hectares). In this area (at the time of writing, January, 1932) 68 producing wells and 2 dry holes have been drilled. Of the producing wells 5 have been abandoned and 13 are showing salt water in amounts ranging from 1 to 20 per cent. On June 1, 1931, 39 wells were producing and 21 wells were shut in because of water or high gas-oil ratio, and 3 wells were used for gas injection, as explained below. The 68 wells on the 1,258 acres of the Sugarland field make an average of 1 well to each 18 acres (7 hectares), which is in sharp and favorable contrast to the excessive drilling that has marked practically all the other coastal salt-dome fields.

Of unusual interest in this connection is the systematic injection of gas produced with the oil into the sand in order to maintain the original pressure as nearly as possible. The gas is taken from the gas separators at the well at a pressure of 40 or 50 pounds to the square inch (2.8 to 3.6 kilograms to the square centimeter) and is compressed to 1,450 pounds (102 kilograms) in a central plant by two stages. The first stage raises the pressure to 400 pounds (28 kilograms) by means of six 100-horsepower compressors, having a capacity of 4,440,000 cubic feet (125,729 cubic meters) daily. The second stage raises the pressure from 400 to 1,450 pounds by means of four 100-horsepower compressors having a daily capacity of 4,800,000 cubic feet (135,924 cubic meters).

Injection of gas began in April, 1930, and 91 per cent of the gas produced with the oil has been returned to the reservoir during the first year. The cost of this injection is between 7 and 8 cents per 1,000 cubic feet (28 cubic meters) or about 2 cents per barrel (159 liters) of oil produced.

The field to January 1, 1932, had yielded almost 13,000,000 barrels (2,066,847,000 liters) of oil having a gravity of 28.3° Baumé, an average of over 10,300 barrels to the acre (4,093,945 liters to the hectare) or an average of 191,000 barrels (29,988,000 liters) from each producing well drilled. The daily production in January, 1932, was 11,800 barrels (1,876,061 liters) from 39 wells, or 300 barrels (47,696 liters) to the well. The wells range in depth from 3,441 feet (1,049 meters) near the center of the field to 3,812 feet (1,162 meters) on the edge.

One well produced a small amount of gas from a sand near the base of the Miocene but has since been deepened to the Oligocene.

Of the 39 wells all are producing through purposely reduced apertures or chokes, except one well that is being pumped.

The reason for reducing the production is twofold—to conform with a plan of oil proration to assist in overcoming the present surplus of oil, and to maintain a production with the minimum amount of gas in order to conserve the gas and gas pressure so that the wells will flow as long as possible. The original pressure of the field was about 1,500 pounds to the square inch (105 kilograms to the square centimeter), and the pressure on January 1, 1932, averaged about 1,300 pounds (91 kilograms). The gas-oil ratio, or the number of cubic feet of gas at atmospheric pressure produced with each barrel of oil, is low for this field. On January 1, 1932, it was 310 (0.5 cubic meter of gas to the liter of oil).

Estimates of the ultimate yield of the field vary, but it is thought that the average for Texas salt-dome fields of 65,000 barrels to the acre (25,835,668 liters to the hectare) should be equaled at Sugarland.

THE BOLING DOME, TEXAS

By A. G. Wolf

The Boling Dome (pl. 10, No. 50) is 16 miles (26 kilometers) southeast of Wharton, Wharton County, Texas, and about 40 miles (64 kilometers) in an air line from the coast.

This dome has no visible surface expression. Attention was first attracted to the area by the presence of sulphur water in a shallow well drilled for water. The Gulf Production Co. acquired the first lease block and in the first prospect well, drilled in 1923, struck barren limestone cap rock at a depth of 445 feet (136 meters). In 1927 the Texas Gulf Sulphur Co. acquired the sulphur rights and started a prospecting program. Plant construction began early in 1928, and the first sulphur was produced in March, 1929. The town that has been built by the company is named Newgulf.

A horizontal section on the 1,500-foot (457-meter) contour is oval, with diameters of approximately 5 miles (8 kilometers) east and west and 3 miles (4.8 kilometers) north and south. The top of the cap rock is at a minimum depth of about 400 feet (122 meters), and the top of the salt about 950 feet (290 meters). The cap-rock series in the sulphur-bearing area consists in descending order of porous and cavernous sulphur-bearing calcite rock, gypsum, and anhydrite; the anhydrite lies upon the rock salt. Outside the sulphur area the cap-rock series consists mainly of gypsum and anhydrite with some irregular bodies of barren calcite rock above. The unconsolidated sediments overlying the cap rock consist of sand, clay, gumbo, and soft "shale" in irregular, lenticular strata of varying extent. Throughout these sediments are lenses of sandy limestone and marl. Figure 26 shows an outline of the dome and its location with respect to the towns of Boling and Newgulf. Figure 27 is a portion of a generalized cross section through the sulphur-bearing area.

The calcite rock in which the sulphur occurs ranges in thickness from thin edges to 200 feet (61 meters). The sulphur-bearing area covers more than 1,200 acres (486 hectares) around the east and south slopes of the dome and is crescent-shaped, as shown in Figure 26. Figure 27 shows a cross section of it. The sulphur formation ranges in sulphur content from a trace to 50 per cent, and the total estimated amount of sulphur is in excess of 40,000,000 tons. The sulphur is scattered irregularly through

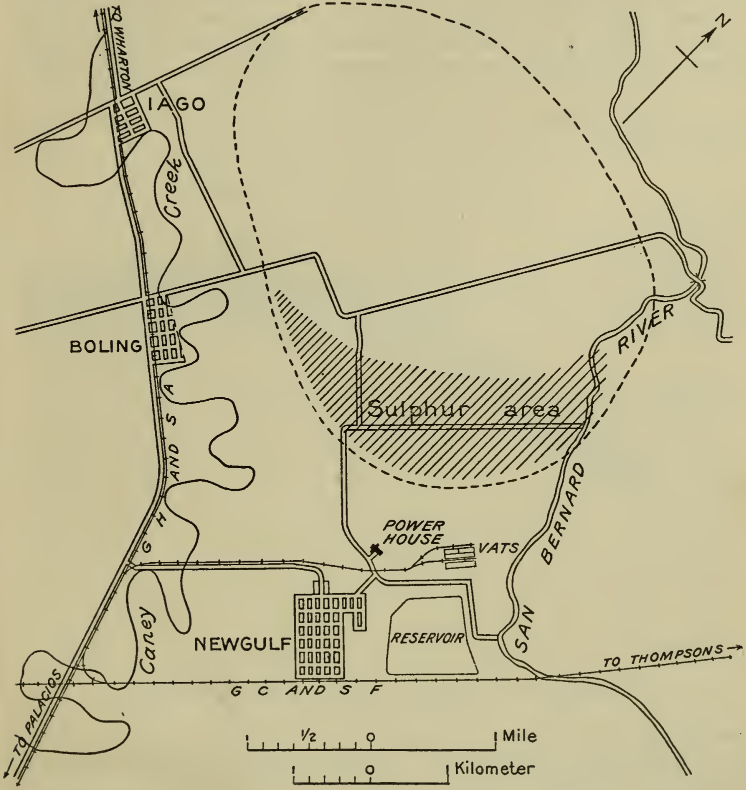

Figure 26.—Approximate outline of Boling salt dome, Texas, on 1,500-foot contour, and sulphur-bearing area

the mineralized zone in massive form filling irregular-shaped cavities; in little bunches, specks, and veinlets; and in orthorhombic crystals in vugs.

The cap-rock series, although consisting principally of calcium carbonate and calcium sulphate, contains a wider range of minerals than is generally known. Considerable quantities of barite, celestite, and pyrite have been found at Boling. Fairly common minerals that have been found in other dome caps and may occur at Boling are galena, sphalerite, and strontianite. More rarely the sulphides of manganese (hauerite and alabandite), aragonite, and traces of a green copper mineral (undetermined) have been found elsewhere. At Boling gypsum, other than the ordinary rock form, occurs as selenite and alabaster, and elsewhere also as satin spar.

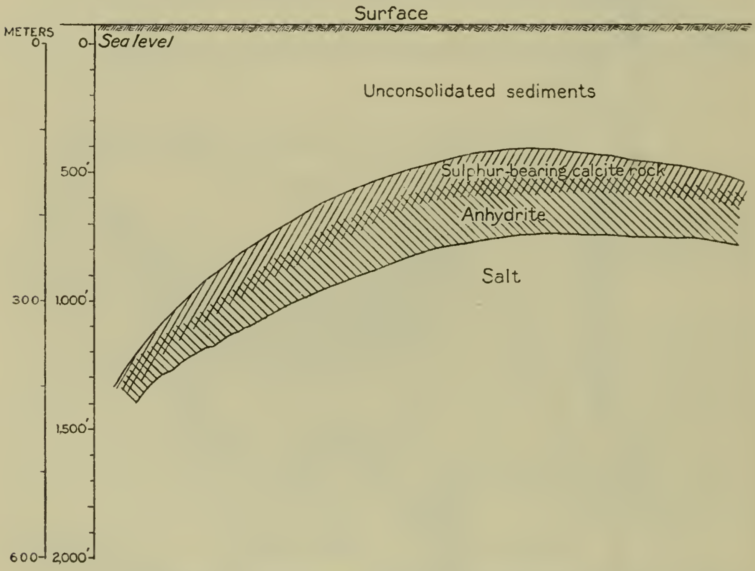

Figure 27.—Typical cross section of Boling salt dome

Primarily, the power plant furnishes hot water for melting sulphur, compressed air for bringing the melted sulphur to the surface, and electricity for pumping the sulphur to the storage vats. The plant equipment consists of ten 1,500-horsepower Sterling water-tube boilers, five high-pressure jet-type mine-water heaters, three turbogenerator sets, three compressors supplying air at a pressure of 500 pounds to the square inch (35 kilograms to the square centimeter), and three groups of turbine-driven centrifugal pumps. Gas is ordinarily used as fuel, but an emergency fuel-oil system is almost instantly available in case of interruption to the gas supply.

All water passing into the plant is first treated in a hot-process water-softening plant, which eliminates scale-forming substances. Cold water destined for the boilers and mine-water heaters is preheated by exhaust steam from the plant auxiliary equipment. One set of pumps supplies water to the boilers; a second group forces preheated "cold" water into the mine-water heaters, where the water temperature is raised to 325° F. by mixing with steam from the boilers; and a third set, called "booster" pumps, takes the water from the heaters and sends it out to the sulphur field stations through 16-inch (40-centimeter) lines.

Six sulphur stations are located at convenient points in the field and serve as centers of well control. Hot water is received from the plant and by means of auxiliary pumps is forced down the wells at pressures as great as 250 pounds to the square inch (18 kilograms to the square centimeter). Molten sulphur from the wells is collected at these stations, measured, and then pumped to the storage vats.

The underground well piping, as illustrated in Figure 28, consists of four strings set concentrically. Typically an 8-inch (20-centimeter) casing rests on top of the cap rock; a 6-inch (15-centimeter) line extends to the bottom of the sulphur-bearing stratum and rests on top of the barren gypsum or anhydrite; a 3-inch (7.6-centimeter) tubing rests on a collar, near the bottom of the 6-inch line, which seals the annular space between the 6-inch and 3-inch lines; a 1-inch (2.5-centimeter) air pipe ends several feet above the collar and is suspended from the surface. The 6-inch line is perforated above and below the collar. The upper set of perforations permits the escape into the sulphur-bearing cap rock of the superheated water, which is introduced at the surface into the space between the 6-inch and 3-inch strings; and the lower set of perforations affords a passage for the molten sulphur into the bottom of the 6-inch pipe and thence up through the 3-inch pipe. The molten sulphur rises about one-half to two-thirds of the distance to the surface, and compressed air, released through the 1-inch pipe, produces a lift which raises it to the surface.

At the sulphur stations the molten mineral is measured and then pumped through insulated, steam-heated lines to a relift station at the vats. Pumps at the relift operate intermittently, as sulphur collects in the sump, and raise the sulphur to the top of the vats. The storage bins, or vats, are 800 to 1,200 feet (244 to 366 meters) in length, 200 to 300 feet (61 to 91 meters) in width, and 40 to 50 feet (12 to 15 meters) in height when completed. The liquid sulphur is distributed in a thin layer and cools rapidly. A vat when completed is one solid block of sulphur.

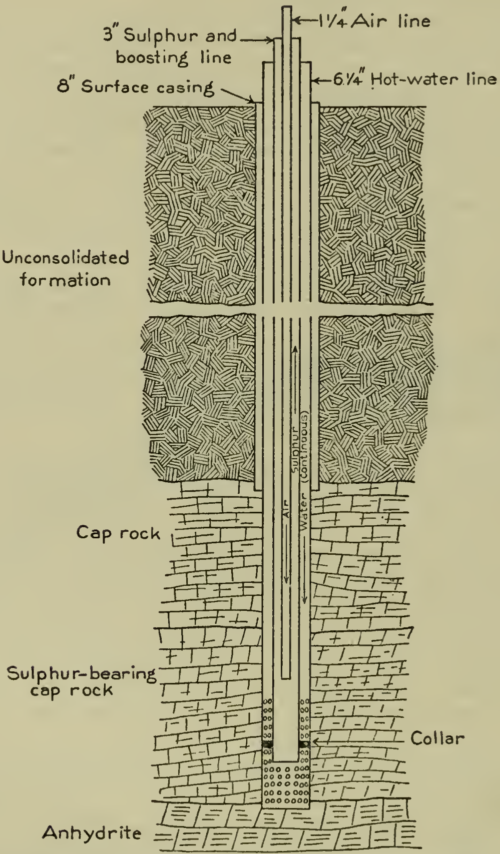

FIGURE 28.—Diagrammatic sketch of sulphur-well equipment, Texas Gulf Sulphur Co., Boling salt dome

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