STRATIGRAPHY OF THE EL DORADO OIL FIELD, ARKANSAS, AS DETERMINED BY DRILL CUTTINGS.

By JAMES GILLULY and K. C. HEALD.

INTRODUCTION.

The problem of constructing a stratigraphic column of the rocks of the El Dorado oil field, Ark., with the aid of drill cuttings was undertaken by the United States Geological Survey in order to facilitate development in the field and to furnish a guide to oil operators prospecting in surrounding territory. If it were possible either to get perfect well records or to interpret correctly the imperfect well records available, the difficulties in developing such a field would be greatly decreased. Extensions to the field would be found quickly and cheaply, the total amount of oil produced would be larger, water troubles would be reduced to a minimum, and prospecting in adjacent territory would go forward with a minimum expenditure for dry holes and greater probability of success. If the driller knew at all times just what formation his drill was passing through he would also know where the water-bearing strata were, if any existed, and where to look for shows of oil and gas. He would rarely drill too deep into the oil sand and thus ruin his well by permitting water to come in, as has been done in many wells in El Dorado. If the oil sand proved dry and he was sure he had reached the sand, he would not have to drill deeper, spending time and money to prove that his chances of success had vanished.

Unfortunately, perfect well logs, like 20,000-barrel oil wells, are rare. In fact, it could hardly be otherwise. It is absurd and unreasonable to expect a driller, whose principal job is not classifying but drilling rocks, to avoid serious mistakes when geologists who have spent years studying the rocks often make grievous errors in interpreting the available data, even where rock exposures are abundant.

In south-central Arkansas the identification of formations pierced by the drill is particularly difficult. Many of these formations are so similar that a geologist trying to differentiate between them can find little upon which to base his decision regarding their age and correlation. The task is further complicated by the notoriously inaccurate records commonly obtained by the rotary method of drilling, which in southern Arkansas is used almost to the exclusion of other methods. The only plan that gives even approximately satisfactory results where the rotary drill is used is to keep a complete set of samples from the well, each sample representing not more than 10 feet of strata, supplemented by core samples. These samples should be examined by a geologist competent to pass upon their mineral character, and any fossils they may contain should be classified by a competent paleontologist. Such a plan has been followed in the El Dorado field. A complete set of samples from the Standard Oil Co. of Louisiana's Ingram No. 5 well, in the center of the north side of the NE. ¼ NE. ¼ sec. 25, T. 17 S., R. 16 W., was supplied to the United States Geological Survey by the company and was carefully studied by Mr. Gilluly, whose determinations form the basis for this paper.

POSSIBLE ERRORS.

The samples were taken at such intervals that each represents about 10 feet of section. However, the introduction of mud into the well and the mixing of material that is unavoidable in work with the rotary drill masked somewhat the character of the beds which the samples represent. The fact that it takes some time for each sample to reach the surface after it is cut introduces a possible error, as the driller's calculations may be wrong and the sample which he marks as coming from one depth may in fact belong to beds a short distance either above or below that depth. The impossibility of completely representing 10 feet of beds by 3 or 4 cubic inches of sample must also be recognized. Because of these shortcomings the limits of the formations can not be fixed closer than 10 feet, and in the determinations based on samples obtained near the bottom of the hole the possible error is at least 20 feet. However, in spite of all these difficulties, which impair precision, it is certainly possible under this plan of examination to obtain definite knowledge about the rocks that have been penetrated and to fix formation boundaries within 10 or 20 feet.

METHOD OF EXAMINATION.

The composition of the samples was determined by examination under a binocular microscope, magnifications of 8 to 50 diameters being used according to the fineness of grain of the material. The proportions of sand and clay in each sample were estimated. In making this estimate all material that would go through a screen having 100 meshes to the inch was classed as clay. Part of the sample was then treated with hydrochloric acid to determine the content of calcium carbonate. Although the relative proportions of the different constituents determined by such estimates are undoubtedly inexact any attempt at refinement, such as weighing sifted samples, would also give erroneous results owing to the presence of drilling mud in the sample. After the percentage of sand, clay, and lime had been estimated, the clayey material was washed out and the residue was closely inspected for fossils and to determine the mineral character of the rock. Such fossils as were found were examined by L. W. Stephenson and Julia Gardner, of the United States Geological Survey, who succeeded in identifying forms that prove the presence of the Wilcox formation (Eocene) at 820 and 1,060 feet and of Upper Cretaceous beds at 1,760 feet.

Throughout the study a careful examination was made of the quartz grains that make up the sandy part of the samples, but no differences in degree of rounding, in sizing, or in surface etching were detected, except the natural association of the smaller grains with the prevailingly shaly members of the section and of the larger grains with the sandy beds. Although careful study was made to discover any correspondence between the positions of the "boulders" and "gravels" reported by the drillers to occur at certain depths and the amount of lime and limonite, possibly indicative of concretions, in the samples from these depths, no such correspondence was noted. This failure might be due to the fact that a small sample is not fully representative of 10 feet of sediments, and hence the rock of thin members might not be reflected in the character of the samples, or to the fact that the state of aggregation of the constituents of the bed is not revealed by the rotary drill, which, except for occasional iron (limonitic) concretions of clay substance, discharges only finely divided material, with very few cohering grains. Thus the same percentage composition of lime might in one sample mean a limestone bed and in another merely a fossiliferous shale.

FORMATIONS ENCOUNTERED.

The different rock types are described below in the order in which they were encountered. The zones indicated are shown by numbers at the left of the percentage log on Plate XXIV.

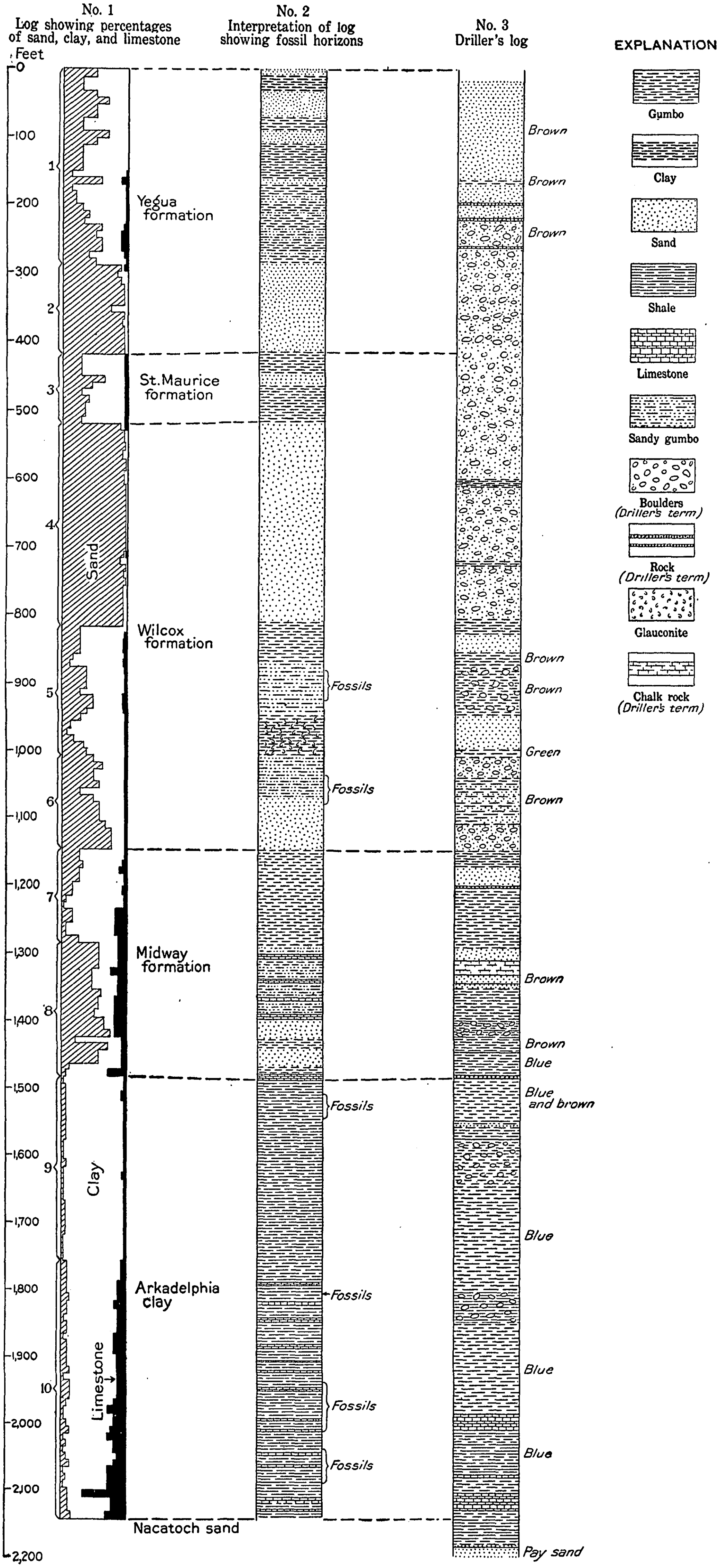
Zone 1. From the surface to a depth of about 290 feet the strata are dominantly sandy shale. Some beds contain so much sand that they may appropriately be called shaly sand, but none of the samples were pure sand The color ranges in general from light gray to medium gray but becomes brown in the samples near 290 feet. Clay makes up from 30 to 83 per cent of the material, averaging 56 per cent; sand averages from 15 to 80 per cent; and lime is present only in the basal part of the zone, where it constitutes from 2 to 10 per cent of the bulk of individual samples. Lignite and limonite are abundant in this zone. Glauconite is also common. No fossils were seen.

Zone 2. The group of beds from 290 to 420 feet is distinguished from the overlying beds by the absence of lignite and by the light-gray color throughout. It is also much more sandy, the beds consisting predominantly of sand, with a little clay and a very little lime near the top of the zone. The sand content of the samples averages 92 per cent and falls as low as 75 per cent in only one sample, so that most drillers would record this series as a single bed of sand. Only two of the samples studied contain lignite. Glauconite and limonite are common. No fossils were seen.

Zone 3. The group of beds from 420 to 520 feet may be distinguished from the overlying strata by its content of lime carbonate, which is uniformly present, by the common occurrence of lignite, and by a much greater percentage of clay. This zone is made up prevailingly of sandy shale, with a few beds of almost pure sand. The color is light gray, slightly bluish when wet, with a noticeable green tinge near the bottom. Sand averages 37 per cent, with a maximum of 65 per cent in a single sample and a minimum of 30 per cent in many of the samples. Clay ranges from 30 per cent in one sample to 65 per cent in several and averages 58 per cent. Limy material is uniformly present to the extent of about 7.5 per cent. Lignite is common, and small quantities of glauconite are also present. No fossils were seen.

Zone 4. The beds in the part of the section from 520 to 820 feet differ from those in zone 3 by showing a much greater percentage of sand, no lime, no limonite, glauconite, or lignite, except in the top 80 feet of the zone, and a few fossils, the first to be found in the section. This zone is almost wholly sand (95 per cent), and the remaining material is practically all shale. The color is light gray but in wet material ranges from light brownish gray to medium grayish brown. Small quantities of lignite, glauconite, and limonite appear in the upper 80 feet. A few shell fragments at widely separated points were the only fossils found.

Zone 5. The beds from 820 to 1,010 feet can be distinguished from the lower beds of zone 4 by the presence of glauconite and limonite, by the presence of calcium carbonate, which occurs in every sample tested, and by their much more shaly character. The change from beds that are practically all sand to beds that are mostly clay or shale is abrupt. The beds of this zone are sandy shale, with small amounts of lime. The sand averages 31 per cent but ranges from 10 to 50 per cent. Clay averages 66 per cent and ranges from 45 to 85 per cent. Limy material averages 3 per cent and does not exceed 5 per cent in any sample. Lignite is completely absent. Glauconite is present through the entire zone but is especially per-



LOG OF STANDARD OIL CO.'S INGRAM WELL NO. 5, SEC. 25, T. 17 S., R. 16 W., ELDORADO, ARK.

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sistent in the lower 20 feet, where it gives a decided greenish tinge to the clay. Limonite occurs in most of the samples. Fossil fragments which, according to Miss Gardner, probably represent forms of Wilcox age were found throughout this zone and are especially abundant at a number of horizons in the upper 100 feet.

Zone 6. The beds from 1,010 to 1,150 feet may be difficult to distinguish from those of zone 5, although strongly glauconitic beds plainly mark the base of that zone, and zone 6 also differs from zone 5 in that it contains lignite and a much greater percentage of sand. This zone is made up largely of shaly sand, which becomes a purer sand toward the base. The proportion of sand ranges from 30 to 80 per cent and averages 56 per cent. Clay ranges from 18 to 68 per cent and averages 42 per cent. About 2 per cent of limy material is commonly present. Limonite occurs in almost every sample, but only small quantities of lignite and glauconite are present. Fossil fragments were found throughout and are prominent at a number of horizons in the upper 70 feet, where the typical Wilcox association of forms was recognized by Miss Gardner.

Zone 7. The zone from 1,150 to 1,290 feet differs from zone 6 in that it contains an abundance of lignite and is also very shaly. The basal part of the zone may be identified by its high content of lime carbonate. The clay content of the samples from this zone ranges from 60 to 94 per cent. Sand ranges from 5 to 25 per cent and averages 21 per cent. Limy material increases from 2 per cent near the top to 15 per cent just above the base. The color ranges from light gray to grayish brown and is slightly darker in wet material. Lignite is abundant, glauconite was found in every sample, and limonite in almost every one. Shell fragments are common throughout the zone and are particularly abundant near the middle, but no recognizable forms were noted.

Zone 8. The zone from 1, 290 to 1, 470 feet differs from zone 7 in being much more sandy. The beds of this zone are limy, sandy shale, with some thin beds of pure sand and of pure clay. The sand content averages about 60 per cent. Clay ranges from 5 to 70 per cent and averages 20 per cent. Limy material ranges from 5 to 20 per cent and averages 12 per cent. The color ranges from light gray to brownish gray and is more strongly brown in wet material. Lignite is present in most of the samples. Glauconite occurs near the top and near the base, but beds near the middle of the zone seem to have little or none. Limonite occurs in almost every sample. Fossil fragments were found in many of the samples and are particularly abundant about 110 feet below the top.

Zone 9. The zone from 1,470 to 1,760 feet should be easily distinguished from the overlying zone 8 by the almost complete absence of sand, which ranges from 2 to 15 per cent and averages about 6 per cent. Limy material ranges from 2 to 25 per cent and averages 3 per cent. The bed containing 25 per cent of lime is at the top of the zone and probably represents a thin bed of limestone. Clay makes up 90 per cent of the samples. The color of the samples from this zone is gray, with a noticeable bluish tinge in samples obtained near the top. When wet the samples range in color from dark gray to brown. Lignite is present only in the upper 100 feet of the zone. Glauconite is present throughout but is not conspicuous. Limonite is commonly present. Many Foraminifera and other fossils were found, especially in the top part of the zone. A fragment of *Inoceramus*, an Upper Cretaceous form, was identified by L. W. Stephenson in a sample representing a depth of 1,760 feet.

Zone 10. The zone from 1,760 to 2,143 feet is distinguished from the overlying zone only by a slightly greater content of sand and by its high content of lime. Sand ranges from 4 to 15 per cent, with an average of about 10 per cent. Clay ranges from 7 to 85 per cent and averages 15 per cent. The samples are light gray to medium gray, with a bluish tinge. They become darker when wet but show no other appreciable color change. Glauconite is present in most of the samples. Limonite is common. Lignite occurs sparingly near the top of the zone. The middle part of the zone is free from limonite, but some is present near the base.

The formations represented by the ten zones above described are thought to be the Yegua, St. Maurice, Wilcox, and Midway, all of Tertiary age, and the Arkadelphia, of Upper Cretaceous age. It is not possible to determine exactly the boundaries of these different formations because of the lack of sufficient fossil evidence. However, fossils were found that definitely fix the Wilcox age of zone 5 and the upper part of zone 6, and the Upper Cretaceous age of the basal part of zone 9. With these bits of evidence, combined with the known characteristics of the formations at their outcrops, the positions of the formation boundaries in this well may be tentatively assigned with a strong probability of accuracy. On this basis, then, zones 1 and 2 are assigned to the Yegua formation, of Eocene age. The Yegua at the type locality is a prevailingly sandy formation, and its thickness agrees with the 420 feet included in these two zones. Zone 3 probably represents the St. Maurice formation, of Eocene age. The St. Maurice has been described as a soft shale, and the thickness of zone 3 (100 feet) is about what the thickness of the St. Maurice should be at El Dorado, which is near the margin of the area where it was laid down. Zone 4 on the basis of lithology should be equivalent to part of the Wilcox formation, of Eocene age. Zones 5 and 6 are shown definitely by fossils to be of Wilcox age, and their composition agrees with the descriptions of exposures of the lower part of that formation. The Wilcox at El Dorado is therefore about 630 feet thick. The 320-foot section comprising zones 7 and 8 is referred to the Midway formation (basal Eocene). This correlation is based upon the amount of lime in the samples, for the Midway is characterized by its high lime content. In other respects these zones do not agree well with the typical Midway. For example, they are very lignitic, and the Midway at its outcrop contains very little lignite. It is possible that the Midway is so thin as to be undetectable in the El Dorado field and that these beds should be assigned to the Wilcox. Zones 9 and 10 are thought to be unquestionably the Arkadelphia clay, of Upper Cretaceous age. This correlation is based on the Cretaceous age of several fossils identified by L. W. Stephenson and on the similarity of the beds in these zones to the Arkadelphia at its type locality. The thickness of 650 feet given to these zones agrees well with the thicknesses measured where the boundaries of the formation could be definitely determined.

No samples representing the Nacatoch sand, which is the producing formation of the El Dorado field,[1] were included in this set, so its character could not be determined.

The utilization of the descriptions given above should aid both in interpreting records of wells that have been drilled and in enabling those who are watching drilling that is in progress to tell just what zone the drill has reached. The 100-foot band of clay or shale which has been assigned to the St. Maurice should be easy to detect. Its top should lie from 350 to 500 feet below the surface in central Union County. The break between the Wilcox and the Midway is also sharp and should not be hard to locate if the driller is looking for it, as the drill would pass from a heavy sandstone into a shale that is only slightly sandy. It is particularly important to recognize this contact, as oil or gas may be encountered anywhere below it, and a constant lookout for showings should be maintained after the Midway has been reached. This contact should lie from 1,100 to 1,200 feet below the surface in the El Dorado region. The contact of the Midway and the Arkadelphia should also be easy to recognize, as it is marked by an abrupt change from a formation which is very sandy and which may also contain thin beds of limestone to one that is dominantly shale (which may be recorded in the log as "gumbo," "clay," or "shale").

Glauconite and lignite should also help the observer in identifying the formations penetrated by the drill. The most strongly glauconitic beds occur in the lower part of the Wilcox, where in places there is so much glauconite that the sand looks decidedly greenish. The presence of abundant lignite at a depth of about 1,200 feet will indicate the Midway formation.

[1] Rubey, W. W., Oil from the Nacatoch sand, El Dorado, Ark.: U. S. Geol. Survey press notice, Feb. 7, 1922.

Fossils should, of course, be carefully looked for. Any company that proposes to drill extensively in Louisiana and Arkansas could to advantage maintain a paleontologist on its staff. Many of the forms that will be encountered will be new, and to obtain the best results from fossil study the paleontologist must devote much time to studying, describing, and portraying the forms he finds. He can not depend upon descriptions that have been already published, for only a comparatively small percentage of the microscopic forms he will find have ever been described. Yet such microscopic forms are in places very abundant and will furnish precise and conclusive evidence as to the age of the beds if they are painstakingly collected and studied.

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