THE GEOLOGY OF THE BLUE SPRINGS GAS FIELD

Jackson County, Missouri

By

GLENN G. BARTLE

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H. A. BUEHLER

Director and State Geologist

ROLLA, MISSOURI

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THE GEOLOGY OF THE BLUE SPRINGS GAS FIELD, JACKSON COUNTY, MISSOURI

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INTRODUCTION

The Blue Springs Gas Field has been developed chiefly by the Production Department of the Panhandle Eastern Pipe Line Company of Kansas City. The first wells in this region were drilled in the Spring of 1928 in the western part of the region, near Raytown. The extension of this field to the east was made in the summer of 1929 under the direction of the writer, and all of the later drilling, responsibility for locations, collection of samples and other geological work has been under his immediate supervision.

Since the geological information has been centralized in this case and since there has been unusually good cooperation with the scattered independent producers in the region, it would appear that this area provides an exceptionally favorable opportunity for studying a region which, in essentials, is typical of the shallow gas fields of northwestern Missouri and eastern Kansas. The chief irregularity in this region which may not be expected elsewhere is the Channel Sand in the Pleasanton, discussed later in detail. In respect to other conditions of structure and stratigraphy, the Blue Springs region is typical.

Three hundred and ten drillers' well logs have been used in this study and more than half of these wells were drilled under the close supervision of the writer. The elevations of all wells have been taken by plane table and alidade. About six hundred elevations have been taken on the top of the Bethany Falls limestone while determining well locations and before and during drilling. These six hundred elevations were also taken by plane table and alidade and referred to sea level datum.

ACKNOWLEDGMENTS

The writer wishes to express his indebtedness to the Panhandle Eastern Pipe Line Company for permission to publish the great bulk of the statistical information in this report, including

the logs of most of the wells, the figures of the production of the wells, and the structural information which was worked out by the writer while in the employ of this company. Thanks are also due to Mr. J. D. Judd and his corps of drillers who took unusual care in keeping accurate logs and saving samples of well cuttings.

The writer was assisted in the field by Mr. Earl E. Marshall, Mr. Joseph Spaulding, Mr. Kenneth Case, Mr. Joseph Clair, Mr. Nester Judd, and by Mr. Richard Schweers, who also served as draftsman.

In working up this material at Indiana University, many valuable suggestions have been made by members of the Department, including Professor C. A. Malott, Professor W. N. Logan and Professor E. R. Cumings. Dr. Cumings has also read the entire manuscript and made helpful suggestions as to arrangement of subject matter and clearness of phraseology.

GEOGRAPHIC RELATIONS

LOCATION AND AREA

The field is located in the south central part of Jackson County, Missouri. As indicated on the map (Fig. 1) it comprises an area of sixty-six square miles, including all of Township 48 N., R. 31 W., except two sections in the extreme southeastern corner and all of Township 48 N., R. 32 W., except two sections in the northwestern part and two sections in the southwestern part.

FIG. I.

Map showing the location of the Blue Springs district.

The northwest corner of this area is within two miles of the eastern boundary of the city limits of Kansas City. Raytown is within the field, near the northwest corner; Lees Summit is in the two sections adjacent to the middle of the south line, and Blue Springs is in the two sections adjacent to the northeast corner of the area.

It may be seen that the whole area is within close proximity to a very populous territory, and is extremely well located for the profitable production of natural gas. Jackson County is in the northwest corner of that part of Missouri which lies south of the Missouri River. It is bounded on the west by Johnson and Wyandotte counties, Kansas; and the gas field area is itself only six miles east of the Kansas state line.

RELIEF

Scarped Plains

The Blue Springs gas field is located in the physiographic region known in Missouri as the Scarped Plains.[1]

The Pennsylvanian series of Missouri is composed of alternating limestones and shales, with minor amounts of sandstones and coals. The limestones are more resistant to erosion than the other units, and a series of escarpments have been developed on the formations, which are dipping gently away from the Ozark uplift. These escarpments do not maintain their new levels but have a dip slope toward the west and northwest until they in turn are succeeded at the surface by younger members of the Pennsylvanian series.

These Scarped Plains are well developed in this vicinity. Immediately to the east the chief outcropping formation is the Pleasanton shale, through which the streams have easily cut. In the Blue Springs region, however, the overlying Kansas City formation, especially the Bethany Falls and the Winterset limestone members, form an escarpment at their first outcrop west of this lowland. Farther west in the district south of Raytown, the Iola limestone, which is the top member of the Kansas City formation, caps the hills. In this region the slope of the hills is composed of the soft Chanute and Cherryvale shales, and the deepest valleys expose the Winterset and Bethany Falls limestones as benches on the hillside. Wherever the streams

[1]Marbut, C. F., Physical features of Missouri, Mo. Geol. Surv., Vol. 10, 1896, pp. 14-109.

are able to cut through the lower part of the Kansas City formation (the bench) they are certain to go on deeply into the Pleasanton.

Uplands

Divides. There are three main divides which are wholly or partly within this region. All three are underlain by the Kansas City formation, and therefore, are broad and gently rolling topographic features, up to the edge of the sharply entrenched stream valleys. This highland is cleared and forms a fertile farming country. The "breaks" into the stream valleys are practically all heavily wooded and can be seen from almost any point on the divides.

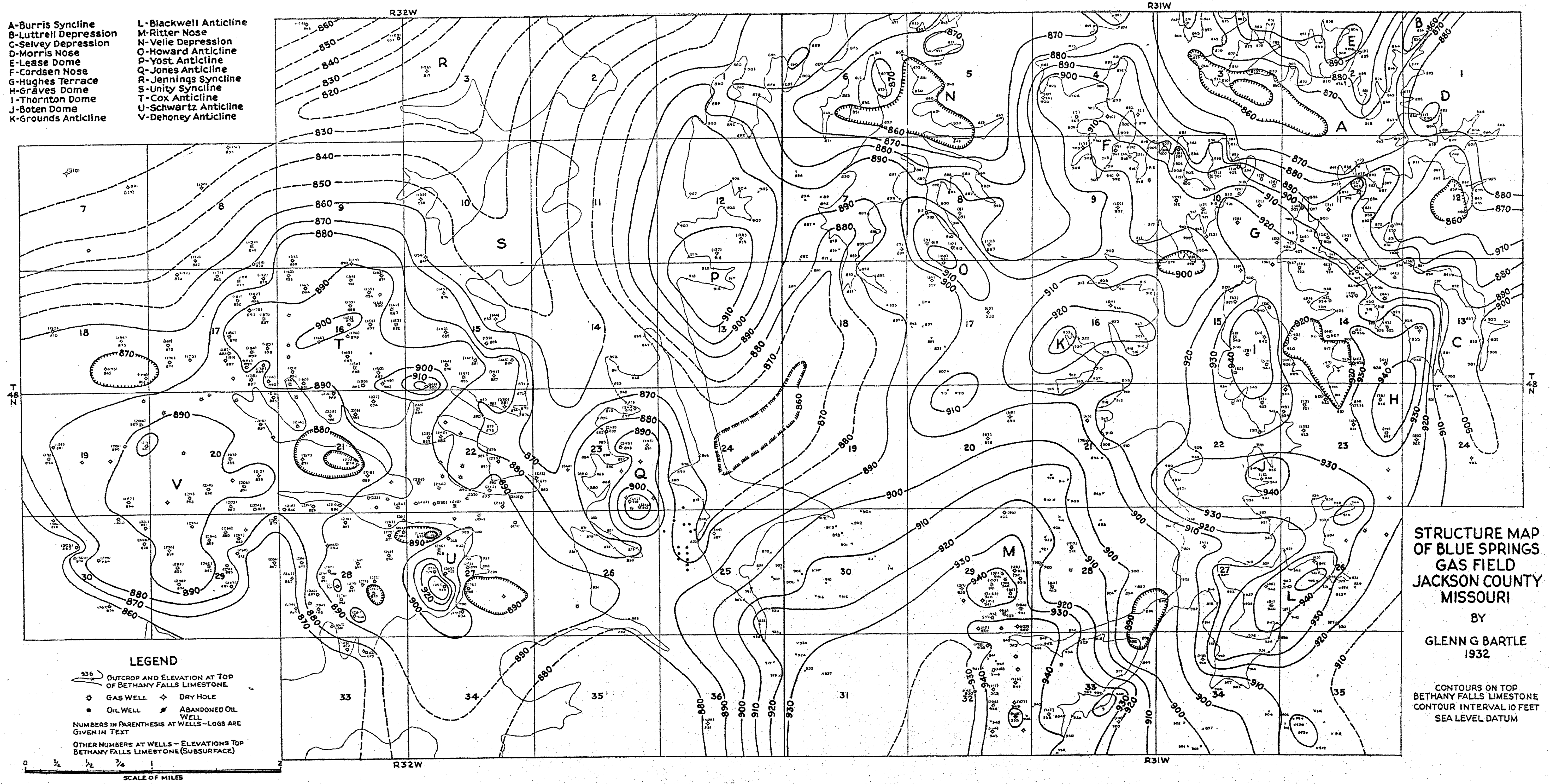
The most easterly divide is between the East Fork of Blue River and Sni-a-bar Creek. Only a small portion of it lies within the area mapped, most of it extending to the east. The tributaries of the East Fork of Little Blue River have cut back into this plain and there are especially prominent long northwest-southeast ridges between them.

The middle divide is between Little Blue River and the East Fork of Little Blue River. It includes the flat country of large farms immediately north of Lees Summit. It is also characterized, especially in the northern part of the area, by many long finger-like projections of highlands overlooking the tributaries of Little Blue River and the East Fork of Little Blue River. The formations exposed along these projections furnished the information which was responsible for the drilling of wells which "brought in" the Blue Springs gas field.

The most westerly divide comprises the region south of Raytown. It is between the Little Blue River and Blue River, which flows through Kansas City. Since the Iola limestone is found in the tops of these hills and the Winterset-Bethany Falls level is represented by a bench, the general type of topography is a little rougher than on the other divides.

There does not seem to be any relation between the structure and the topography of this region, except that of the Scarped Plains which result from the monoclinal dip away from the Ozarks.

Bethany Falls escarpment. The Bethany Falls limestone, quite uniformly about 20 feet thick, is underlain in order by the Ladore shale, about 10 feet thick, the Hertha limestone, about 7 feet thick, and the Pleasanton shale, about 175 feet thick.



Structure map of Blue Springs gas field, contours on top of Bethany Falls limestone.

The Bethany Falls limestone is much more resistant to denudation than these underlying units and forms the cliff-like Bethany Falls escarpment, by far the most conspicuous topographic feature of the entire region.

The joint planes are very definite and far apart, and solution is active along them, so that the ledge of Bethany Falls limestone is usually broken into large blocks averaging about twenty feet square. These blocks frequently slump down the side of the stream valleys and may even be recognized in the stream beds. Usually, however, they are close to the parent ledge and are weathering by solution at the present time, as isolated boulders.

This remarkably persistent ledge of rock may be followed for miles, without once losing sight of it. It was used in making the structural geological map of the region and the position of the outcrop in the district is indicated on the map (Pl. I). Because of the tendency to slump, the top rather than the base of the formation was used as the datum plane for taking elevations and drawing structure contours.

Loess. Deposits of loess clay cap the divides. It serves to increase the heights of the divides and to obscure the outcrop of the upper formations. This is especially true where the loess is deposited on top of the Chanute or Cherryvale shale. In many cases it is difficult to distinguish the weathered loess and the weathered shale. This condition makes it impossible to do stratigraphic work on the divides over certain parts of this area. The dip of the rock formations must be determined on the Bethany Falls and Winterset formations at the break of the hills and then projected back into the flat lying, loess-covered divides.

STRATIGRAPHY

PENNSYLVANIAN SYSTEM

General relations. In this area the bed rock formations at the surface and in the shallow gas wells are all of Pennsylvanian age. In Missouri the Pennsylvanian is represented by about 1900 feet of sediment. This includes shale, sandstone, limestone, fireclay, and coal. It is the surface formation over the entire northwestern portion of the State, covering about 24,000 square miles.

In the area under discussion, only the lower portion of the section is represented, the total thickness being about 850 feet. The formations present are shown in the following table:

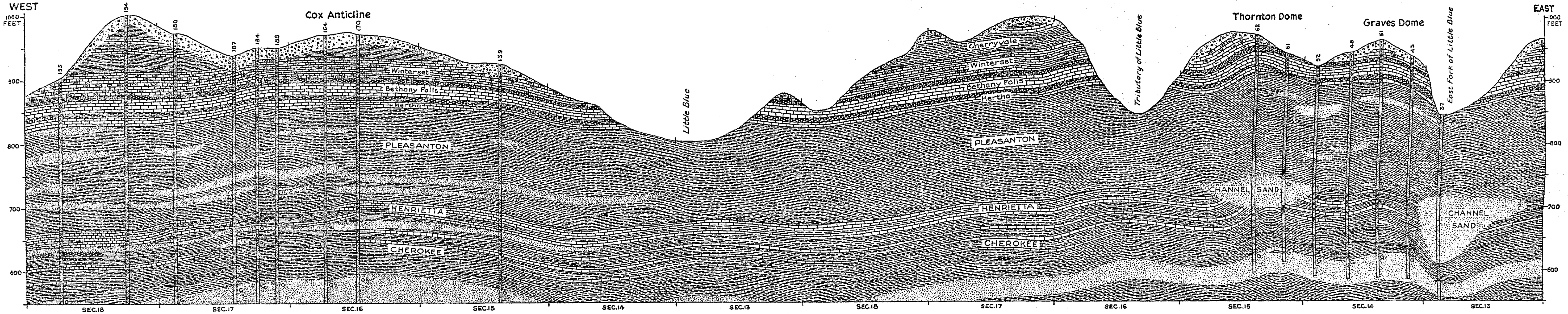
Group.	Formation.	Member.	Thickness.
Missouri.	Kansas City.	*Iola limestone **Chanute shale with Raytown and Cement City limestone. **Drum limestone. **Cherryvale shale. **Winterset limestone. **Galesburg shale. **Bethany Falls limestone. **Ladore shale. **Hertha limestone.	215 feet.
Des Moines.	***Upper Pleasanton.	Not subdivided.	175 feet.
	****Lower Pleasanton.	Not subdivided.	
	****Henrietta.	Pawnee limestone. Labette shale. Fort Scott limestone.	45 feet.
	****Cherokee.	Not subdivided.	440 feet.

*Only lower portion exposed in this area.
**Exposed in this area.
***Only upper portion exposed in this area.
****Not exposed but known by well drilling.

The structural relations in Missouri are relatively simple. The Ozark uplift in the southeastern part of the state has brought the oldest strata to the surface and permitted erosion of the younger formations. The younger rocks are in an elliptical band, therefore, around this old geanticline. Each formation including the Pennsylvanian has its beveled edges exposed at the surface. The regional dip is outward and younger formations are exposed at the surface with progressive distance from the Ozark uplift.

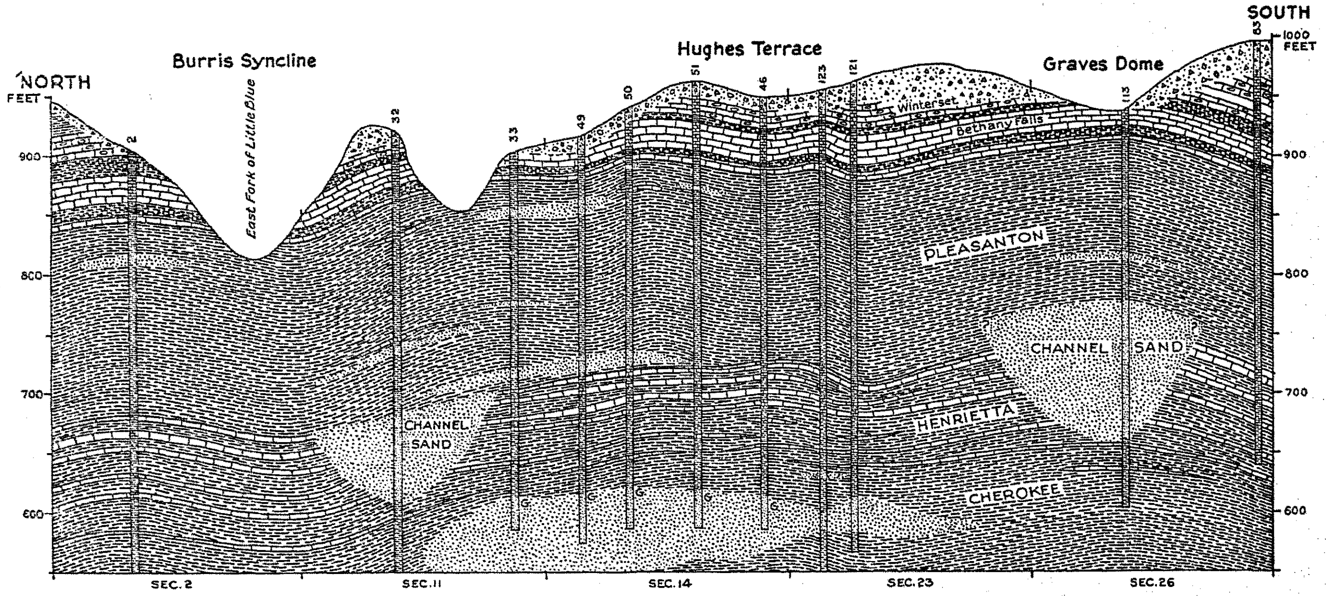
The total thickness of the Pennsylvanian rocks in Missouri may be found in wells in the extreme northwest corner of the State. At any single point in northwestern Missouri a well will penetrate formations which outcrop towards the southeast. There are some structural terraces and local reversals of dip and thinning of beds, but in the main these conditions are remarkably uniform.

It was originally thought that there were great differences in these groups owing to the presence of much limestone in the Missouri group and its absence in the Des Moines group. It



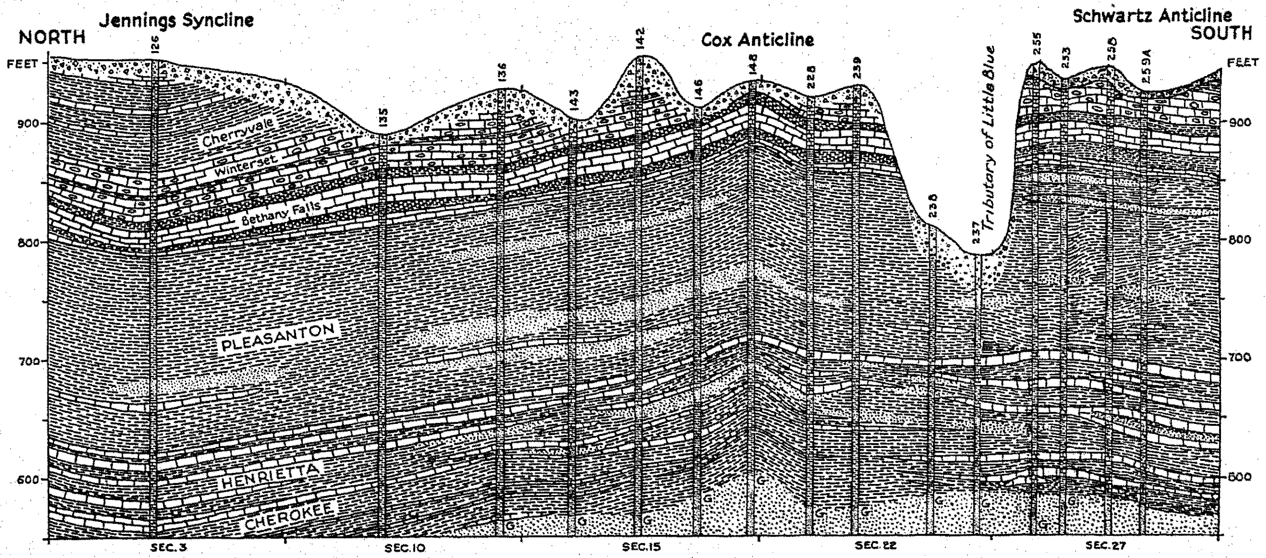
EAST-WEST GEOLOGIC SECTION THROUGH THE BLUE SPRINGS GAS FIELD. A-A OF SQUIRREL SAND STRUCTURE MAP

VERTICAL EXAGGERATION 26.4



NORTH-SOUTH GEOLOGIC SECTION THROUGH EASTERN PART OF THE BLUE SPRINGS GAS FIELD. B-B OF SQUIRREL SAND STRUCTURE MAP

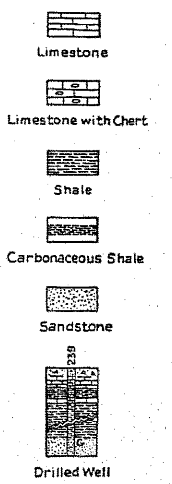
VERTICAL EXAGGERATION 26.4



NORTH-SOUTH GEOLOGIC SECTION THROUGH WESTERN PART OF THE BLUE SPRINGS GAS FIELD. C-C OF SQUIRREL SAND STRUCTURE MAP

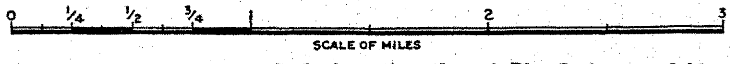
VERTICAL EXAGGERATION 26.4

LEGEND



SEA LEVEL DATUM

GLENN G BARTLE
1932



Geologic sections through Blue Springs gas field.

now seems more plausible to draw the line between these groups within the Pleasanton formation at the level of the unconformity rather than at the top of the Pleasanton, but no recent revision of the Pennsylvanian nomenclature of Missouri has been attempted.

In the Mid-Continent region Moore[1] has recently reclassified the stratigraphy of the Pennsylvanian system. In this report, however, the nomenclature adopted by this Survey in a former publication is used.[2]

The formations of the Pennsylvanian system exposed in the central part of Jackson County are indicated by the geologic cross-sections (Pl. II), which also show the structure of the Blue Springs district. As indicated in these tables and diagrams the Pennsylvanian in this district is composed of alternating limestones and shales, in the Missouri group; and of shales, sandstones, limestones, coals and fireclays in the Des Moines group. A detailed description of these formations is given in the remainder of this section.

CHEROKEE FORMATION

The Cherokee is the oldest formation of Pennsylvanian age in Missouri. It is usually undifferentiated and is so considered in this report. Locally, it has been subdivided but these subdivisions do not apply to this area and may be omitted from this discussion.

Lithologic character. The Cherokee is mainly a series of shales. These are interbedded with comparatively small layers of sandstone, limestone, or coal, but the formation as a whole is always characteristically argillaceous.

In Callaway County in Central Missouri there are local beds of limestone which are important in the Cherokee; and in Johnson, Henry and Bates counties, immediately southeast of the Blue Springs district there are also thick limestone beds. In Jackson County there are no outcrops of the Cherokee of importance, but wells show two persistent thin beds of limestone within the upper 50 feet of the formation.

In drilling in this region beds of coal which are known to occur elsewhere in Missouri are usually logged by drillers as black shale or "slate".

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[1]Moore, R. C., A reclassification of the Pennsylvanian system in the northern Mid Continent region, The Kansas Geol. Soc., Guide Book, 6th Ann. Conference, pp. 79-98, 1932.

[2]Hinds, Henry, and Greene, F. C., The stratigraphy of the Pennsylvanian series in Missouri; Mo. Bur. Geol. and Mines, Vol. XIII, 2nd Ser., 1915.

The sandstone lenses within the Cherokee have been important producers of oil and gas in eastern Kansas and more recently in western Missouri. In this district two chief gas bearing formations have been recognized, the Bartlesville and the Squirrel. The Bartlesville is about 225 feet below the top of the Cherokee and has been found in only a few places in western Missouri although many wells have been drilled to the level at which it might be expected. It is the chief producing formation in Greenwood County, Kansas;[1] in the Eldorado, Kansas fields[2] and in many other fields in eastern and southeastern Kansas and northern Oklahoma. One well in the Blue Springs field produces gas from this horizon. This well, Graves No. 1, Map No. 78, NE. ¼ sec. 23, T. 48 N., R. 31 W., evidently struck a small lens, since wells one-quarter of a mile away both south (Map No. 79) and west (Map No. 123) did not obtain any gas nor any considerable amount of sand. When present the Bartlesville is a fine-grained, brown colored sandstone, without shale partings, and usually about 40 feet thick.

The Squirrel sand is the chief gas producing horizon in western Missouri. It may be absent locally but in the Blue Springs field it is present in most of the wells drilled. It is usually found about 50 feet below the top of the Cherokee, but in some wells it is as much as 20 feet lower than that figure. The Squirrel sand is coarse grained, porous, buff to brown in color, occasionally broken by hard calcareous or argillaceous layers. Usually when gas is found, drilling is stopped and there is no way of knowing the total thickness of the sand. Wells which have drilled through this horizon indicate that this sand will average about 40 feet in thickness.

Other non-persistent lenses of sandstone are frequently found in the Cherokee, especially toward the base of the formation. They are usually logged as water sands when encountered in wells. At the outcrop these sands have been studied and named separately. At the base of the Cherokee a considerable body of sandstone, sometimes conglomeratic, is usually found. Because this is the horizon of the major unconformity between the Mississippian and the Pennsylvanian, there are sometimes large pieces of chert in the loose conglomerate at the base of the series. This chert surface, often called "Chat" yields gas in

[1]Cadman, W. K., The golden lanes of Greenwood County, Kansas, Bull. Am. Ass. Pet. Geol. Vol. II, pt. 2, 1927, pp. 1151-1173.

[2]Fath, A. E., Geology of the Eldorado oil and gas field, Butler County, Kansas, State Geol. Surv. of Kansas, Bull. 7, 1921, 187 pp.

the Osage Nation of Oklahoma and the Longton arch of southern Kansas; but in western Missouri it has always been found full of water.

It will be seen, therefore, that the Cherokee shales are broken by (1) lenses of sandstone, (2) beds of coal and black shale, and (3) thin bedded limestones. In addition, the shale assumes somewhat different characteristics from place to place, with respect to color, bedding, hardness, and nature of impurities. In the main these phases are non-persistent; but in drilling a well the careful driller will report several different types of shale. It is possible that careful stratigraphic work at the outcrop would reveal differences in the nature of the shale and the position of the sandstones, coals, and limestones, which would justify the subdivision of the Cherokee into members, with local facies changes accounting for the irregularities. Such work has not been done as yet.

Thickness. The thickness of the Cherokee will vary sharply within a small area, due to the fact that the floor of Mississippian limestone had been previously eroded. At the outcrop both stream valleys and sink holes may be recognized in the Mississippian limestone surface. Undoubtedly both these features exist throughout most of the area now covered by the Cherokee formation.

In the Blue Springs district the diamond drill hole known as the Raytown well, Map No. 310, NW. ¼ sec. 7, T. 48 N. R. 32 W., shows a total of 420 feet of Cherokee; the Unity well Map No. 249, NW. ¼ sec. 25, T. 48 N., R. 32 W., shows 387 feet; the Oscar Boten well, Map No. 84, SW. ¼ sec. 28, T. 48 N., R. 31 W., shows 366 feet; and the Lund well, Map No. 60, NE. ¼ sec. 15, T. 48 N., R. 31 W., shows 401 feet. Since these figures are measurements of the thickness of a formation which immediately overlies an unconformity, such irregularities might be expected, and are without any particular significance. Reference to the Oscar Boten well, Map No. 84, will show the details of the Cherokee section.

HENRIETTA FORMATION

Subdivisions. The Henrietta formation as defined by the Missouri Geological Survey and as used in this paper, includes the Ft. Scott member at the base, the Labette member in the middle and the Pawnee member at the top. This represents the middle formation of the Des Moines series. It includes the members of the same name making up the lower part of the Marmaton of Kansas.

Lithologic character. The upper limestone of the Pawnee and the lower limestone of the Fort Scott are quite persistent and may usually be readily identified either at the outcrop or in a drill hole. The middle of the formation is much more variable, however, because adjacent wells show gradation into sandy lime and pure limestone at the same level.

The black shales interbedded between the Henrietta limestones are the main source of shale gas in the Cherryvale, Chanute and Paola gas fields of eastern Kansas. They are usually less than five feet in thickness, for any one bed, but produce as much as 300,000 to 400,000 cu. ft. of gas open flow per day. As indicated elsewhere in this report a few wells produce shale gas from this level in the western part of the Blue Springs field. In this field, however, the average open flow of the shale gas wells is only about 100,000 cu. ft. per day. A great deal of salt water is produced with the shale gas and the structural conditions are not especially important in determining the amount of gas produced. This production of shale gas has been carefully discussed by Charles and Page.[1]

As the stratigraphic cross-sections show, the limestones and the shales of the Henrietta formation intergrade over most of the Blue Springs area, four limestones of Henrietta age being distinguished. In some wells there are five, however, and in a few only three.

In Bates and Vernon counties there are beds of coal within the Henrietta formation. Farther north, however, these horizons are not definitely recognized or are represented by black shales.

Thickness. In the Blue Springs field the total thickness of the Henrietta is about 45 feet with very little variation from that figure. There is no regularity about the slight changes in thickness of the formations, and, as has been mentioned, no apparent relation to structure.

PLEASANTON FORMATION

Subdivisions. The beds between the Hertha limestone member of the Kansas City formation and upper Pawnee limestone of the Henrietta formation make up the Pleasanton.

[1]Charles, Homer H., and Page, James H., Shale—Gas industry of eastern Kansas, Bull. Am. Ass. Pet. Geol., vol. 13, pt. 1, 1929, pp. 367-383.

There has been a further subdivision of this formation in Kansas, but unfortunately the limestones of the Kansas section are not persistent in Missouri and the whole series has remained undifferentiated. The unconformity within the Pleasanton may make it necessary to subdivide this formation later, but this has not been done in Missouri because of the similar lithologic conditions above and below the break.

Lithologic character. The Pleasanton is a shale with very little variation except an occasional sandy phase. It usually is very difficult to distinguish the horizons of this formation because of the similarity of the lithology.

In the Blue Springs area there is one sandstone member which occurs with greater regularity. This lens is about 10 feet thick and lies about 50 feet below the top. Other sandstone lenses seem to be entirely irregular.

Thin limestones are found in this formation in Bates County in southwestern Missouri, which may be correlated with the Altamont limestone of Kansas. Other limestone members in the northern part of the State, however, are probably not of exactly the same age. In a few wells within the Blue Springs district, a foot or two of limestone has been logged within the Pleasanton, but in every case these beds are non-persistent and cannot be located in wells a mile or so away.

Two thin coal seams have been mined from within the formation. The Ovid coal is near the top and the Mulberry coal lies near the base. Neither of these have been recognized in Jackson County.

Near the base of the Pleasanton formation considerable sandstone has been recognized in Livingston County[1] and also in a large number of wells in Miami County, Kansas, where oil is produced from this level. This is known as the Big Lake sand. It is very probable that this sand is to be correlated with the channel deposit rather than with the Pleasanton formation. This deposit will be discussed in detail in the next section.

Thickness. In Jackson County a thickness of 175 feet has been measured at many places, with very little change from that figure. Where the channel deposits are found the total thickness of the Pleasanton cannot, of course, be measured because the base is not known, but elsewhere a variation of thickness of ten feet is quite unusual.

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[1]Hinds, Henry, and Greene, F. C., The stratigraphy of the Pennsylvanian series in Missouri, Mo. Bur. Geol. and Mines, 2nd series, vol. 13, 1915, pp. 1-256.

is full of salt water. In the lower part of the sand in Well No. 10, T. C. Howard No. 2, a considerable showing of oil was encountered, but no commercial oil well has been found in this formation in the Blue Springs field.

The location of this channel sand can only be known in so far as drilling has brought the information to light. The Ritter nose in secs. 29 and 32, T. 48 N., R. 31 W., the Howard anticline in secs. 8 and 17, T. 48 N., R. 31 W., and the Blackwell anticline in secs. 26 and 27, T. 48 N., R. 31 W., all produce gas from this sand. Two other scattered wells show the deposit, Well No. 37, at the edge of the Graves dome in sec. 13, T. 48 N., R. 31 W., and Well No. 32 at the edge of the Hughes terrace in sec. 11, T. 48 N., R. 31 W. In so far as any direction may be determined from the location of these wells it would seem that the trend of these deposits is north-south. This is a very incomplete observation, however, since it is limited to a very large extent by the direction of drilling. Enough drilling has been done to indicate that the channel deposits are most certainly discontinuous, with no single connection between all of them. If this type of deposit represents stream valley fillings there must have been more than one of them within the eastern part of the Blue Springs gas field area.

It is interesting to note that from about 125 wells in the eastern township of the Blue Springs area, thirty wells showed the channel type of deposit, but 185 wells in the western township failed to show it in a single well. It may be suggested, however, that the oil and gas horizon fifty miles toward the southwest in the Paola, Kansas, field, known as the Big Lake sand, may be correlated with this channel deposit.

Other channel deposits. Channel deposits which have been the most carefully studied at the outcrop, are the Warrensburg and Moberly. Each of these, known from many observations, extends a long distance laterally, and forms definite stratigraphic horizons. Others which are known only from one or two exposures are at Hallsville, Boone County; at Duncan's Bridge, in Monroe County; at Woodville, in Macon County; and at Wheeling, in Livingston County. There are many other places in northern Missouri where the Pleasanton has a great deal of sandstone and exhibits other peculiarities which might be an indication of an unconformity; but these are not at all conclusive.

Significance. While at this time the exact age of these deposits is not known, obviously they are younger than the

In the Blue Springs gas field there is little variation from the general section. The slight local thickening and thinning of these formations is shown on the stratigraphic profile sections (Pl. II).

Hertha limestone member. The Hertha, the lowest member, is co-extensive with the Kansas City formation but does not always outcrop because of the unusually massive nature of the Bethany Falls limestone above, which has a tendency to slump over it. It varies in thickness in the Blue Spring field from 5 to 15 feet, being somewhat thicker in the western half of the area. Thicknesses greater than 15 feet usually include part of the Ladore which has some limestone in it.

The Hertha is light gray but weathers to chocolate brown and is locally known as the "Chocolate Rock." Because of its position just above a large body of shale, it may be recognized in a well by drillers. A great deal of the subsurface correlation in this part of Missouri has been on the base of the Hertha. Drillers are usually required to run a measuring line at this level.

The upper part is nodular and sometimes passes into the overlying shale without a definite break. The lower part is dense, fine-grained, and less argillaceous. Calcite replaces many fossils in this formation and irregular spots of clay are not unusual. At the outcrop good joints are found in the Hertha but the blocks developed by the jointing system are usually somewhat less than one foot square.

Ladore shale member. Like the Hertha, the Ladore is co-extensive with the Kansas City formation but it is not often seen in outcrop, owing to the slumping of the Bethany Falls limestone. It is usually less than 10 feet thick, but varies locally and seems to have some slight tendency to thin toward the west. There is usually one small bed of limestone within the Ladore shale horizon and in some places there are two such beds.

Where there is any considerable thickening of the Ladore it is usually through the enlargement of the black shale member. This is not important in the Blue Springs field, but in the southern part of Jackson County near Greenwood there are outcrops of Ladore which could easily be mistaken for the Galesburg black shale except for its relations to the limestones above and below. Phosphatic, fossiliferous concretions are common in the black shale.

ing Bethany Falls. This is due to the fact that a heavy bed of shale overlies the Winterset, and that the thin breaks within the formation permit various intermediate topographic levels to develop. The presence of a quantity of loose chert in the soil in this area is almost a sure indication of the horizon of the Winterset, since no other limestone in the region contains any considerable amount of this material.

A thickness of 30 to 35 feet is common in this bed, but the top of the formation is frequently eroded away, especially in the eastern part of the Blue Springs field. As indicated on the stratigraphic profile, the total thickness is usually broken into several beds of limestone with thin shale partings between them. The limestone is quite crystalline, usually blue or gray and has slight irregularities in the bedding planes. There is chert throughout the formation, but in greater proportion near the top. This chert may be nodular or laminated. On a weathered surface there is a greater percentage of siliceous material.

At the base of this member a very thin limestone and a thin shale are found. Above this level is one of the most persistent ledges—a 5 or 6-foot bed which splits up into blocks about one cubic foot in size. Above this bed is a thin shale parting, then a two-foot ledge similar to the preceding. Another thin shale is followed by a ledge from six to eight feet thick. These three ledges make up the Lower Winterset.

The base of the Upper Winterset is made up of two or three feet of gray shale. This is followed by a bed about 15 feet thick of massive limestone and black chert. On weathering the entire upper Winterset separates into irregular beds with undulating surfaces.

Locally the Winterset is oölitic and cross-bedded; but this is rare. In any event it could hardly be confused with the overlying Drum which is much more massive.

Cherryvale shale member. It is difficult to determine positively whether or not the Cherryvale shale is present in the Blue Springs area, since the Drum limestone which accompanies this member is usually absent because of unconformity, and the Cherryvale itself can rarely be distinguished from the Chanute. McCourt and Bennett have mapped the Cherryvale-Drum as the chief plateau formation in the area. This is logical, based upon the height of the land surface above the underlying Bethany Falls and Winterset formations; but there are few outcrops to substantiate this conception. Well records show shale under-common, although, as has been indicated, it is doubtful in many instances where the line between the Chanute and the Cherryvale should be drawn.

The thickness varies from 54 to 80 feet in Jackson County[1] but is nearer to the smaller figure in the central part of the County. It is composed largely of gray shale but is interbedded with thin limestone members, the two most persistent ledges being the Cement City and the Raytown. It is customary to speak of the shale between the Drum and the Cement City as the lower Chanute, the shale between the Cement City and the Raytown as the middle Chanute, and the shale between the Raytown and the Iola as the upper Chanute.

The lower Chanute shale is about 10 feet thick. The upper portion is green to blue shale and the lower portion is yellowish with calcareous concretions and thin lenses of limestone. The Cement City limestone is commonly exposed in the bluffs at Kansas City and is known as the "building ledge." It is drab in color and weathers to a yellowish brown. Joints are prominent and sometimes filled with clay. The ledge splits irregularly along wavy bedding planes. The Cement City is between 9 and 13 feet thick.

The middle Chanute shale varies from 10 to 23 feet. It is irregular and highly colored, being especially notable for a distinct "red bed" which is usually, although not always, present. This "red bed" is very noticeable when drilling a well since it is inclined to slump and cave in the hole and since it is very brightly colored, varying from maroon to dark purple. The Raytown limestone, known locally as the "calico rock" is quite irregular in both texture and color. It is usually gray to blue with decided spotches of red clay and limonite within the limestone. It has extremely large fossils and prominent veins of calcite, and weathers to a rough surface because of these irregularities. The Raytown is between 3 and 8 feet in thickness and is persistent enough to be used as a datum plane for mapping the structural conditions within the city limits of Kansas City.[2]

The Upper Chanute shale is from 5 to 25 feet thick. McCourt mentions[3] the fact that it thickens between the south and the north part of Kansas City; thickens again toward the south part of the County; thins eastward from the city limits; and

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[1]McCourt, W. E., The geology of Jackson County. Mo. Bur. Geol. and Mines, 2nd ser., vol. 14, 1917, p. 55.
[2]Ibid., Pl. 16.
[3]Ibid., p. 58.

PALEONTOLOGY.

It is not within the province of this paper to discuss the biologic implications of the fossils of the Pennsylvanian of this region but a summary of the species described from these beds may be of stratigraphic interest. The writer has therefore worked over the list of fossils which have been identified and described from each of these formations in Missouri with a view to evaluating them stratigraphically. These fossils are classified especially with respect to the unconformity within the Pleasanton which shows so distinctly in the Blue Springs area.

The most exhaustive study of invertebrates in the Pennsylvanian of Missouri has been made by Dr. George H. Girty. He has taken the collections of Mr. F. C. Greene of the Missouri Geological Survey and Mr. Gilbert Van Ingen of the United States Geological Survey and has identified about 350 species of invertebrates from 253 separate collections. The results are published in Chapter VIII of the Stratigraphy of the Pennsylvanian[1] and make an invaluable source of reference for any geologist working in the region.

Other studies of fossils from this vicinity have been made by McCourt[2] and by Sayre.[3] These three reports have been used in this study and the descriptions taken at their face value, so it may be freely admitted that any single authority working over all of this material might classify certain of these forms as identical, or might further subdivide other species. Such refinement would not materially change the proportions of new forms, however, so that the results of these mixed lists may still be valuable.

It must also be kept in mind that these fossils were collected at the outcrops of the formations in Western Missouri and not, for the most part, actually within the Blue Springs region. They apply to this problem stratigraphically but not geographically.

The details of the lists of fossils will be published by the writer at an early date. For the present a summary of these species, analyzed as to their occurrence with respect to the

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[1]Girty, G. H., in Hinds and Greene; The stratigraphy of the Pennsylvanian series in Missouri; Mo. Bur. Geol. and Mines, 2nd ser., Vol. 13, pp. 263-375.

[2]McCourt, W. E., The geology of Jackson County; Mo. Bur. Geol. and Mines, 2nd ser., Vol. 14, 1917, pp. 158.

[3]Sayre, Albert Nelson, The fauna of the Drum limestone of Kansas and Western Missouri, Bull. 17, State Geol. Surv. of Kansas, 1930, pp. 75-203.

STRUCTURAL GEOLOGY

DESCRIPTION OF STRUCTURAL FEATURES

Published Accounts

Because of the similarity to conditions in Eastern Kansas where oil and gas have been produced for many years, there has been considerable interest in the structural conditions within the area of the outcrop of the Pennsylvanian system of Missouri. The work done has been of a very general nature, however, and largely without the instruments of precision which are necessary to obtain accurate results in such a region.

Hinds and Greene[1] published a structure map of the entire region of Pennsylvanian outcrop in Missouri. On this map there are indicated a number of low folds, trending northwest-southeast. One of these folds, called the Centerview-Kansas City axis, crosses Jackson County, entering near the southeast corner and heading toward Kansas City. Such an anticlinal axis crosses the Blue Springs region from about the center of the south line to the northwest corner. The accompanying syncline, unnamed, is parallel to this axis and a little north of it. This syncline probably corresponds, in a very general way, to the Burris syncline of this report, which is mapped in detail. Their map is based on (1) the Bevier Coal, (2) an arbitrary horizon 100 feet below the upper member of the Ft. Scott limestone, and (3) an arbitrary horizon 300 feet below the Hertha limestone. It is drawn with a contour interval of 50 feet and is on a small scale, so that correspondence with more detailed structural work is not to be expected. As a general guide to the structural conditions, however, it is very valuable. Hinds and Greene were very conservative in discussing the possibilities for oil and gas in this type of a fold. Now that the nature of the anticlines, domes, and terraces that accompany these dominant major synclines are known, this general map is all the more important to petroleum geologists.

Wilson[2] discussed the general geologic conditions in Jackson County and published a structural contour map of a region south of Kansas City, including T. 46 and 47 N., R. 33 W.

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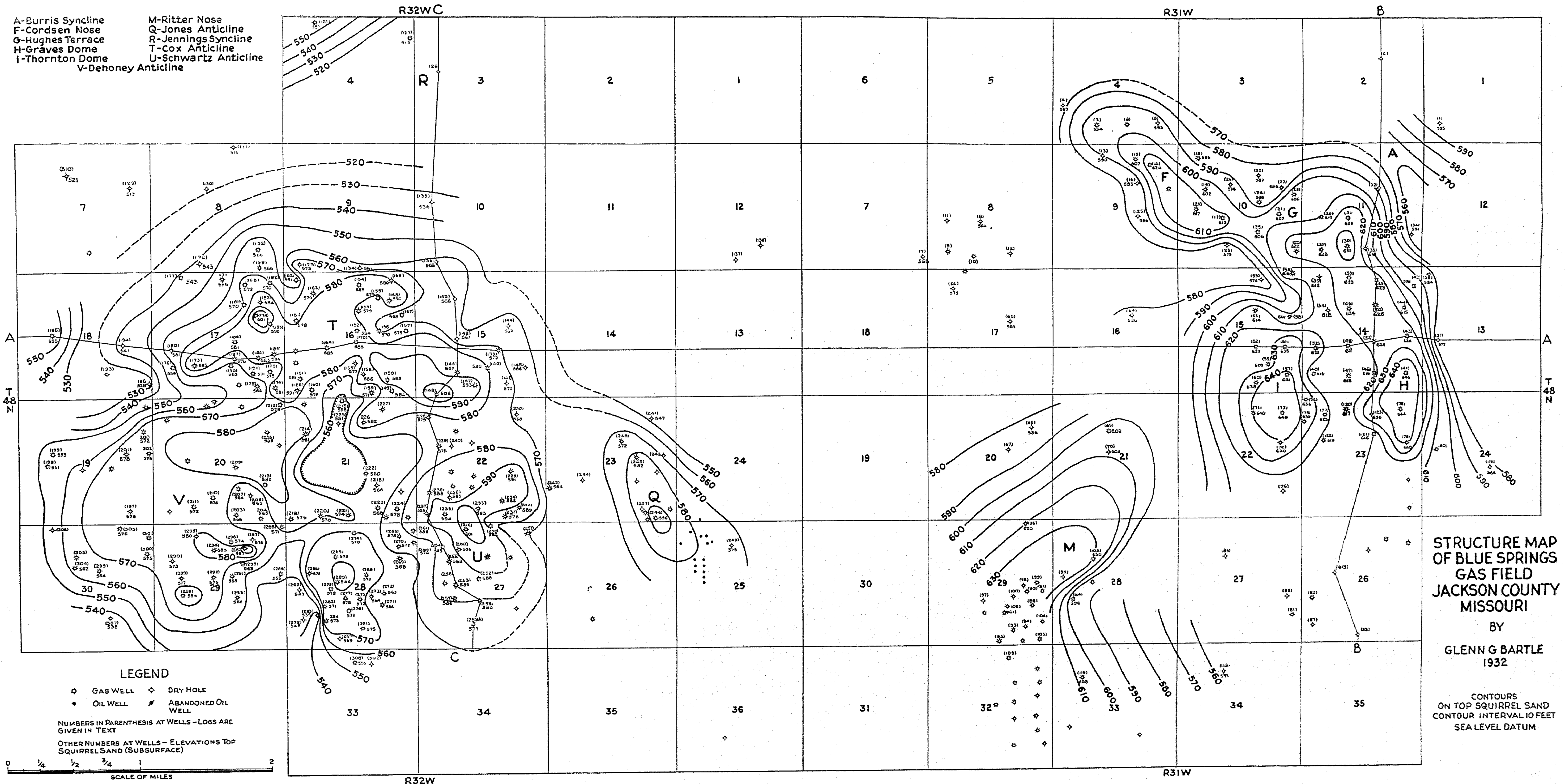
[1]Hinds, Henry, and Greene, F. C.; The stratigraphy of the Pennsylvanian series in Missouri; Mo. Bur. Geol. and Mines, 2nd ser., Vol. 13, 1915, pl. 23, p. 202.

[2]Wilson, M. E., The occurrence of oil and gas in Missouri; Mo. Bur. Geol. and Mines, 2nd ser., vol. 16, 1922, 284 pp.



Structure map of Blue Springs gas field, contours on top Squirrel sand.

dix; the others are on file in the office of the Missouri Geological Survey, together with a table showing a summary of subsurface structural conditions. Each well is classified as to (1) number of well, (2) location, (3) surface elevation, (4) elevation of top of Bethany Falls limestone, (5) thickness of Pleasanton and Henrietta formations, (6) elevation of base of Ft. Scott limestone and (7) elevation on top of Gas Sand.

Detailed Structural Features

The chief structural feature in the northeast part of the Blue Springs field is the Burris syncline. It may be located readily on the structural geological maps. In the deepest basin within this syncline, the top of the Bethany Falls limestone sinks to a low level of 850 feet. This may be compared to a level of 920 feet on the Cordson terrace, one and one-half miles southeast; or to a level of 940 feet on the Thornton dome two miles directly south.

The Burris syncline is joined by the Luttrell depression, the Selvey depression and the Velie depression and is parallel to the persistent elevated structures, the Cordson nose, the Hughes terrace and the Graves dome. It would seem that the Burris syncline is the controlling factor in the structure of this area. If considered a part of the low fold indicated by Hinds and Greene, it may be traced to Centerview in Johnson County, at least twenty miles toward the southeast.

The Luttrell depression from the northeast is lost to observation by the loess covered plain but seems to be subordinate. The Selvey depression toward the east may be traced about two miles. It is significant that this depression is more pronounced on the subsurface formations than it is on the surface. This seems to be the outstanding case in the Blue Springs field where there is an increase of structural irregularity with depth. Steep surface dips, locally as much as three to four degrees, have been observed on the flanks of this depression. The cross-section A-A, Pl. II, shows this relationship.

The Morris nose evidently does not rise high enough out of the dominant syncline to allow the production of gas. The Lease dome also produced water rather high on the east dip.

The Cordson nose, however, has produced considerable gas. The subsurface maps correspond to the surface except that it is somewhat narrower. As a result, there is a line of wells in a northwest-southeast direction with scattered dry holes both north and south of this axis. Wells on the line of the axis were as large as one million cubic feet per day open flow but have neither held up as well nor produced as much gas as wells of similar size in the heart of the field.

The Hughes terrace is an outstanding example of the value of a flattening of formations on the reversal of dip. The largest well in the field, Map No. 21, Hughes No. 4, SE. ¼ sec. 10, T. 48 N., R. 31 W., is located here with an open flow of two million two hundred thousand cubic feet per day at a depth of only 220 feet.

In other regions nearby it has been demonstrated that a terrace on the normal dip, on the contrary, is of very doubtful value. It is interesting to know that between the terrace proper and the Graves dome, there is a local breakdown of the terrace structure, shown especially on subsurface formations.

The Graves dome reaches a height 949 feet on the top of the Bethany Falls limestone. This is one of the structural peaks of the field. It is on this dome that the isolated well from the Bartlesville sand, Map No. 78, NE. ¼ sec. 23, T. 48 N., R. 31 W., previously mentioned, occurs. The Thornton dome merges with the Boten dome on the subsurface map but on the surface is a separate structure. From the Thornton dome there is an east dip of fifty feet in one and one-half miles; a northeast dip of ninety feet in two and one-half miles, and a north dip of ninety-nine feet in two miles. These dips are very unusual for this part of the country and this structural condition is unusual.

The first well to be drilled in the east part of the Blue Springs field was Map No. 73, J. O. Boten No. 1, NE. ¼ sec. 22, T. 48 N., R. 31 W. It was drilled for water early in the summer of 1929 and a small showing of gas was encountered although it was not considered to be of commercial size. The first commercial well was not drilled until the whole area had been carefully mapped and the appearance of the dome was outlined essentially as it is now known. This well is No. 61, Thornton Map No. 1, SE. ¼, sec. 15, T. 48 N., R. 13 W., which came in for nine hundred and fifty thousand cubic feet of gas per day open flow at a depth of three hundred and twenty-five feet. On the west side of the Thornton dome, the wells are much smaller. For that reason there has been no drilling low on the west dip. This peculiarity can be explained only by the chance location of favorable bodies of porous sand on the reverse dip of the strata. It is clear that the accumulation of this gas depends upon two factors, (1) structural irregularities; (2) the presence of porous sands. In many cases, of course, these factors do not occur together.

On the Boten dome, dry holes have been encountered quite high on the structure, even in some cases where there is at least some porous sand. It may be noticed that these dry holes are frequently on the heel of a structure where, in spite of the fact that they are high, there is very little opportunity for gas to be trapped. This explanation would help also to justify the presence of gas rather low on a structure at the end of the noses or terraces, as on the Hughes terrace.

The common explanation is that sand on top of the structure is too compact and cannot, therefore, hold gas. It is a little difficult to say why this should be consistently true. The presure on the sand on top of a structure should not be very much different than that on the sides or in a syncline. Locally a tight sand might be due to special conditions such as unusual cementation by ground waters, faulting, etc., that might also occur at any other place on the structure.

The entire absence of sand on top of structures is a different problem. In many districts[1] there has been a persistent absence of sand on top of structures probably due to the fact that diastrophic movement had started at the time of the deposition of the Cherokee formation, and therefore, the uplifted portions were frequently being eroded while the adjacent areas received clastic sedimentary material. It is very doubtful if this factor is of great importance in the Blue Springs field where sand is found apparently without relation to the structural conditions. It may be possible, however, that, in some instances, structures have been tested near the top of the folds and abandoned because of the absence of sand. There is always the possibility of the occurrence of porous sands and gas should the structure be tested farther down the flank.

In the Blue Springs area it is especially noteworthy that there are no wells which are not closely connected with structural "highs." Drilling in the synclines or on the normal dip has been uniformly unsuccessful. If all of the sedimentary conditions could be thoroughly understood, the drilling of wells would be an exact science and uniformly successful. Since

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[1]Cadman, W. K., The golden lanes of Greenwood County, Kansas, Bull. Am. Ass. Pet. Geol., vol. 11, pt. 2, 1927. p. 1179.

only the structural condition can be known before at least some drilling has been done and the sedimentary and stratigraphic conditions are unknown as to detail, some dry holes are unavoidable.

The Ground anticline is a somewhat smaller structure and appears to trend northeast-southwest. It may be considered, therefore, a cross fold with respect to the general field. It is unproductive. The Blackwell anticline toward the southeast is also a cross fold. It has several wells on it producing from the channel sandstone. The lower formations have not been penetrated however. A dry hole south of the Blackwell anticline shows an unusual thickness of the Henrietta and Pleasanton formations, so that the small depression between the Ritter nose and the Blackwell anticline is accentuated on the subsurface formations into a major synclinal condition. This would tend to draw the Blackwell anticline into the geographical district of the northeastern Blue Springs structures and to separate it from the Lees Summit production.

The Ritter nose includes the area sometimes called the Lees Summit City gas field. It is probable that this nose is an extension of a larger anticlinal formation which underlies Lees Summit. The southern and the southwestern limits of the field have not been determined by drilling and the topography is loess-covered. This production is also from the channel sandstone at a depth of less than three hundred feet. Unfortunately there has been extremely close spacing of these wells. The little peaks on this nose reach a height of nine hundred and fifty-four feet and nine hundred and fifty-three feet above sea level, respectively, on the Bethany Falls formation. Considering the normal dip toward the northwest, however, this is not higher in proportion than the other structures in the region.

In the extreme north central portion of the area the Velie depression reaches a low level of 849 feet on the Bethany Falls. Little drilling has been done within this area and wells are dry still farther north, indicating that the influence of this depression is persistent over a considerable area. Wells on the Howard anticline produce from the channel sandstone with only 50 pounds of rock pressure. Howard well No. 2, Map No. 10, SW. ¼, sec. 8, T. 48 N., R. 31 W., with a production of five hundred thousand cubic feet of gas in the channel deposit, was deepened to reach the Squirrel horizon in the Cherokee. One hundred and sixty-five feet of solid sandstone was drilled, covering the interval usually represented by the horizons of the lower Pleasanton, the entire Henrietta and a part of the upper Cherokee. This was the first evidence of the true nature of the channel sandstone deposit in this area. It had been previously thought to be a lens in the Pleasanton, the "Peru" of the drillers. Wells, Map No. 8 and No. 12, one-quarter of a mile north and east respectively showed no channel sandstone.

The Yost anticline is flat topped and appears to be unusually favorable for the production of gas but showed no sand body of any consequence. There is a small amount of gas being produced from the Jones anticline and a small oil field occurs on the flank of the structure, which is owned and operated in fee by the Unity School of Christianity. This oil is also produced from the Squirrel sand, but since the gas in the Jones anticline is not especially rich in gasoline content, it is a little difficult to explain the relations between the two.

The Jennings syncline in the extreme northwestern corner of the Blue Springs area is undoubtedly second in importance only to the Burris syncline. One wildcat well NE. ¼ sec. 3, T. 48 N., R. 32 W., shows an elevation on the Bethany Falls limestone as low as 817 feet. This gives a total structural relief of 134 feet in a little more than seven miles. Since the normal dip is about 10 feet per mile, the total structural irregularity in this case is about sixty feet. The Unity syncline is shown in its entirety and is also of considerable importance. No subsurface conditions are known regarding it, however, due to the absence of logs.

The Cox anticline is also flat topped but has two small structural knobs on it near the middle of the anticlinal axis. The gas production continues down the structure on the north and northwest flanks to a low level. Some shale gas is also produced. The Schwartz anticline is somewhat similar but is interrupted by three small structural sinks. These sinks do not show on the subsurface maps. The Dehoney anticline is unusually flat topped on the surface formations but shows structural knobs on the subsurface maps.

SUMMARY OF STRUCTURAL FEATURES

In considering this field as a whole it seems that there are four outstanding peculiarities which are important:

(1) There are numerous anticlines but evidently the synclines are the dominant structural features.

(2) There is a very close relation between the structural highs and the accumulation of gas.

(3) Unusually good wells are found at the ends of terraces, noses and anticlines where the zone of accumulation may be well developed.

(4) The lower formations correspond to the upper formations in their general structural relations but not in absolute detail. With respect to the surface structures, the subsurface structures are intensified in some places, lessened in others, widened in some places, and narrowed in others. There seems, however, to be no general tendency in these differences.

ORIGIN OF STRUCTURES

The problem of the origin of the structures of the Mid-Continent region, of which the Blue Springs field is a part, has been discussed voluminously in the literature. Many explanations have been advanced, including tangential compression, deep-seated rock flowage, warping of sediments accompanied by faulting, initial dips, removal of soluble beds, and compacting of sediments over buried hills.

In the field discussed in this report, the results of shallow drilling do not justify definite conclusions regarding the origin of the general structural features. The writer believes that more satisfactory conclusions toward the solution of this important problem in Missouri will be forthcoming with additional development of the present productive horizons and future prospecting of the pre-Pennsylvanian sediments.

ECONOMIC GEOLOGY

NATURAL GAS PRODUCTION

Production Statistics.

Since the Panhandle Eastern Pipe Line Company furnishes the major outlet for gas from the Blue Springs field, the production statistics which are on file are unusually complete. In addition to the data which have been obtained from the files of this Company, the figures for the gas produced and used within this area by the Knobstone Development Company in the manufacture of brick and tile have been added to the tables. The only gas not accounted for is that which is used by the landowner, unmetered, as a part of his lease contract, the leakage and line loss, and the gas lost in cleaning the wells. New equipment has been used throughout, all pipes are welded instead of screwed, and modern methods generally have been employed, so that leakage is small. Probably the largest item of waste has been the "blowing off" of the gas wells to clean them of excess water when they are old, and in order to obtain the record of the open flow. Better methods of obtaining the open flow are now being used by the Panhandle Eastern Pipe Line Company for their large wells in Texas, but these methods were not in use in the early history of this field. It seems probable, however, that the total amount of gas produced in this field is less than 10 per cent greater than the figures given in the summary of the table.

The Blue Springs field has been divided into districts based upon the date of the connection of the wells to the main line system. These districts correspond roughly, but not exactly, to the structures outlined and described previously. The West District includes the Jones anticline, the Schwartz anticline, the Cox anticline and the Dehoney anticline. The South District includes the Ritter nose. The Northeast District includes the Cordsen nose and two wells which were connected late on the Graves dome. The East District includes the Graves dome, the Thornton dome and the Hughes terrace. Because of the close connection between the East District and the Northeast District the cumulative figures, acreage yield, etc., of these districts have been considered together, but they have been plotted separately because there is six months difference in the date of connection.

Any method of evaluating a gas field depends upon the production figures such as given for the Blue Springs field in these tables. Very few such records have been published. Many are not available because they are divided among several pipe line companies. Others are incomplete because the fields are not yet drilled out and it is contrary to the policy of the companies to release the information. It is extremely fortunate that this information is available for this field and that the Panhandle Eastern Pipe Line Company is generous enough to release it for publication. The lease records from which the summaries by fields have been prepared are also on file with the Missouri Geological Survey.

Since the field is drilled out and almost entirely through producing at the present time, the consideration of methods of estimating reserves is of little value to this particular district. It is to be hoped, however, that a consideration of the most common methods of estimating reserves, in the light of the complete history of this field, will be helpful in refining and correcting these methods so that other similar fields may be considered more intelligently in the future.

BLUE SPRINGS GAS FIELD.

Summary of Production Statistics.

	Districts.			
	West.	East.	Northeast.	South.
Production to 1-1-29...	42,255,000	....	....	....
Production to 4-1-29...	149,387,000	....	....	....
Yield 1-1-29 to 4-1-29..	107,132,000	....	....	....
Rock pressure 4-1-29..	77.1	....	....	....
Vol. Open Flow 4-1-29	43,708,000	....	....	....
Production to 7-1-29..	353,791,000	....	....	....
Yield 4-1-29 to 7-1-29..	204,404,000	....	....	....
Production to 10-1-29..	601,275,000	....	....	....
Yield 7-1-29 to 10-1-29.	247,484,000	....	....	....
Rock pressure 10-1-29.	71.8	....	....	....
Vol. open flow 10-1-29.	47,848,000	....	....	....
Production to 1-1-30...	904,641,000	....	....	....
Yield 10-1-29 to 1-1-30.	303,366,000	....	....	....
Rock pressure 1-1-30..	65.6	....	....	....
Vol. open flow 1-1-30..	42,991,000	....	....	....
Production to 4-1-30...	1,167,929,000	78,430,000	....	....
Yield 1-1-30 to 4-1-30..	263,288,000	....	....	....
Rock pressure 4-1-30..	57.0	86.0	....	....
Vol. open flow 4-1-30..	32,021,000	28,642,000	....	....
Production to 7-1-30...	1,427,968,000	198,537,000	....	....
Yield 4-1-30 to 7-1-30..	260,039,000	120,107,000	....	....
Rock pressure 7-1-30..	50.3	76.5	....	....
Production to 10-1-30..	1,656,108,000	330,482,000	22,423,000	....
Yield 7-1-30 to 10-1-30.	228,140,000	131,945,000	....	....
Rock pressure 10-1-30..	47.2	68.6	81.3	....
Vol. open flow 10-1-30.	21,730,000	22,420,000	8,228,000	....
Production to 1-1-31...	1,862,637,000	496,016,000	53,549,000	....
Yield 10-1-30 to 1-1-31.	206,529,000	165,534,000	31,126,000	....
Rock pressure 1-1-31..	37.6	51.7	51.6	....
Production to 4-1-31...	2,031,799,000	620,676,000	75,929,000	23,441,000
Yield 1-1-31 to 4-1-31..	169,162,000	124,660,000	22,380,000	....
Rock pressure 4-1-31..	34.7	49.8	50.2	52.8
Vol. open flow 4-1-31..	11,719,000	14,387,000	3,056,000	12,208,000
Production to 7-1-31...	2,175,434,000	701,331,000	88,922,000	64,357,000
Yield 4-1-31 to 7-1-31..	143,635,000	80,655,000	12,993,000	40,916,000
Production to 10-1-31..	2,314,700.000	780,034,000	98,179,000	92,871,000
Yield 7-1-31 to 10-1-31.	139,266,000	78,703,000	9,257,000	28,514,000

BLUE SPRINGS GAS FIELD—Continued.

	Districts.			
	West.	East.	Northeast.	South.
Rock pressure 10-1-31.	27.0	38.2	41.3	23.4
Vol. open flow 10-1-31..	9,396,000	9,611,000	1,788,000	5,005,000
Production to 1-1-32...	2,439,211,000	867,465,000	106,815,000	117,862,000
Yield 10-1-31 to 1-1-32.	124,511,000	87,431,000	8,636,000	24,991,000
Rock pressure 1-1-32..	24.0	37.5	34.7	....
Vol. open flow 1-1-32..	2,167,000	9,412,000	822,000	....

APPLICATION TO METHODS OF ESTIMATING RESERVES.

Production Decline Curve Method.

It is believed that the regularity of the decline in the production of oil wells is due to the loss of gas pressure. It would seem, therefore, that a production decline curve for gas wells would show great regularity and would conform closely to mathematical laws.

Several other factors are to be considered, however. There are usually no facilities for the storage of gas and it must be taken from the ground in accordance with the demand. In the case of large industrial users this demand is practically constant but in the case of domestic consumption it is highly seasonal and also varies considerably from year to year, in accordance with the weather conditions.

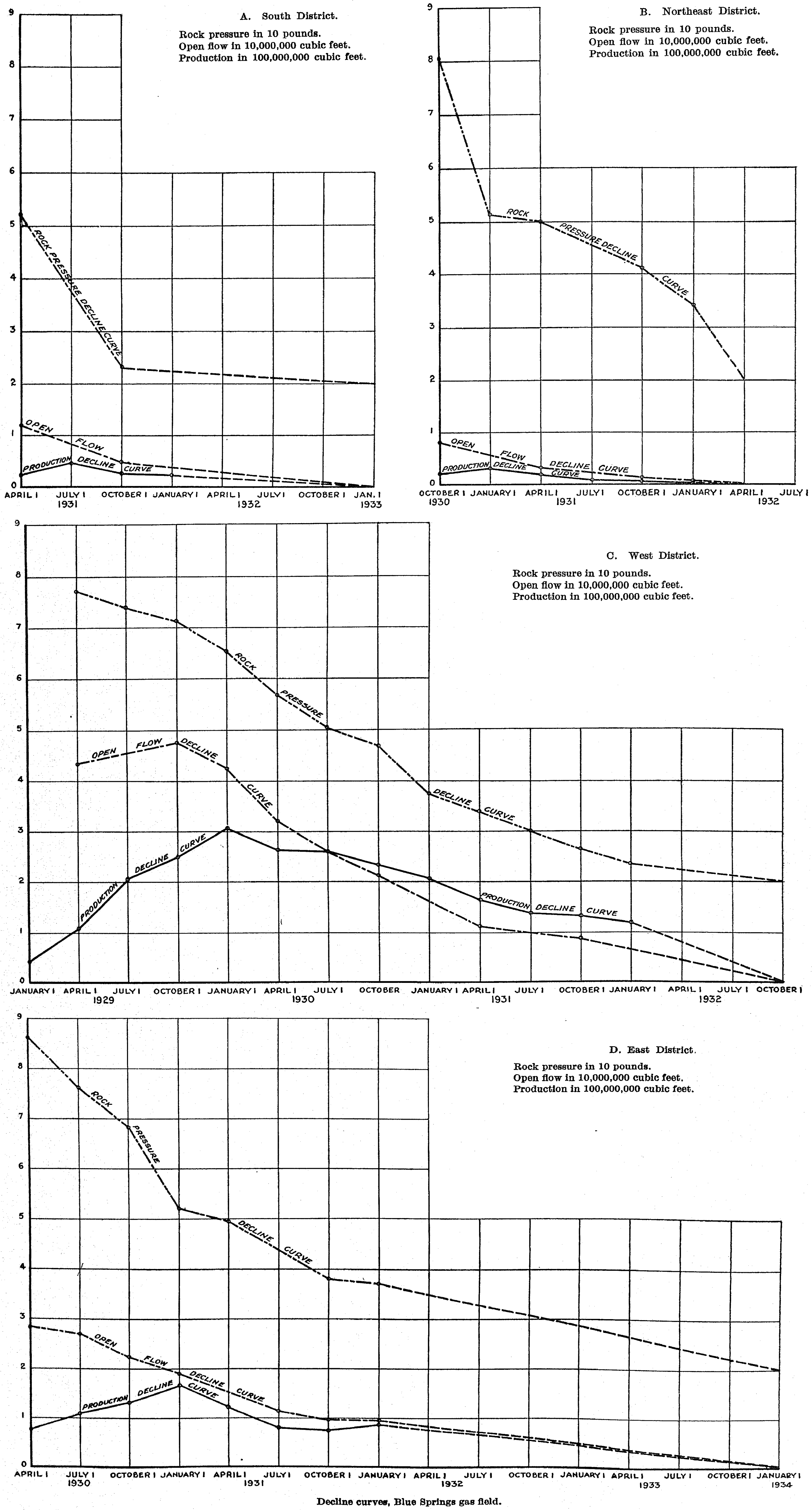
It will be noticed from the production decline curves of the Blue Springs field that in the East and Northeast Districts the peak of production was reached in the three months' period which ended January 1, 1931, and that there was a corresponding slight increase in production in the period which ended January 1, 1932. In the South District, which is a small area, the peak of production was reached just after the wells were connected to the line in July, 1931. In the large West District, the peak of production was reached rather more slowly than usual, because some of the wells were connected a few months late in the history of the District. In this case, the highest point was reached in January, 1930.

It will be seen, therefore, that in the Blue Springs field the gas production has been very largely based upon the capacity of the wells and only to a minor extent influenced by the seasonal demand. Probably the chief factor which has brought about this condition, so favorable from the point of view of the producing company, is the fact that for the Kansas City market the nearby gas has been used and the distant gas held in reserve. It is possible also that the Kansas City consumption is not as irregular as that of many cities owing to the large number of domestic consumers who use gas in grates for cooking, and as a minor heat, but who heat their homes with coal during the most severe weather.

The production figures have been plotted for each district of the Blue Springs field. For convenience the decline of open flow and the decline of rock pressure have been put on the same graph (Pl. IV). Since this field is largely exhausted, this provides simply a graphical history of the field and a record for comparison with other fields which are incompletely developed. The curves have all been extrapolated into the future, however, for the comparatively short time during which these wells may be expected to produce. It is assumed that the wells will have to be abandoned at an average pressure of 20 pounds.

On the basis of this extrapolation the East and Northeast Districts, which have already produced 974,280 M. cu. ft. of gas, may be expected to produce 440,000 M. cu. ft. more, a total of 1,414,280 M. The South district, which has already produced 117,862 M. cu. ft. of gas, may be expected to produce 52,000 M. cu. ft. more, a total of 169,862 M. The West District, which has already produced 2,439,211 M. cu. ft. of gas, may only be expected to produce 172,000 M. cu. ft. more, a total of 2,611,-211 M. To summarize these figures: The whole Blue Springs field has produced 3,531,353 M. cu. ft. of gas up to January 1, 1932, and it may reasonably be expected to produce a total of 4,195,353 M. cu. ft. of gas before it is finally abandoned. This figure will probably not be increased by drilling, but it may be increased as much as 100,000 M. cu. ft. by the connection of the small wells on the Howard anticline in the middle of the area.

Various refinements of this method have been suggested and practiced in the estimation of oil reserves, but very little has been done which applies directly to gas. Logarithmic paper may be used instead of quadrille paper. The chief advantage of this change is that the record is shown in a straight line instead of in a curve.



Decline curves, Blue Springs gas field.

Brown has suggested[1] that a much more compact record may be kept of oil fields when only the coordinates of the logarithms are kept and the curve may be reproduced readily by plotting these coordinates on logarithmic paper. He gives the logarithmic coordinates of production decline curves for a large number of oil fields[2] based upon tables worked out by the Treasury Department of the United States for taxation purposes.

It is frequently necessary to "smooth out" a decline curve, especially when the time coordinate is for a short period. It is considered permissible to do this by making averages of three months when one month seems to be highly irregular, or by plotting equal areas which fall first above, then below the smooth line, and considering the reconstructed line as representing the true condition. In the study of the Blue Springs gas field there has been no effort made to "smooth out" the production curves, since the record is made by quarterly periods and the decline has been quite rapid and regular. The lines on the graph therefore represent actual records.

It is obvious that there may be an irregularity in a production curve due to drilling activity. In cases of drilling on separate leases this may be figured separately; but when there is additional drilling on the same lease there is no way to show this except by a rise in the production curve or by dividing the record into curves for the "average well" instead of for the field as a whole. Even in this latter case the flush production of a new well will somewhat increase the average.

The East, Northeast and South Districts were developed over a considerable period of time, but in each district all wells were hooked into the main line system at about the same time. The production record is the same, therefore, as if all the wells in each district had been drilled at the same time. In the West District there was some additional drilling about six months after the line was completed and the earliest wells connected. This is reflected in the decline curve by the rise in production and in open flow capacity. Since these new wells are so closely related geographically and geologically to the wells which have a slightly longer history, it is not possible to subdivide this district and the rise in production must be accepted as a necessary part of the record.

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[1]Brown, R. W., Valuation of oil and gas lands, 1st edition, 1924, p. 19, McGraw Hill Book Co.

[2]Ibid., pp. 189-197.

There may also be irregularities of production curves due to the abandonment of wells. When the field as a whole is plotted on a graph it may be considered that the abandonment of wells is a part of the decline of the gas in the area, and that the production curve is essentially correct. There is a slight error in taking the average of the rock pressures, however, after wells are abandoned. Wells which have been small when dropped from the list will permit the stronger wells to show a higher average rock pressure than they would show had these small wells been left. In extreme cases the average rock pressure might rise when actually the production and the possibilities for production have declined. In the Blue Springs field there have not been enough wells abandoned in any one quarter to make any great difference in the rock pressure figure; but it is recognized that this is a factor which detracts from the value of the rock pressure record.

The same information that has been given in the tables and in the production decline curves might be assembled into a cumulative production curve. This curve rises constantly with each additional increment of production, however slight and it is possible to indicate on the same curve the percentage of the first year's production, produced in any one year subsequently. In the larger districts of the Blue Springs field about one-half of the total production is obtained in the first year. The other half is spread over the next two years and nine months, gradually decreasing each month.

The appraisal curve has been used by Arnold,[1] who gave a typical appraisal curve for each important oil field in the United States at the time of his study. It consists essentially of an average cumulative production curve worked out for each district, with the horizontal coordinate expressed in yearly production instead of time units. The appraisal curve is designed to be used on the basis of yearly production, regardless of the age of the wells and is based upon the Law of Equal Expectation, worked out by Beal[2] in the Manual for the Oil and Gas Industry. This law is stated: "If two wells under similar conditions produce equal amounts during any given year, the amounts they will produce thereafter, on the average, will be

[1]Arnold, Ralph, and others, Manual for the oil and gas industry under the revenue act of 1918 (Revised 1921), Treasury Department of the U. S., Internal Revenue Bureau, Washington, D. C., 1921, pp. 86-175.

[2]Beal, C. H., and others, Manual for the oil and gas industry, Treasury Department of the U. S., Internal Revenue Bureau, 1st edition, 1919, p. 72.

approximately equal, regardless of their relative ages." No effort has been made to apply the appraisal curve method to the production of gas, but when the essential information is available for a large number of fields it is probable that appraisal curves may be worked out which should be quite satisfactory for the evaluation of gas properties.

It must be emphasized that all production curves represent averages and are valuable only in so far as similar and average conditions apply. The great need at the present time is for the publication of the essential information concerning the production records of gas fields so that proper comparisons may be made.

PORE SPACE METHOD.

General relations. When a gas field is first discovered and no gas has been taken from the field there is usually no other way to estimate the amount of gas available except by the pore space or saturation method. This method was applied in 1929 for tentative estimates of the yield of the Blue Springs field, although no figures were published at the time, and it is interesting to see to what extent the present figures of actual production check the former tentative estimates. There are many hazards in using this method, since several arbitrary figures must be taken; and the effort will now be made to check these arbitrary figures, of porosity, relative saturation, and coefficient of recovery, in the light of actual recovery of gas from the field.

This method, as introduced by Shaw,[1] consists of multiplying the area of the reservoir in square feet by the thickness of sand and the percentage of porosity to obtain the volume of the reservoir. This figure is multiplied by the rock pressure in pounds and divided by the pressure at which abandonment is expected. A correction for temperature may be made if necessary. This figure in turn must be multiplied by the percentage of relative saturation and the percentage factor of recovery.

This relation may be expressed algebraically as follows:

$$R. = a \times t \times p \left(\frac{p'}{p''}\right) r$$

in which;
R is the recoverable gas.
a is the area in square feet.
t is the thickness of the sand.

[1] Shaw, E. W., Matson, G. C., and Wegeman, C. H., Natural gas resources of parts of northern Texas, U. S. Geol. Surv., Bull. 629, 1916, pp. 73-75.

p is the percentage of porosity.
P′ is the absolute original pressure of the gas in pounds.
P″ is the absolute pressure of the gas at abandonment.
r is the factor of recovery in percentage.

This equation is true disregarding temperature and assuming that the saturation of the gas within the formation is complete.

Area. The extent of the reservoir in the Blue Springs field is now very well known, because of the large amount of structural information both subsurface and surface which is available. The acreage which produces gas is analyzed and subdivided according to the districts which have been previously used. It will be seen that in the East and Northeast Districts gas is being produced from an area of 2,080 acres, in the South District from 560 acres, and in the West District from 4,880 acres. Up to date there has been produced an average of 463,403 cu. ft. of gas per acre from the East and Northeast Districts, 210,468 cu. ft. from the South District, and 499,832 cu. ft. from the West District.

AREA PRODUCING GAS.

East and Northeast Districts.

640 acres, all of sec. 14, T. 48 N., R. 31 W.
320 acres, E. ½ sec. 15, T. 48 N., R. 31 W.
160 acres, SW. ¼ sec. 11, T. 48 N., R. 31 W.
160 acres, portion of E. ½ sec. 10, T. 48 N., R. 31 W.
160 acres, portion of W. ½ sec. 10, T. 48 N., R. 31 W.
80 acres, N. ½ NE. ¼ sec. 9, T. 48 N., R. 31 W.
80 acres, S. ½ SW. ¼ sec. 4, T. 48 N., R. 31 W.
160 acres, NW. ¼ sec. 22, T. 48 N., R. 31 W.
320 acres, N. ½ sec. 23, T. 48 N., R. 31 W.

2,080 acres, or a total of 3 ¼ sections.

South District.

320 acres, E. ½ sec. 32, T. 48 N., R. 31 W.
160 acres, SE. ¼ sec. 29, T. 48 N., R. 31 W.
80 acres, portion of E. ½ sec. 28, T. 48 N., R. 31 W.

560 acres, or a total of 7/8 of a section.

West District.

320 acres, W. ½ sec. 27, T. 48 N., R. 32 W.
160 acres, NE. ¼ sec. 27, T. 48 N., R. 32 W.
560 acres, all except W. ½ SW. ¼ sec. 28, T. 48 N., R. 32 W.
320 acres, N. ½ sec. 29, T. 48 N., R. 32 W.
160 acres, NW. ¼ sec. 30, T. 48 N., R. 32 W.
320 acres, E. ½ sec. 19, T. 48 N., R. 32 W.
640 acres, all sec. 20, T. 48 N., R. 32 W.
480 acres, all except 160 acres, sec. 21, T. 48 N., R. 32 W.
320 acres, S. ½ sec. 22, T. 48 N., R. 32 W.
80 acres, W. ½ NW. ¼ sec. 22, T. 48 N., R. 32 W.

80 acres, portion of W. ½ sec. 23, T. 48 N., R. 32 W.
160 acres, SW. ¼ sec. 15, T. 48 N., R. 32 W.
640 acres, all of sec. 16, T. 48 N., R. 32 W.
640 acres, all of sec. 17, T. 48 N., R. 32 W.

4,880 acres, or a total of 7-5/8 sections.

If the figures for the total gas yield estimated on the basis of the production decline curves may be accepted, the East District will eventually yield 679,942 cu. ft. per acre, the South District 303,325 cu. ft. per acre and the West District 535,084 cu. ft per acre. While these figures are not large they show a very considerable production for wells which average less than 400 feet in depth and which are extremely inexpensive to drill.

Since these figures are now reduced to the basis of yield per acre it is possible to consider the pore space method of estimating gas reserves without the complication of an indefinitely outlined reservoir.

Thickness. The thickness of the Squirrel sand is not everywhere known because the productive wells stop within the formation as soon as the gas ceases to increase with continued drilling. Earlier in this report an estimate of 40 feet of thickness of the Squirrel sand was made. It would be very unusual if this total thickness was saturated with gas, however. Usually only the upper part of the sand has gas and the lower part is dry or in some cases full of water. With these considerations in mind, the amount of sand, which on the average will carry gas, has been taken as 20 feet.

Porosity. The porosity of sands is also a difficult factor to estimate. It is known that when spheres are uniform in size and packed in the most compact manner there is a porosity of 25.95 per cent. Sand grains which are irregular in size may have a porosity either greater or less than this figure but it is usually less because the smaller grains fill up part of the space by fitting between the larger ones. A table of porosity of oil sands has been compiled from various sources by Brown.[1] The averages vary from 12.2 per cent to 26.7 per cent with more fields approaching the latter figure. Since the sand in the Blue Springs field is loose and poorly consolidated it is conservative practice to estimate the porosity at 20 per cent.

Pressure. The gas pressure for the larger districts was originally 90 pounds per square inch above atmospheric pressure. The atmospheric pressure is about 14.4 pounds per square inch

[1]Op. cit., p. 74.

to which must be added .5 lb., or 8 ounces, necessary to deliver gas to the surface under ideal conditions.

Factor of recovery. To make a practical application of these figures to the case of a single acre, underlain by 20 feet of sand with an estimated porosity of 20 per cent, the reservoir space is first computed as follows: 20 per cent of 20 acre-feet = 20 per cent of 871,200 cu. ft. = 174,240 cu. ft. This product, multiplied by 104.4 and divided by 14.9 gives 1,220,849 cu. ft. as the amount of gas theoretically under each acre. The actual yield in the East District is estimated to be 679,942 cu. ft. per acre, which is 55.7 per cent of the theoretical amount. The actual yield in the West District is estimated to be 535,084 cu. ft., which is 44.3 per cent of the theoretical figure.

In the South District the total rock pressure was only 60 pounds per square inch above atmospheric pressure. The percentage of porosity and the thickness of the sand are about the same, however, so that the reservoir under each acre is 174,240 cu. ft., as in the other examples. This figure, 174,240, multiplied by 74.7 and divided by 14.9 gives 870,030 cu. ft. as the amount of gas theoretically under each acre. The actual yield is estimated to be 303,325 cu. ft. per acre, which is 34.9 per cent of that figure.

It is customary to consider the relative saturation as 100 per cent in the case of gas. In a field of this depth the correction for temperature is unimportant. The factor of recovery may be taken therefore, as 55.93% for the East District, 44.3% for the West District and 35.2% for the South District, or an average of 45.1% for the field. This factor of recovery is the figure which is the most difficult to compute, and the establishment of this figure for this district may be of some value in comparison with other fields.

Other methods. A possible refinement of the pore space method has been recently suggested by Versluys.[1] He takes as his thesis that the flow of a liquid through capillary tubes may be compared to the motion of gases through sands and that Darcy's law for liquids[2] will apply in this case. He suggests that different distributions of pressure may be obtained by means of a "venting well." By the application of these laws of hydro-

[1]Versluys, J., An investigation of the problem of the estimation of gas reserves, Bull. Am. Ass. Pet. Geol., vol. 12, No. 11, p. 928, pp. 1095-1105.

[2]Versluys, J., Voruntersuchung und Berechnung der Grundwasser-fassungsanlagen, 1920, Munich, and Myer, O. E., Ueber die innere Reibung der Gase, Ann. der Phys. und Chemie, 1873.

dynamics to the differences in pressure in the "venting well" he builds up an elaborate mathematical formula to replace the product, porosity times thickness, in calculations such as those which have just been given. There has been no experimental work along this line and, of course, the other arbitrary factors of areal extent and factor of recovery still remain.

The pore space method should not be used except for tentative estimates at the time of the opening of a gas field. Since that is the time of greatest interest in the area, however, it is commonly used by geologists and gas production engineers. It is a great advantage if similar fields whose history is known may be used for comparison.

Rock Pressure Decline Method.

The most common method of estimating the life of a gas field after a small amount of gas has been taken out is by the application of Boyle's law. This is the principle that the pressure of the gas within a reservoir will vary in proportion to the amount of gas it contains. Stated mathematically it means that the volume multiplied by the pressure is a constant. This equation must be modified unless the temperature remains the same.

Theoretically there is a slight deviation from this law in the case of natural gas, which is a mixture of gases. This deviation has been worked out by the U. S. Bureau of Mines (Technical Paper 158) for cases in which the analysis of the gas is known. It is expressed thus:—

$$B \text{ equals } \frac{0.154\ p(m + 4e + 3c + 0.22a)}{1000} \text{ in which}$$

B equals the deviation in per cent, p equals the gauge pressure in pounds per square inch, m equals the methane in per cent, e equals the ethane in per cent, c equals the carbon dioxide in per cent, and a equals the air in per cent. Since this total deviation is usually less than 5 per cent, it is common for geologists and engineers to ignore this theoretical deviation from Boyle's law.

Assuming that p v equals k there should be an equal amount of gas produced for each pound of pressure decline. For example, if a field has an original pressure of 1,000 pounds and the pressure drops to 900 pounds while 100,000,000 cu. ft. of gas is being produced, there is one million cu. ft. of gas produced for each pound of pressure lost. The total yield of the field would be expected to be one million times one thousand or one billion cu. ft. The gas left in the ground at 900 pounds pressure would be nine hundred million, and in proportion throughout the decline.

The first published indication that this method is not sound was the analysis of the McKeesport gas field of Pennsylvania by Brown.[1] The production figures were analyzed on the basis of the millions of cubic feet produced during each month for each pound of pressure decline. They varied from 6.13 million at the beginning of the production to 61.2 about one year later and then dropped to 15.3 and 28.6 for the last two months. There was no regular fall and decline in this yield, but it was evident that the greatest production per pound was toward the end of the life of the field. Brown does not try to explain these discrepancies, but mentions the unequal spacing of the wells and the rapid exhaustion of the field, which was quite small, covering only about one square mile.

More recently Johnson and Morgan have criticised the equal pound loss method[2] on the following grounds:

(1) The underground losses which do not show in the yield are not constant.

(2) The encroachment of water is not uniform.

(3) Technological irregularities (line pressure, etc.) are not equally distributed throughout the life of the well.

(4) The peripheral zone of the well may be gradually enlarged by the decrease of pressure.

(5) The yield per pound loss is partially dependent upon the number of wells.

(6) The seasonal cycles become more marked with age.

(7) Methane being a mixture of gases does not follow Boyle's law.

They suggest that the best way to estimate future production from pressure data is to make a curve of the yield per pound loss by successive time units, and to extrapolate this line directly or to derive an empirical formula by which the future years can be calculated. From this pressure decline curve a yield curve might be calculated.

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[1]Brown, R. W., Valuation of oil and gas lands, 1924, p. 180.

[2]Johnson, R. H., and Morgan, L. C., A critical examination of the equal pound loss method of estimating gas reserves, Bull. Am. Ass. Pet. Geol., vol. 10, 1926, pp. 901-904.

Yield per pound.
Blue Springs gas field.
West District.

January 1, 1929, to April 1, 1929.
90.0 lbs. to 77.1 lbs. shows 12.9 lbs. loss.
107,132 M. yield in same time.
$\frac{107{,}132}{12.9}$ equals 8,305 M. yield per pound.

April 1, 1929, to October 1, 1929.
77.1 lbs. to 71.8 lbs. shows 5.3 lbs. loss.
204,404 M. and 451,988 M. equals 656,392 M. yield in same time.
$\frac{656{,}392}{5.3}$ equals 123,847 M. yield per pound.

October 1, 1929, to January 1, 1930.
71.8 lbs. to 65.6 lbs. shows 6.2 lbs. loss.
303,366 M. yield in same time.
$\frac{303{,}366}{6.2}$ equals 48,927 M. yield per pound.

January 1, 1930, to April 1, 1930.
65.6 lbs. to 57.0 lbs. shows 8.6 lbs. loss.
263,288 M. yield in same time.
$\frac{263{,}288}{8.6}$ equals 30,614 M. yield per pound.

April 1, 1930, to July 1, 1930.
57.0 lbs. to 50.3 lbs. shows 6.7 lbs. loss.
260,039 M. yield in same time.
$\frac{260{,}039}{6.7}$ equals 38,811 M. yield per pound.

July 1, 1930, to October 1, 1930.
50.3 lbs. to 47.2 lbs. shows 3.1 lbs. loss.
238,140 M. yield in same time.
$\frac{238{,}140}{3.1}$ equals 76,819 M. yield per pound.

October 1, 1930, to January 1, 1931.
47.2 lbs. to 37.6 lbs. shows 9.6 lbs. loss.
206,565 M. yield in same time.
$\frac{206{,}565}{9.6}$ equals 21.473 M. yield per pound.

January 1, 1931, to April 1, 1931.
37.6 lbs. to 34.7 lbs. shows 2.9 lbs. loss.
169,126 M. yield in same time.
$\frac{169{,}126}{2.9}$ equals 58,319 M. yield per pound.

April 1, 1931, to October 1, 1931.
34.7 lbs. to 27.0 lbs. shows 7.7 lbs. loss.
143,635 M. and 139,266 M. equals 282,901 M. yield in same time.
$\frac{282{,}901}{7.7}$ equals 36,766 M. yield per pound.

October 1, 1931, to January 1, 1932.
27.0 lbs. to 24.0 lbs. shows 3.0 lbs. loss.
124,511 M. yield in same time.
$\frac{124,511}{3.0}$ equals 41,503 M. yield per pound.

Average for entire period

January 1, 1929, to January 1, 1932.
90.0 lbs. to 24.0 lbs. shows 66.0 lbs. loss.
2,396,956 M. yield in same time.
$\frac{2,396,956}{66.0}$ equals 36,317 M. yield in whole history.

Yield per pound
Blue Springs gas field.
East District.

January 1, 1930, to April 1, 1930.
90 lbs. to 86 lbs. shows 4 lbs. loss.
78,430 M. yield in same time.
$\frac{78,430}{4}$ equals 19,607 M. yield per pound.

April 1, 1930, to July 1, 1930.
86 lbs. to 76.5 lbs. shows 9.5 lbs. loss.
110,107 M. yield in same time.
$\frac{110,107}{9.5}$ equals 11,590 M. yield per pound.

July 1, 1930, to October 1, 1930.
76.5 lbs. to 68.6 lbs. shows 7.9 lbs. loss.
131,945 M. yield in same time.
$\frac{131,945}{7.9}$ equals 16,702 M. yield per pound.

October 1, 1930, to January 1, 1931.
68.6 lbs. to 51.7 lbs. shows 16.9 lbs. loss.
165,536 M. yield in same time.
$\frac{165,536}{16.9}$ equals 9,795 M. yield per pound.

January 1, 1931, to April 1, 1930.
51.7 lbs. to 49.8 lbs. shows 1.9 lbs. loss.
124,660 M. yield in same time.
$\frac{124,660}{1.9}$ equals 65,610 M. yield per pound.

April 1, 1931, to October 1, 1931.
49.8 lbs. to 38.2 lbs. shows 11.6 lbs. loss.
80,655 M. and 78,703 M. equals 159,358 M. yield in same time.
$\frac{159,358}{11.6}$ equals 13,737 M. yield per pound.

October 1, 1931, to January 1, 1932.
38.2 lbs. to 37.5 lbs. shows 0.7 lbs. loss.
87,431 M. yield in same time.
$\frac{87,431}{.7}$ equals 124,901 M. yield per pound.

Average for entire period

January 1, 1930, to January 1, 1932.
90 lbs. to 37.5 lbs. shows 52.5 lbs. loss.
867,425 M. yield in the same time.
$\frac{867,425}{52.5}$ equals 16,522 M. yield per pound in whole history

Yield per pound.
Blue Springs gas field.
Northeast District.

July 1, 1930, to October 1, 1930.
90 lbs. to 81.3 lbs. shows 8.7 lbs. loss.
22,423 M. yield in same time.
$\frac{22,423}{8.7}$ equals 2,577 M. yield per pound.

October 1, 1930, to January 1, 1931.
81.3 lbs. to 51.6 lbs. shows 29.7 lbs. loss.
31,126 M. yield in same time.
$\frac{31,126}{29.7}$ equals 1,048 M. yield per pound.

January 1, 1931, to April 1, 1931.
51.6 lbs. to 50.2 lbs. shows 1.4 lbs. loss.
22,380 M. yield in same time.
$\frac{22,380}{1.4}$ equals 15,985 M. yield per pound.

April 1, 1931, to October 1, 1931.
50.2 lbs. to 41.3 lbs. shows 8.9 lbs. loss.
12,993 M. and 9,257 M. equals 22,250 M. yield in same time.
$\frac{22,250}{8.9}$ equals 2,500 M. yield per pound.

October 1, 1930, to January 1, 1931.
41.3 lbs. to 34.7 lbs. shows 6.6 lbs. loss.
8,636 M. yield in same time.
$\frac{8,636}{6.6}$ equals 1,308 M. yield per pound.

Average for entire period.

July 1, 1930, to January 1, 1931.
90 lbs. to 34.7 lbs. shows 55.3 lbs. loss.
106,815 M. yield in same time.
$\frac{106,815}{55.3}$ equals 1,931 M. yield per pound in whole history.

Yield per pound.
Blue Springs gas field.
South District.

January 1, 1931, to April 1, 1931.
60 lbs. to 52.8 lbs. shows 7.2 lbs. loss.
23,441 M. yield in same time.
$\frac{23,441}{7.2}$ equals 3,256 M. yield per pound.

April 1, 1931, to October 1, 1931.

52.8 lbs. to 23.4 lbs. shows 29.4 lbs. loss.

28,514 M. and 40,916 M. equals 69,430 M. yield in same time.

$\frac{69{,}430}{29.4}$ equals 2,361 M. yield per pound.

Average for entire period.

January 1, 1931, to October 1, 1931.

60 lbs. to 23.4 lbs. shows 36.6 lbs. loss.

$\frac{92{,}871}{36.6}$ equals 2,537 M. yield in whole history.

Johnson and Morgan's objections are important although the fourth and fifth points may be overcome by considering the field instead of the well as a unit. The strongest objection, it would seem, is the fact that the encroachment of water reduces the size of the reservoir, but not regularly or uniformly.

In spite of these objections the rock pressure decline method has continued to be used in the great majority of estimations made of gas reserves. This is largely because no other simple method has been suggested and the majority of geologists and production men have felt that it "ought to work" and have not known of anything better.

In the Blue Springs gas field each district has been analyzed in the tables giving the yield per pound by quarterly periods. Since these districts are of varying size there is no reason to expect the separate districts to conform, but if Boyle's law applies the same figure should be reached for each quarter in the same district. In the East District the yields per pound are 19,607 M., 11,590 M., 16,702 M., 9,795 M., 65,610 M., 13,737 M., and 124,901 M., with an average yield of 16,522 M. In the Northeast District these yields are 2,577 M., 1,048 M., 15,985 M., 2,500 M., 1,308 M., with an average yield of 1,931 M. In the South District there is a yield of 3,256 M., 2,361 M., and an average yield of 2,537 M. In the large West District there are yields of 8,305 M., 123,487 M., 48,927 M., 30,614 M., 38,811 M., 76,819 M., 21,473 M., 58,319 M., 36,766 M., and 41,503 M., with an average yield of 36,317 M.

The suggestion of Johnson and Morgan has been followed and these figures have been plotted on bar graphs. It would seem, however, that there is no reasonable mathematical relation between them except the tendency to start small, to reach one or two maxima within the first 15 months, and to decline at the end.

DECLINE OF OPEN FLOW METHOD

The open flow of a gas well is a theoretical figure, but it is in common usage to measure the volume of gas. The open flow is the total amount of gas which would be produced in 24 hours if the gas were allowed to blow freely into the air. Thus a gas well which is labeled 1,000,000 cu. ft. per day open flow, theoretically could produce this amount in one day but as a matter of common field practice is allowed to produce about one-tenth of that figure, or 100,000 cu. ft. per day. In many states the law restricts the production of gas to one-fourth of the open flow, on the theory that a larger production will allow water to come in prematurely and to drown out the well before it has produced its maximum amount of gas.

The open flow is commonly obtained by opening the well to the air, allowing the pent-up pressure in the pipes to be released, until the readings do not decrease. Then a measurement of the velocity of the gas is obtained by an instrument known as the Pitot tube.

The Pitot tube consists of a small tube, with one end bent in a curve, which is held into the flowing gas about one-fourth of the diameter of the pipe from the edge. The plane of the opening in the tube is held at right angles to the flowing gas. This tube is connected to an inverted siphon, a U-shaped gauge, which is usually mounted for convenience on a solid background. The gauge is half-filled with mercury or water and is calibrated in inches so that the displacement of the water or mercury by the moving gas may be measured. Tables have been worked out which show the volume of the open flow in thousands of cubic feet for any reading of the liquid displaced. For wells of any considerable size mercury must be used instead of water. The tables are usually based upon a temperature of 60 degrees F., a pressure of 14.65 pounds absolute and a specific gravity of 0.6. Any considerable deviation from these figures must be taken into consideration.

The measurement of the open flow by the method outlined has been a regular part of the field practice in the Blue Springs field and the tables which show the total production from each lease also give the cumulative open flow for all the wells on the lease. The open flow has been taken every six months, in a few cases at intervals of three months, and the cumulative open flow for the districts are tabulated in the totals.

Better methods of taking the open flow in which the gas is not wasted by blowing into the air have been described by Diehl.[1] As has been stated, the Panhandle Eastern has adopted these methods for the large wells in Texas and western Kansas, but has not changed the system in the Kansas City district.

An analysis of the yield of gas per cubic foot of open flow is given in the accompanying table. The figures are obtained by dividing the loss of open flow by the total yield of gas in the same period. In the East District the yield per cubic foot for each cubic foot of open flow decline is 38.5, 36.1, and 33.4. In the Northeast District it is 10.3, 17.4 and 8.9. In the South District it is 9.6. In the West District it is 62.4, 24.0, 48.4, 37.5, and 121.7. These figures have been plotted on the same graphs which show the yield of gas per pound of pressure decline. While they are not regular they show much less variation than the figures based upon pressure loss.

Yield per cubic foot open flow.

West District.

October 1, 1929, to January 1, 1930.
47,848 M. to 42,991 M. shows 4,857 M. loss.
303,366 M. yield in same time.

$\frac{303,366}{4,857}$ equals 62.4 cu. ft. yield for each cu. ft. of open flow decline.

January 1, 1930, to April 1, 1930.
42,991 M. to 32,021 M. shows 10,970 M. loss.
263,288 M. yield in same time.

$\frac{263,288}{10,970}$ equals 24.0 cu. ft. yield for each cu. ft. of open flow decline.

April 1, 1930, to October 1, 1930.
32,021 M. to 21,730 M. shows 10,291 M. loss.
260,039 M. and 238,140 M. equals 498,179 M. yield in same time.

$\frac{498,179}{10,291}$ equals 48.4 cu. ft. yield for each cu. ft. of open flow decline.

October 1, 1930, to April 1, 1931.
21,730 M. to 11,719 M. shows 100,11 M. loss.
206,565 M. and 169,126 M. equals 375,691 M. yield in same time.

$\frac{375,691}{10,011}$ equals 37.5 cu. ft. yield for each cu. ft. of open flow decline.

April 1, 1931, to October 1, 1931.
11,719 M. to 9,395 M. shows 2,324 M. loss.
143,635 M. and 139,266 M. equals 282,901 M. yield in same time

$\frac{282,901}{2,324}$ equals 121.7 cu. ft. yield for each cu. ft. of open flow decline.

[1]Diehl, John C., Natural gas handbook, Metric Metal Works of American Meter Co., Inc., Erie, Pa., 1927, 578 pp.

Yield per cubic foot open flow.
East District.

April 1, 1930, to October 1, 1930.
28,642 M. to 22,420 M. shows 6,222 M. loss.
110,107 M. and 131,945 M. equals 242,052 M. yield in same time.
$\frac{242,052}{6,222}$ equals 38.5 cu. ft. yield for each cu. ft. of open flow decline.

October 1, 1930, to April 1, 1931.
22,420 M. to 14,387 M. shows 8,033 M. loss.
124,660 M. and 165,536 M. equals 290,196 M. yield in same time.
$\frac{290,196}{8,033}$ equals 36.1 cu. ft. yield for each cu. ft. of open flow decline.

April 1, 1931, to October 1, 1931.
14,387 M. to 9,611 M. shows 4,776 M. loss.
80,655 M. and 78,703 M. equals 159,358 M. yield in same time.
$\frac{159,358}{4,776}$ equals 33.4 cu. ft. yield for each cu. ft. of open flow decline.

Yield per cubic foot open flow.
Northeast District.

October 1, 1930, to April 1, 1931.
8,228 M. to 3,056 M. shows 5,172 M. loss.
31,126 M. and 22,380 M. equals 53,506 M. yield in same time.
$\frac{53,506}{5,172}$ equals 10.3 cu. ft. yield for each cu. ft. of open flow decline.

April 1, 1931, to October 1, 1931.
3,056 M. to 1,788 M. shows 1,268 M. loss.
12,993 M. and 9,257 M. equals 22,250 M. yield in same time.
$\frac{22,250}{1,268}$ equals 17.4 cu. ft. yield for each cu. ft. of open flow decline.

October 1, 1931, to January 1, 1932.
1,788 M. to 822 M. shows 9,666 M. loss.
8,636 M. yield in same time.
$\frac{8,636}{966}$ equals 8.9 cu. ft. yield for each cu. ft. of open flow decline.

Yield per cubic foot open flow.
South District.

April 1, 1931, to October 1, 1931.
12,208 M. to 5,005 M. shows 7,203 M. loss.
40,916 M. and 28,514 M. equals 69,430 M. yield in same time.
$\frac{69,430}{7,203}$ equals 9.6 cu. ft. yield for each cu. ft. of open flow decline.

It is possible that the yield per cubic foot of open flow decline may furnish the best basis for estimating the reserves in gas fields in which there is a large flow and a long life. Of course the longer the history before the estimation, the more accurate the figures on the remainder. This is an essential weakness in the method, since the greatest interest is usually in the first part of the history of a field.

CONCLUSIONS REGARDING METHODS OF ESTIMATING RESERVES

In a field of this depth it is interesting to note that a total yield of from 500,000 cu. ft. to 700,000 cu. ft. per acre may be obtained; that when taking about 10 per cent of the open flow per day from the wells about one-half of the total production will be secured in the first year and that the total life will average about 3 years and 9 months.

The production decline curve method of estimating reserves may be used if the gas is not held back owing to lack of market, and if the decline of the rock pressure is also considered.

The pore space method of estimating reserves must be used conservatively, with rather low figures for porosity and thickness of sand, and with a factor of recovery of 50% or less.

The rock pressure decline curve method is not reliable. The decline of open flow method should be substituted for the rock pressure method and it must be based upon many wells and a reasonably long history of production.

It is obvious that no empirical formula can be developed for the estimation of gas reserves. Each field must be studied with relation to its peculiar geological conditions and with respect to similar conditions in other districts.

Composition of the gas. The average composition of the natural gas from the Blue Springs field is indicated by the analysis given below, which was furnished by the Chemical Laboratory, Panhandle Eastern Pipe Line Company. The sample was collected at the Dodson Compressor Station.

ANALYSIS OF GAS, J. T. Russell, Analyst.

Constituent	**Per cent.*
Carbon Dioxide (CO_2)	1.2
Nitrogen (N_2)	2.6
Methane (CH_4)	96.2
Total	100.0

Calculated from above analysis:

Gross heating value, b. t. u. per cu. ft. at 60° F-30″ Mercury	971
Gross heating value, b. t. u. per cu. ft. at 60° F-14.9 pounds abs	982
Net heating value, b. t. u. per cu. ft. at 60° F-30″ Mercury—	878
Net heating value, b. t. u. per cu. ft. at 60° F-14.9 pounds abs	888

*Calculated air-free. Air in sample, 1.9 %.

Note: Sample showed no trace of hydrogen sulphide (H_2S).

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY.

E. H. Graves No. 11.

Sec. 14, T. 48 N., R. 31 W., Map No. 51.
Drilled Jan. 28 to Feb. 1, 1930.
Elevation, 968 feet.

	Thickness, Feet.	Depth, Feet.	
Recent age:			
Soil and clay	12	12	
Pennsylvanian system:			
Kansas City formation:			
Winterset limestone and chert:			
Lime	14	26	
Galesburg shale:			
Dark shale	2	28	
Black slate	1	29	
Shale	3	32	
Bethany Falls limestone:			
Lime	23	55	
Ladore shale:			
Black slate	1	56	
Boulders	2	58	
Dark shale	5	63	
Hertha limestone:			
Lime	5	68	
Pleasanton formation:			
Light shale	12	80	
Gray shale	10	90	
Sand	10	100	
Sandy shale	20	120	
Gray shale	15	135	
Sandy shale	25	160	
Gray shale	40	200	
Sandy shale	30	230	
Sand	5	235	Showing oil.
Gray shale	5	240	
Henrietta formation:			
Lime	5	245	
Gray shale	5	250	
Lime	7	257	
Gray shale	5	262	
Lime	8	270	
Shale	2	272	
Black slate	1	273	
Shale	3	276	
Lime	2	278	
Cherokee formation:			
Gray shale	12	290	
Red bed	5	295	
Gray shale	5	300	
Lime	2	302	
Gray shale	16	318	
Lime	1	319	
Gray shale	6	325	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY—Continued.

	Thickness, Feet.	Depth, Feet.	
Lime	1–6	326.6	S. L. M. 332.
Sandy shale	17.6	344	S. L. M. 349.
Sand	11	355	
Sand	5	360	350,000 cu. ft. gas.
Sand	5	365	650,000 cu. ft. gas.
Sand	5	370	785,000 cu. ft. gas.
Sand	5	375	896,000 cu. ft gas.
Sand	5	380	Oil.
T. D. 380			

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY.

Pressley No. 1.

Sec. 8 T. 48 N., R. 31 W., Map No. 8.
Drilled Sept. 9 to 13, 1929.
Elevation, 918 ft.

	Thickness, Feet.	Depth, Feet.	
Recent age:			
Soil and Clay	8	8	
Pennsylvanian system:			
Kansas City formation:			
Winterset limestone and chert:			
Lime	12	20	
Galesburg shale:			
Shale	2	22	
Black slate	3	25	
Shale	2	27	
Bethany Falls limestone:			
Lime	2	53	
Black slate	2	55	Little water.
Shale	3	58	
Hertha limestone:			
Lime	5	63	
Pleasanton formation:			
Gray shale	5	68	
Sand	2	70	
Gray shale	20	90	
Lime and sand	5	95	
Gray shale	67	162	S. L. M. 162.
Sand	10	172	
Gray shale	9	181	
Red bed	5	186	
Gray and sandy shale	31	217	
Sand	5	222	
Sand	8	230	Showing oil.
Sand	5	235	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY—Continued.

	Thickness.	Depth.	
Henrietta formation:			
Lime	5	240	
Green shale	3	243	
Lime	5	248	
Gray shale	3	251	
Lime	9	260	
Gray shale	5	265	
Dark shale	6	271	
Lime	5	276	
Gray shale	1	277	
Black slate	3	280	
Gray shale	5	285	
Lime	3	288	
Cherokee formation:			
Gray shale	22	310	
Lime	3	313	
Shale	15	328	
Lime	3	331	S. L. M. 330.
Black slate	7	338	Water strong.
Lime	6	344	
Sandy shale	10	354	
Sand	6	360	
Sand	19	379	Showing oil.
Dark shale	2	381	
Total depth		381	

Material used two 6¼-inch plugs, one ¼-inch plug.

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY.

R. Dehoney No. 3.

Sec. 16, T. 48 N., R. 32 W., Map No. 163.

Drilled April 16 to 23, 1929.

Elevation, 959 feet.

	Thickness, Feet.	Depth, Feet.	
Recent age:			
Soil	4	4	
Clay	11	15	
Pennsylvanian System.			
Kansas City formation:			
Cherryvale shale:			
Light shale	12	27	
Lime	2	29	
Blue shale	5	34	
Winterset limestone and chert:			
Lime	36	70	
Galesburg shale:			
Blue shale	5	75	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY—Continued.

	Thickness, Feet.	Depth, Feet.	
Bethany Falls limestone:			
Lime	19	94	
Ladore shale:			
Black shale	6	100	
Hertha limestone:			
Lime	15	115	L. M.
Pleasanton formation:			
Light shale	25	140	
Sandy shale	20	160	
Gray shale	10	170	
Light shale	20	190	
Gray shale	15	205	
Sand	18	223	
Gray shale	3	226	
Red bed	9	235	
Gray shale	5	240	
Sand	10	250	
Light shale	18	268	
Henrietta formation:			
Lime	5	273	
Shale	2	275	
Lime	5	280	
Shale	2	282	
Soft lime	4½	286½	
Shale	1½	288	Set packer at 291 ft.
Lime	5	293	
Sand	12	305	
Black shale	7½	312½	
Lime	3½	315½	
Black shale	3	318½	
White lime	10½	329	
Cherokee formation:			
White shale	8	337	
Dark shale	13	350	
Lime	2	352	
Black shale	3	355	L. M.
Gray shale	5	360	
Light shale	5	365	
Lime	2	367	
Gray shale	3	370	
Lime	1	371	
Dark shale	4	375	L. M. 380.
Sandy shale	5	380	No gas.
Sand	15	395	
Sand	5	400	775 M. cu ft.
Sand	5	405	786 M. cu. ft.
Sand	5	410	900 M. cu. ft.
Sand	4-6	414-6	1,039 M. cu. ft.

6¼-inch casing 39 feet.
Top packer set at 291 feet.
Bottom packer set at 380 feet.
Top of 1st gas, 293 feet.
Top of 2nd gas, 380 feet.

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY.

Emmanuel No. 2.

Sec. 23, T. 48 N., R. 32 W., Map No. 276.
Drilled October 2 to 8, 1928.
Elevation, 940 feet.

	Thickness, Feet.	Depth, Feet.	
Recent age:			
Soil and clay	15	15	
Gravel	5	20	
Pennsylvanian System:			
Kansas City formation:			
Winterset limestone and chert:			
Lime	5	25	
Gray shale	3	28	
Lime	12½	40½	
Galesburg shale:			
Shale	6	46½	
Bethany Falls limestone:			
Lime	18½	65	
Ladore shale:			
Dark shale	5	70	
Hertha limestone:			
Lime	12½	82½	
Pleasanton formation:			
Light shale	3½	86	
Sand	6	92	
Light shale	23	115	
Sand	9	124	
Gray shale	64	188	
Oil sand	12	200	
Dark gray shale	10	210	
Red bed	3½	213½	
Sand	½	214	
Gray shale	23	237	L. M. 240.
Sand	8	245	
Henrietta formation:			
Lime	7	252	
Gray shale	1	253	
Lime	10	263	
Shale	1	264	
Lime	7½	271½	
Gas sand	7	278½	Gas.
Dark shale	7½	286	
Lime	4½	290½	
Black slate	1½	293	Gas.
Lime	2	295	
Sand	5	300	
Lime	8	308	
Cherokee formation:			
Light shale	7	315	
Red bed	13	328	
Dark shale	4	332	
Lime	2	334	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY—Continued.

	Thickness, Feet.	Depth, Feet.	
Lime	2	334	
Light shale	11	345	
Dark shale	5	350	
Gray shale	2	352	
Gray lime	2	354	
Dark shale	3½	357½	
Black lime	1	358½	
Light shale	3½	362	
Light shale	6	368	
Sand	2	370	Light gas.
Sand	5	375	Fair gas.
Sand	5	380	150 M. cu. ft. gas.
Sand	5	385	180 M. cu. ft.
Sand	5	390	315 M. cu. ft.
Sand	2½	392½	320 M. cu. ft.
Sand	2½	395	368 M. cu. ft.
Sand	2½	397½	400 M. cu. ft.
Sand	2½	400	410 M. cu. ft.

Set lower packer at 363 feet.
Set upper packer at 267 feet.
6 feet anchor under lower cage.

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY.

N. W. Boyd No. 1.

Sec. 29, T. 48 N., R. 31 W., Map No. 86.
Drilled, December 27 to 30, 1930.
Elevation, 1,001 feet.

	Thickness, Feet.	Depth, Feet.	
Recent age:			
Surface	16	16	
Gravel	5	21	
Pennsylvanian system:			
Kansas City formation:			
Winterset limestone and chert:			
Lime	6	27	
Shale	2	29	
Lime	6	35	
Shale	4	39	
Lime	11	50	
Galesburg shale:			
Shale	10	60	
Bethany Falls limestone:			
Lime	22	82	
Ladore shale:			
Shale	7	89	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY—Continued.

	Thickness.	Depth.	
Hertha limestone:			
Lime..	5	94	
Pleasanton and Channel formation:			
Shale...............	29	123	
Lime...............	2	125	
Shale...............	120	245	
Red shale...........	10	255	
Shale..............	13	268	
Gas sand............	22	290	

Packer set at 260 feet.
Cage 278 feet.
Vol. 527, 520.
R. P. 61 lbs.

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY.

T. C. Howard No. 2.

Sec. 8, T. 48 N., R. 31 W., Map No. 10.
Drilled Aug. 8 to Aug. 14, 1929.
Elevation, 929 feet.

	Thickness, Feet.	Depth, Feet.	
Recent age:			
Soil and clay........	10	10	
Pennsylvanian system:			
Kansas City formation:			
Bethany Falls limestone:			
Lime...............	21	31	
Ladore shale:			
Dark shale..........	2	33	
Black slate..........	2	35	
Dark shale..........	3	38	
Hertha limestone:			
Lime...............	5	43	
Pleasanton and channel formation:			
Dark shale..........	24	67	
Sand...............	6	73	
Gray shale..........	67	140	
Sand...............	10	150	
Gray shale..........	34	184	
Sand...............	6	190	
Sand...............	5	195	
Sand...............	5	200	
Sand...............	2–6	202–6	
Sand...............	2–6	205	368 M. cu. ft.
Sand...............	2–6	207–6	400 M. cu. ft.
Sand...............	2–6	210	452 M. cu. ft.

LOG OF PANHANDLE EASTERN PIPE COMPANY—Continued.

	Thickness. Feet.	Depth. Feet.	
Sand	2–6	212–6	468 M. cu. ft.
Sand	2–6	215	468 M. cu. ft.
Sand	5	220	Inc. 554, 440.
Sand	2–6	222–6	554, 400.
Sand	2–6	225	S. L. M. 225.
Sand	15	240	Water and showing of oil.
Oil sand	88	328	S. L. M. 329 ft.
Sandy lime	5	333	Reduced hole at 329 feet.
Soft sand	3	336	
Black slate	10	346	
Gray sand	1½	347½	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY.

Oscar Boten, No. 1.

Sec. 28, T. 48 N., R. 31 W., Map No. 84.

Drilled September 30 to October 12, 1929.

Elevation, 981 feet.

	Thickness, Feet.	Depth, Feet.	
Recent age:			
Soil and clay	15	15	
Creek gravel	4	19	
Pennsylvanian System:			
Kansas City formation:			
Winterset limestone and chert:			
Lime	13	32	
Blue shale	3	35	
Lime broken	28	63	
Galesburg shale:			
Black shale	5	68	
Bethany Falls limestone:			
Lime	23	91	
Ladore shale:			
Black slate	2	93	
Hertha limestone:			
Lime	4	97	
Pleasanton formation:			
Gray shale	24	121	
Lime	3	124	
Dark shale	10	134	Little water.
Lime	1	135	
Sandy shale	30	165	
Gray shale	35	200	L. M. 200.
Sand	6	206	Silent.
Gray shale	14	220	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY—Continued.

	Thickness, Feet.	Depth, Feet.	
Red bed	4	224	
Lime	1	225	
Shale	40	265	S. L. M. 260.
Henrietta formation:			
Lime	6	271	
Gray shale	4	275	
Lime	6	281	
Gray shale	8	289	
Lime	4	293	
Red bed	2	295	
Gray shale	6	301	
Black shale	4	305	S. L. M. 304.
Gray shale	2	307	
Lime	7	314	
Dark shale	5	319	
Black slate	3	322	Little gas.
Lime	3	325	
Cherokee formation:			
Light shale	6	331	
Red bed	5	336	
Gray shale	9	345	
Lime	2	347	
Black slate	4	351	S. L. M. 352.
Gray shale	7	358	
Lime	3	361	
Gray shale	4	365	
Lime	3	368	
Black shale	4	372	
Light shale	13	385	
Sand	15	400	S. L. M. 385 trace of oil.
Gray shale	20	420	
Black shale	3	423	
Lime	2	425	
Black shale	21	446	S. L. M. 431 set 4-7/8
Gray shale	9	455	
Black shale	6	461	
Sandy shale	13	474	
Red bed	7	481	
Gray shale	9	490	
Light sandy shale	14	514	S. L. M. 505.
Sand	4	518	
Black shale	6	524	
Gray shale	19	543	
Sand	11	554	S. L. M. 546.
Gray shale	20	574	
Black shale	3	577	
Light shale	17	594	S. L. M. 598.
Sand	5	599	
Black shale	2	601	
Light sandy shale	7	608	
Sand	7	615	Silent.
Dark shale	9	624	
Light sandy shale	4	628	

LOG OF PANHANDLE EASTERN PIPE LINE COMPANY—Continued.

	Thickness, Feet.	Depth. Feet.	
Sand..............	5	633	Silent.
Dark sandy shale.....	12	645	Water.
Gray sandy shale.....	18	663	S. L. M. 690.
Sand..............	34	697	Silent water.
Mississippian system:			
Lime..............	8	705	