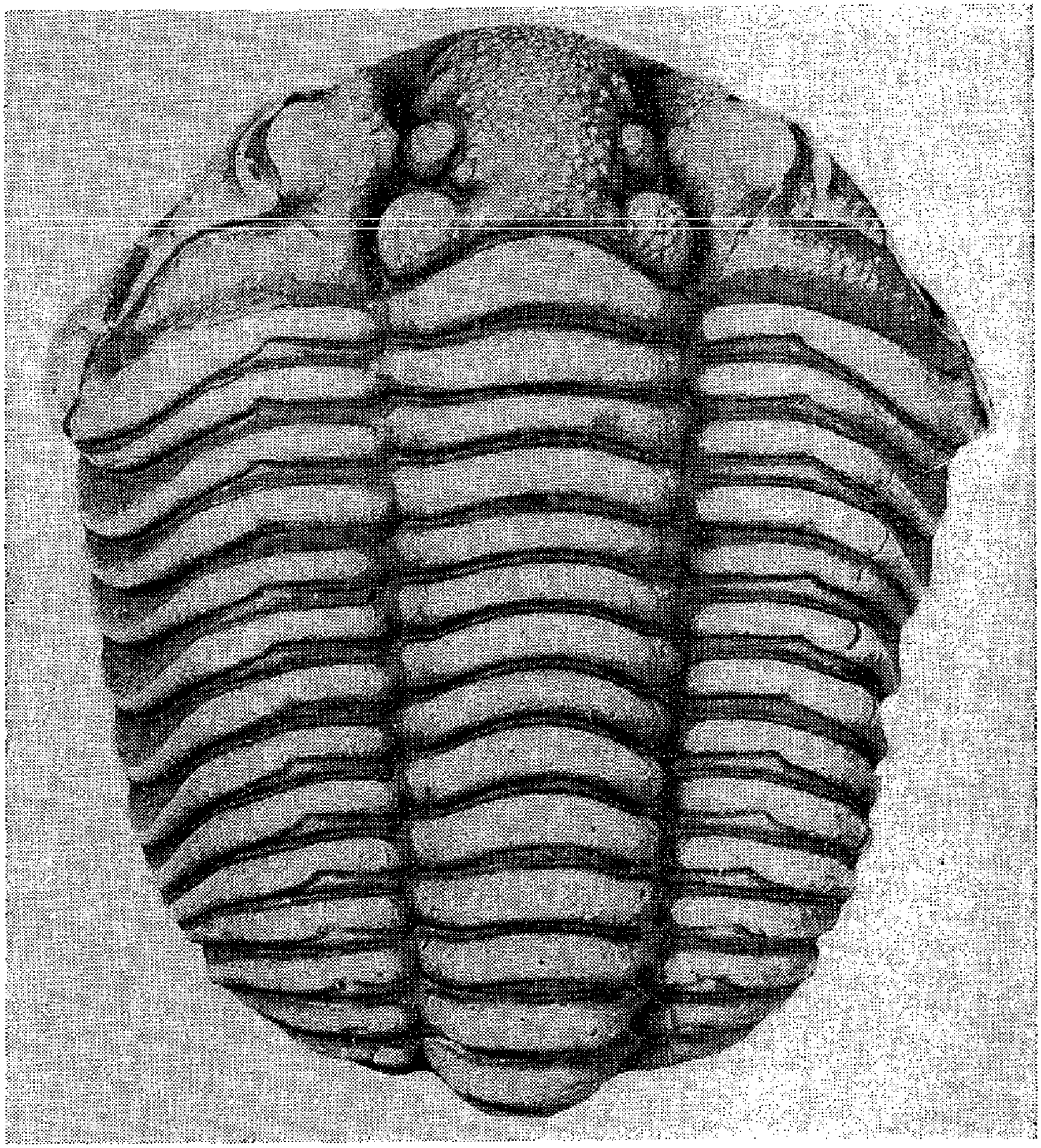
OKLAHOMA GEOLOGY NOTES



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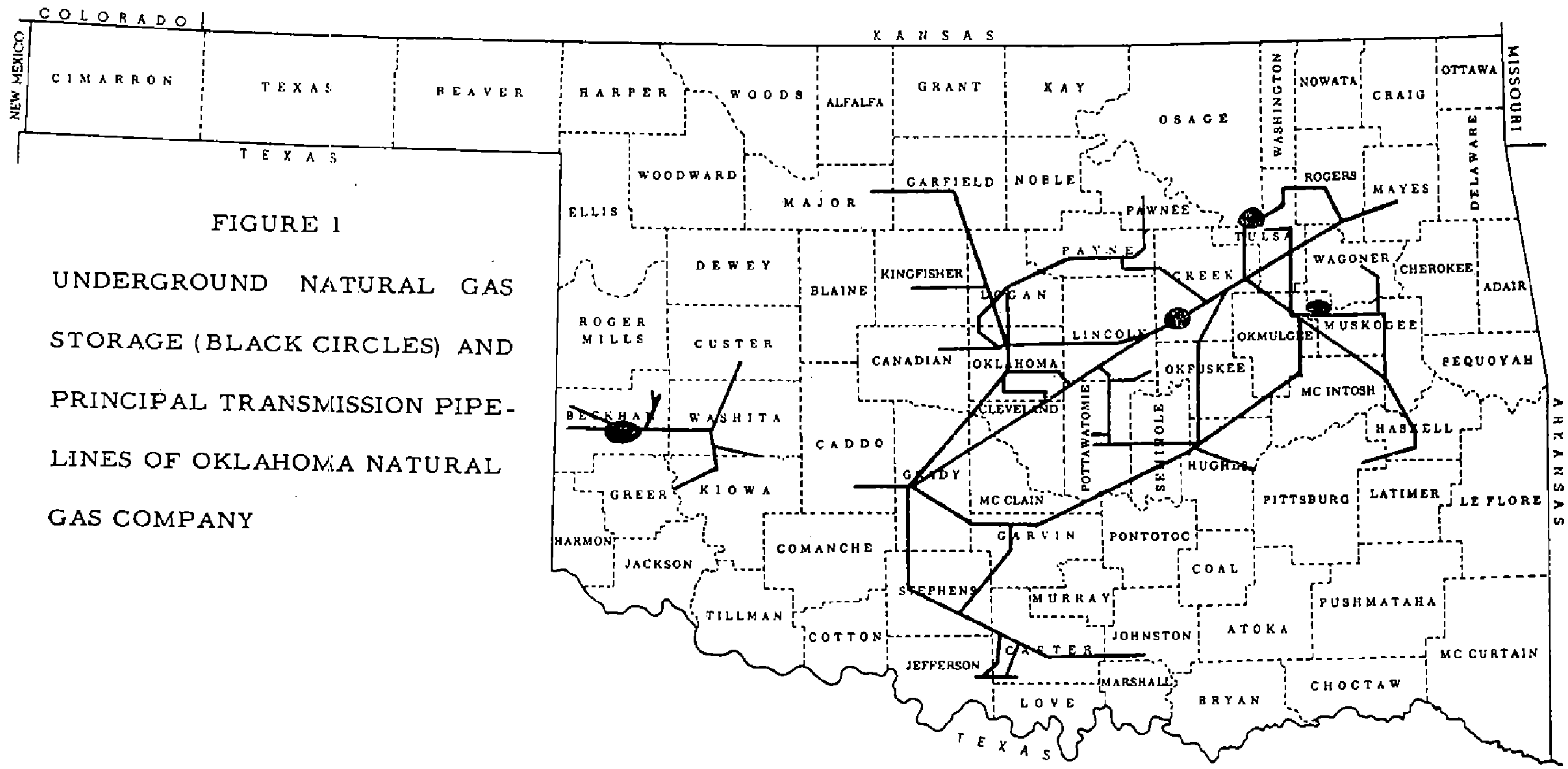

FIGURE 1

UNDERGROUND NATURAL GAS STORAGE (BLACK CIRCLES) AND PRINCIPAL TRANSMISSION PIPELINES OF OKLAHOMA NATURAL GAS COMPANY

Natural Gas Storage in Oklahoma

Louise Jordan

Introduction

The earliest successful underground natural-gas storage was completed in 1915 in Welland County, Ontario, Canada. In 1916 operations were begun at Zoar Field near Buffalo, New York. but developments of many such facilities did not commence until 1937. By 1939, only eight billion cubic feet of natural gas was stored in the United States. Ten years later in 1949, there were 100 storage fields with a capacity of 440 billion cubic feet(Davis, 1951, p. 103). The American Gas Association (1959, p. 7) reports 205 storage pools in operation and seven under construction in 19 states, and estimates that capacity for storage will reach more than 2,780 billion cubic feet during the year. This information differs slightly from that of the Oil and Gas Journal's 1959 survey (Bizal, 1959, p. 95), which reports 207 projects in operation or planned in 21 states. The total capacity of underground-storage facilities for natural gas has increased 68 percent since 1955. All the marketable gas produced in 1958 could be stored in Oklahoma, Kansas, New Mexico, West Virginia and California, yet except for West Virginia, the total storage capacity in any one of these states is less than that of Oklahoma. Oklahoma ranks fifth (Table 1) among the states in this respect, primarily due to the foresight of the Oklahoma Natural Gas Company.

Table 1

Total planned and completed underground storage reservoir capacity for natural gas in the United States, by rank of States, in million cubic feet (*American Gas Association*, 1959, p. 8, 9.)

1. Ohio	468,769	11. Kansas	83,623
2. Pennsylvania	456,696	12. New York	65.257
3. Michigan	383,671	13. Wyoming	62,972
4. West Virginia	333,728	14. New Mexico	61,033
5. Oklahoma	179.988	15. Texas	54,536
6. Illinois	159,302	16. Kentucky	25,388
7. Iowa	140,770	17. Indiana	9,594
8. California	106,117	18. Arkansas	5,063
9. Missouri	90,495	19. Mississippi	4,051
10. Montana	89.270	TOTAL	2,780,323

The more desirable locations for underground natural-gas storage are near large sales areas farthest removed from source of supply and favorably located with respect to existing pipe lines. Storage is needed to meet peak sales requirements and to maintain constant pressure of the gas to the consumer. A storage facility is valuable for the conservation of gas produced with oil which otherwise is wasted because of lack of market; it creates a safety measure for pipe line failures; and insures a just share of purchases in highly competitive supply areas. An underground storage area requires a closed geologic structure where the gas reservoir is partially or completely depleted and has high permeability and porosity. The relation of "cushion gas" to annual turn-over should be as low as possible.

In Oklahoma, six old fields have been converted to natural-gas storage by three companies. Pertinent statistics compiled by the subcommittee on underground gas storage statistics of the American Gas Association (December 31, 1958) concerning capacity of these storage facilities are listed in Table 2 by companies and fields.

Table 2

Underground natural gas storage in Oklahoma, in million cubic feet.

Company Field or area — County	Working-gas capacity	Required as cushion gas	Total capacity of reservoir
Consolidated Gas Utilities Corp.			
Ulan—Pittsburg	7,495	6,005	13,500
Oklahoma Natural Gas Co.			
Depew—Creek	19,600	37,400	57,000
Haskell—Muskogee	2,500	8,400	10,900
Osage—Osage	830	1,900	2,730
Sayre—Beckham	63,500	25,800	89,300
Southwest Natural Gas Co.			
North Ada—Pontotoc	993	5,564	6,557
Total	94,918	85,069	179,987

Information on the geology, development, and costs of the six storage areas has been supplied by the operating companies.

Gas Storage near Depew, Haskell, Sayre and Tulsa

Oklahoma Natural Gas Company has in operation four natural gas storage fields named respectively Depew, Haskell, Osage, and Sayre. One additional field area now under study will be converted to use probably by 1960. Because of storage capacity, Oklahoma Natural has not curtailed service to its more than 300,000 customers in eight years. For the cold day, January 17, 1957, a record 69 percent of the natural-gas requirements was supplied from storage. Total operating expenses of the four underground facilities amount to about 11 cents per thousand cubic feet of gas withdrawn. The capital costs of finding suitable structure, acquiring storage rights, and then conditioning the structure for retention of stored gas are high. The costs of plugging and re-plugging of 99 old wells in order to create the storage alone amount to $3.9 million as of December 1, 1957. The difficulties encountered in plugging wells are numerous and expensive because of 1) incomplete or inaccurate original well data, 2) inaccuracy of available plugging records, 3) crooked holes, 4) junk thrown into hole when originally plugged, and 5) high pressure now in reservoir. Drilling of new wells for injection and withdrawal of gas adds to the capital outlay.

The four storage areas of Oklahoma Natural Gas Company have a total capacity of 159,930 million cubic feet of gas of which 54 percent or 86,430 million is available for delivery during any input-output cycle. The total volume of gas injected since conversion amounts to 215,054 million and that withdrawn to 129, 856 million cubic feet as of January 1, 1959. Figure 1 is a map of Oklahoma showing the locations of the storage fields and in a generalized manner some of the transmission pipe lines which indicate the area serviced by the Company.

The *Depew storage* is under a 7,360-acre tract in the Big Pond Field, secs. 25, 36, T. 15 N., R. 7 E., and secs. 19, 20, 30, 31, T. 15 N., R. 8 E., Creek County. The facility, completed in May 1950, supplies gas to Oklahoma City and Tulsa, respectively 80 and 50 miles distant. A Pennsylvanian sandstone termed Dutcher, probably Atokan in age at this place, and at a average depth of 3,250 feet is used for storage. Dry gas at an original pressure of 1,500 psig (pounds per square inch gauge) was discovered in the sandstone in 1922. The structure of the field is an anticline and the sand body is reported to be a continuous sheet in the area. Temperature of the reservoir is 112° F. Water encroachment is from the edge of the structure.

Prior to conversion to storage use, 32 wells in the area produced about 54,600 million cubic feet of gas. Six producing gas wells remained in the field at time of conversion. Some 46 wells have been replugged since conversion at a cost of over $3,000.000. Ten new wells used for injection and withdrawal of gas have been drilled and one test is used for storage-pressure observations. The maximum net volume of foreign gas to be stored in the field will be the same as that which has been produced prior to conversion so that the highest pressure used in storage will not be above the original pressure at time of discovery.

The *Haskell storage* is under 7,000 acres in parts of secs. 7-10, 14-20, T. 15 N., R. 15 E., Muskogee County, in the area of the old Boyle pool of 1935 official nomenclature but now included in the Bald Hill Field by the Oklahoma Nomenclature Committee. This storage field, completed in June 1944, supplies gas to Tulsa and Muskogee, respectively 30 and 19 miles away. Early Desmoinesian sandstone termed Booch sand occurs on an anticline at an average depth of 800 feet, and also grades to shale forming a stratigraphic trap. Dry gas was discovered in the Booch at an original pressure of 325 psig in 1914. Temperature of the reservoir is 76° F.

Prior to conversion 51 wells had produced 10.6 billion cubic feet of gas and 46 wells had been abandoned. Since conversion 78 wells have been re-plugged and 16 new wells have been drilled. The cost of plugging one of these comparatively shallow holes ranges from $1,000 to $30,000. Four wells are used for pressure observations and 14 wells for injection and withdrawal of gas. Since time of conversion to January 1, 1959, the total volume of gas injected has been 47,460 million cubic feet and of that withdrawn has been 35,535 million cubic feet.

The *Osage storage* is under a 1,920-acre tract centering about sec. 29, T. 20 N., R. 12 E., Osage County, in the field once called Country Club, now Turley District, 1.5 miles from the city of Tulsa. Dry gas discovered in 1922 at an original pressure of 565 psig and at an average depth of 1,600 feet was produced from the Burgess sand, a basal Desmoinesian sandstone of Middle Pennsylvanian age. The structure is an anticline and the sand body is continuous. Temperature of the reservoir is 65° F. Six wells had produced gas but none was producing at the time storage was commenced in April 1943. Re-plugging of the six wells cost over $100,000. Seven new wells were drilled for injection and withdrawal purposes. The maximum net volume of foreign gas stored in the field is 2,670 million cubic feet. As of January 1, 1959, 16,846 million cubic feet has been injected and 14,530 million has been withdrawn.

The *Sayre storage* is located south of Sayre in secs. 20, 21, 27, 28 T. 9 N., R. 23 W., Beckham County. It serves the Clinton-Sayre pipeline system and is 19 miles from Elk City and 45 miles from Clinton. This storage field of 5,000 acres is in the Sayre Gas District where 32 wells prior to conversion had produced gas from the Panhandle dolomite of Early Permian age at an average depth of 2,650 feet and at an original pressure of 940 psig. The structure is anticlinal and the reservoir contains edge- and possibly bottom-water. Temperature of the reservoir is 85° F. Eight wells were producing gas at the time of conversion in October 1953. Two wells have been replugged and seven wells have been reworked for injection and withdrawal purposes at a total cost of over $50,000. The maximum net volume of foreign gas which can be stored in the field is 86,000 million cubic feet. As of January 1, 1959, 16,567 million cubic feet has been injected since conversion and 130 million cubic feet withdrawn.

Gas Storage North of Ada, Pontotoc County

Southwest Natural Gas Company stores gas north of Ada in a stratigraphic trap in part of the depleted gas field called Ada gas field by R. A. Conkling (1927, p. 26) in his report on the geology of Pontotoc County. The oil producing area is now officially named West Oakman District. The storage reservoir extends under approximately 2,000 acres of land in secs. 8-10, 16, 17, T. 4 N., R. 6 E. (Figure 2). Primary market served is the town of Ada but the company has a pipeline to Seminole and some gas is moved there during the winter period.

The earliest gas discovery in the area, according to Oklahoma Geological Survey files, was the Rex-Corsicana No. 1 R. C. Jeter (SW¼ SW¼ SW¼ sec. 8, T. 4 N., R. 6 E.) completed in December 1915 with an initial production of 9,240,000 cubic feet of dry gas. Later in 1917, American Oil and Refining Company completed in the SW¼ of the section several wells which tested as much as 16,000,000 cubic feet per day at a rock pressure of about 400 psi. Most of the gas wells in the storage area were drilled in the early twenties. The field area is essentially an anticline bisected by a major strike fault and at least one minor dip fault. The reservoir is defined by the faults and by wedge-out of the upper Cromwell sand. Structure of the reservoir is shown in Figure 2 by a map contoured on top of the upper Cromwell sand, a Morrowan sandstone near the base of the Pennsylvanian. Upper Cromwell sand is at a depth of 1,200 to 1,400 feet and at greater depths in downthrown fault blocks. The sandstone underlies Union Valley limestone in downdip position, but, at higher points on structure, the Union Valley is absent and part of the upper Cromwell seems to be missing.

G. D. Morgan (1924, pl. 7, p. 43) in his report on the Stonewall quadrangle shows an east-west trending fault through secs. 7 and 8 on a structure map contoured on top of the Hunton terrane. Two wells and two surface outcrops are used as control points in the township. He mapped a northwest-trending fault at the surface just east of Byng in secs. 3 and 4 (pl. 24). R. C. Conkling (1927, p. 26) illustrated the structure of the field contoured on top of the "producing horizon". His data do not conform to present interpretation based on more reliable information.

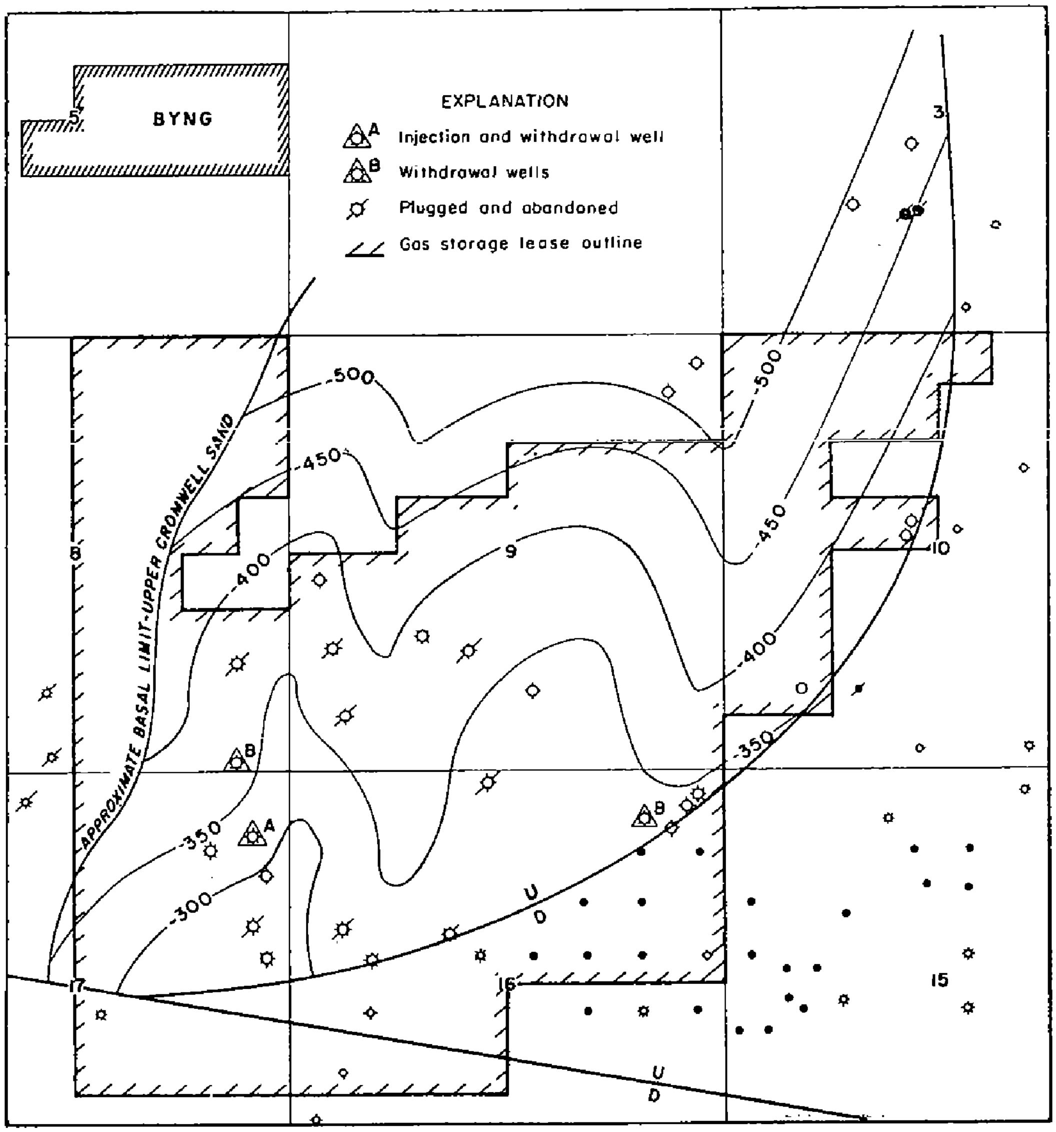

Figure 2. Structure map using upper Cromwell sand as datum, showing gas storage area of Southwest Natural Gas Company, north of Ada in Pontotoc County, location of injection and withdrawal wells, and other drilled holes.

According to the map, Figure 2, the upper Cromwell sand is beveled along a northeast-trending line in secs. 8 and 17. Maximum gross permeable sandstone is 150 feet thick in a downdip direction, but, where post-Morrowan erosion is greatest, the permeable section ranges from 60 to 80 feet in thickness within the reservoir area. Gas in the storage area was discovered in the early twenties. No record of the amount of original gas produced was made but estimates range from 28 to 60 billion cubic feet. At the time the field was developed, gas was not measured and each well had a flat yearly rental. In 1930, working pressure of the field had declined to 35 psi from an original pressure of somewhere between 425 to 451 psi. From 1930 to May 1944, the field floated on the line, and beginning in May 1944, all gas injected and withdrawn has been measured and accurate records have been made.

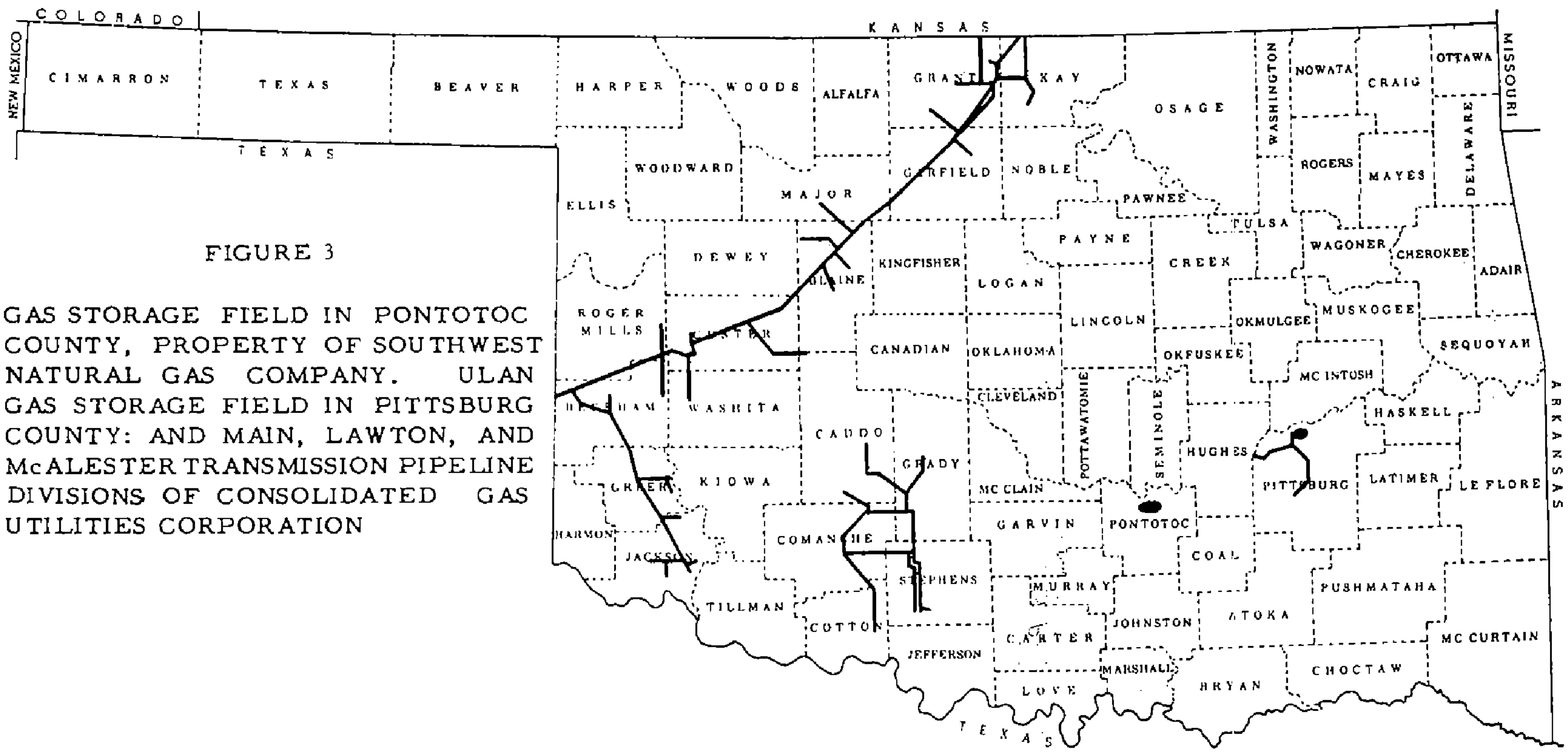

FIGURE 3

GAS STORAGE FIELD IN PONTOTOC COUNTY, PROPERTY OF SOUTHWEST NATURAL GAS COMPANY. ULAN GAS STORAGE FIELD IN PITTSBURG COUNTY: AND MAIN, LAWTON, AND McALESTER TRANSMISSION PIPELINE DIVISIONS OF CONSOLIDATED GAS UTILITIES CORPORATION

Since 1944 four wells have been abandoned and plugged at an average cost of $3,500 per well. One well (Figure 2, well A in SE¼ NE¼ NE¼ sec. 17) is used for injection and withdrawal of gas. Gas can be withdrawn also from two other wells (Figure 2, wells B).

Several years ago Southwest Natural Gas Company believed, as a result of geological studies of the area based on information of old drilled holes and of electric logs of new holes, that they had leases on the land surface above the storage reservoir. However, a location drilled by others just outside of the controlled area brought in a "good" well from the company's stored gas. Such a problem may confront a company where gas or liquefied petroleum gas is stored in a reservoir in a faulted area.

Gas Storage at Ulan, Pittsburg County

Consolidated Gas Utilities Corporation converted the Ulan gas field (officially named East Ulan Field) into a storage reservoir in January 1953. The field was discovered in March 1945 by the Public Service Company of Oklahoma No. 1 Wayne Travis (NW¼ NE¼, sec. 5, T. 7 N., R. 14 E.) which produced from Booch sand in the McAlester formation (Desmoinesian, Pennsylvanian) at a depth of 1,884 to 1,920 feet. The well tested 4,248.000 cubic feet of gas per day with 470 pounds rock pressure. By the middle of 1946 Public Service completed nine productive wells with individual open-flow potential ranging from 1,500,000 to 25.000,000 cubic feet of gas per day. In 1947, Consolidated bought the property and formed its McAlester Division which includes a gas transmission system and gas distribution systems in the cities of McAlester, Krebs, and Savanna (Figure 3). The United States Naval Ammunition Depot near Savanna is one of the large customers. The Ulan field, 13 miles northwest of McAlester and underlying approximately 1,700 acres in secs. 31-33, T. 8 N., R. 14 E. and secs. 5, 6, T. 7 N., R. 14 E., has been the principal source of gas supply for the Division.

The structure controlling the accumulation of gas is an anticlinal fold with an east-west trending axis (Figure 4). Two transverse faults roughly paralleling one another in north-south direction delimit the gas-producing portion of the structure. Gas is obtained from two stratigraphic levels: sandstone in the Savanna formation, locally termed Savanna sand, at about 1,000 feet; and Booch sand, probably equivalent to the surface Warner sandstone member of the McAlester formation, at an average depth of 2,000 feet.

Consolidated had brought the total number of producing wells to 10 in 1949 by drilling its No. 3 Mickle (SW¼ NE¼ sec. 31, T. 8 N., R. 14 E.). At the end of 1951, the Savanna sand had been proved productive in six wells and was being produced in three dual completions. Original gas in place in the reservoir was calculated to be in the order of one billion cubic feet, of which 850 million cubic feet was considered recoverable. Booch sand had an original average shut-in well-head pressure of 455 psi and the indicated original volume of gas in place in this sandstone was calculated to be about 13 billion cubic feet, of which 11 billion were considered recoverable. This source of supply based on remaining reserves and rate of withdrawal had a future life of about 6 years.

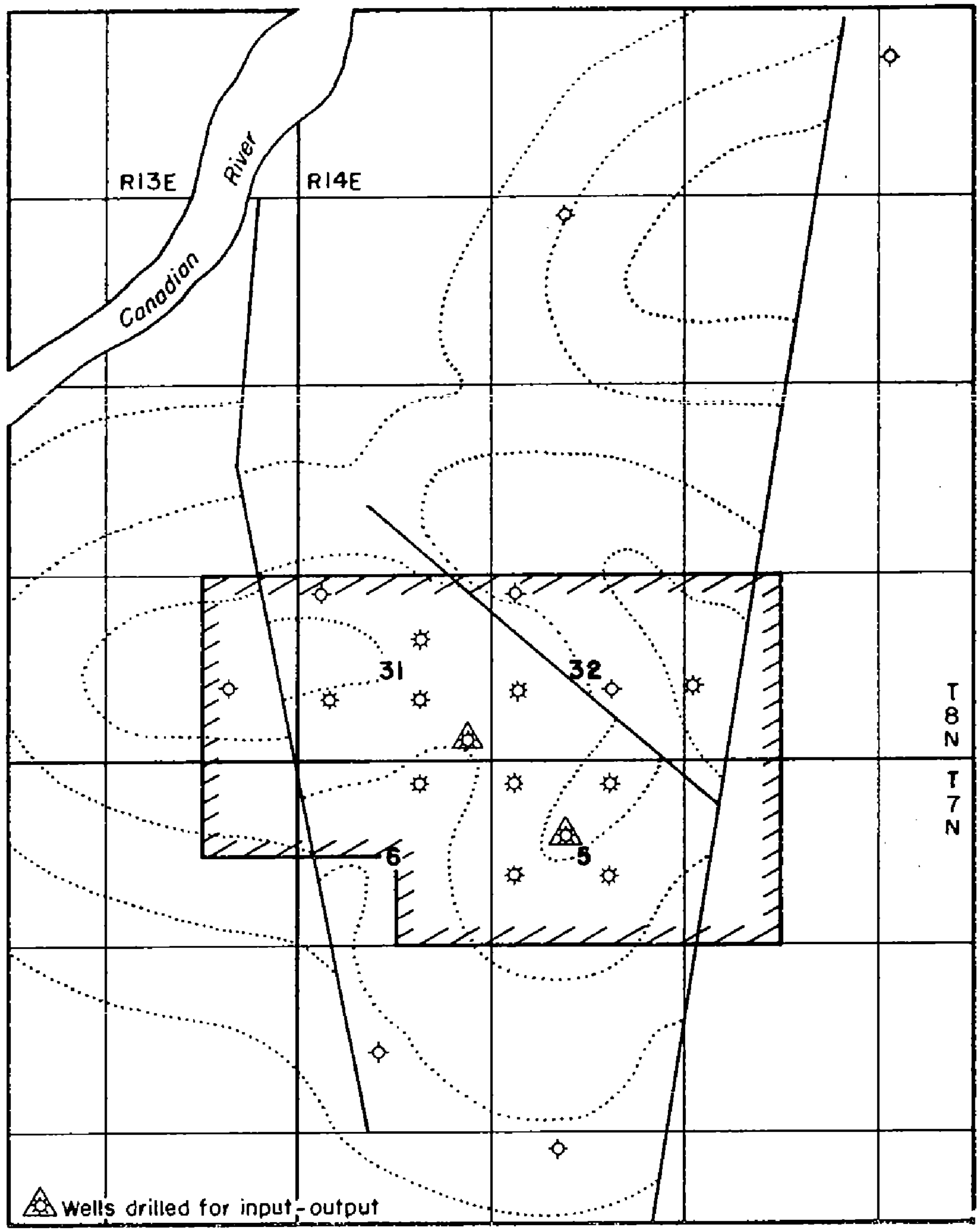

Figure 4. Structure map showing gas storage area at Ulan field in Pittsburg County operated by Consolidated Gas Utilities Corporation, and location of two wells drilled for injection and withdrawal purposes when the field was converted to storage.

Because of the rapidly depleting gas supply which could deliver only 60 percent of a winter peak-day requirement, Consolidated in 1952 decided to convert Ulan field into a gas storage field. Gas for underground storage became available through a long-term contract for purchase of off-peak gas from Oklahoma Natural Gas Company. Consolidated built 14.7 miles of 6-inch and 8-inch pipe line from its McAlester compressor station west to the Canadian River. Oklahoma Natural built 20.46 miles of 8-inch pipeline from its 16-inch transmission line which crosses the northwestern corner of Hughes County line to connect with Consolidated's. Consolidated, under terms of the contract, may purchase up to 15 million cubic feet of gas per day during the 210 days of off-peak summer months. Mineral rights to a depth of 2,200 feet were purchased and gas storage leases to the same depth were acquired under 3,520 acres of the storage area held by approximately 300 different owners of royalty and surface interest. Because the storage project was started before Ulan field was depleted, Consolidated had to purchase the remaining gas reserves. The reservoir contained about 6.0 billion cubic feet of native gas when the rock pressure registered 236 psi gauge, or, in effect, was about 44 percent depleted of native gas. Two of the existing wells were reworked in order to increase the ability of the sandstone reservoir to take gas. Two new wells were drilled to increase the rate of injection and to add to the open flow for withdrawal of gas during the winter peak periods.

Most of the preliminary work was either completed or was in progress when actual gas injection into the underground storage started in January 1953. The cost of conversion was in the order of $650,000. Gas was injected at an average rate of eight million cubic feet per day throughout the summer of 1953. Eight of the 12 wells in the area are used as injection and withdrawal wells. The remaining four wells are shut-in and are used for pressure observations. The capacity of the reservoir is estimated to be approximately 13.7 billion cubic feet at the initial rock pressure of 470 psi gauge.

The supply of gas available to Oklahoma Natural Gas Company from its connections in the gas-rich areas of Garvin and Stephens Counties is ample to assure continuous replenishment of the supply available to Consolidated's McAlester Division for many years, and the Ulan storage reservoir is adequate in all respects to accommodate the volumes of gas necessary to afford dependable service at all times.

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Evolution of Coined Words

The noun "outcrop" and its variant, "outcropping," have long been part of the English language. The verb "to crop out" is preferred over the more recent form, "to outcrop." Thus one writes, "There is an excellent outcrop of the Haragan marlstone at White Mound, and the formation crops out in hills north of the Mound." The Merriam-Webster dictionary of 1942 even lists "outcropper", one who works an outcrop, presumably in distinction from an underground miner.

Subsurface geologists have invented the noun "subcrop" for exposures which existed at an unconformity and are now rocks immediately below the overlapping rocks. A map showing the distribution of rock units on the pre-Woodford unconformity surface (for example) is termed a "subcrop map". This map is not precisely like a paleogeologic map, in which pre-Woodford structural conditions are restored. By extension, the coined word "subcrop" is now being used as a verb, "to subcrop". For instance, "The Sylvan subcrops locally at the base of Desmoinesian rocks in Oklahoma County." To be consistent with "to crop out" the verb might be required to be "to crop sub", a ridiculous form. The danger in coined words lies in the invention of analagous parts of speech. We can expect to see subcropped, subcropping, subcrop-like, non-subcropping, pseudosubcrop.

A language grows by use, but there should be some standard of acceptance. The monstrosities of "Business English" (to research, to contact, insurance-wise, seventeenth instant) and of "Federal Prose" (building engineer for janitor, under review for shelved and inactive) are sufficient warning of what can happen when standards are lacking.

C.C.B.

An Outlier on the Muenster-Waurika Arch

By

Philip A. Chenoweth

The Muenster-Waurika arch is a buried mountain range extending diagonally across southern Oklahoma and north Texas. It diverges at a small angle from the Wichita-Amarillo range in northern Tillman County, Oklahoma, and plunges gently southeastward to Denton County, Texas, a distance of more than 125 miles. It probably continues southeastward as a gentle upwarp beneath the Tertiary, Cretaceous, and the Ouachita facies in the Tyler basin. Except for the very northwestern extremity in the western Wichita Mountains, the entire uplift is concealed by Permian, Pennsylvanian, and Cretaceous rocks. In spite of the present lack of topographic expression the arch actually represents a mountain range of considerable magnitude. It was raised by tectonic forces in Late Mississippian and Early Pennsylvanian time, forces which created a mountainous land mass in the Red River region from the Texas panhandle across southwestern Oklahoma to northeast Texas. The arch is estimated to have had a topographic relief in excess of 5,000 feet. Erosion following the greatest period of uplift in early Pennsylvanian time removed all sedimentary rocks from parts of the uplift so that by Middle Pennsylvanian time the bedrock in the higher portions of the range consisted of Precambrian crystalline rocks; granite, volcanics, and metasedimentary rocks. Elsewhere, all the early Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician rocks were stripped off and the crest of the arch consisted of rocks of the Timbered Hills and lower Arbuckle groups (Cambrian). The eroded units are preserved in the intermontane Marietta basin to the north and the Fort Worth basin to the south.

In south-central Jefferson County, Oklahoma, however, a deep graben very near the crest of the range protected from erosion the Viola, Simpson, and uppermost Arbuckle groups. It is quite probable that parts of the

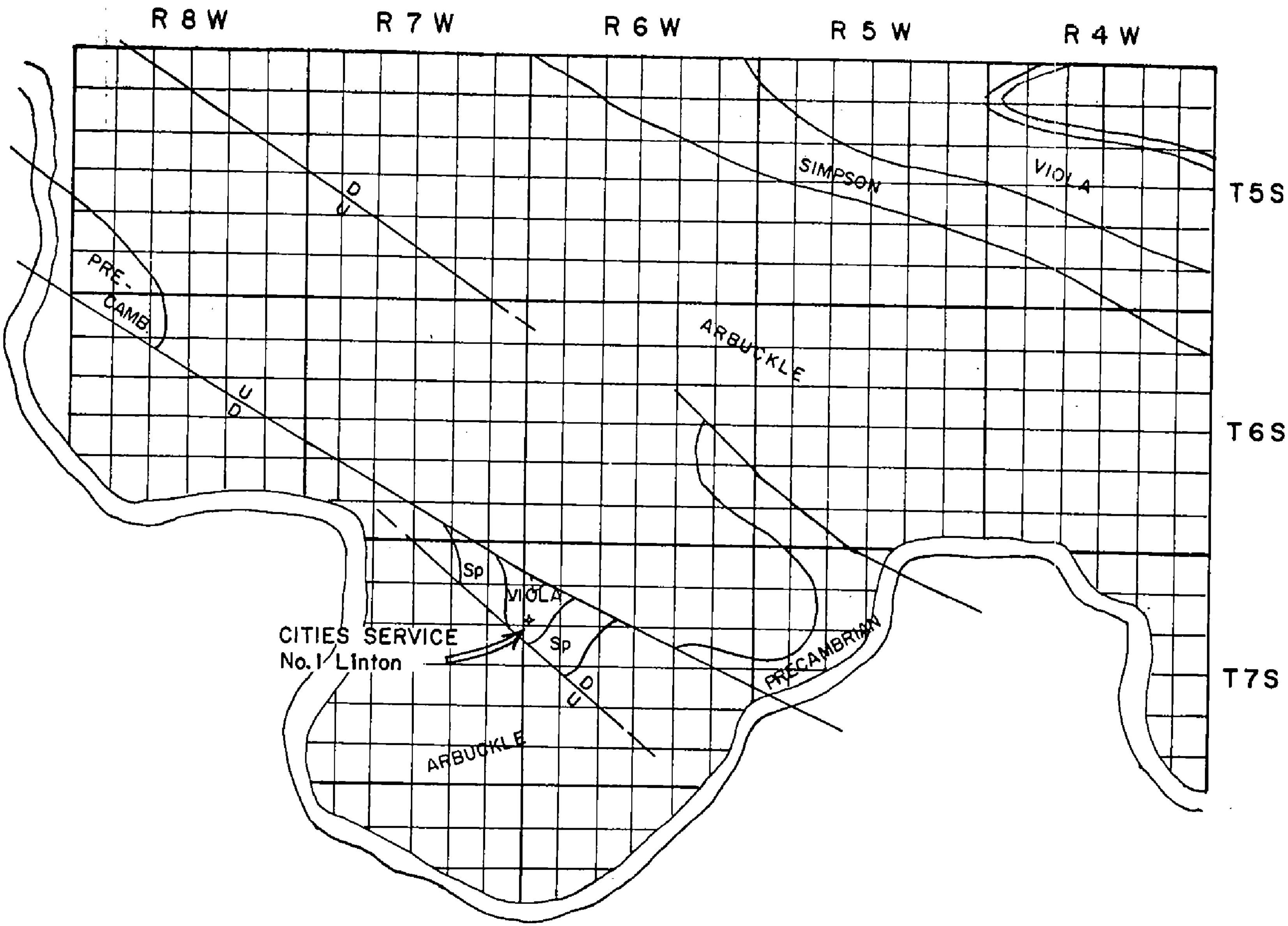

Figure 1. Pre-Pennsylvanian subcrop map of part of southern Jefferson County, Oklahoma, showing an outlier of upper Ordovician

Sylvan shale are likewise preserved in this down-faulted block. The Cities Service Oil Company's No. 1 Linton, a dry hole in SW¼ SW¼ SW¼ sec. 7, T. 7 S., R. 6 W., encountered Viola limestone at a depth of 4,734 feet beneath a thin cover of detrital limestone. The Simpson was entered at 5,296 feet, and the upper Arbuckle, West Spring Creek, at 5,894 feet. The well is situated between two large northwest-southeast faults which bound a triangular graben on the south flank of the Muenster-Waurika arch. The nearest known occurrence of Viola limestone is approximately 16 miles northeast, near the trough of the Marietta syncline, and the truncated Sylvan shale probably lies another 3 or 4 miles beyond. This outlier with the near-by pre-Pennsylvanian exposures of granite, testifies to the complexity of faulting and folding along the arch, although it has been noted that this arch, of the many which comprise the Red River Uplift, lacks evidence of thrust faulting and overturning of folds.

The Use of the Emission Spectograph in the Geochemistry Laboratory

Part II

John A. Schleicher

Part I of this series dealt with some general considerations of the role of the Emission Spectrograph in the Geochemistry Laboratory. This article will cover some of the more specific uses and limitations of the instrument.

The primary standard of wave length, and hence the starting-point from which the true wave lengths of all the other lines of the emission spectrum are determined is the color emitted by cadmium at a wave length of 6438.4696 Angstrom Units (A. U.). Because cadmium is not generally found in all types of rocks, but iron is normally present spectrum lines of iron are used as a secondary standard, whereby the position of a line of an unknown element is determined by its proximity to an iron line, whose position is known by comparison with the primary standard line. Another benefit derived from the use of iron lines as a secondary standard of wave length, besides its ubiquity, is the fortunate circumstance that, after cerium and uranium, iron emits the greatest number of lines of any element. Of the 100,000 principal lines in the emission spectrum to 10,000 A. U., these three elements furnish 15,750 lines, of which 4757 are iron lines. In any region of the spectrum under examination, therefore, there will be spectrum lines of iron in near enough proximity to allow exact wave length measurements.

The common method of qualitative analysis of a sample of rock or mineral of unknown composition is to place, in juxtaposition with the spectrum of the unknown, a comparison spectrum which contains not only the principal emission lines of all the common elements, but also a spectrum of iron in rather extensive detail, that is, not only the strongest iron lines, but also the lines of medium strength and many of the more common weaker ones. The two spectra are then *oriented* by *aligning* the corresponding iron lines, and compared for the presence of lines of other elements. From such a comparison, a certain degree of mineral identification can be made, as the major components can be readily distinguished from the minor simply by observation. It can be immediately seen, for instance, whether a clay mineral is primarily a sodium rather than a potassium silicate, even though a certain minor amount of the potassium mineral may be included in the sample. On the other hand, in such a sample, it is not possible to determine by this method whether there is also present an appreciable amount of uncombined silica. For this purpose, a quantitative spectral analysis procedure must be followed, which, however, as explained in Part I would not be as accurate as a quantitative chemical analysis.

Qualitative or quantitative determination, by classical means, of elements which belong to a group, all of which are similar in their chemical behavior, is the bane of analytical chemistry. The worst-offending group in this respect is the rare-earth, or lanthanide group. It is, even with the most advanced wet methods, time-and-effort consuming in the extreme to produce an analysis of even moderate accuracy of minerals containing a mixture of these elements. Any substance which contains one of the fourteen members of this group invariably contains greater or lesser amounts of several of the others. Their spectra, too, are complex and intermingled, but to analyze them accurately spectrographically requires only extra care in interpretation of the mixed spectra, and very little or no extra effort or time is consumed in obtaining an accurate result. Other groups which require considerable expenditure of time and effort in their conventional analysis, but which are easily analysed spectrographically are mixtures of calcium, strontium and barium, mixtures of lithium, sodium, potassium, rubidium and cesium, and the so-called "amminia Group": aluminum, iron, manganese, titanum, vanadium, zirconium,, chromium, cobalt, molybdenum and nickel. The latter group can be determined accurately by conventional means, but the separation of any one from the others is time-consuming. Spectrographic analysis has also made possible, through its rapidity of analysis, the large-scale exploration for elements which are found nowhere in concentration but are present in many places in small amounts. These elements are usually economically valuable enough so that the difference between a small amount and a very small amount makes the difference between an economic and a non-economic deposit. Such elements as germanium, niobium and others fall within this category. In point of fact, many of the elements have first been discovered by their spectra being found as impurities in the spectra of common and well-known members of the same group of elements. Among others, gallium was discovered spectrographically as an impurity in aluminum, and rubidium and cesium as impurities in sodium and potassium compounds.

The Occurrence of Galateacrinus Allisoni in Oklahoma

Harrell L. Strimple

The unique and distinctive genus *Galateacrinus* Moore (1940) is one of the rarer crinoids of the Pennsylvanian system. When the genus was established by Moore, he only reported eight dorsal cups, five of which were types of *G. stevensi* Moore (1940) from the Oologah formation, Marmaton group, Des Moines series, at Garnett Quarry east of Tulsa, Tulsa County, Oklahoma. It is therefore of considerable interest to record the discovery of another specimen from the Wann formation, Ochelata group, Missouri series, at a road cut just west of the E¼ corner section 25, T. 24 N., R. 12 E., about 3 miles west of Ramona, Washington County, Oklahoma. The specimen is assigned to *G. allisoni* Moore (1940), the holotype and only recorded specimen of which came from the upper part (probably the orange-yellow crinoidal clay) of the Iola formation, Missouri series, at the Portland Cement quarry, Iola, Kansas. The Oklahoma specimen is from a calcareous shale clay zone just above the weak limestone about 30 feet above the Iola formation. This is Zone 1 of Oakes (1952) in the Wann formation. The location and horizon are identical with the type locality of *Apographiocrinus arcuatus* Strimple (1949) and *Exocrinus pallium* Strimple (1949).

The holotype of *G. allisoni* is reported to be devoid of surface ornamentation, whereas the Oklahoma hypotype has weak granules marking the outline of the basal and radial plates, as well as the distad edge of the primibrachs. These markings are not visible without magnification and, because the structure and appearance of the dorsal cup are so close to those of the holotype, there is little hesitation in assignment to the species. The hypotype has three primibrachs attached, though not in place. In addition to the weak granulations reported above, there is a light median keel that extends to the base of the small broken spine marking the apex of the plate. All three primibrachs are axillary, narrowing below mid-length and widening almost imperceptibly at the distal extremity. They are unequal in length.

The three anal plates of the posterior interradius are of the "Normal type" (see Strimple, 1948) in both the holotype and typotype; however, a distinctive characteristic that heretofore has not been mentioned is the common plane formed by the upper surfaces of anal X and the right tube plate. This characteristic is apparently of generic significance from existing evidence, since it is common to all described species of the genus, and has been reported for several unrelated forms; for example, *Haerteocrinus* and *Texacrinus* (see Strimple, 1952a and 1952b). In most genera having three anal plates the right tube plate projects higher than the anal X.

Four or five alternatingly large and thick, and small and thin segments of the column are in place on the hypotype. The larger segments have longitudinally curved outer surfaces.

Measurements of the hypotype are; height of dorsal cup 2.8 mm, maximum width 9.5 mm, width of stem 1.5 mm, approximate width of infrabasal circlet 2.1 mm and width of basal circlet 5.6 mm.

The hypotype has been deposited in the paleontological collection of the University of Oklahoma School of Geology, No. 3178.

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