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Cover Picture

YOUNG SINKHOLES

The cover photograph is a vertical view of sinkholes in northwestern Oklahoma. The area includes secs. 23 and 26 and parts of secs. 22 and 27, T. 5 N., R. 28 ECM in Beaver County and sec. 27 and parts of secs. 21, 22, 28, 33, and 34, T. 28 N., R. 26 W., in Harper County. In the southwestern part of the area is Gate Lake, which is a permanent lake. The other lakes are intermittent. Each lake is in its own basin and all drainage is centripetal into the basin. On the day the photograph was taken, January 8, 1951, all sinks contained water.

The rock at the surface is a sandstone of the Pleistocene Crooked Creek Formation, and it is underlain by the Pliocene Ogallala and the Permian Whitehorse Group, Dog Creek Shale, Blaine Formation, and Flowerpot Shale. North and east of the area the Whitehorse is exposed, and in the eastern part of Harper County the Dog Creek, Blaine, and Flowerpot crop out.

At the surface the Blaine is characterized by massive beds of gypsum and the Flowerpot contains lenses of gypsum. In the subsurface, a few miles north, west, and south of the area, 200 to 300 feet of salt-bearing Flowerpot occurs within 600 feet of the surface. Immediately below the area of the photograph the salt is absent.

Ground water moving through the soluble Permian beds dissolves salt and/or gypsum and emerges as salt springs along the Cimarron River. Sinks form as a result of the subsidence of surface deposits in places where the underlying beds have been removed by solution. Hydrostatic pressure has caused upward movement of water through soluble beds, and salt-water springs have formed in areas where a sink has broken through to bedrock.

In Early Pleistocene time (Nebraskan and Kansan) meltwater streams from the Rocky Mountains deposited the sand and gravels which make up the surface of the area in the photograph. Whether sinks determined at least in part the position of these streams has not been determined. During Illinoisan time sink development was rather extensive and many sinks were subsequently filled with material washed into them from the surrounding land. In the area of the photograph the sinks are just beginning to be filled.

—A. J. M.

Underground Storage of Natural Gas in Oklahoma*

Louise Jordan

General Remarks

Oklahoma in 1961 ranked third in the nation in marketed output of natural gas, according to preliminary figures of the U. S. Bureau of Mines. Marketed production amounted to an estimated 874,000 million cubic feet, an increase of 6 percent over that of 1960, when production was 824,266 million cubic feet (final figure). Production was reported from 65 of the 77 counties of the State, with Texas, Garvin, Beaver, Harper, and Grady Counties leading in that order. Roger Mills County became the 66th county to report natural gas productivity. During 1961 net production, which equals gross withdrawals less gas injected into producing reservoirs and excludes changes in underground storage or gas loss due to natural-gas-liquids recovery, amounted to 1,016,485 million cubic feet (14.65 psia at 60°F).

At year-end, proved recoverable reserves were estimated at 17.4 trillion cubic feet, of which 12.6 trillion is free natural gas (nonassociated); 2.2 trillion is natural gas (associated) in immediate contact, but not in solution, with crude oil; 2.4 trillion is natural gas (dissolved) in solution with crude oil in the reservoir; and 0.12 trillion in underground storage (Amer. Gas Assoc. and others, 1962, p. 21). The large reserves are in gas fields in the Panhandle and northwestern Oklahoma, but southeastern Oklahoma's Arkoma basin is also emerging as a big new source of natural gas.

Cumulative natural-gas production from 1902 through 1961 amounted to more than 16.9 trillion cubic feet. Of this amount, more than 7 trillion cubic feet has been marketed since 1950. The gas fields, shown on figure 1, have produced or are producing primarily nonassociated natural gas, but the map does not show where associated gas has been or is being produced. In 1959, only 55 percent of the gas production came from the 5,300 wells classified as gas wells. (In 1960, the number increased to 5,800.) As development proceeds and pipe-line connections are made in northwestern Oklahoma and in the Arkoma basin area of east-central Oklahoma, a greater percentage of natural gas will be produced from areas designated as gas fields. It is probable that gas will be exported primarily from this area.

In 1960, annual marketed production of natural gas in Oklahoma reached 824,266 million cubic feet, with an average value at the well head of 11.9 cents per thousand. Net export of gas transmitted by pipe lines to industrial areas of eastern and north-central United States and to adjacent states amounted to 426,066 million cubic feet, or more than 50 percent of the total production. Consumption in Oklahoma amounted to 383,042 million cubic feet (Mineral yearbook, vol. 2, Fuels, 1960,

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*Revised to 1961 from: Jordan, Louise, 1962, Oklahoma, in Underground storage of natural gas in the United States: Interstate Compact Commission, p. 163-169, figs. 83-86, table 30.

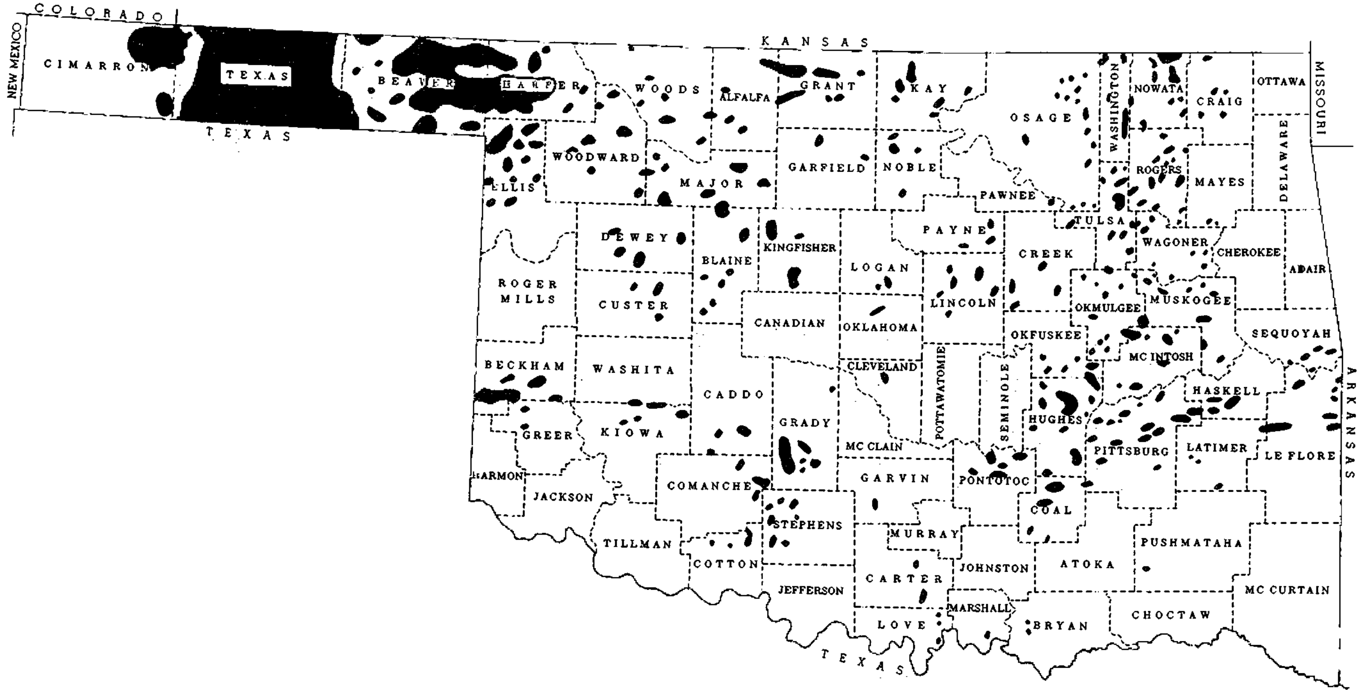


Figure 1. Map of Oklahoma showing location of active and abandoned gas fields. Areas of small new fields are exaggerated in northwestern Oklahoma.

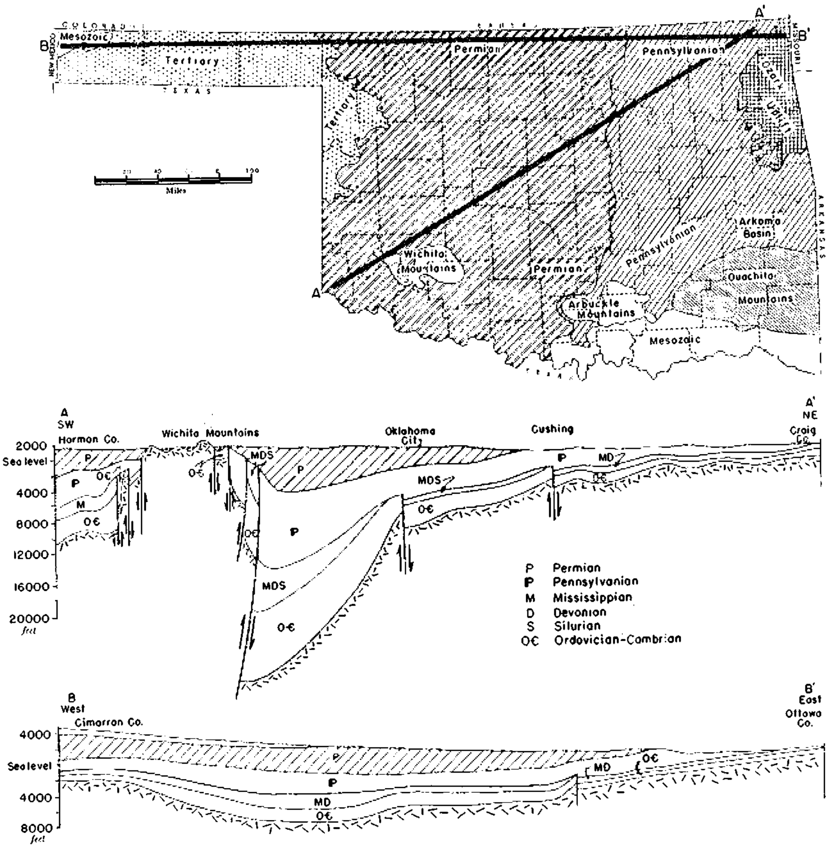
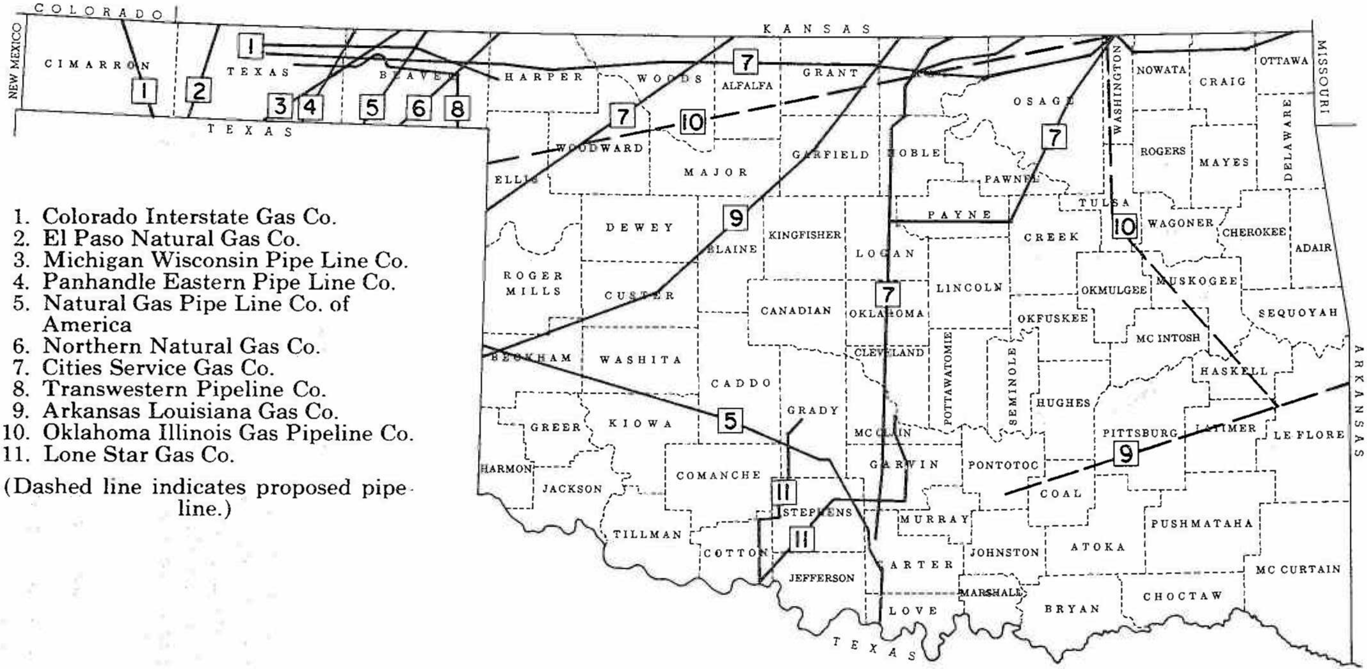


Figure 2. Generalized areal geologic map of Oklahoma and cross sections A-A′ and B-B′.

p. 324). There were 551,000 residential consumers, utilizing 59,801 million cubic feet at an average value of 70.7 cents per thousand. Commercial consumers totaled 59,000 and used 28,827 million cubic feet valued at 41.1 cents per thousand. Other industrial users of natural gas, such as refineries, oil-field and gas-field operators, and power plants, consumed 294,414 million cubic feet. The value of natural gas at point of consumption in Oklahoma was estimated, by the U.S. Bureau of Mines, to be $101,109,000 in 1960. The American Gas Association excluded revenues from sales for resale and arrived at a total revenue for utilities of $88,272,000.

Geological Conditions for Storage

Discussion of the complex structural geology and stratigraphy of Oklahoma is beyond the scope of this report. References to subsurface



1. Colorado Interstate Gas Co.
2. El Paso Natural Gas Co.
3. Michigan Wisconsin Pipe Line Co.
4. Panhandle Eastern Pipe Line Co.
5. Natural Gas Pipe Line Co. of America
6. Northern Natural Gas Co.
7. Cities Service Gas Co.
8. Transwestern Pipeline Co.
9. Arkansas Louisiana Gas Co.
10. Oklahoma Illinois Gas Pipeline Co.
11. Lone Star Gas Co.

(Dashed line indicates proposed pipe line.)

Figure 3. Major interstate gas transmission pipe lines which cross Oklahoma.

mapping and stratigraphy for the period 1940-1960 may be found in the Oklahoma Geological Survey's 1961 publication, *Index to geological mapping in Oklahoma.* Figure 2 shows distribution of outcrop areas of rocks of various geologic systems and two generalized sections across the State, A-A′ from the southwest corner to near the northeast corner and B-B′ along the northern boundary of the State from Cimarron County in the Panhandle to Ottawa County at the east. Sedimentary rocks above the basement range in age from Upper Cambrian to a thin veneer of Mesozoic rocks in southern Oklahoma and in the Panhandle. The youngest rocks are of Pliocene age in the Panhandle region. Thickness of sedimentary rocks in basin areas probably reaches a maximum of 40,000 feet in the Anadarko basin (cross section A-A′). Porous sandstone and limestone reservoirs for underground storage are present at most places. Areas in which such storage is least feasible are the Arbuckle Mountains, Ouachita Mountains, and Wichita Mountains provinces, and the Ozark region. The Early Paleozoic rocks of the Arbuckle Mountains are closely folded and faulted. Igneous rocks are at the surface in the Wichita Mountains. Mississippian sandstone and shale and older rocks are complexly faulted in the Ouachita Mountains. Mississippian and older carbonates, which are sources of ground water in the Ozark region, are probably of little use as reservoirs for storage because of absence of impermeable sealing beds.

Storage Facilities in Oklahoma

The primary reasons for operating underground gas storages are (1) to balance relatively fixed-rate supplies of gas, such as gasoline-plant residue, with fluctuating gas sales and (2) to eliminate additional pipe lines or peak-load shaving devices near major markets. The locations of underground storage reservoirs are controlled by the needs of pipeline companies rather than by the availability of suitable fields. In general, a great many abandoned gas fields or abandoned gas zones, which could be converted to underground storage, are available in the east-central and northeastern parts of the State. In contrast, virtually none is in the northwestern part of the State, where, at present, most of the reserves are located and where most of the major interstate gas transmission pipe lines are situated (fig. 3). Thus, although there are many areas suitable for gas storage in abandoned fields in Oklahoma, abandoned fields will be little used for the construction of large storage facilities for major transmission pipe lines in the near future.

Underground storage of natural gas in Oklahoma is related directly to the major nonindustrial (fluctuating) markets of the State. Figure 4 is a map of Oklahoma showing locations of the eight underground storage facilities now in operation and of the network of pipe lines related to these facilities. Storage reservoirs at Depew, Haskell, Osage, and West Edmond, owned by Oklahoma Natural Gas Company, are for peak-load requirements of Oklahoma City and Tulsa. Oklahoma Natural's Sayre storage serves the Sayre-Clinton area. The North Ada storage, developed by Southwest Natural Gas Company, supplies gas to Ada and, during winter peak-periods, some gas to Seminole. The Ulan facility in

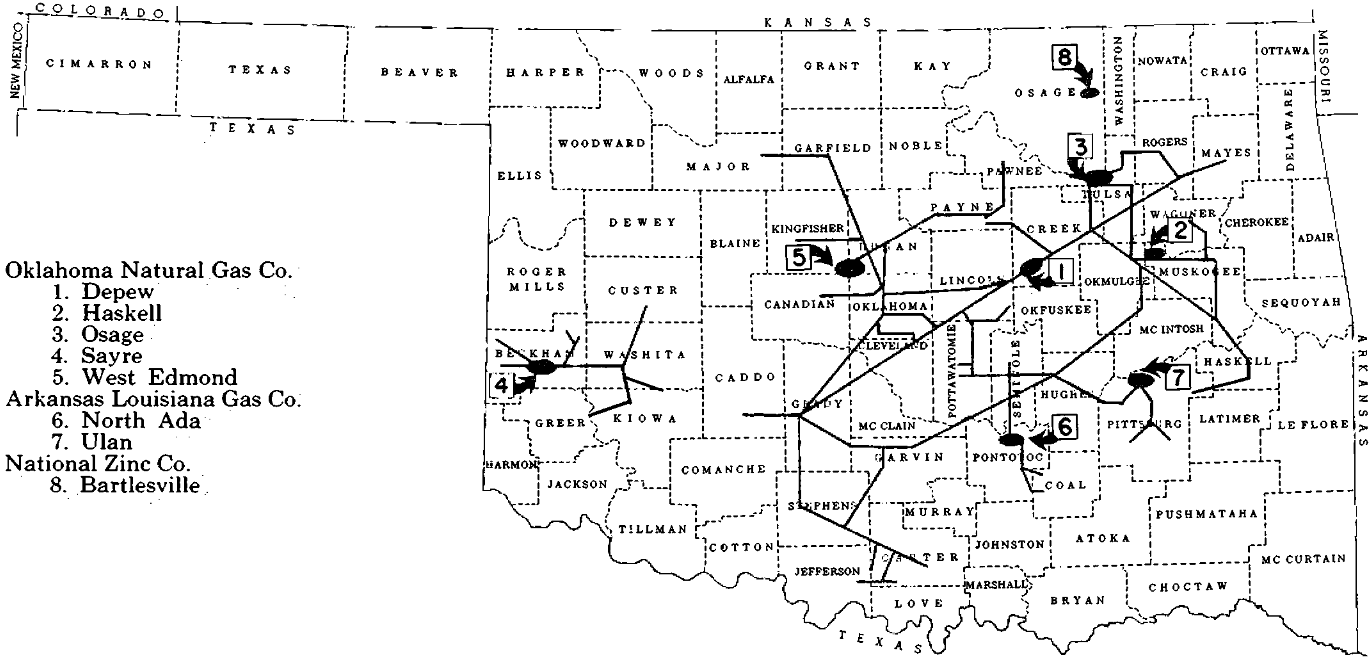


Figure 4. Map of Oklahoma showing location of underground natural-gas storage facilities and principal related pipe lines.

Table I. Underground Natural-Gas Storage Statistics in Oklahoma, 1962

Storage / County / Location	Year of discovery	No. of productive wells	Input-output wells	Observations wells	Storage surface area (acres)	Producing depth average (feet)	Date of first injection	Capacity, million cubic feet*: Working gas	Capacity, million cubic feet*: Cushion gas	Capacity, million cubic feet*: Total reservoir	Structure / Zone / Age	Max. pressure (psig)
OKLAHOMA NATURAL GAS CO.												
1. Depew Creek secs. 25, 36, T. 15 N., R. 7 E. secs. 19, 20, 30, 31, T. 15 N., R. 8 E.	1922	32	11	0	7,360	3,250	5/6/50	18,500	45,000	63,500	Anticline Dutcher Pennsylvanian	1,480
2. Haskell Muskogee secs. 7 10, 14-20 T. 15 N., R. 15 E.	1914	51	17	3	7,000	800	6/12/44	2,800	9,700	12,500	Anticline, strat trap Booch Pennsylvanian	325
3. Osage Osage secs. 28, 29, T. 20 N., R. 12 E.	1922	32	7	0	1,920	1,600	4/21/43	1,300	1,900	3,200	Anticline Burgess Pennsylvanian	565
4. Sayre Beckham sec. 20, 21, 27, 28 T. 9 N., R. 23 W.	1922	32	6	1	5,000	2,650	10/12/53	68,000	21,300	89,300	Anticline Panhandle dolomite Permian	940
5. West Edmond Kingfisher and Logan sec. 27-30, T. 15 N., R. 4 W. sec. 25-27, T. 15 N., R. 5 W.	1944	38	16		3,292	6,550	12/1961	44,000	14,000	58,000	Monocline, strat trap Bartlesville Pennsylvanian	2,350
ARKANSAS LOUISIANA GAS CO.												
6. North Ada Pontotoc sec. 8-10, 16, 17, T. 4 N., R. 6 E.	1915	16	4	0	2,000	1,300	5/1944	6,000	4,000	10,000	Anticline, strat trap, faulted. Cromwell Pennsylvanian	425
7. Ulan Pittsburg sec. 31-33, T. 8 N., R. 14 E. sec. 4-6, T. 7 N., R. 14 E.	1945	12	4	8	3,250	1,000 2,000	1/1953	7,495	6,005	13,500	Anticline, faulted, Booch (2,000-foot depth) Pennsylvanian	470
NATIONAL ZINC CO. 8. Bartlesville	(No report)											
							Total (million cubic feet)	148,095	101,905	250,000**		

*Revised, data from Oil and Gas Journal, vol. 60, no. 20 (May 14, 1962) p. 134

**American Gas Association, 1962, The underground storage of gas in the United States: Amer. Gas Assoc. OP-62-3, p. 8, gives the following data: working gas, 64,212, cushion gas, 92,658, unused capacity 88, 934, total reservoir capacity 245,804 million cubic feet. The data include an 8th storage facility in Ordovician rocks.

Pittsburg County, installed by Consolidated Gas Utilities Corporation, serves McAlester, Krebs, and Savanna. The last two facilities are now owned by the Arkansas Louisiana Gas Company. An eighth storage facility is operated by the National Zinc Company to satisfy the fuel requirements of their smelter near Bartlesville. Pertinent data for each of the storage facilities are listed in table I.

Possibilities for Additional Storage

In almost all parts of Oklahoma, geologic conditions are favorable for storage of natural gas in porous rocks. Additional storage fields may be economically feasible in the future near some of the smaller cities of the State. Through economic necessity, such fields would be located near the cities that they would serve. In the future some of the interstate pipe-line companies, which have pipe lines primarily in the western part of the State, may require underground storage reservoirs in order to balance their steady gas supplies with their fluctuating summer-to-winter markets. Ideally such storage fields would be located near markets, but if no fields were available in market areas, it might be feasible to have underground storage in supply areas. These companies rely mainly on interruptible industrial loads to balance their supplies and sales. In other words, during peaks of residential and commercial consumption, companies decrease the amount deliverable to industrial users. However, increased well-head gas prices in the future might cause supply-area underground storage facilities to be more economical than interruptible gas sales to industrial customers at relatively low rates. When such a condition comes about, the pipe-line companies will develop suitable reservoirs in porous limestone or sandstone, or in cavities artificially dissolved in Permian salt layers. In 1961, the first storage of natural gas in a salt cavity was developed by the Morton Salt Company in St. Clair County in the Port Huron area of eastern Michigan for Southeastern Michigan Gas Company. The total capacity of the reservoir is 384,729,000 cubic feet (Bizal, 1962, p. 126). Each type of formation is conveniently available in northwestern Oklahoma and in the Panhandle.

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Bizal, R. B., 1962, Gas-storage capacity spurts: Oil and Gas Jour., vol. 60, no. 20 (May 14), p. 125-138.

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ASSOCIATED *Cryphiocrinus* AND *Agassizocrinus*

HARRELL L. STRIMPLE

A few months ago I mentioned to Dr. Carl C. Branson that all of the Hindsville Formation exposures known to me, where the large pseudo-agassizocrinids *(Cryphiocrinus)* occur as basal plates, were either under water or covered by weeds and grass. He referred me to a small road-metal quarry on the Will Rogers Turnpike east of Vinita about 0.6 mile east of milepost 50 in SE¼ SW¼ sec. 7, T. 25 N., R. 21 E., Craig County, Oklahoma. On May 11, 1962, I visited the quarry and collected 110 basal plates which are identified as *Cryphiocrinus bowsheri* (Strimple). One fused infrabasal circlet belonging to the species and several radial plates also were found. In direct association were 57 infrabasal cones of *Agassizocrinus globosus* Worthen. Only a few basal plates that could be referred to *Agassizocrinus* with certainty were found. The two forms are readily separable because *A. globosus* has a perfectly smooth exterior and *Cryphiocrinus bowsheri* has a roughened or ornate exterior. Both forms are eleutherozoic; however, the holotype of *C. bowsheri* has a delicate stem attached and the plates are thick, indicating an optimum calcium supply or proximity of reefs.

Aside from its stratigraphic value, *Cryphiocrinus bowsheri* is important because it is the only species of the genus for which the arms are known. The species is slightly more primitive than are those described by Kirk (1929) such as *C. girtyi* and *C. rotundus*, both of which are from late Chesterian formations, whereas the Hindsville is considered to be early Chesterian.

It appears that these forms with heavy calices, and especially *Agassizocrinus* with the pointed infrabasal cone, must have reposed on the bottom of the ocean, perhaps even when feeding, because it must have taken considerable arm movement to bring about locomotion or even suspension in the water. There must not have been a strong movement or current directly on the specimens else it seems they would have been constantly falling over. Possibly the cones penetrated the bottom muck, and thus the elongate cones, such as those of *A. conicus* Owen and Shumard, would have been more stable in a slight current. If the cones were imbedded at the time of death, the cones would be preserved; but the upper calyx plates and arms could be carried away or destroyed, depending upon the depositional environment. This fact probably explains the presence of numerous cones with a paucity of other cup elements, as is the case here and as has been previously observed among some of the *Paragassizocrinus* (e. g. *P. elevatus* Strimple, 1961, and *P. bulbosus* Strimple, 1961, from the Atokan of southern Oklahoma).

If then the associated *Cryphiocrinus* also rested upon the bottom, the proximal and midportions of the basals could have become embedded in the muck so that large numbers of the plates were preserved as well the infrabasal cones of *Agassizocrinus*.

Huffman (1958) listed *Agassizocrinus conicus* Owen and Shumard from the Hindsville Formation, but this listing apparently was made through a misunderstanding of the specific characteristics. The infrabasal cone of the holotype of *A. conicus* is quite elongate, with a pointed termination. I have not seen this type of cone in the Hindsville Formation. Some topotypes ascribed to the species have broader cones, but they are more elongate than are the presently considered specimens.

Disarticulated basal plates of *Cryphiocrinus (Mooreocrinus) bowsheri* (Strimple) are widespread in the Hindsville Formation. Unless carefully examined, they might be identified as *Agassizocrinus*. The plates are abnormally thick, have strongly tumid exteriors, and normally have narrow proximal edges. The species, or a closely related form, has been observed in the overlying Fayetteville Formation. The holotype is a crown collected by Arthur Bowsher many years ago at Cedar Crest Lake. Doctor Branson directed my attention to the fact that the location originally given as "Center north line, section 20, T. 19 N., R. 20 E.," should be SE¼ NE¼ sec. 22, T. 19 N., R. 19 E., Mayes County, Oklahoma. Assignment of the species to *Cryphiocrinus* was considered by the author in the original description, and in 1961 the designation was changed to *Cryphiocrinus* (Strimple, 1961b). The genus *Mooreocrinus* Wright and Strimple has been reduced to a synonym of *Dicromyocrinus* Jaekel, which genus was validated by Moore and Plummer in 1940 through casual designation of the genotype species.

It has been possible to restore a dorsal cup of *Cryphiocrinus bowsheri* from the material at hand. Even a cursory examination of the basal arrangement discloses the impossibility that the basal plates belong with the relatively large infrabasal cones of the associated *Agassizocrinus* species. Three radial plates, anal X and RX are represented in clay.

Huffman (1958, p. 63) considered the fauna of the Hindsville Formation to be indicative of early Chesterian age.

Order Inadunata Wachsmuth and Springer
Suborder Dendrocrinoidea Bather

Family Cromyocrinidae Jaekel
Genus *Cryphiocrinus* Kirk
Cryphiocrinus bowsheri (Strimple), 1949
Figures 1-7

The holotype of *Cryphiocrinus bowsheri* has a small stem attached. Kirk (1929, p. 156) recognized such a possibility and stated that a crinoid should not be excluded from the genus upon that basis. Both of the species he described had lost their columns, although a trace of a cicatrix remained on one specimen. Probably large specimens of *C. bowsheri* entirely discarded the stem but the presence of a stem is not a character-

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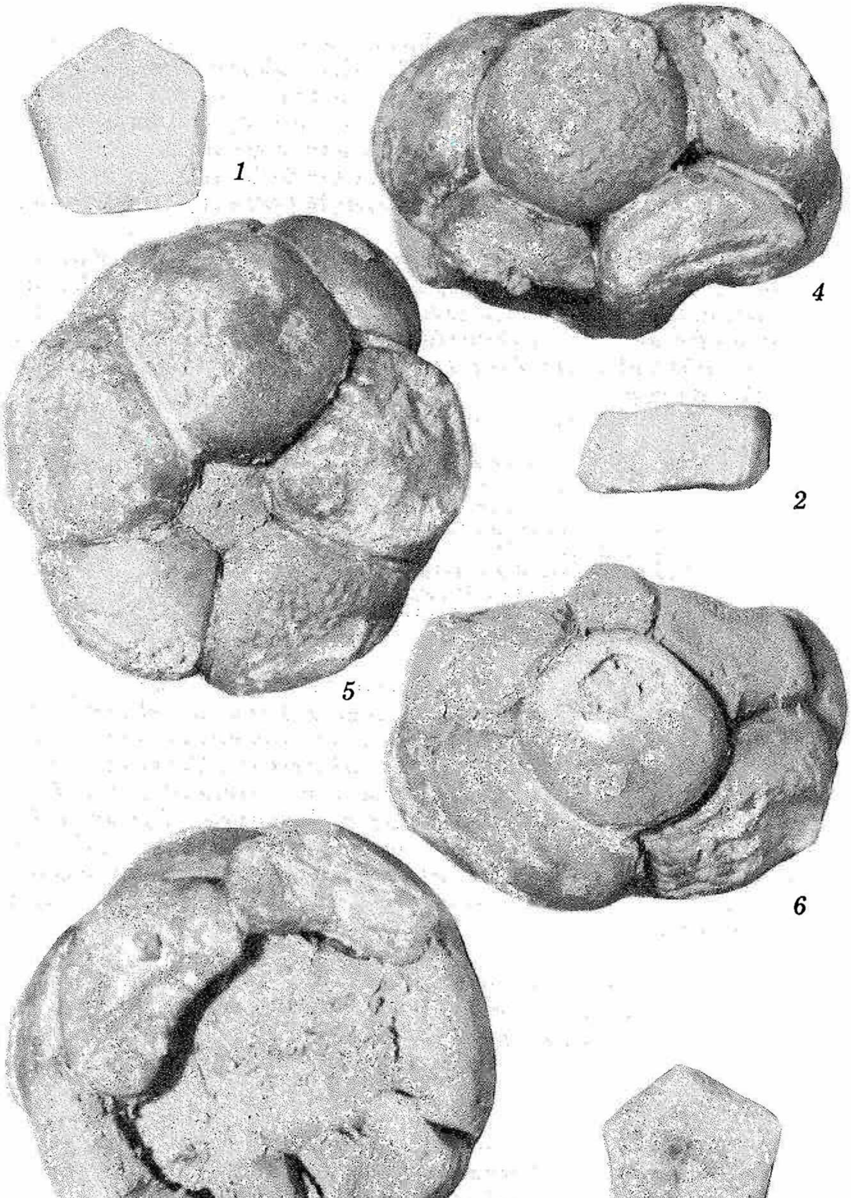
Cryphiocrinus bowsheri **(Strimple), x2.3**

Figures 1-3. **Fused infrabasal disk viewed from above, side and exterior, OU 5000.**

Figures 4-7. **Restored dorsal cup viewed from anterior, base, posterior (radianal to the fore), and summit. Three radial plates, anal X and RX are represented in clay, OU 5001.**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istic of immaturity. One infrabasal disk of the species has been found and discloses fusion of the infrabasal plates, a condition normally accompanying the final elimination of a stalk. Close affinity among *C. girtyi*, *C. rotundus*, and *C. bowsheri* is readily established by the large, wide basals which curve strongly into the basal concavity and have narrow proximal edges. A small area is left for the infrabasal circlet.

The restored dorsal cup discloses all the features of the holotype and in addition its surface is not only uneven, but normally is ornamented by narrow ridgelike protuberances.

A few plates exhibit unusual tumidity, so pronounced that the exterior has the appearance of a sphere. The facets of these plates are distinctive in that they are slightly separated from one another, or do not entirely fill the width of the plate edge. These may represent a different species or subspecies, but there are not enough specimens to attempt restoration of a cup.

Measurements in millimeters of the restored cup:

Maximum width of cup	28.2
Height of cup to transverse ridge of radial	16.1
Width of basal concavity (approximate)	8.5
Width of infrabasal circlet	5.0
Height of basal plate	14.9
Width of basal plate (maximum)	14.2
Width of basal plate (proximal edge)	4.0
Height of radial plate (to transverse ridge)	5.8
Width of radial plate	12.9

A form that appears to be closely related to *Cryphiocrinus* is *Epipetschoracrinus borealis* Yakovlev (1956) from the Permian of Russia. The basal plates have the same outline as that of *Cryphiocrinus* and area for the infrabasal disk is restricted. *Epipetschoracrinus* Yakovlev (1956) has a single anal plate within the dorsal cup in contrast to the three anal plates of *Cryphiocrinus*. Reduction in the number of plates in the posterior interradius is a normal evolutionary process. Yakovlev assigned his genus to the family Graphiocrininae Bather, but I consider it to be an advanced genus of the family Cromyocrinidae, closely related to *Cryphiocrinus*.

Family Agassizocrinidae S. A. Miller
Genus *Agassizocrinus* Owen and Shumard
Agassizocrinus globosus Worthen
Figures 8-13

The specimens of *Agassizocrinus globosus* considered here all came from the small road-metal quarry east of Vinita, Craig County, Oklahoma, 0.6 miles east of milepost 50 on the Will Rogers Turnpike.

The type locality for the species is Chester, Illinois, Okaw Formation, Chesterian. Bassler and Moodey (1943, p. 290) also showed the species to occur in the Gasper Formation of Breckenridge County and Bowling Green, Kentucky. I have assigned the present specimens to the species because it is possible to discern the sutures between infrabasals in most specimens. Springer (1926) considered the only appreciable difference between *A. globosus* and *A. ovalis* Miller and Gurley (1896) to be the division of infrabasals found in the former. In mildly weathered specimens from Oklahoma, the external sutures are in most cases plainly visible and in few cases form a straight line. Under magnification, the external sutures are seen to be uneven. Oblique illumination on unweathered specimens normally shows the external sutures. Almost all specimens show the internal sutures, which are even and straight. In only a few specimens do the sutures have a common meeting point. Small specimens do not normally show the sutures as plainly as do the larger specimens. Of 57 specimens, not one shows any trace of an external attachment with a column. One specimen, broken naturally, shows a perfectly preserved rudimentary stem within the cone. It extends about two-thirds the depth of the cone. It thus appears that the species had a stalk in its embryonic or young stages. These "captured" columnals fall into the category of *basilarids*, which term I have proposed elsewhere for proximal columnals having a function other than, or in addition to, that of a stalk.

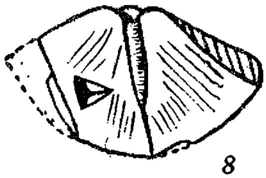

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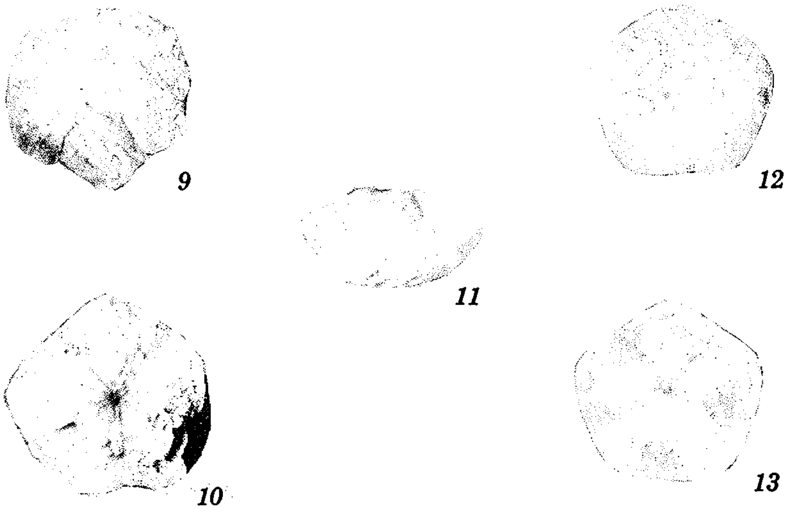
Figure 8. Agassizocrinus globosus **Worthen. Drawing made from photograph of broken infrabasal cone showing a small, rudimentary stem in the interior, ca. x2.3, OU 5002.**



Agassizocrinus globosus **Worthen. Unretouched photographs, x2.3**

Figures 9, 10. **Infrabasal cone showing uneven sutures on the exterior and even sutures on the interior. OU 5005.**

Figures 11-13. **Infrabasal cone in side view, from exterior, and from interior or summit. OU 5006.**

A rudimentary stem within an infrabasal circlet which has not entirely developed into a cone has been shown by Yakovlev (1956, pl. 15, fig. 6) for the Permian species *Petschoracrinus variabilis* Yakovlev, 1928. A rudimentary stem, entirely within the infrabasal cone of *Paragassizocrinus asymmetricus* Strimple, was illustrated by Strimple (1960, pl. 1, fig. 5).

Measurements of infrabasal cones in millimeters:

	OU 5003A LARGEST	OU 5003B	OU 5003C SMALLEST
Greatest width	16.0	15.0	8.2
Height (to summit, interior)	--	9.0	6.0
Height (maximum, exterior)	--	6.2	4.7

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All cited references may be found in Bassler, R. S., and Moodey, M. W., 1943, **Bibliographic and faunal index of Paleozoic pelmatozoan echinoderms:** Geol. Soc. America, Spec. Paper 45, 745 p., with the following exceptions:

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Yakovlev, N. N., 1956, Morskie lilii i blastoidi kamennougolnykh i permskikh otlozhenii SSSR; Pt. II: Vsesoyuznogo Nauchno-Issledovatel'skogo Geologicheskogo Instituta (VSEGEI), Trudy, new series, vol. 11, p. 43-142 (Moskva).

THE TYPE OF *Tricoelocrinus*, A CORRECTION

ROBERT O. FAY

In the description of *Tricoelocrinus woodmani* published by Fay (1961a) text-figures 1 and 2 (p. 92, 93) are identified as *T. woodmani*, whereas the specimen illustrated is that of *Metablastus varsouviensis* (Worthen). It is specimen 1885-2 of the Illinois State Geological Survey and the magnification of the illustration is x24, not x14. In summit view *Metablastus* and *Tricoelocrinus* are nearly identical and the error came about through a mixup in film numbers. Text-figure 1 (Fay, 1961a, p. 92) also appears in Fay (1961b, pl. 52, fig. 6) where it is correctly identified as *M. varsouviensis*.

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Fay, R. O., 1961b, Blastoid studies: Kans., Univ., Paleont. Contrib. [27], Echinodermata, Art. 3, 147 p., 54 pls., 221 figs.

New Mississippian Blastoids from the Lake Valley Formation (Nunn Member), Lake Valley, New Mexico

Robert O. Fay

Blastoids were recognized from the Lake Valley region, Sierra County, New Mexico, in 1884, when Springer (p. 102) listed *Granatocrinus, Troostocrinus,* and *Codaster* from the Apache Hill area near the village of Lake Valley. Cline (1937, p. 648) listed *Cryptoblastus pisum* (Meek and Worthen) from the Lake Valley beds at Lake Valley, and Laudon and Bowsher (1941, p. 2156) listed *Schizoblastus* sp. from the blue-gray marl facies (now Nunn Member) of the Lake Valley Formation in San Andres Canyon, San Andres Mountains, New Mexico. Fay (1961) used the name *Monadoblastus granulosus,* new genus and new species, for what had formerly been termed *Granatocrinus, Cryptoblastus,* and *Schizoblastus*?, based upon a study of several specimens collected by Irving G. Reimann, who placed the material in the Buffalo Society of Natural Sciences Museum. Since then, Allen Graffham of Ardmore, Oklahoma, has sold a collection of 35 blastoids from Lake Valley to The University of Oklahoma. This collection forms the basis for the present study. Two genera (one new), each represented by one species, are present, in addition to 24 specimens of *Monadoblastus granulosus.* Probably the forms previously called *Troostocrinus* and *Codaster* belong to *Phaenoblastus* Fay, 1961, and *Hadroblastus,* new genus, respectively.

The blastoids occur in the Nunn Member of the Lake Valley Formation, and those of the Graffham collection and the Buffalo collection come from Apache Hill, NE¼ NW¼ sec. 21, T. 18 S., R. 7 W., just outside Lake Valley, Sierra County, New Mexico. Detailed measured sections, stratigraphic diagrams, and paleogeographic interpretations are given by Laudon and Bowsher (1941, 1949). The type section of the Nunn Member is in Apache Hill. The Nunn was named by Laudon and Bowsher (1949, p. 13), and may be characterized as a weakly indurated blue-gray marl and nodular crinoidal limestone, approximately 65 feet thick, above the Alamogordo Member and below the Tierra Blanca Member. This portion is considered to be early Osagean in age and may be correlated in part with the Fern Glen Formation of Missouri. The blastoids are new species and belong to new genera, one of which is similar to *Phaenoblastus caryophyllatus* of the Tournaisian of Belgium.

Order Fissiculata Jaekel, 1918
Genus *Hadroblastus,* new genus

Hadroblastus includes fissiculate blastoids having 10 exposed hydrospire fields (those on the anal side reduced in number), the anus between a large epideltoid and equally large hypodeltoid, and lancet exposed along middle one-third of its width. The form is wider than high, with broad flat sinus areas, convexly rounded summit, and equally rounded base composed of three large basal plates. The vault height is almost equal to that of the pelvis; the ambulacra are moderately long and linear. The occurrence is Mississippian, Osagean, New Mexico.

The only genus with similar characteristics is *Phaenoblastus*, from the Tournaisian beds of Belgium and the Lake Valley beds of New Mexico. *Hadroblastus* differs by being broad with wide, flat sinus areas and rounded base, with large hypodeltoid; whereas *Phaenoblastus* is steeply conical, with deep sinus areas and conical base, with hypodeltoid small or missing in most specimens, and large side plates covering many hydrospire slits.

Type species.—Hadroblastus convexus, new species.

Hadroblastus convexus, new species
Plate I, figures 1-4, 6

Theca calcitic, rounded hexagonal in top view, with rounded base and highly convex summit, 10 mm high by 12.5 mm wide, vault 4 mm high, pelvis 6 mm high, periphery slightly above midheight at radial lips, pelvic angle on radial bodies approximately 80-90 degrees, and 180 degrees on flat base. Basalia cup-shaped, large, 4 mm high by 8 mm wide, composed of three large, normally disposed basal plates, broadly pentagonal in shape. Radials five, each hexagonal, short, wide, each 5 mm high by 7 mm wide, with short limbs 2 mm long, and broad, flat radial sinuses 2 mm long by 7 mm wide, above which the lancet and side plates project. The sinus areas, including the portions on the deltoids, are broadly diamond-shaped, 7.5 mm long by 7 mm wide, seen in side view, with lancet and side plates only 1.5 mm wide in the middle of each facet. The vault angle is approximately 105 degrees, with flat summit.

Deltoids four, broadly lancet-shaped, projecting down sides, each 6.5 mm long by 4 mm wide, with approximately 11 hydrospire slits on each side of an ambulacrum, the admedial one covered by side plates. On the anal side, the broad horseshoe-shaped epideltoid plate on the adoral side of the anal opening, has approximately four hydrospire slits

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Explanation of Plate I

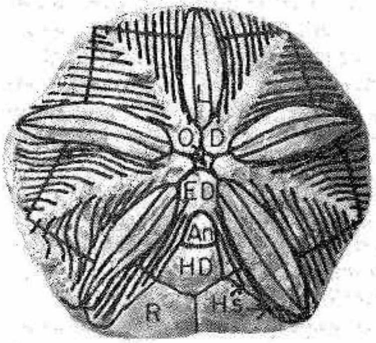
Hadroblastus and Phaenoblastus from Nunn Member, Lake Valley Formation, Osagean, Mississippian; Apache Hill, NE¼ NW¼ sec. 21, T. 18 S., R. 7 W., Lake Valley, New Mexico. Types on deposit in The University of Oklahoma paleontology collection.

Figures 1-4, 6. Hadroblastus convexus, **new genus and new species. Oral, aboral, "D" ambulacral, and "B" ambulacral views of holotype OU 4341, x4.0, and enlarged view of summit of paratype OU 4343, x16.7.**

Figure 5. Phaenoblastus conicus, **new species. "C" ambulacral view of paratype OU 4346, x7.0.**

An—anal opening	**HD—hypodeltoid plate**
B—basal plate	**Hs—hydrospire slits**
D—deltoid plate	**L—lancet plate**
Db—deltoid body	**O—oral opening**
Dl—deltoid lip	**R—radial plate**
Ds—deltoid septum	**Sp—side plate**
ED—epideltoid plate	**Z—azygous basal plate**

Plate I



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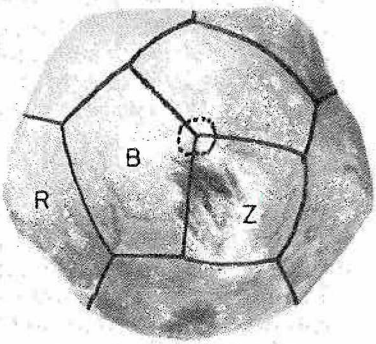

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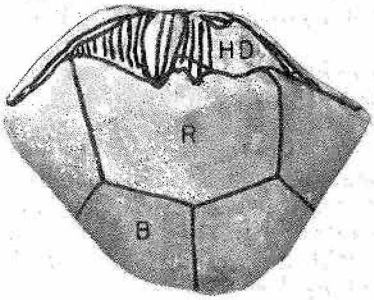

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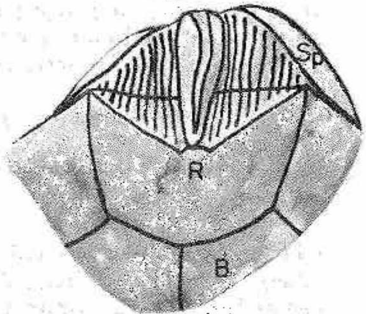

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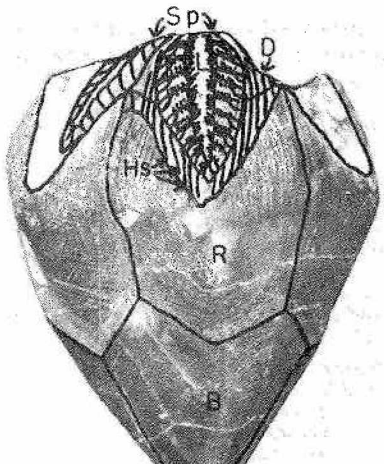

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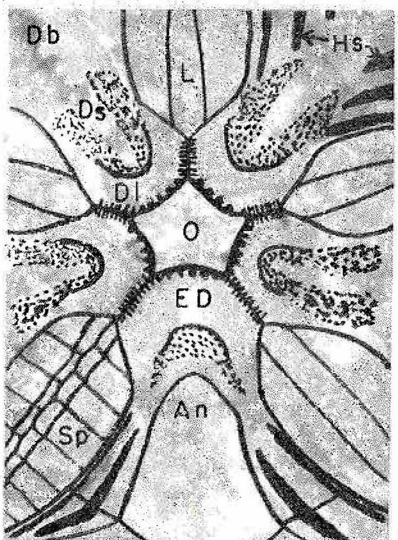

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on each side of the anal opening, continuous with folds in the adjacent radial limbs. The hydrospires are excavated in the other radial limbs almost to the edge of the sinus areas. The hypodeltoid, on the aboral side of the anal opening, is elongate pentagonal, 3 mm long by 3 mm wide, abutting against the adjacent radial limbs and resting upon the epideltoid limbs. The deltoid lips surround the oral opening, and the lancet stipes are well away (1 mm) from the opening. Four to five cover-plate lobes are on each deltoid lip, adjacent to the oral opening, five to six lobes are along the sides of the lips adjacent to the main food groove. The sinus areas are broad and flat, with a sharp deltoid crest, away from which the sinus areas slope at an angle of 35 degrees.

Ambulacra five, linear, with lancet exposed along the median one-third of its width for the length of an ambulacrum. Each ambulacrum is 6 mm long by 1.5 mm wide, with about 20 small side plates in 10 mm length of an ambulacrum, and large subtriangular secondary side plates normally disposed on the abmedial-adoral corners of each primary side plate. There are approximately five cover-plate lobes per side plate along the main food groove, excavated in the lancet plate. The surfaces of the thecal plates are ornamented with fine growth lines subparallel to plate margins.

The only form similar to *Hadroblastus* in shape is *Notoblastus* from Permian deposits of Australia, but this latter form is almost flat and discoidal, and the lancet is covered by the side plates.

Types and occurrence.—Holotype, OU 4341, one specimen; paratypes, OU 4342, a polished section of anal area, and OU 4343, a small specimen, Allen Graffham collection, The University of Oklahoma paleontology collection. From Nunn Member, Lake Valley Formation, Osagean Series, Mississippian, Apache Hill, NE¼ NW¼ sec. 21, T. 18 S., R. 7 W., near Lake Valley, Sierra County, New Mexico.

Genus *Phaenoblastus* Fay, 1961

Fissiculate blastoids with 10 hydrospire fields (partly hidden), an epideltoid and presumably a small hypodeltoid, with reduced number of

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Explanation of Plate II

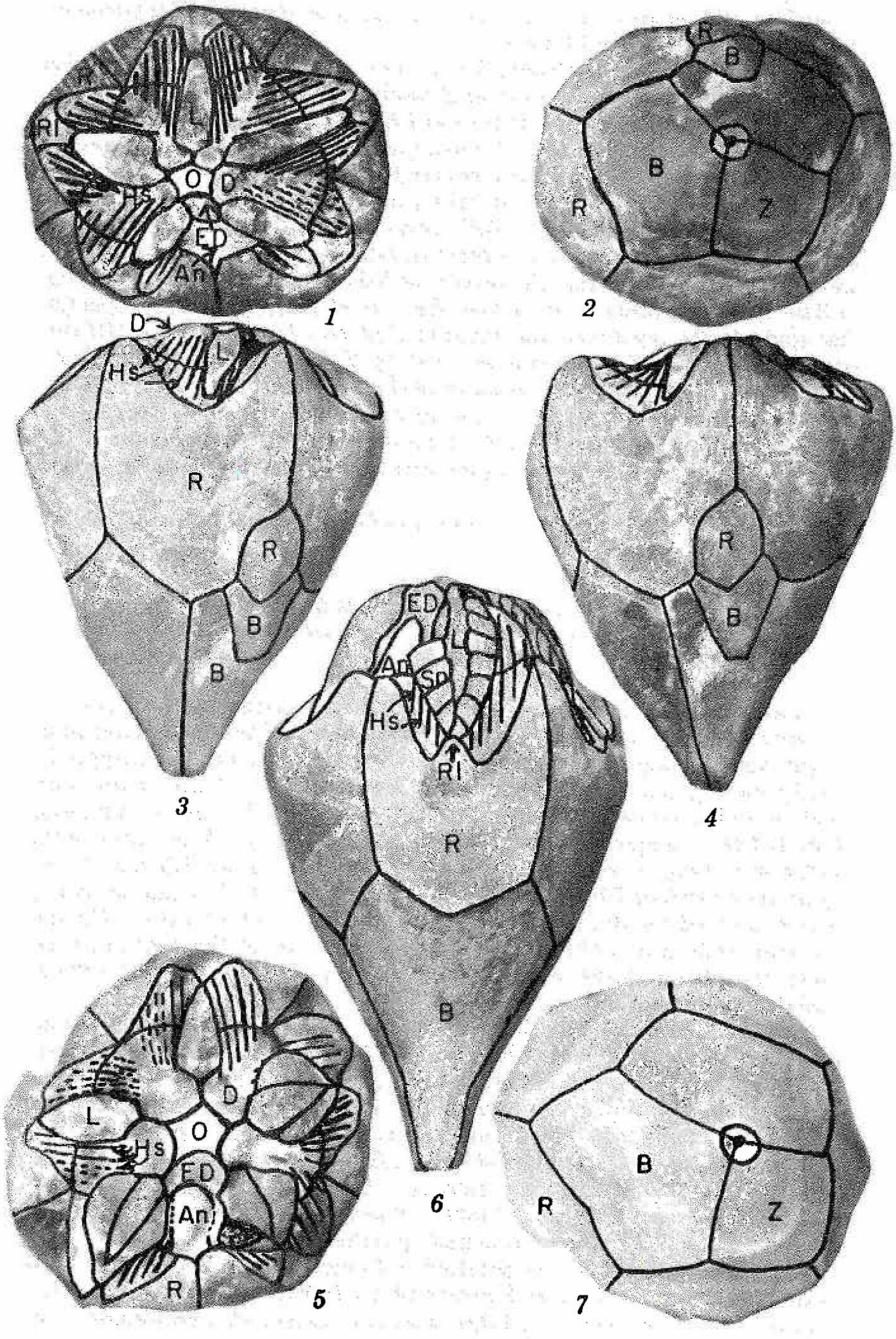
Phaenoblastus conicus, new species. Nunn Member, Lake Valley Formation, Osagean, Mississippian; Apache Hill, NE¼ NW¼ sec. 21, T. 18 S., R. 7 W., Lake Valley, New Mexico. Types on deposit in The University of Oklahoma paleontology collection.

Figures 1-4. Oral, aboral, "D" ambulacral, and anal views of paratype OU 4345, showing a new basal and a new radial plate on the anal side in the "C-D" position, x9.4.

Figures 5-7. Oral, "C" ambulacral, and aboral views of holotype OU 4344, with weathered radial limbs, x12.3.

An—anal opening	**L—lancet plate**
B—basal plate	**O—oral opening**
D—deltoid plate	**R—radial plate**
ED—epideltoid plate	**Rl—radial lip**
Hs—hydrospire slits	**Sp—side plate**
Z—azygous basal plate	

Plate II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hydrospire folds on the anal side, lancet completely exposed, steeply conical to club-shaped in side view, and narrow sinuses. Tournaisian, Belgium; Osagean, New Mexico.

The genus *Phaenoschisma* Etheridge and Carpenter, 1882, with type species *Pentatrematites acuta* Sowerby, 1834, from the Carboniferous limestone of England, differs from *Phaenoblastus* in having the lancet covered by the side plates. *Conoschisma* Fay, 1961, differs in having broad radial sinuses and lancet covered by side plates. Possibly the forms referred to *Codaster blairi* Miller and Gurley, 1895, and *Codaster jessieae* Miller and Gurley, 1896, from the Chouteau Limestone of Missouri, may belong to *Phaenoblastus,* but the types are evidently lost and the plesiotypes at the University of Missouri have been misplaced, so that it is impossible to determine the correct position of these species. One imperfectly preserved specimen of *Codaster jessieae* in the University of Missouri collection was studied by Fay (1961) and tentatively referred to *Conoschisma,* but from published accounts and other illustrations, it may be better to place this species under *Phaenoblastus.* It is also possible that *C. blairi* and *C. jessieae* belong to a new genus if the statement, "There are no hydrospire slits in the anal interradius" (Peck, 1938, p. 60), is correct.

Type species.—Pentremites caryophyllatus de Koninck and LeHon, 1854.

Phaenoblastus conicus, new species

Plate I, figure 5; plate II, figures 1-7

Calyx calcitic, conical in side view, rounded pentagonal in top view, 6.75 mm long by 4 mm wide, with periphery at radial lips well above mid-height, vault 2 mm long, pelvis 4.75 mm long, and pelvic angle approximately 45 degrees. Basalia conical, 3.5 mm long by 3 mm wide, with small rounded crenellar stem impression at base, 0.25 mm in diameter. Radials five, elongate hexagonal, each 3.5 mm long by 2.5 mm wide, with moderately long, wide, shallow sinus 1.5 mm long by 1.5 mm wide. Approximately 6 or 7 hydrospire slits are on each side of an ambulacrum, mostly covered by the large side plates, but exposed aborally. On the anal side, only 2 to 4 slits are present on each side of the anal opening, where the radial limbs appear to be slightly shorter than the others. Radials overlap deltoids.

Deltoids four, narrow, lancet-shaped, each 1.5 mm long by 1 mm wide, mostly visible in side view, with a sharp deltoid crest that is low. On the anal side, the epideltoid is pentagonal, 0.5 mm wide, with probable extensions or limbs on either side of the anal opening to the adjacent radial limbs, with 2 to 4 hydrospire slits excavated in each limb. The large gap between the epideltoid and radial limbs was probably covered by a small hypodeltoid plate (missing) that probably abutted against the adjacent truncated radial limbs. The wide ambulacra almost cover the hydrospire slits in the deltoid and epideltoid plates.

Ambulacra five, broadly petaloid, 1.75 mm long by 1 mm wide, with lancet completely exposed and 66 side plates in 10 mm length of an ambulacrum. The side plates are large, normally disposed, and almost completely cover the hydrospire slits. The surfaces of the calyx plates are ornamented with fine growth lines parallel to plate margins. There are approximately five cover-plate lobes per side along the main food groove, and three side cover-plate lobes along each side of a side food groove.

P. conicus differs from *P. caryophyllatus* mainly in that the deltoid crests of the latter species are high.

Types and occurrence.—Holotype, OU 4344, one specimen; paratypes, OU 4345, one specimen, OU 4346, one specimen, and OU 4347, five fragmentary specimens, Allen Graffham collection, The University of Oklahoma paleontology collection. From Nunn Member, Lake Valley Formation, Osagean Series, Mississippian, from Apache Hill, NE¼ NW¼ sec. 21, T. 18 S., R. 7 W., near Lake Valley, Sierra County, New Mexico.

Monadoblastus granulosus Fay, 1961, has already been described. The 24 topotypes are numbered OU 4340, The University of Oklahoma paleontology collection. *Cryptoblastus* has two hydrospire folds on each side of an ambulacrum and *Monadoblastus* has one fold on each side of an ambulacrum. Most of the Kinderhookian and Chouteau species previously referred to *Cryptoblastus* (concave base) belong to *Tanaoblastus* Fay, 1961 (convex base). It is quite possible that *Monadoblastus* and *Cryptoblastus* were derived from *Tanaoblastus* by means of reduction of the hydrospires to one on each side of an ambulacrum and invagination of the base (*Monadoblastus*), or by means of invagination of the base, depression of interradial sutures, and wedging of adoral tips of radial limbs in deltoids (*Cryptoblastus*).

The Lake Valley blastoids are mostly new, but may be considered younger than the Chouteau forms from Missouri, and older than the Tournaisian forms from Belgium. If *Phaenoblastus* were derived from *Phaenoschisma,* then the Tournaisian and Lake Valley forms must be younger than the Lower Carboniferous blastoids from England.

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Ground-Water Resources of Beaver County

Buletin 97 of the Oklahoma Geological Survey was released on May 30, 1962. It is entitled *Ground-water resources of Beaver County, Oklahoma,* and is coauthored by I. Wendell Marine and Stuart L. Schoff, both of the Ground Water Branch of the U. S. Geological Survey. The report comprises the results of a long-range study covering the occurrence, use, and availability of ground water in the county. It contains two colored maps, each at scale one inch equals one mile. One shows the distribution of principal hydrologic units and the thickness of the Pliocene and Pleistocene deposits. The other shows the configuration of the water table and the depth to water.

The book consists of 74 pages, 12 figures, 11 tables, and two plates. It may be purchased at the Survey offices for $5.00 cloth bound, or $4.00 paper bound.

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