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OKLAHOMA GEOLOGY NOTES

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Cover Picture

School Field Trip on Top of Mount Scott

The Saturday morning mists faded right on schedule last October 23 as more than 50 students and faculty from the School of Geology and Geophysics gathered around Professor Emeritus Clifford A. Merritt for a sermon on Mount Scott.

The idea for departmental field trips was revived last spring by the School's student-faculty relations committee. The excursion pictured, a very successful 2-day trip through southwestern Oklahoma, was organized and led by students, faculty, and staff from the School and the Oklahoma Geological Survey. At least one trip each semester is anticipated. (In fact, a 3-day trip through the Ouachita Mountains was made on the weekend of November 19-21.)

Dr. Merritt is in a familiar setting—surrounded by eager listeners and boulders of Mount Scott Granite. Cliff is pointing to the southwest toward the type locality of the Quanah Granite in the southern part of the Wichita Mountains Wildlife Refuge.

—George Thomas Stone

(Photograph by Ronald M. Macomber)

Reclamation of Mined Coal Lands in Eastern Oklahoma

Kenneth S. Johnson[1]

INTRODUCTION

Large reserves of bituminous coal are distributed over an area of 10,000 square miles in eastern Oklahoma (fig. 1), and these deposits have been mined continuously since 1872. Early production in Oklahoma was almost entirely from underground mines, but with the development of large power equipment, surface mining became increasingly important until it accounted for about 50 percent of annual production in 1943 and 99 percent or more in 1964-67 (fig. 2). Surface mining will continue to account for most of the State's coal production in the near future in spite of the recent opening of two major underground mines.

A surface-mining operation begins with the digging of a long, open trench, or "box cut," through the overburden to expose a portion of the coal, which is then removed. As each succeeding parallel cut is made, the cverburden, or spoil, is placed in the cut previously excavated. The final cut leaves an open trench bounded on one side by the last spoil bank and on the other by the undisturbed highwall. Unless the ridges of spoil are graded or leveled, the mined area resembles a giant washboard (fig. 3).

Most of the mined land in Oklahoma has not been leveled and reconditioned for sequential use, and according to 1968 statistics more than 24,000 acres have been disturbed during surface-mining operations. Although restoration of newly mined lands is now required as a result of the State's Mining Lands Reclamation Acts of 1968 and 1971, no program has been established for reconditioning acreage disturbed before 1968. Through the cooperative efforts of many agencies, companies, and individuals, however, we can restore these disturbed lands to productivity; this is being demonstrated in southeastern Kansas through a highly successful program of mined-land redevelopment. Oklahoma has many persons who wish to see these lands restored, but their efforts must be concerted to achieve the best results.

[1]Geologist, Oklahoma Geological Survey.

Appreciation is extended to Ward Padgett, chief mine inspector, Oklahoma Department of Mines, for providing much of the information in this report as well as for reviewing the report, and to Robert H. Arndt, U.S. Bureau of Mines liaison officer for Oklahoma, for critical review.

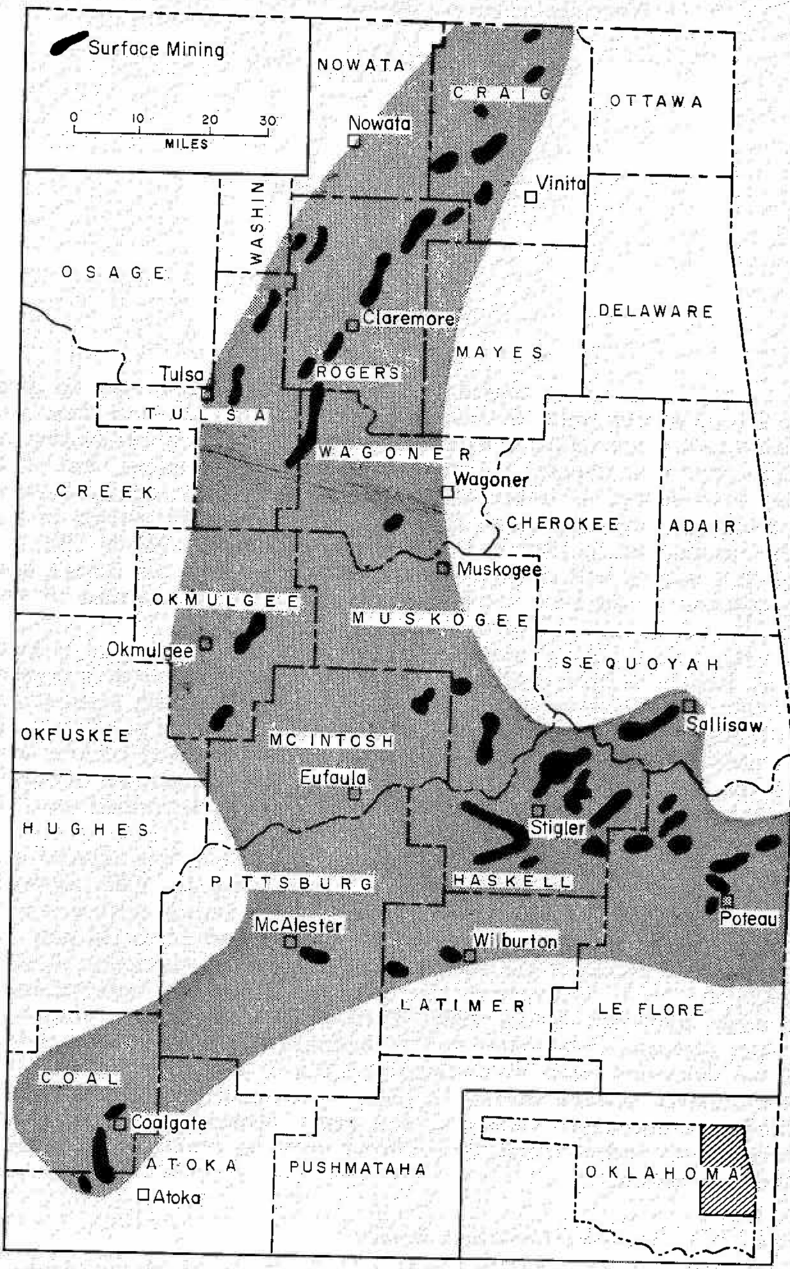

Figure 1. Map showing eastern Oklahoma coal field (shaded) and principal areas of surface mining for coal (modified from Doerr, 1961, p. 27).

Oklahoma's first step toward mined-land restoration was taken on January 1, 1968, with passage of the Open Cut Land Reclamation Act. The act set mining-permit fees, required that a bond be posted for reclamation, and specified minimum restoration requirements. It affected only surface mines that began operating after that date or new extensions of preexisting mines. In June 1971 the Oklahoma Legislature passed the Mining Lands Reclamation Act (House Bill 1492) to replace the original law by strengthening reclamation requirements. Enforcement of this legislation is carried out through the office of Chief Mine Inspector, Oklahoma Department of Mines.

Under the new act, companies planning to extract minerals (excluding liquids and gases such as oil and natural gas) by surface or underground mining must obtain a permit, pay an application fee of $50 each year, and post a bond of $350 to $650 for each acre of land to be affected, with a minimum bond of $5,000. In addition, each application for a mining permit must be accompanied by a reclamation plan that meets the requirements of the act and sets forth the following: (1) the proposed use to be made of the land after mining, (2) the grading to be done, (3) the type of vegetation to be planted, and (4) the approximate time of grading and initial revegetation effort. A mining permit will not be issued unless these conditions are met, and any operator engaged in mining without a valid permit is liable to a fine of $50 to $1,000 for each day of operation.

The operator determines the subsequent use of the land, that is, he determines which parts of the land are to be reclaimed for forest, pasture, crop, homesite, recreational, or industrial use. He is required to grade all spoil ridges and peaks to "a rolling topography traversable by machines or equipment customarily used in connection with the use to be made of the land after reclamation." In addition, the operator must cover mineral seams containing significant concentrations of acid-forming materials with 3 feet of earth that will support plant life or cover them with a permanent water impoundment. Grading is to be completed within 1 year after mining, and initial seeding or planting is to be made at the first appropriate time following completion of the grading. Violation of any provision of the act will bring forfeiture of the operator's bond.

Reclamation does not come without cost. Oklahoma mineral producers reportedly spend from $300 to $500 per acre in reclaiming newly mined lands, and at one mine the operator has voluntarily set aside the original topsoil and then spread it over the leveled spoils at a total cost of $1,600 per acre. These costs appear high when considered on a dollars-per-acre basis, but they are relatively small when compared to the quantity and value of coal being mined (table 1). For example, a company that mines a 36-inch-thick coal bed and spends $500 per acre on restoration is actually incurring a reclamation cost of only 12 cents per ton of coal recovered. Most of the coal mined in Oklahoma is 12 to 48 inches thick, so reclamation costs in the State are generally 5 to 35 cents per ton. Oklahoma coal has had an average value of about $6 per ton each year for more than a decade (U.S. Bureau of Mines, Minerals Yearbooks). If effective land reclamation adds even 30 cents to the price of a ton of coal (a 5-percent increase), the cost to the public is small when compared to the positive results achieved.

OKLAHOMA'S UNRECLAIMED MINE LANDS

Prior to passage of the reclamation acts of 1968 and 1971, Oklahoma companies were not obligated to do anything toward restoring mined land, and the need for low-cost production of minerals in a highly competitive field caused most companies to minimize their expenditures on land reclamation. More than 24,000 acres of land in 15 counties were mined for coal before 1968 (table 2), with over half the total in Haskell, Craig, Rogers, and Wagoner Counties. These mined areas are now commonly marked by ridges and piles of spoil (fig. 3) that consist of unweathered rock and clay heaped upon or thoroughly mixed with a small percentage of original topsoil. Spoil ridges left by mining operations prior to 1960 are generally 20 to 30 feet high (trough to crest) and 40 to 60 feet wide (crest to crest); large modern shovels and draglines now pile spoil heaps 60 feet high and 120 feet wide.

With few exceptions, soil textures and structures in spoil are inferior to the original topsoil. Spoil generally is deficient in organic matter and other usable plant nutrients and commonly is acidic. No single treatment or vegetation is applicable for reclaiming all the mined land in Oklahoma. Variations in soil condition in terms of physical and chemical characteristics, different climates, orientation

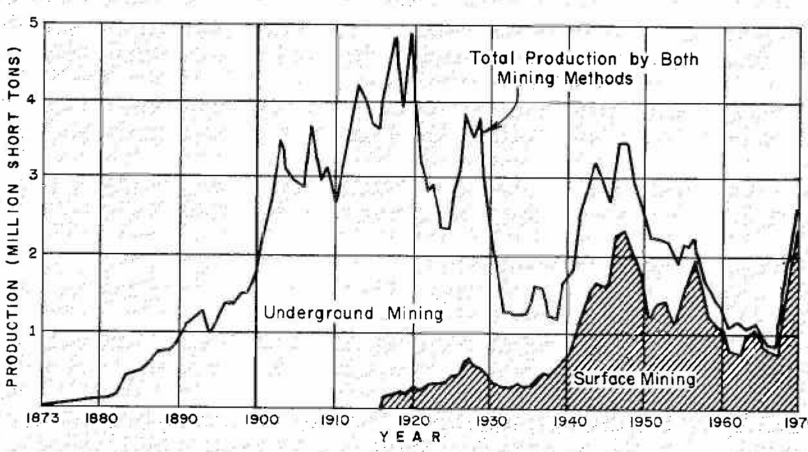

Figure 2. Coal production in Oklahoma, 1873-1970, showing amounts of coal mined by underground and surface methods. Data for 1873-1952 from Trumbull (1957), for 1953-69 from U.S. Bureau of Mines Minerals Yearbooks, for 1970 from annual report of Oklahoma Department of Mines.

of spoil ridges, steepness of slopes, presence or absence of toxic substances, and seed sources all play a part in determining the rate of revegetation and the type of vegetation that succeeds in a given area (Doerr, 1961, p. 29).

Figure 3. Aerial views of unreclaimed land mined for coal before passage of Oklahoma's reclamation act of 1968. Sparse vegetation is taking root on spoil banks, and water fills the final cut. Photographs taken in Rogers County, May 1971.

Most of the spoil in old mine areas has been allowed to revegetate on its own. As a result, weeds, grasses, and shrubs commonly have appeared shortly after mining, with trees such as sycamore, cottonwood, and sassafras becoming conspicuous after several years. In most cases, the slopes and ridge crests were less than 50 percent covered 10 years or more after mining (Doerr, 1961, p. 30). Some spoils, however, are so toxic that they do not accept natural revegetation for 20 years or more.

Tracts of disturbed land in Oklahoma commonly are long and narrow. The average width is less than 0.1 mile, and a length of 1 to several miles is not uncommon (Doerr, 1961, p. 26). Long, narrow lakes have formed in virtually all tracts of mined land, because rainwater fills the steep-walled final cut.

Coal-bearing lands should be put back into productive use after their minerals have been extracted, but there has been minimal effort toward effective use of the 24,000 acres disturbed prior to 1968. Forage grass for animals has been seeded in some tracts, and trees suitable for making fence posts have been planted occasionally. Lakes formed in the open pits have been used for watering livestock and, to a certain degree, for recreational purposes. An ideal use for open pits near urban areas is for refuse disposal in sanitary land-fill operations and subsequent use of the filled land for parks and recreational areas. Such pits should be tested and prepared to assure that ground water will not be contaminated as a result of the land-fill use.

MINED-LAND REDEVELOPMENT IN KANSAS

One answer to the problem of reclaiming old surface-mine areas may lie in a program similar to that employed by the Kansas Mined-Land Redevelopment Office (MLRO), a mineral-resources task group established to encourage the redevelopment of 45,000 acres of mined land in the southeastern Kansas coal field (State Geological Survey of Kansas and others, 1971). The Kansas task group, consisting of professional persons interested in reclamation plus a paid technical staff, is funded by the Ozarks Regional Commission and the State Geological Survey of Kansas.

TABLE 1.—RECLAMATION COSTS PER TON OF COAL FOR COAL BEDS 12 TO 60 INCHES THICK

THICKNESS OF COAL (INCHES)	ESTIMATED PRODUCTION PER ACRE (TONS)[1]	COST PER TON OF COAL, IF RECLAMATION COST IS:			
		$300 PER ACRE	$500 PER ACRE	$700 PER ACRE	$1,000 PER ACRE
12	1,440	$ 0.21	$ 0.35	$ 0.49	$ 0.69
24	2,880	0.10	0.17	0.24	0.35
36	4,320	0.07	0.12	0.16	0.23
48	5,760	0.05	0.09	0.12	0.17
60	7,200	0.04	0.07	0.10	0.14

[1]Assumed rate of recovery is 80 percent of original coal, or 1,440 tons per acre-foot.

The main goals of MLRO are to acquire accurate data on reclamation costs and returns, to demonstrate the economic feasibility of redeveloping mined land into grassland, and to accumulate technical information on better methods of reclamation. To accomplish these objectives, members of the MLRO have directed the leveling and revegetation of four plots of unreclaimed mined land, each consisting of 40 acres. All the plots are near Pittsburg, in southeastern Kansas. A 1-acre research area has been set aside on each plot to test adaptability of various grasses and the use of various fertilizers and soil conditioners.

The MLRO program's initial results, along with data obtained from several local farmers and ranchers who have reclaimed land on their own, indicate a high degree of success; and a number of positive results were observed or pointed out at a mined-land redevelopment workshop held at Pittsburg in May 1971. Cattle grazed on wheat and grasses grown on reclaimed land have shown yearly production gains of 180 pounds of beef per acre (compared to 20 pounds of beef per acre before reclamation). One tract of land leveled in the summer of 1970 was expected to yield 40 to 50 bushels of wheat per acre the following summer, a yield about 75 percent that of nearby unmined land. As a result of these and other benefits, land values have increased sharply from $70 or $75 per acre for disturbed land to about $200 per acre after reclamation, nearly as much as the $250-per-acre value of unmined land. Another significant finding of the MLRO study is that fly ash, a waste material produced in large quantities when coal is burned, appears to have great potential as a soil conditioner for acid soils; its use has increased productivity sharply on test plots. Persons attending the workshop were favorably impressed

TABLE 2.—ACREAGE DISTURBED BY SURFACE MINING IN OKLAHOMA COAL FIELDS PRIOR TO 1968[1]

COUNTY	ACREAGE
Atoka	148
Coal	1,090
Craig	3,644
Creek	2
Haskell	4,322
Latimer	1,010
Le Flore	1,066
McIntosh	796
Muskogee	1,650
Nowata	60
Okmulgee	1,801
Pittsburg	202
Rogers	3,520
Tulsa	1,695
Wagoner	3,051
Total	24,057

[1]Data compiled by Ward Padgett, chief mine inspector, and Edna Havens, secretary, Oklahoma Department of Mines.

with these results and were especially pleased with the restoration of mined land to a gently rolling topography such that the land was suited to a great variety of sequential uses (figs. 4, 5).

The major cost in the Kansas reclamation program is the grading or shaping of the land. Minimum grading requirements set by the MLRO for preparation of each 40-acre test plot were as follows.

1. Maximum slope allowed on 90 percent of the land was 10 percent (1 foot vertical to each 10 feet horizontal), and the maximum slope allowed on the remaining 10 percent of the land was 15 percent (1 foot vertical to each 6.67 feet horizontal).

2. All slopes to be seeded with grass were leveled sufficiently to permit travel by wheeled tractors and to permit the use of conventional farm machinery for grass establishment and maintenance.

3. Where existing water was available, livestock access was provided on slopes no steeper than 25 percent (1 foot vertical to each 4 feet horizontal).

4. Needed drainage was to be part of the leveling operation.

5. Stumps and boulders were covered. If trees could not be buried, they were piled for burning.

6. For seedbed preparation, the final step in leveling was a heavy offset disking and a heavy I-beam dragging.

7. Soil tests determined the amount of lime to be applied, and nitrogen was applied at a rate of 100 pounds per acre.

8. Tentative seeding plans called for 15 to 20 pounds of tall fescue grass seed per acre, with a cover crop of small grain such as wheat or oats.

The cost of meeting these requirements in reclaiming old surface-mined areas in this part of Kansas is $100 to $200 per acre and averages about $150 per acre. Modern mining machinery, however, is much larger and moves more overburden than machinery of earlier days; thus, the cost of leveling and reclaiming newer ridges and piles in the area is about $300 to $500 per acre.

Much attention was given at the workshop to a new idea in the design of equipment used in leveling spoils. One local contractor modified a bulldozer by setting the blade at an angle to the direction of movement so that spoil is cast aside into the trough as the bulldozer makes a pass down the full length of a spoil ridge. Using a D-8 Caterpillar with the angled blade in tandem with another D-8, dirt in spoil banks 60 feet wide was moved at an estimated rate of 4,000 cubic yards per hour and at an estimated cost of about 3 cents per cubic yard. This contractor's time and cost of leveling ridges were considerably less than those of other contractors using conventional bulldozing methods, and his concept should be more fully tested by companies interested in designing and building heavy earth-moving equipment.

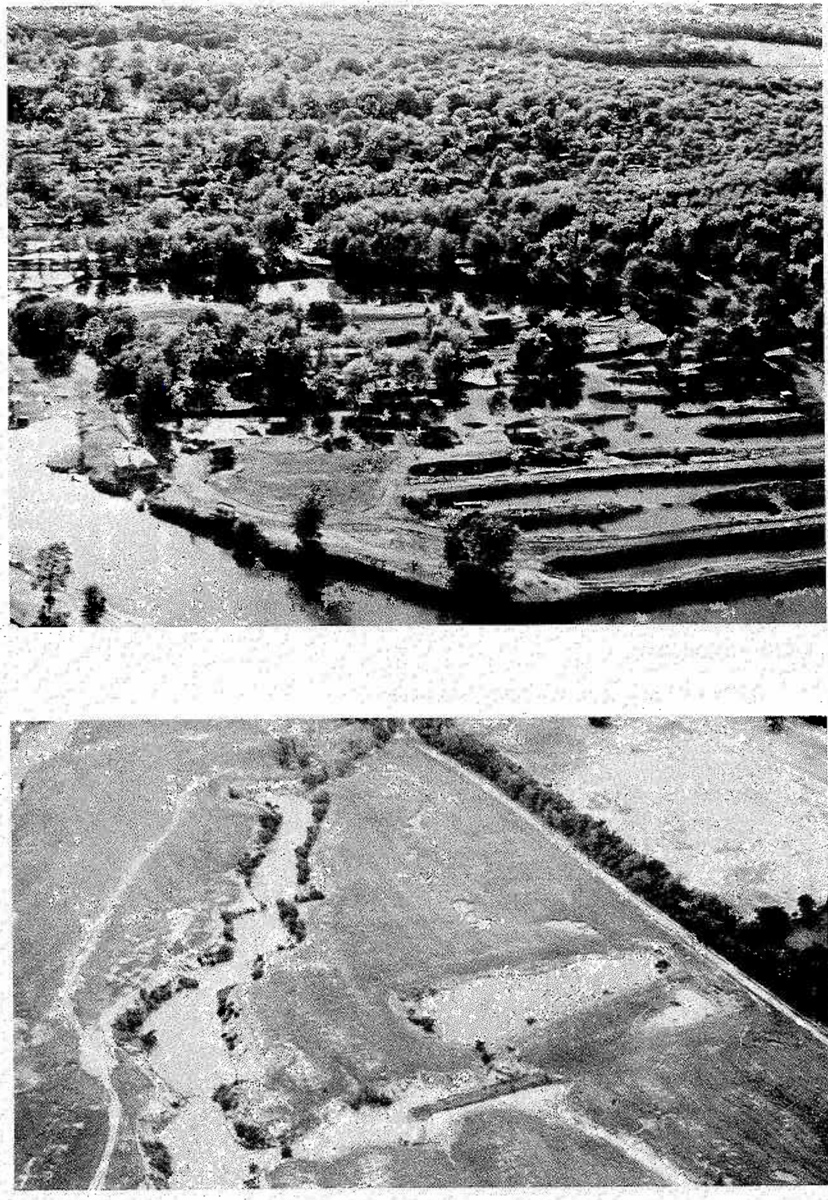

Figure 4. Aerial views of reclaimed land in southeastern Kansas.
Top: Recreational area developed 4 miles northwest of Pittsburg in sec. 10, T. 30 S., R. 24 E.
Bottom: Leveled land and stock ponds developed for cropland and pasture in sec. 35, T. 31 S., R. 22 E.

Unreclaimed coal-mine lands in Oklahoma can be leveled and restored to productivity, but for maximum effectiveness a program of assistance and demonstration must be organized to marshal the expertise of the many persons interested in reclamation. Based on cost estimates from reclamation programs in eastern Oklahoma and southeastern Kansas, restoration of individual tracts of land can be accomplished within 1 year at a cost ranging from $100 to $500 per acre; and most of the land probably can be reclaimed for $100 to $200 per acre. The major cost is in grading or leveling the spoil banks, so the size of the ridges and the nature of the spoil will largely determine total cost. Other major costs are in conditioning and fertilizing the leveled spoil and in revegetation of the land.

Persons or companies who could contribute much to the success of any coal-land-reclamation program, either in a participatory or advisory role, include experts in the fields of mining, agronomy, soil science, geology, hydrology, forestry, wildlife management, farming, ranching, banking, economics, law, labor management, earth moving, heavy-equipment design, news reporting, and public relations. Government agencies that can contribute valuable assistance and expertise in a reclamation project include the following.

State Agencies

Agricultural Experiment Station
Department of Agriculture
Department of Health
Department of Mines
Geological Survey
Industrial Development and Park Department
Office of Community Affairs and Planning
Soil Conservation Board
Wildlife Conservation Department

Federal Agencies

Agricultural Stabilization and Conservation Service
Bureau of Mines
Bureau of Reclamation
Environmental Protection Agency
Forest Service
Geological Survey
Ozarks Regional Commission
Soil Conservation Service

Toward a major concerted effort for restoration of Oklahoma's unreclaimed lands, the following program is recommended.

1. *Inventory.*—Make a complete inventory of unreclaimed lands and their ownership.

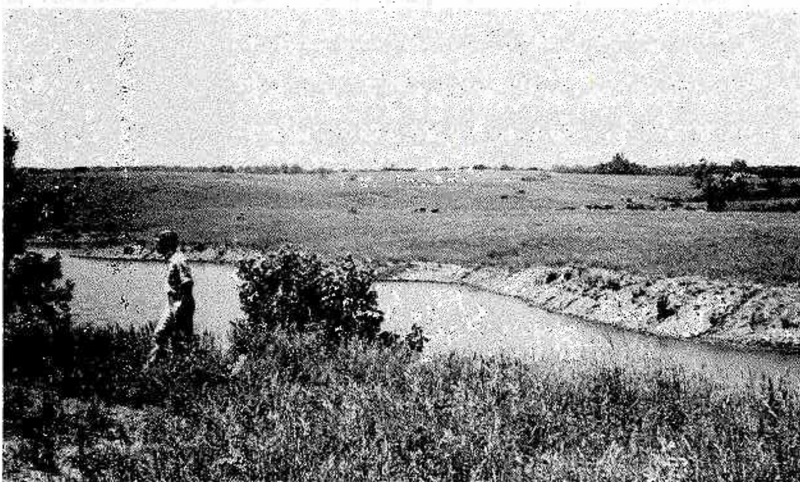

Figure 5. Ground views of reclaimed land in southeastern Kansas.
Top: View of same area seen in bottom photo of figure 4 showing gently rolling topography after leveling.
Bottom: Wheat and grasses on reclaimed land in sec. 9, T. 29 S., R. 25 E.; land was leveled in the summer of 1970, seeded in the fall of 1970, and photographed in May 1971.

2. *Potential land use.*—Evaluate the various potential uses for disturbed land and open pits, and establish general priorities for these uses. A methodology should be developed for determining the most desirable use for individual tracts of land based on the nature of the land and the needs of the surrounding area. In particular, determine the suitability of various open pits as sites for sanitary land fills.

3. *Land grading.*—Evaluate the slopes and the degree of land grading or shaping required for various subsequent uses of mined land. Also determine the cost of grading various spoil-bank materials for these subsequent uses.

4. *Land conditioning.*—Investigate the quantity and costs of various soil conditioners and fertilizers needed for optimum use of reclaimed land, with special emphasis on utilizing waste products such as fly ash and municipal sewage. The similarities and differences between spoil banks in various parts of the coal field should be classified or evaluated in order to determine predictability of various reclamation techniques.

5. *Revegetation.*—Evaluate the yields of various crops and grasses on reclaimed land, and determine costs in reseeding.

6. *Encouraging reclamation.*—Encourage landowners to recondition mined land by demonstrating that reclamation can be profitable. Determine whether aid is now available to landowners for reclamation under existing Federal or State programs and explore the possibility of recommending additional programs that will encourage reclamation. Also, explore the possibility of an incentive program, such as tax incentives, to partially defray reclamation costs.

7. *Equipment and machinery.*—Explore the possibility of developing equipment and machinery that can restore mined land more efficiently.

8. *Interstate cooperation.*—Work closely with the Mined-Land Redevelopment Office of Kansas to benefit fully from its program in the southeastern Kansas coal field, and freely exchange information with other Arkansas, Kansas, and Missouri groups interested in land reclamation. Our four states constitute the southern part of the Western Interior Coal Basin, and many of our reclamation problems are similar.

In achieving these objectives, Oklahoma will take a great step toward restoring its 24,000 acres of disturbed land and will help develop a methodology for accomplishing the same results in other parts of the United States. By developing economical methods of land restoration for agricultural, recreational, housing, and other uses, the program will also have a strong impact on present and future reclamation activities in Oklahoma.

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U.S. Bureau of Mines, Minerals Yearbooks for 1953-69.

Earth Science Editors Routed to Reno

The Nugget Convention Center, one of the largest and most highly rated entertainment centers in the Reno, Nevada, area, was the site of the fifth annual conference of the Association of Earth Science Editors October 10-12, with some 50 members and guests in attendance from the United States and Canada. In addition to touring Lake Tahoe, Carson City, and Virginia City (scene of the Comstock mining boom of the late 1800's), conferees were invited to try their luck in the casino between sessions. Most participants exercised rare foresight in having bought round-trip tickets, and one or two were reported departing unencumbered by luggage or coats.

Two panel discussions were geared toward definition of the present and future roles of the editor in earth science publishing. Technical sessions addressed to "Geologic and Geographic Nomenclature" and "Future Style Trends in Publications" brought forth suggestions for cutting costs and lessening elapsed time between determination of research results and publication. It was generally agreed that "editors should be leading—not following kicking and screaming," as aptly put by George Becraft of the U.S. Geological Survey's office of technical reports.

Guest speakers included Bennie W. Troxel, scientific editor for GSA; state geologists William W. Hambleton of Kansas and Don H. Baker of New Mexico; George V. Cohee, chairman of the U.S. Geological Survey's geologic names committee; and Armand Hacquaert, president of Editerra, the European association of earth science editors, who made a special trip from Belgium to attend.

The program was prepared by a committee chaired by Doris E. Zeller of the Kansas Geological Survey, and Ira A. Lutsey, editor for the Nevada Bureau of Mines and Geology, was responsible for the excellent conference arrangements. New officers for the association include Gerald M. Friedman, Rensselaer Polytechnic Institute, chairman, and Richard V. Dietrich, dean of the School of Arts and Sciences, Central Michigan University, vice-chairman. Bill Rose, editor for the Oklahoma Geological Survey, happily relinquished his position as secretary-treasurer to Pat Wood, former OGS associate editor.

Introducing the Survey's New Associate Editor

Rosemary L. Kellner has joined the Oklahoma Geological Survey staff as associate editor, replacing Carol (Patrick) Hare, who resigned to move to Tulsa, where her husband Ben has accepted a position as exploration geologist with Amerada Hess Corporation.

A native of Sedalia, Missouri, Rosemary has a bachelor's degree in English from Park College in Parkville, Missouri, where she graduated with distinction. Later, at Kansas State University, she completed course requirements for a master's degree in English.

She has been at OU for 3 years, where she has held positions in employment services and public relations. Most recently she was assistant editor for *Books Abroad,* the widely recognized international literary quarterly published at OU. Not content to rest on her academic laurels, Rosemary is completing work on a master's degree in Political Science as well as assimilating geological knowledge from one of Dr. Myers' courses.

The members of the Survey consider themselves fortunate indeed to gain an editor with such substantial qualifications. Welcome aboard, Rosemary!

AIPG State Section Meeting Held

The Oklahoma Section of the American Institute of Professional Geologists convened September 25 at the Petroleum Club in Oklahoma City for its annual meeting. Featured speakers were Charles Nesbitt, chairman of the Oklahoma Corporation Commission, who presented his views on how a proper concept of conservation can provide exploration incentives, and Herman Woebcke, an engineer with Stone and Webster Engineering Corporation of Boston, who explained the feasibility study of a coal-gasification plant for eastern Oklahoma that his firm is making for Gulf General Atomic Corporation.

Committees reporting at the business sessions included the following: professional and scientific standards, relations with government agencies, statutory regulations and legislative, man's geologic environment, park development and highway signs, and public schools education.

Eugene Culp gave a special report on a proposed conference to review the present status of Oklahoma's mineral resources, consumer demands, and the future of the extractive industries. It was recommended that the conference be sponsored jointly by the Oklahoma Section of AIPG, the Oklahoma Geological Survey, and possibly other interested professional organizations (see following page).

Oklahoma Section officers for the coming year are Suzanne Takken, president; Philip A. Chenoweth, vice-president; and Tom K. Hendrik, secretary-treasurer. Additional members of the executive committee are Robert C. Saultz, Oklahoma City representative; Edward L. Johnson, Tulsa representative; and Charles W. Johnston, Jr., representative-at-large. Leroy Gatlin is past-president; Herbert G. Davis and Jerry E. Upp are representatives to the national advisory board.

New national AIPG officers were also announced: Neilson Rudd, president; Adolf U. Honkala, vice-president; Jackson M. Barton, secretary-treasurer; Robert E. Hershey, editor.

Larger Scale Topographic Maps Under Consideration

According to Winston Sibert of the Topographic Division, U.S. Geological Survey, the Federal government is considering adding new, larger scale maps to its National Topographic Map Series. This step may be necessary to meet the more exacting requirements of pollution-control experts, environmental managers, and metropolitan and regional planners. Thus the standard large-scale topographic maps (1:24,000, or 1 inch equals about 2,000 feet) would not be detailed enough for some planning needs.

Sibert stressed that these larger scale maps should be issued by the Federal government to assure uniformity of scale, content, and accuracy needed to best serve the national interest. He expressed the hope that larger scale maps could be produced primarily by use of extensive contractual services supported in part by Federal funding in accordance with Federal specifications, inspection, and acceptance.

"Justification for Federal management of a larger scale map series is clear when we consider that urban sprawl caused by increasing concentration of population is not confined by a state boundary, county line, or city limit," he said, adding that "when a larger scale national map series suitable for most urban planning purposes is adopted, the various urban planning organizations will have the means of obtaining uniform solutions to their large-scale mapping problems."

Taking into consideration all environmental and planning requirements, such a program of large-scale mapping would provide coverage for about one-fifth the total land area of the United States.

Oklahoma Minerals Symposium Scheduled for March

A symposium on Oklahoma's mineral resources will be held March 10, 1972, at Norman in the Forum Building of the Oklahoma Center for Continuing Education on The University of Oklahoma campus. The conference is expected to attract economic geologists throughout the State and from adjacent areas. Sponsors will include the Oklahoma Section of the American Institute of Professional Geologists, the Oklahoma Industrial Development and Park Department, and the Oklahoma Geological Survey. Papers will evaluate the many minerals of Oklahoma having economic potential. A detailed program will be distributed in the near future.

OGS Coal Program Gets Under Way

With the arrival of coal geologist Samuel A. Friedman in July, the Oklahoma Geological Survey's program of coal investigation has gotten off to a fast start. The initial part of the long-range program is a 2-year study, funded by the Ozarks Regional Commission, that provides for a comprehensive evaluation of Oklahoma's minable reserves. Although several published reports and maps are available on Oklahoma coals, this is the first time a thorough study of the total coal resources has been undertaken. The previous work has been essential to the building of the present program, of course, especially U.S. Geological Survey Bulletin 1042-J, *Coal Resources of Oklahoma*, by James Trumbull, published in 1957.

The first phase of the program consists of the collection and evaluation of existing data in order to establish a valid geologic framework for subsequent work. Richard P. Lockwood, a graduate student in the OU School of Geology and Geophysics, is assisting Mr. Friedman on a half-time basis with gathering and plotting such data as outcrop, drill-hole, and mine locations. It is noteworthy that industry personnel have shown excellent cooperation in making their data available.

The second phase of the program calls not only for the drilling of test holes to supplement the geologic information collected and evaluated in the first phase but also the systematic mapping and sampling of individual coal beds on a county-by-county basis.

A related program involving the Survey and coal resources is the investigation of the feasibility of setting up a coal-gasification plant in the Oklahoma coal field utilizing a nuclear heat source. The Survey has been asked to provide basic coal data for Stone and Webster Engineering Corporation, a Boston firm making the feasibility study for Gulf General Atomic Corporation, which holds the 1-year, $300,000 State contract. High-volatile bituminous coal is considered most suitable for the gasification process, and a minimum of 100 million tons of recoverable reserves is necessary for establishment of the plant site. If these requirements are met, the proposed plant would be capable of producing at least 250 million cubic feet of gas per day. Thus it is obvious that the ultimate success of this venture would be of great importance to Oklahoma as well as to the nation through developing a dependable source of gas to bolster dwindling reserves and satisfy growing demand. Should the study reach favorable conclusions, gas production would not begin for at least 6 years, however.

In support of these investigations, David A. Foster, the Survey's new analytical chemist, will perform the important task of supplying values for fixed carbon, sulfur, ash, and Btu from coal samples brought in for analysis; and Kenneth S. Johnson, staff geologist, will be instrumental in advance planning for the reclamation of mined coal lands (see related article beginning on page 111 of this issue).

Distribution of Dissepimental Corals in Pennsylvanian Missourian Rocks of Northeastern Oklahoma

J. M. Cocke[1]

INTRODUCTION

In many Upper Pennsylvanian Missourian limestones of the American Midcontinent, dissepimental corals occur abundantly with phylloid algae and marine invertebrates. The purpose of this paper is to identify Missourian units in northeastern Oklahoma that contain dissepimental coral genera and to note their vertical and lateral distribution.

Missourian rocks crop out in a broad band across this area (fig. 1) and consist largely of thick clastics interspersed with thin, nonpersistent limestones; these units (fig. 2) contrast strikingly with the more persistent limestones and thinner clastics of Kansas. The Oklahoma clastic units locally contain prolific brachiopod and molluscan faunas which, in some places, are accompanied by abundant nondissepimental lophophyllid corals or amplexi-zaphrentid corals. As in Kansas, Missouri, and Iowa, dissepimental corals are found exclusively in limestone formations. Four general limestone varieties exist: (1) thin, impure crinoidal-molluscan calcarenites and calcilutites that in some places contain lophophyllid or amplexi-zaphrentid corals, (2) thick, poorly fossiliferous calcilutites that contain no corals or scarce lophophyllids, (3) algal-rich calcilutites generally associated with algal-mound complexes that usually contain four dissepimental genera (discussed below), and (4) calcilutites that contain abundant invertebrates but little phylloid algae and scarce dissepimental corals.

DISSEPIMENTAL CORAL GENERA

Dissepimental rugose corals are represented by four genera in the Missourian rocks of northeastern Oklahoma: *Caninia, Neokoninckophyllum, Dibunophyllum,* and *Geyerophyllum*. Only caniniids were noted by early workers in the area. Ohern (1910) and Oakes (1940) discussed the presence of numerous *Campophyllum torquium* in the Dewey Formation in Washington County. Many caniniids of the Midcontinent that are more properly assigned to *Caninia* (see Easton, 1944) have been included in this species. More recently, Moore and

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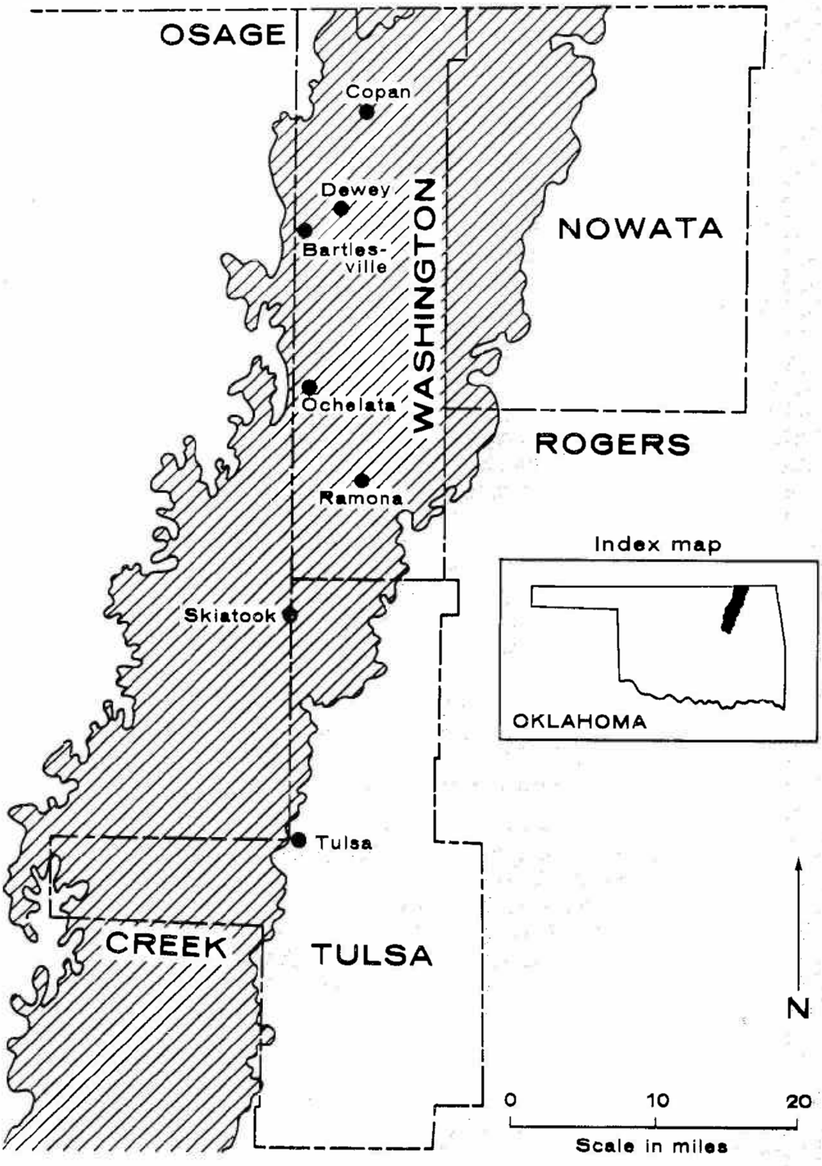

Figure 1. Outcrop of Pennsylvanian Missourian units in northeastern Oklahoma between bottom of Checkerboard Limestone and top of Wann Formation.

Jeffords (1945) and Rowett and Sutherland (1964) described several dissepiment-bearing species of *Dibunophyllum* and *Koninckophyllum* from Lower Pennsylvanian rocks of Oklahoma. Jeffords (1948a) described *D. moorei* from Oklahoma Desmoinesian rocks. Dissepimental forms from Missourian rocks have only been discussed or described by Cocke (1962, 1965, 1966, 1970), Cocke and others (1971), and Sutherland and Cocke (1960).

Following is a brief description of the four dissepiment-bearing genera.

Dibunophyllum.—Solitary, rarely budding; epitheca smooth, crossed by fine transverse growth lines; calyx deep with prominent axial boss; major septa long; minor septa usually prominent; dissepimentarium of normal dissepiments, lonsdaleoid dissepiments rare; inner wall commonly well developed; tabularium narrow, consisting of widely separated convex tabulae; columella typically compact, consisting of median lamella, radiating lamellae, and numerous closely packed, steeply inclined tabulae (fig. 3a, b).

Neokoninckophyllum.—Generally solitary or loosely fasciculate; epitheca smooth and crossed by closely spaced transverse growth lines; calyx deep with low axial structure; major septa long; minor septa missing or short where locally present; dissepimentarium of normal dissepiments, lonsdaleoid dissepiments rare; inner wall absent or poorly developed; tabularium of widely spaced, gently inclined tabulae; columella of loosely packed tabulae and axial ends of major septa (fig. 3c, d).

Geyerophyllum.—Solitary, rarely budding; epitheca with prominent longitudinal ribbing; calyx flat and shallow in outer area, cylindrical and deep in center; prominent columella; major septa long; minor septa typically more than three-fourths major septal length; normal dissepimentarium present; lonsdaleoid dissepiment prominent; inner wall absent to well developed; tabularium of gently inclined to periaxially sagging tabulae; columella solid to loosely fenestrate (fig. 3e-g).

Caninia.—Solitary; epitheca smooth, crossed by closely spaced growth lines; major septa long in early stages, amplexoid in late stages, typically thickened in cardinal quadrants with cardinal septum in prominent fossula; minor septa generally well developed; tertiary septa absent or rare; dissepimentarium of normal dissepiments, lonsdaleoid dissepiments rare; inner wall well developed; tabularium of wide, complete to incomplete tabulae (fig. 3h). Corals similar to those from northeastern Oklahoma have been referred to *Pseudozaphrentoides* by Moore and Jeffords (1945), Sutherland (1958), and others.

For further discussion of *Dibunophyllum* and *Caninia*, see Jeffords (1948b).

STRATIGRAPHY AND CORAL DISTRIBUTION

Limestones assigned to four Oklahoma formations by previous workers contain dissepimental rugose corals. In ascending order, they

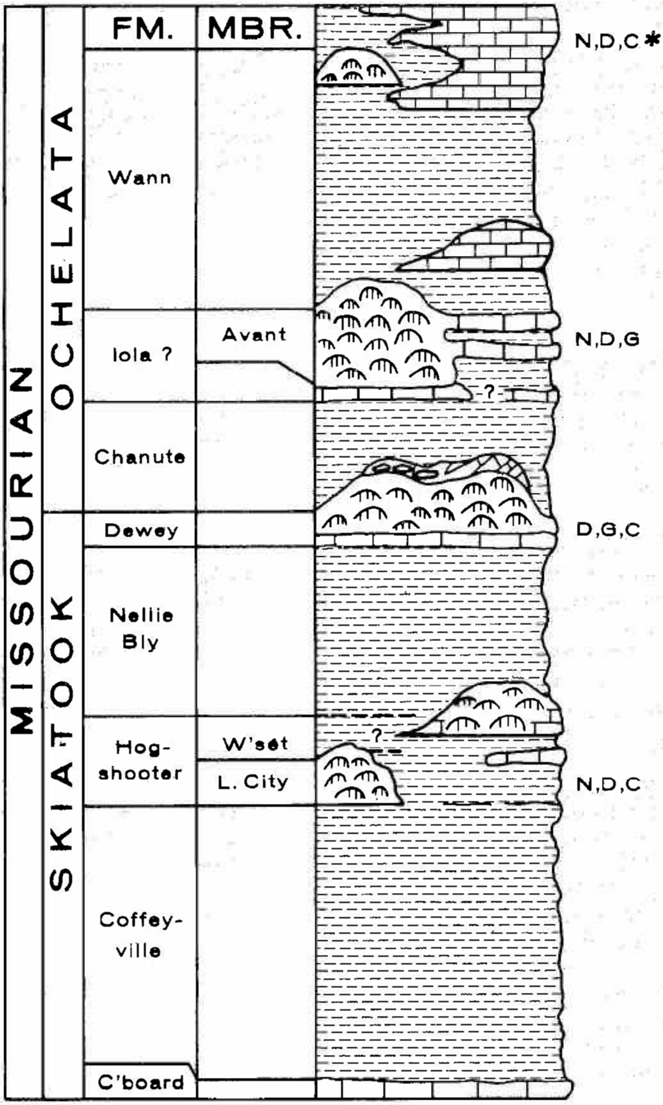

Figure 2. Generalized stratigraphic column showing major limestones of Missourian Series and dissepimental coral distribution in northeastern Oklahoma. Units abbreviated are as follows: C'board, **Checkerboard;** L. City, **Lost City;** W'set, **Winterset. Symbols are conventional, except that hachured convex lines indicate phylloid algal-mound limestone. Exact stratigraphic positions are not precisely known for Lost City Limestone, Avant Limestone, and limestones here assigned to Wann Formation. Generic abbreviations:** N, Neokoninckophyllum; D, Dibunophyllum; G, Geyerophyllum; C, Caninia. **Asterisk indicates occurrence of both** Dibunophyllum **and** Caninia **in small phylloid algal-mound complex near top of Wann;** Neokoninckophyllum **and** Dibunophyllum **are in normal limestone as indicated.**

are the Hogshooter Limestone, Dewey Limestone, Iola Limestone, and three limestone beds in the Wann Formation, which is predominantly shale and sandstone. No dissepimental corals have been collected from the Checkerboard Formation, the lowest limestone of the Missourian. The Birch Creek Limestone, which, according to Oakes (1940, 1952), is a persistent bed in the upper part of the Missourian, contains no dissepimental corals. Limestones presently assigned to the unit are now thought to occupy several stratigraphic positions (Tanner, 1956; Strimple and Cocke, 1969).

Hogshooter Formation.—The Hogshooter Formation crops out from Osage County, Oklahoma, southward to Creek County, Oklahoma. According to Oakes (1940), the unit continues northward into Kansas as the Dennis Formation. Several facies are present in Oklahoma: (1) a northern calcarenitic facies in the Winterset Member, which extends several miles south of the Kansas-Oklahoma boundary; (2) a phylloid algal complex, which extends several miles along the outcrop belt to a few miles north of Ramona, Washington County, Oklahoma; (3) a small patch reef near Ramona, characterized by abundant invertebrates, particularly the tabulate corals *Michelinia* sp., *Striatopora* sp., *Cladochonus* sp., and *Sutherlandia* sp. and by the non-dissepimental rugosa *Amplexi-Zaphrentis* sp. and *Lophophyllidium* sp.; (4) a thin fossil-rich calcilutite, which extends southward a few miles north of the Arkansas River in Tulsa County; and (5) the areally restricted Lost City algal-mound complex, which attains a thickness of 42 feet, at the southern extent of the Hogshooter Formation (Heckel and Cocke, 1969). Assignment of the Lost City Limestone to the Hogshooter Formation is tentative.

The Lost City algal-mound complex is a massive algal calcilutite buildup with few bedding surfaces of calcareous shale beds and is the only unit within the Hogshooter that is known to contain dissepimental corals. The dissepimental *Neokoninckophyllum* and *Dibunophyllum* have been collected throughout the limestone. They are rare in the lower 10 feet. A single specimen of *Caninia* sp. was collected near the top of the unit. Except for algal remains, the limestone is poorly fossiliferous. Above the Lost City is a calcareous shale zone with abundant calcarenitic lentils, phosphate nodules, and algally coated invertebrates including an elongate species related to *Lophophyllidium,* large michelinids, abundant molluscans, and crinoids.

Dewey Formation.—The Dewey Formation as described by Oakes (1940, 1952) extends from the western edge of Nowata County across parts of Washington, Osage, Tulsa, and Creek Counties. Throughout most of Washington County it is an algal mound underlain by crinoidal calcareous shales and limestones and overlain by either a cobbly algal calcilutite or a dolomitized skeletal calcarenite. At its northern limit it is replaced by the sandy limestone conglomerate of the Noxie Sandstone Member of the Chanute Formation.

Two dissepimental coral zones can be delineated in the Dewey: (1) a lower zone consisting of alternating calcareous shales and thin beds of algal calcilutite and (2) an upper zone consisting of cobbly algal calcilutite or dolomitized skeletal calcarenite.

The lower fossil zone contains one of the most prolific coral faunas in the Pennsylvanian of the Midcontinent. Many of the corals are excellently preserved, and some are in growth position. Dissepimental corals include *Caninia* sp., *Dibunophyllum brucei*, and *Geyerophyllum* sp. In addition, the zone contains the nondissepimental *Lophamplexus* sp. and *Stereostylus* sp. as well as the tabulates *Sutherlandia* sp., *Michelinia* sp., and *Cladochonus* sp. The noncoral fauna is abundant and variable. The zone can be traced definitely from the northernmost outcrop of the Dewey Formation to the southern extent of the algal-mound complex in southern Washington County. Southward, crushed caniniids mark the formation at least as far as Skiatook, on the Osage-Tulsa County line.

The upper Dewey coral zone, in both calcarenitic and cobbly calcilutitic limestone, contains *Caninia* sp., *Dibunophyllum oklahomense*, and *Geyerophyllum* sp. as well as *Lophamplexus* sp., *Michelinia* sp., and *Cladochonus* sp. Corals in the dolomitized calcarenite are badly abraded; those in the cobbly limestones are not abraded but are highly contorted. This zone can be identified in few places. Intervening beds of the Dewey are massive and contain very abundant algal remains to the almost complete exclusion of invertebrates. No dissepimental corals have been collected from the Belle City, a supposed Dewey equivalent which crops out in central Oklahoma.

Iola Formation.—The Iola Formation is one of the few limestone units that can be correlated with Kansas units with a reasonable degree of certainty. Near the Kansas-Oklahoma boundary it is a thin skeletal calcarenitic calcilutite characterized by a zone of phosphate nodules near its base. Seemingly, this zone can be identified throughout most of the Kansas outcrop belt. Phosphate nodules are present in the Iola 4 miles south of Bartlesville, Washington County. The unit contains abundant *Amplexi-Zaphrentis* sp. Southward, identification of the formation is doubtful, although phosphate nodules have been noted by Oakes (1940) near the stratigraphic position of the Iola a few miles north of Ochelata, Washington County.

A few neokoninckophyllids and dibunophyllids have been collected from the Avant algal-mound complex, which Oakes (1940) assigned to the Iola Formation. South of the algal-mound complex near Skiatook, a single, poorly preserved specimen of *Geyerophyllum* sp. was collected from the nonalgal skeletal-rich calcilutite of the Avant Limestone.

Wann Formation.—The Wann is a thick clastic formation which contains local calcareous shales and several limestone lentils. A 14-foot-thick limestone appears near the base of the formation a short distance south of Ochelata, Washington County. This unit consists of calcilutite containing abundant marginiferid brachiopods, questionable phylloid algae, algally coated grains, and scarce dibunophyllids. Dissepimental corals have been collected from a thick limestone lentil in the upper Wann Formation 3 miles west of Ramona, Washington County. This lentil is an invertebrate-rich calcilutite which contains abundant blue-green-algal structures. Laterally, within 2 miles north

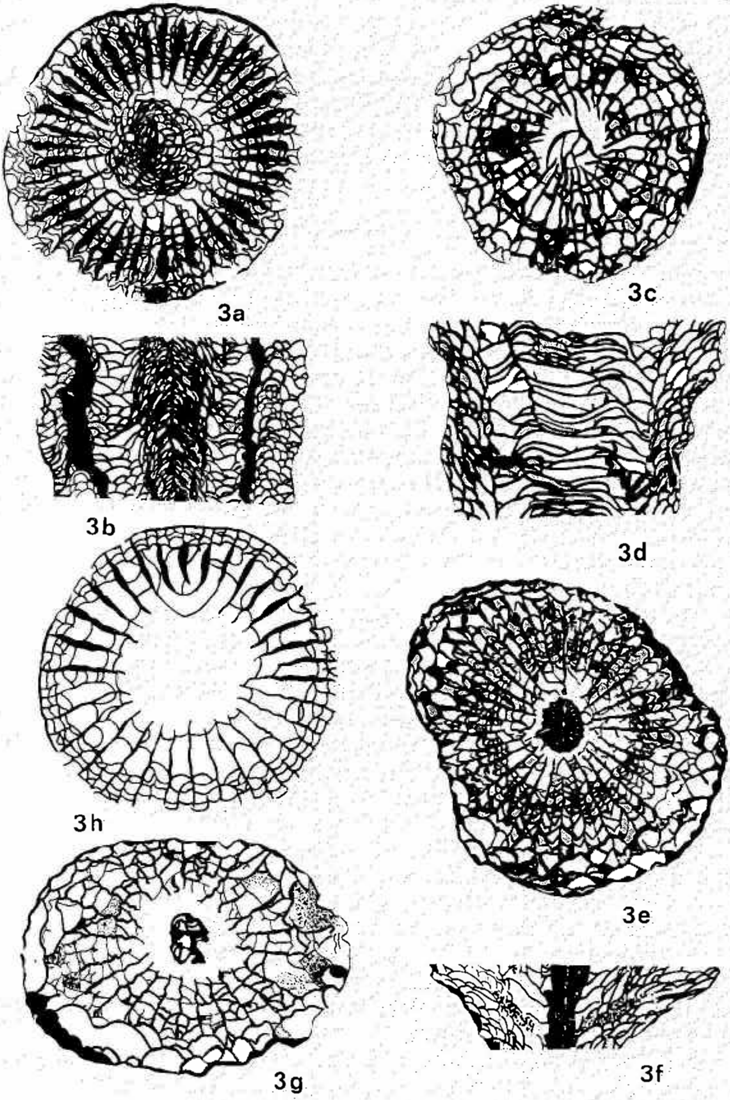

Figure 3. Dissepimental corals from Missourian rocks of northeastern Oklahoma: a,b, **transverse and longitudinal sections of** Dibunophyllum, **Wann Formation;** c,d, **transverse and longitudinal sections of** Neokoninckophyllum, **Lost City Limestone;** e,f, **transverse and longitudinal sections of** Geyerophyllum, **lower Dewey Limestone;** g, **transverse section of** Geyerophyllum, **upper Dewey Limestone;** h, **transverse section of** Caninia, **upper Wann Formation.**

and half a mile south of this exposure, the limestone pinches out into sandstone and shales of the Wann. Near the middle of the limestone, *Neokoninckophyllum* sp. and two species of *Dibunophyllum* occur with the nondissepimental *Stereostylus* sp. Many of the dissepimental corals are seemingly in growth position and are coated with blue-green algae. In a small Wann algal-mound complex near Copan, Washington County, both dibunophyllids and caniniids are relatively abundant.

SUMMARY

Two distinct coral faunas occur in Missourian rocks of northeastern Oklahoma. One, the *Lophophyllidium* assemblage, contains abundant members of that genus in addition to large numbers of gastropods, pelecypods, nautiloids, chonetid brachiopods, productid brachiopods, and crinoid remains. This fauna occurs in thin calcareous shales or in thin, impure limestone lentils with thick clastic units. A rather aberrant fauna, which is similar to the *Lophophyllidium* assemblage, is present in a small reef at the southern edge of the Hogshooter phylloid algal-mound complex. The corals include large colonies of *Michelinia* sp., *Cladochonus* sp., and *Striatopora* sp. as well as the solitary *Lophophyllidium* sp. and *Amplexi-Zaphrentis* sp. Accompanying the corals is a diverse fauna dominated by bryozoans, crinoids, and brachiopods.

The second assemblage consists of the four dissepimental genera discussed herein and commonly *Michelinia* sp., *Cladochonus* sp., *Sutherlandia* sp., *Stereostylus* sp., and *Lophamplexus* sp. Accompanying faunas are diverse and include large numbers of fenestrate and fistuliporid bryozoans, crinoids, and the brachiopods *Neospirifer* sp., *Punctospirifer* sp., *Composita* sp., *Crurithyris* sp., *Reticulatia*? sp., *Echinoconchus* sp., *Echinaria* sp., *Pulchratia* sp., and *Meekella* sp. This faunal suite is found commonly in thicker limestone of the phylloid algal-mound complexes or in thick normal marine limestone.

Generally, the occurrence of dissepimental corals in Missourian rocks of northeastern Oklahoma is summarized as follows.

1. None occurs in thick clastic units. These units locally contain rich faunas of the *Lophophyllidium* assemblage.
2. Dissepimental corals are locally abundant in normal marine limestones and phylloid algal-mound complexes that attain thicknesses of at least 4 feet. However, they may be very abundant in calcareous shales within these limestones.
3. Where present in phylloid algal-mound complexes, dissepimental corals do not contribute significantly to the composition of the structure and cannot be considered as framebuilders.
4. In most instances, dissepimental corals are accompanied by the lophophyllid corals *Stereostylus* sp. and *Lophamplexus* sp. but never by *Lophophyllidium* s.s. or by *Amplexi-Zaphrentis* sp. The tabulates *Cladochonus* sp., *Michelinia* sp., and *Sutherlandia* sp. are common with dissepimental corals. *Striatopora* sp., which is abundant locally, has not been collected in units containing dissepimental corals.
5. The only formation in Oklahoma that can be zoned internally is the Dewey Formation. However, dissepimental corals of the Lost

City Limestone are similar to those from Zone 1 of Kansas; those of the Avant Limestone and Wann Formation are similar to those of Zone 4 (Cocke, 1970; Cocke and others, 1971). Further, those of the Dewey Formation seemingly evolved from Zone 1 corals of Kansas and in turn gave rise to species in Zones 2 and 4.

6. Few calcarenites contain dissepimental corals; these corals, where present, are commonly abraded, and none occur in growth position.

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Helium in Hugoton Gas Field

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The chronologic development of the Hugoton field of Kansas, Oklahoma, and Texas, and the related Panhandle field of Texas has been reviewed as background for a study of the problems of origin, migration, and accumulation of the helium, nitrogen, and natural gas in these areas. Within the past decade, the release and publication of analyses from the Hugoton field and other areas have been commonplace. In addition, in-depth studies concerning helium, resulting from the past few years of litigation, have provided abundant data on the occurrence of helium, which may shed light on, and give impetus to the study of problems of origin, migration, and accumulation in general.

[1687]

Mathers Ranch

HERSHEL CARVER, Jake L. Hamon, Amarillo, Texas

The Mathers Ranch field in Hemphill County, Texas, represents another major discovery of gas reserves from the Siluro-Devonian Hunton limestone in the Anadarko basin of Oklahoma and Texas. It is the seventh significant Hunton field discovered in the deep Ana-

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OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

darko basin and is the result of continued exploratory drilling for Hunton and deeper objectives in the Cambro-Ordovician. Mathers Ranch field has more than 10 wells completed and the field limits are not yet defined in any direction. The discovery lies on a south-plunging structural nose transected by east-west faulting which, coupled with north dip, contributes structural entrapment. The degree to which porosity development is important as an entrapment agent is not yet defined and may be as important as structure, or even more so when the field is outlined completely by drilling. Production comes from below 17,000 ft from both intergranular and fracture porosity.

[1687]

Morrow-Springer Trend, Anadarko Basin, Target for the 70's

HERBERT DAVIS, Davis, Northcutt and Cochrane, Oklahoma City, Oklahoma

The Morrow Formation has accounted for much of the gas reserves on the shelf area and a limited part of the deep area in the Anadarko basin from 1947 to 1970.

The Morrow-Springer Formations offer multiple stratigraphic targets in this vast sedimentary basin. Deep drilling during the 70's could account for additional gas reserves from the Morrow-Springer.

As the stratigraphy, sedimentation, and depositional patterns are revealed through drilling, additional fields similar to Buffalo Wallow upper Morrow gas field, Hemphill County, Texas; East Elk City Springer gas field, Beckham County, Oklahoma; Indianapolis Springer gas field, Custer County, Oklahoma; and Laverty Springer gas field, Grady County, Oklahoma; will account for much of this reserve.

[1687]

Geology, Petrology, and Reservoir Characteristics of Marchand Sandstone in Grady and Caddo Counties, Oklahoma

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Marchand sandstone (Pennsylvanian-Missourian) oil production was discovered in 1967 at NE Verden, T8N, R8W, Grady County, Oklahoma. The play developed slowly but discoveries since 1970 by Samedan Oil Co. at Dutton townsite, Apache Corp. at NW Chickasha, and Midwest Oil Co. and Eason Oil Co. at NW Norge led to the most concentrated drilling boom in Oklahoma's Anadarko basin in recent years.

The fields are on the east flank of the east end of the deep Anadarko basin. Production to date has been excellent. Initial potentials are more than 1,000 BOPD. Liberal allowables of up to 580 BOPD and payouts of 4-6 months for the better wells account for the rash of drilling activity.

At the end of May 1971, 74 producing wells had been completed on 160-acre spacing in a producing trend extending over 15 mi from just west of Chickasha in T6N, R8W, to Dutton townsite in T9N, R9W. Th re are presently 10 wells drilling to the Marchand sandstone, 5 announced locations, and 18 wells that have run production casing and are in some stage of completion. Depths range from 10,100 to 1 , 00 f and drilling costs are from $100,000 to $120,000 to casing int and $180,000 to $200,000 for a completed producer.

The Marchand is a fine-grained, well-sorted sandstone and is ge eral y highly laminated with shale. Silt and clays are found in the matrix. egional correlations and examinations of samples, cores, and thin sections lead the writer to believe that the sandstone is of deltaic o gin. Th deltaic deposition apparently was complicated by channeling and offshore bar development. Regional structure at the Missourian l el is relatively uncomplicated, dip being monoclinal at approxim tely 1°/mi toward the basin axis and interrupted only by slight nosing. The trap appears to be purely stratigraphic.

Marchand sandstone pay thicknesses range up to 125 ft. The reservoir is undersaturated and oil wet with solution gas drive. Gas/oil ratios are approximately 700 to 1 and original bottomhole pressures between 4,600 and 6,300 psi. Primary recoveries should range between 12 and 16% of the oil in place and reserves for the better wells with the thickest pay sections should be more than 750,000 bbl of oil.

The excellent production from the Marchand sandstone touched off an extensive leasing campaign in southwestern Grady and southeastern Caddo Counties, Oklahoma. The Marchand is only one of several sandstones developed in the Missourian section and chances ar good that wildcat drilling will uncover additional stratigraphic produc on from the Missourian section in this part of the Anadarko basin.

[1687-1688]

Natural Gas in Anadarko Basin

ROBERT A. HEFNER III, Glover Hefner Kennedy Oil Company, Oklahoma City, Oklahoma

Geologists tend to think of natural gas in geologic terms. However, Mid-Continent geologists also should think of gas in the Mid-Continent, and particularly in the deep Anadarko basin, in terms of the economics of the total system of production and delivery to market from the Mid-Continent area, and the overall economics of the energy industry in the United States.

Good exploration geologists have understood for years the importance of the interface between their discipline and others, but there are now more disciplines to which they must relate as they think of gas exploration in the long term. Geologists have included in their thought-processes operating constraints of the production phase of the business, but with the search for greater reserves, and particularly ultra-deep reserves, production technology has changed so substantially that a new and more comprehensive view of this developing technology is required. In addition, geologists must become economists in a sense, because the development of commercial reserves is closely related not only to the cost of production, transportation, and distribution, but also to the costs of all alternate sources of energy when delivered to the consumer.

[1688]

Hamon Locke Multipay Field

JOHN W. MASON, Amarex, Inc., Oklahoma City, Oklahoma

The Hamon Locke field on the Wheeler-Roberts county line in the Texas Panhandle was discovered late in 1970 by the Jake L. Hamon No. 1 Locke. To date, 4 wells have been completed and 1 is currently staked. Producing formations are the Ellenburger, Simpson, Hunton, and Brown dolomite with proved productive granite wash and Mississippian zones behind pipe in 3 of the wells. The field is structurally controlled and was drilled on seismic information refined by subsurface data from 2 nearby dry holes which were also drilled on seismic information, emphasizing again the need for continuing review and interdisciplinary coordination. The hydrocarbons produced are significantly different from other nearby lower Paleozoic fields, and some conjectures are presented to stimulate further work to account for these differences.

[1688]

Geochemistry and Geology of Helium

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Helium is formed as a product of radioactive decay of trace elements in several rocks and minerals. It is being produced continually in the earth's crust by the disintegration of uranium, thorium, and other elements which are alpha-particle emitters.

Helium-generating potential of a material is a measure of its alpha emission activity. One gram of uranium may generate 1.16×10^{-7} ml of helium in 1 year.

Nearly all igneous rocks contain trace amounts of the uranium series. The acidic types are usually significantly more radioactive than those of the basic types. The helium-generating potential of sedimentary and metamorphic rocks appears to be dependent upon the rock type and its history rather than on the age or location of the sample. Comparative Specific Radiation Activity (SRA) values for the three classes of rocks are presented, with the calculated percentages of uranium in each sample.

The helium-generating potential of sedimentary rocks is a particular study: as a uranium-bearing granite is emplaced, cooled, uplifted, and eroded, for example, alpha particles are emitted at a constant rate. During transportation of the sands, silts, and shales, and deposition as sediments, these clastic grains continue to give off alpha particles which become helium atoms that are trapped in the rocks.

Helium cannot be trapped permanently in a geologic trap. Rather, the helium will diffuse out, or migrate out, over a period of geologic time. Helium must either be generated or migrate into a trap, be detained by the geometry of the rock and then either move out by migration or by diffusion. The helium that is produced is "in transit" through the rocks in the trap. A given trap has the ability to hold no more than 2% helium depending on the geometry of the rock, the pressures, and the helium holders associated with the trap.

[1688-1689]

GSA Annual Meetings, Washington, D.C. November 1-3, 1971

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Size of Quartz Grains in Mudrocks

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Seventeen mudrock samples ranging in age from Ordovician to Tertiary were collected from Oklahoma, New Mexico, and Arizona and were disaggregated using ultrasonic techniques. A combination of sieving (down to ten microns) and x-ray techniques were used to determine the size of distribution of quartz in the samples.

Percentages of quartz in the samples range from 15.1 to 46.7 and average 30.9 (σ=8.0). Mean grain size of detrital quartz ranges from 4.4ϕ to 6.3ϕ. Percentage of quartz and mean size of quartz in each sample are positively correlated; r=.59, which is significant at the 99

percent level. The best fit linear regression line is

$$\% \text{ qtz} = 78.09\text{-}9.06 \text{ mean qtz size } (\phi) \pm 6.49\% \ (\sigma).$$

Extrapolation of the regression line indicates that, on the average, detrital quartz is lacking in mudrocks in grain sizes finer than 8.6ϕ (2.5 microns), a result consistent with observations by clay mineralogists. Extrapolation to coarser sizes indicates that a medium grained sandstone (1.5ϕ) contains 64.5% quartz, which supports earlier estimates based on geochemical and petrographic data.

The average size distribution of quartz in the mudrocks is Gaussian, with a mean of 5.2ϕ (medium silt) and standard deviation of 1.0ϕ. The average sample contains 13.0% sand size quartz (σ=10.6%), 86.0% silt size quartz (σ=10.4%), and 1.0% clay size quartz.

Modes of the 17 size distributions range from 4.2ϕ to 6.2ϕ and average 5.2ϕ. This indicates that no deficiency of modes in the 4-5ϕ range exists in clastic rocks, despite published assertions to the contrary.

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Buried Basement Rocks of North America: Their Evidence for Continental Rifting and Drifting

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Distribution of Precambrian rock types, structural, and isotopic age provinces furnish limiting data on intracontinental lateral faulting as well as defining lines for pre-continental drift assemblies. Study of buried basement rocks from North America permits extension of the identifiable geologic and structural provinces of the Canadian Shield to the remainder of North America. These data show that lateral offsets of the structural boundaries throughout the continental interior are small but offsets along the Atlantic and Gulf of Mexico-Mexico boundaries are extensive.

The arcuation of orogenic trend lines for each of the major Precambrian structural provinces, by analogy with modern island arcs, indicate the sense of motion of continental drifting during these episodes. Spall's (1970) paleomagnetic data indicate that the amount of drift between each of the Precambrian structural eras was great and comparable in magnitude to the present cycle.

Keweenawan rifting (ca. 1.1-1.2 b.y.) opened a wedge from Lake Superior south to eastern Kansas that transects older structure but which changes in width and is offset along older features.

Large right-lateral offsets of the Grenville front, possibly associated with the Pan-African orogeny, are found across the Illinois-Kentucky-Rough Creek Fault zone, Wichita-Arbuckle trend, and Texas lineament.

The margin of the Gulf of Mexico is bounded by Paleozoic or older crustal boundaries. The Dietz and Holden (1970) reconstruction fits this interpretation.

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