THE UNIVERSITY OF TEXAS BULLETIN

No. 3501: January 1, 1935

QUARTER-CENTENNIAL MEMORIAL VOLUME OF THE DIVISION OF NATURAL RESOURCES

Division of Conservation and Development of the
Natural Resources of Texas

E. H. Sellards, Chairman

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Additional copies of this publication may be procured from the Bureau of Economic Geology, Bureau of Engineering Research, and Bureau of Industrial Chemistry, The University of Texas, Austin, Texas.

THE UNIVERSITY OF TEXAS PRESS

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PUBLISHED BY THE UNIVERSITY FOUR TIMES A MONTH AND ENTERED AS
SECOND-CLASS MATTER AT THE POSTOFFICE AT AUSTIN, TEXAS,
UNDER THE ACT OF AUGUST 24, 1912

The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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PREFACE

The Division of Natural Resources of The University of Texas, consisting of the Bureaus of Industrial Chemistry, Engineering Research, and Economic Geology, completed in 1934 a quarter of a century of service in the study of the State's mineral resources. In recognition of the services rendered the State by several pioneer geologists in Texas, by the first two directors of the Bureaus, Drs. Phillips and Udden, and by other staff members of the early years, the Division held on December 15, 1934, a Quarter-Centennial Celebration at which papers were given contributing to a knowledge of mineral resource development and related subjects in Texas.

This program, given jointly by the Division of Natural Resources and the Departments of Geology and Chemistry and the College of Engineering of the University, was as follows:

FORENOON SESSION

8:30 A.M.–9:30 A.M.—Reception and registration of visitors in the foyer of the Hogg Memorial Auditorium.

9:30 A.M.—Hogg Memorial Auditorium.

E. P. SCHOCH, Presiding

Welcoming address by President H. Y. Benedict.

W. B. Tuttle, President, San Antonio Public Service Company:
The Economic Aspects of Industrial Development in the State of Texas During the Past Twenty-five Years.

F. W. SIMONDS, Presiding

Alexander Deussen, Consulting Geologist, Houston, Texas:
Thirty-five Years of Progress in the Knowledge of the Geology of Texas.

E. P. SCHOCH, Presiding

A. M. McAfee, Chief Research Chemist, Gulf Refining Company:
The Aluminum Chloride (Alchlor) Process of Refining Petroleum, followed by a sound motion picture giving a review of the whole petroleum industry from production to distribution.

12:30 P.M.—Luncheon at the Union Building. Address by W. W. Scott, Chief Engineer, Production Department, Humble Oil and Refining Company: The Trend of Oil Production and Petroleum Engineering.

AFTERNOON SESSION

MEETINGS IN TWO SECTIONS

Section A—Chemistry and Engineering, Chemistry Building, Room 15.

2:00 P.M.—S. P. FINCH, Presiding

M. M. Leighton, State Geologist of Illinois:
Researches in Rock Wool Resources.
S. M. Udden, Vice-President, Central Power and Light Company, Corpus Christi
Electrical Development in Texas During the Past Twenty-five Years.
W. E. Simpson, President, W. E. Simpson Company, San Antonio:
Some Problems in Foundation Design, The Soil Laboratory as an Aid in Their Solution.
D. M. and L. V. Phillips, Producing and Refining Engineers, The Texas Company, Riverside and Port Arthur:
Production and Utilization of Texas Bleaching Clays.

Section B—Geology, Geology Building, Room 14.

2:00 P.M.—E. H. SELLARDS, Presiding

Wallace Lee, Geologist, United States Geological Survey, Washington, D.C.:
Stratigraphic Studies in the Cisco Group of the Pennsylvanian of North-central Texas.
F. M. Bullard, Studies in the Pennsylvanian of McCulloch County, Texas.

SYMPOSIUM ON MAJOR UNCONFORMITIES IN THE TEXAS GEOLOGIC SECTION.

2:45 P.M.—Pre-Cambrian Unconformities.
C. L. Baker, Pre-Cambrian Unconformities in the Trans-Pecos Region.
H. B. Stenzel, Pre-Cambrian Unconformities in the Llano Region.
3:25 P.M.—Paleozoic Unconformities—F. B. PLUMMER, Presiding.
M. B. Arick, Early Paleozoic Unconformities in Trans-Pecos Texas (Cambrian to Devonian Inclusive).
H. P. Bybee, The Geologic Section in the Big Lake Oil Field, Reagan County.
M. G. Cheney, Late Paleozoic Unconformities in North-central Texas.
E. W. Owen, Correlation of Type Wells in the Gulf Coastal Plain.[1]
G. E. Condra, The Nebraska Section.
A. S. Romer, Evidence from Vertebrate Fauna (written communication).
J. B. Carsey, Unconformities in the Humble White and Baker Deep Test, Pecos County, Texas.
The North Texas Geological Society, Major Unconformities in the Wichita Falls District of North-central Texas.
The Panhandle Geological Society, Major Unconformities in the Geologic Section of the Texas Panhandle.

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[1] Paper not given on account of the absence of the author

4:25 P.M.—Mesozoic Unconformities—J. T. LONSDALE, Presiding.
W. C. Spooner, Unconformities on Top of Comanche Cretaceous.[1]
F. L. Whitney, Unconformities at the Top of the Edwards Formation.
W. S. Adkins, Upper Cretaceous Unconformities in Texas.
5:00 P.M.—Cenozoic Unconformities—W. F. BOWMAN, Presiding.
A. R. Denison, The Geologic Section Encountered in Deep Drilling in Frio County.
M. A. Hanna, Cenozoic Unconformities in the Gulf Coast Region.

A meeting of the committee on coöperative geologic mapping was held immediately following the close of this program.

BANQUET

7:00–10:00 P.M.—Informal dinner at the Union Building, followed by a program as follows:
Dean T. U. Taylor: Tribute to a Pioneer in the Development of the Natural Resources of Texas.
Terrell Bartlett, Consulting Engineer, State Planning Board: Relation Between Geology and Engineering in Water Conservation.
M. M. Leighton, State Goelogist of Illinois, Chairman, National Research Council Committee on a Model State Geological Survey: A Model State Resource Survey.

The papers of this program that have been completed and submitted for publication are included in this volume. The papers not included have been omitted in accordance with the wishes of the authors. Five other papers, not listed in the program, have been added. The paper on "Stratigraphic studies in the Cisco group of the Pennsylvanian of north-central Texas," by Wallace Lee, which has not yet been completed, will be published subsequently. The paper on "Studies in the Pennsylvanian of McCulloch County, Texas," by F. M. Bullard, is published in a more complete form under the title "The Upper Pennsylvanian and Lower Permian Section of the Colorado River Valley, Texas," by F. M. Bullard and R. H. Cuyler. The substance of the communication by A. S. Romer is contained in a paper which he has prepared for later publication.

The University appreciates very much the generous assistance of these contributors which made this volume possible and thanks the many friends whose presence and participation added so much to the success of the Quarter-Centennial Celebration of this Division. To all of these, the University and the departments concerned express grateful acknowledgment.

E. H. SELLARDS, *Chairman*
Division of Natural Resources.

WILLIAM BATTLE PHILLIPS

William Battle Phillips came from a family rich in traditions of scholarship. According to The University of Texas Record, Vol. 11, No. 4, Dec., 1900, his father, the Rev. Charles Phillips, occupied for ten years each the chairs of Civil Engineering and of Mathematics in the University of North Carolina; while his grandfather, the Rev. James Phillips, was for over thirty years Professor of Mathematics in the same University.

Dr. Phillips was born at Chapel Hill, North Carolina, July 4, 1857. He was graduated from the University of North Carolina in 1877 and received his doctorate there in 1883. He studied also at the School of Mines at Freiburg, in Saxony, then the most famous mining school in the world. Positions held by him were as follows: Chemist, North Carolina Experiment Station, 1877–82, and of the Navasso Guano Company, 1882–85; professor of agricultural chemistry and mineralogy, University of North Carolina, 1886–88; mining engineer, Birmingham, Alabama, 1888–92; professor of chemistry and metallurgy, University of Alabama, 1891–93; chemist, Tennessee Coal, Iron, and Railway Company, 1894–98; staff of Engineering and Mining Journal, American Manufacturer and Iron World, 1893 and 1897–98; instructor in economic geology, University of Texas, 1900–05; director, University of Texas Mineral Survey, 1901–05; mining engineer, 1905–08; director, Bureau of Economic Geology and Technology, University of Texas, 1909–15; president, Colorado School of Mines, 1915–16. He died at Houston, Texas, June 8, 1918.

Dr. Phillips was the author of about 300 articles and books. He was a proficient mining engineer, chemist, geologist, mineralogist, metallurgist, and technologist. Some of his more notable accomplishments were the development of the Chisos quicksilver mine, his work on iron making in Alabama, on the utilization of lignite, coal, petroleum, and natural gas in Texas, and directing the Mineral Survey and the Bureau of Economic Geology and Technology of The University of Texas.

Dr. Phillips was memorable for sincerity and integrity, fearlessness and independence in mind and character, a widely-interested, versatile, well-stocked, and broadly-liberal mentality, untiring industry, thoroughness and earnestness of purpose. The very efficient utilization of these qualities enabled him to accomplish numerous important works in a relatively short and crowded lifetime occupied in doing well very many exacting and laborious tasks. Rudyard Kipling's poem "If," one of the finest tributes ever made to the great Washington, brings back to his friends William Battle Phillips; so does likewise Hamlet's appreciation of his friend Horatio:

> "for thou hast been
> As one, in suffering all, that suffers nothing;
> A man that fortune's buffets and rewards
> Hast ta'en with equal thanks: and blest are those
> Whose blood and judgement are so well commingled
> That they are not a pipe for fortune's finger
> To sound what stop she please."

QUARTER-CENTENNIAL MEMORIAL VOLUME OF THE DIVISION OF NATURAL RESOURCES

PAPERS GIVEN AT THE QUARTER-CENTENNIAL CELEBRATION, DECEMBER 15, 1934

SECTION I—GENERAL SESSION

A HISTORY OF THE DIVISION OF NATURAL RESOURCES

E. P. SCHOCH[1]

The need for a systematic enquiry into the natural resources of Texas had been felt by its citizens for many years and led to the establishment of the State Geological Survey, which under the able leadership of E. T. Dumble did a splendid piece of work during its short period of existence—1888 to 1892. The same feeling led The University of Texas Board of Regents to secure from the State Legislature a special appropriation for the establishment of a State Mineral Survey in 1901, to carry on essentially the work of the State Geological Survey. It was not a part of the University but merely placed under The University of Texas Board of Regents. An unusually able man, Dr. Wm. B. Phillips, was made director of this Survey. While the work of the Mineral Survey, like that of the State Geological Survey, was carried on in an unusually vigorous and capable manner, yet the time seemed not to be ripe for the continuous maintenance of such work, and in 1905 the Mineral Survey also had to discontinue its work because the State Legislature had failed to make an appropriation for it. However, the University Board of Regents, realizing keenly the need for this work and appreciating the extraordinary ability of Dr. Phillips, established within the University the Bureau of Economic Geology in 1909 with Dr. Phillips as director. In this connection the Board of Regents made the following statement:

> The action of the Board of Regents in providing means for the maintenance of such a Bureau marks an entirely new departure in educational work. No other institution of learning in the country has taken upon itself the duty of providing, at its own expense, an office to which anyone may apply for information of this character (*i.e.*, the mineral wealth of the State).

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[1] Director, Bureau of Industrial Chemistry of the Division of Natural Resources.

Issued February, 1936.

In the fall of 1910 the activity of this Bureau was enlarged by the addition of a testing laboratory with Mr. S. H. Worrell, B.S., in charge; and in the fall of 1911 its activity was further enlarged by the addition of Dr. J. A. Udden, who devoted himself primarily to geological problems. To indicate its enlarged activity, its name was changed in 1911 to "Bureau of Economic Geology and Technology." In the fall of 1914, when Dr. Phillips resigned to accept the presidency of the Colorado School of Mines, the personnel of the Bureau had increased to include the following beside the director:

J. A. Udden, Geologist
Charles L. Baker, Assistant Geologist
J. P. Nash, Testing Engineer
J. E. Stullken, Chemist
E. L. Porch, Assistant Chemist

The work of the Bureau was then directed along three distinct lines: geology, engineering, and chemistry, and thus it attempted to do the work usually done by (a) geological surveys, (b) engineering experiment stations, and (c) industrial chemistry laboratories. Since each of these three lines requires equally competent direction, it was decided, when Dr. Phillips resigned, to appoint three coördinate heads of these divisions, and to allow them to work independently, yet to keep them closely associated so that they might coöperate whenever it was deemed desirable. The heads of the divisions then appointed were:

J. A. Udden, Head of the Division of Economic Geology;
F. E. Giesecke, Head of the Division of Engineering; and
E. P. Schoch, Head of the Division of Chemistry.

The general title of "Bureau of Economic Geology and Technology" was retained with Dr. Udden as nominal director.

Since then, these three divisions have functioned with practically the same plan of organization, but in order to indicate more clearly the scope of the work and also the mutual relations of these divisions, the titles were changed in 1925. The aggregate was thereafter designated as the Division of the Conservation and Development of the Natural Resources of Texas, while the parts were named as follows:

(a) Bureau of Economic Geology;

(b) Engineering Experiment Station—changed in 1926 to Bureau of Engineering Research; and

(c) Industrial Chemistry Experiment Station—changed in 1927 to Bureau of Industrial Chemistry.

The chiefs of the three bureaus were designated as directors, who are independently responsible for the work done in their bureaus, while one of them is designated as chairman to preside at meetings of the three coördinate bureaus.

A history of this Division should not be closed without a word of acknowledgment of the work of its founder, Dr. Wm. B. Phillips, and also of its second director, Dr. J. A. Udden, both of whom have passed away.

It is no exaggeration to say that this Bureau would not have been started had it not been for the foresight and vision of Dr. Phillips and the vigor with which he pushed this work. All aspects of the work now pursued by the three bureaus were fully developed during the first few years during which he directed the work; his enthusiasm made a lasting impression not only on his co-workers but on everybody who ever came in contact with him; and it was largely this impression which has served to make this Division a permanent organization.

Dr. J. A. Udden's disposition and ability may be aptly described by the old maxim: "Still waters run deep." He was preëminently a scientist—more particularly a geologist. The great value of his geological studies is too well known to need further comment here, but justice demands that his great service in revealing potash in this part of the United States and much of the petroleum in west Texas be pointed out. Texas has been vastly enriched by Udden's work.

To close this history, we will present brief statements of the objects, personnel past and present, and publications of each of the three bureaus.

BUREAU OF ECONOMIC GEOLOGY

The Bureau of Economic Geology serves essentially the function of a State geologic survey. The staff includes trained geologists who devote their time to field work and the preparation of reports on this work, and to such geologic matters in the State as are of particular interest to the citizens. The results are given out through personal interview, correspondence, and publication. The time and attention of its staff are at the disposal of all persons who wish advice or information on subjects within the scope of the Bureau's work.

Geologists from the United States Geological Survey do field work in Texas, from time to time, in coöperation with the Bureau.

A laboratory is maintained for the examination of samples of all kinds sent in for identification. Particular attention is given to the careful examination of well samples from deep borings in all parts of Texas, and the data thus obtained are of great geologic and economic importance.

The Bureau has published a considerable number of bulletins embodying the results of investigations conducted by members of the staff. A complete list of these publications may be had on application.

A museum collection illustrating the rocks, minerals, and fossils of Texas is maintained in connection with the work of the Bureau. These are preserved in a fireproof building on the Little Campus of the University, a part of the collections being on exhibit, and the remainder in cases accessible for study.

The former and present members of the staff are as follows:

Former Members

J. A. Udden
E. L. Porch, Jr.
Emil Böse
J. W. Beede
J. R. Roberts
V. V. Waite
H. P. Bybee
C. E. Bowman
E. B. Stiles
D. D. Christner
W. S. Adkins
Mrs. Etta Mae Clark Nelson
R. A. Liddle
T. M. Prettyman
G. C. M. Engerrand
Hedwig Kniker
R. L. Cannon
Jack Frost
E. W. Brucks
E. M. Hawtof
Elisabeth Stiles
Joseph Hornberger, Jr.
Mrs. Lelia Lambert Clark

Present Members

E. H. Sellards
F. B. Plummer
C. L. Baker
H. B. Stenzel
J. T. Lonsdale
Gayle Scott
Mrs. Helen Jeanne Plummer
Josephine Casey

PUBLICATIONS OF BUREAU OF ECONOMIC GEOLOGY

A complete set of the publications of the Bureau of Economic Geology of The University of Texas cannot now be secured, all publications issued previous to 1914 and some later reports being out of print. The reports now available consist of the publications of the Bureau complete for the years 1914, 1915, and 1919 to 1934 inclusive. The entire set, 20 volumes cloth bound, includes 56 bulletins (93 papers).

Following is a list by years, bulletin numbers, and titles of these publications. The bulletins are bound in order as issued, each bulletin being separately paged and indexed. As a rule there is one volume of bulletins per year. However, the bulletins of 1919, 1927, 1930, and 1932 are bound in two volumes each per year and the bulletins of 1924 and 1925 are combined as one volume for the two years.

Year	*No.*	*Title of Bulletin (abbreviated) and Author*
1914	365	Mineral resources of Texas. Wm. B. Phillips
1915	17	Potash in the Texas Permian. J. A. Udden
	57	The northern Llano Estacado. C. L. Baker
1919	1902	On a new Exogyra from the Del Rio clay. Emil Böse
	1931	Tarrant County. W. M. Winton and W. S. Adkins
	1932	Bexar County. E. H. Sellards
1919	1945	Fredericksburg and Washita formations. W. S. Adkins and W. M. Winton
1921	2132	Pennsylvanian formations of north-central Texas. Plummer and Moore
1922	2229	Johnson County. W. M. Winton and Gayle Scott
	2230	Webb and Zapata counties; and Austin formation in Bexar, Atascosa, and Medina counties. E. H. Sellards
	2232	Well records of Panola County. E. H. Sellards
	2234	Texas alkali lakes. Meigs, Basset, and Slaughter
	2239	The Rios well in Caldwell County. E. H. Sellards
1923	2327	Oklahoma-Texas boundary suit. Sellards, Tharp, and Hill
	2330	Potter County. L. T. Patton
	2333	Colorado County. T. L. Bailey
	2340	McLennan County. W. S. Adkins
	2346	University Block 46 in Culberson County. J. W. Beede
1924–25	2433	The genus Schwagerina. J. W. Beede and Hedwig T. Kniker
	2509	Etched potholes. J. A. Udden
	2539	The Lytton Springs oil field. H. P. Bybee and R. T. Short
	2544	Denton County. W. M. Winton
1926	2607	San Angelo formation; and Foard County. Beede and Christner
	2609	The Southwest earthquake of 1925. J. A. Udden
	2612	Foraminifera of the Cretaceous. Dorothy Ogden Carsey
	2644	Foraminifera of the Midway formation. Helen Jeanne Plummer
	2645	The Gueydan formation. T. L. Bailey
	363	Deep boring at Spur (reprinted). J. A. Udden

1927	2703	The Bend and Ellenburger limestones. J. A. Udden and V. V. Waite
	2710	Cooke County. H. P. Bybee, F. M. Bullard, and E. M. Hawtof
	2738	Fort Stockton quadrangle. W. S. Adkins
	2744	Igneous rocks of the Balcones fault region. J. T. Lonsdale
	2745	Southwestern Trans-Pecos Texas. C. L. Baker
1927	2748	Rio Grande Valley and northern Mexico. Emil Böse and O. A. Cavins
1928	2801	Contributions to Geology, 1928 (contains six papers)
	2807	Tom Green County. G. G. Henderson
	2838	Handbook of Texas Cretaceous fossils. W. S. Adkins
1929	2901	Contributions to Geology, 1929 (contains nine papers)
	2907	Ostracoda of the Cretaceous. C. I. Alexander
	2913	North-central Texas. M. G. Cheney
1930	3001	Contributions to Geology, 1930 (contains eight papers)
	3016	Bell County. W. S. Adkins and M. B. Arick
	3019	Foraminifera in the Brownwood shale. Helen Jeanne Plummer. Foraminifera of the Cisco group. J. A. Cushman and J. A. Waters
	3027	Stonewall County. L. T. Patton
1930	3038	The Glass Mountains, Part 1, Descriptive geology. P. B. King.
	3042	The Glass Mountains, Part 2, Faunal summary. R. E. King
1931	3101	Contributions to Geology, 1931 (contains six papers)
	3125	Grayson County. F. M. Bullard
	3138	Woodbine sand of northeast Texas. F. B. Plummer and E. C. Sargent
1932	3201	Contributions to Geology, 1932 (contains ten papers)
	3211	Some Texas Fusulinidae. M. P. White
	3224	Wise County. Gayle Scott and J. M. Armstrong
	3231	Hemphill County. L. C. Reed and O. M. Longnecker, Jr.
1932	3232	Geology of Texas, Vol. I, Stratigraphy. Sellards, Adkins, and Plummer
1933	3301	Midway group of Texas. Julia Gardner
1934	3401	Geology of Texas, Vol. II, Structural and economic geology. Sellards, Baker, and others.

BUREAU OF INDUSTRIAL CHEMISTRY

The purpose of the Bureau of Industrial Chemistry is to give advice concerning Texas raw products. First and most important among these is water used for industrial purposes; this Bureau examines water samples, free of charge, for the purpose of advising people whether or not it is suitable for household use, irrigation or boiler use, and how to treat it to improve its usability. In years past, much attention was given to lignite, but there is no call for such work today.

This laboratory has recently equipped itself to examine crude petroleum and its products and is now doing the work on oil and gas for the State Railroad Commission. Clays are tested by standard methods to determine their suitability for brick tile and crockery. In general, mineral products are examined with the view of determining their commercial usability, and to give advice concerning economic and technical questions involved in their commercial use. However, the mere making of analyses for private parties is not done, and in any case the work done is limited to the development of natural resources.

The following officials are, or have been, connected with the Bureau of Industrial Chemistry:

F. W. Jessen, Assistant Chemist (1928–1930)
David McKnight, Jr., Ceramic Engineer and Secretary (1930–)
R. A. McNees, Chemist (1919–1920)
E. L. Porch, Assistant Chemist (1914–1916)
A. D. Potter, Ceramic Engineer and Secretary (1920–1930)
W. T. Reed, Chemist (1916–1918)
E. P. Schoch, Director (1915–)
J. E. Stullken, Chemist (1913–)
S. H. Worrell, Chemist (1910–1913)

PUBLICATIONS OF THE BUREAU OF INDUSTRIAL CHEMISTRY

Ozokerite from the Thrall Oil Field, E. P. Schoch: Ind. and Eng. Chem., *8*. 1095.

Boiler Waters: Their Chemical Composition, Use and Treatment, W. T. Read: University Bulletin 1752, 1917.

Chemical Analyses of Texas Rocks and Minerals, E. P. Schoch: University Bulletin 1814, 1918.

Manual for Works Operators in Water Purification and Sewage Disposal Plants, E. P. Schoch: University Bulletin 3014, 1930.

Direct Titrometric Methods for Magnesium, Calcium and Sulfate Ions in Water Analysis, E. P. Schoch: Ind. and Eng. Chem., *19*, 112.

Minable Deposits of Potash Minerals in Midland County, Texas, E. P. Schoch and E. H. Sellards: Ind. Eng. Chem. (News Ed.), *5*, No. 21.

Core Drill Tests for Potash in Midland County, Texas, E. H. Sellards and E. P. Schoch: University Bulletin 2801, pp. 159–201, 1928.

The Clays and the Ceramic Industries of Texas, A. D. Potter and David McKnight, Jr.: University Bulletin 3120. 1931.

BUREAU OF ENGINEERING RESEARCH

The functions of this Bureau are to carry on research in the various branches of engineering; to aid members of the Faculty of the College of Engineering to conduct research; to coöperate with engineers, architects, contractors, and manufacturers throughout the State in the solution of technical problems arising in their work; and to stimulate and develop an interest in engineering research in the minds of engineering students.

The following officials have been, or are, connected with the Bureau of Engineering Research:

F. E. Giesecke, Director (1915–1924; 1926–1927)
T. U. Taylor, Director ex officio (1924–1926)
S. P. Finch, Director (1927–   )
R. G. Tyler, Research Associate (1917–1920)
J. P. Nash, Testing Engineer (1914–1918)
H. R. Thomas, Testing Engineer (1919–1928)
R. F. Dawson, Testing Engineer (1928–   )
G. A. Parkinson, Assistant Testing Engineer (1915–   )
J. Knudsen, Headlight Engineer (1926–1927)
L. L. Antes, Headlight Engineer (1927–1929)
J. P. Woods, Headlight Engineer (1929–1934)

BULLETINS ISSUED BY THE BUREAU OF ENGINEERING RESEARCH

Bulletin
No.

62 November 5, 1915: J. P. Nash, Road materials of Texas.
1725 May 1, 1917: J. P. Nash, Texas Granites.
1733 June 10, 1917: R. G. Tyler, Editor, Papers on Water Supply and Sanitation.
1735 June 20, 1917: R. G. Tyler, Editor, Papers on Roads and Pavements.
1759 October 20, 1917: F. E. Giesecke, The Friction of Water in Pipes and Fittings.
1771 December 20, 1917: J. P. Nash, Tests of Concrete Aggregates Used in Texas.
1815 March 10, 1918: F. E. Giesecke and S. P. Finch, Physical Properties of Dense Concrete as Determined by the Relative Quantity of Cement.
1839 July 10, 1918: J. P. Nash, coöperation with C. L. Baker, E. L. Porch, and R. G. Tyler, Road Building Materials in Texas.
1855 October 1, 1918: F. E. Giesecke, H. R. Thomas, and G. A. Parkinson, The Strength of Fine-Aggregate Concrete.
1922 April 15, 1919: R. G. Tyler, Papers on Pavements Presented at Engineering Short Course.
2215 April 15, 1922: F. E. Giesecke, H. R. Thomas, and G. A. Parkinson, Progress Report of the Engineering Research Division of the Bureau of Economic Geology and Technology.
2712 March 22, 1927: F. E. Giesecke, C. P. Reming, and J. W. Knudsen, The Friction of Water in Elbows.
2730 August 8, 1927: F. E. Giesecke, H. R. Thomas, and G. A. Parkinson, Effect of Various Salts in the Mixing Water on the Compressive Strength of Mortars.
2813 April 1, 1928: C. R. Granberry, Testing of Motor Vehicle Headlighting Devices and Investigation of Certain Phases of the Headlight Glare Problem.

2814 April 8, 1928: H. R. Thomas and G. A. Parkinson, Effect of Physical Properties of Stone Used as Coarse Aggregate on the Wear and Compressive Strength of Concrete.

2825 July 1, 1928: G. A. Parkinson, S. P. Finch, and J. E. Hoff, Preliminary Report on Relation between Strength of Portland Cement Mortar and Its Temperature at Time of Test.

2922 June 8, 1929: J. A. Focht, A Study of Test Cylinders and Cores Taken from Concrete Roads in Texas during 1928.

3134 April 8, 1931: J. P. Woods, A Method of Calculating the Performance of Vacuum Tube Circuits Used for the Plate Detection of Radio Signals.

3128 July 22, 1931: B. E. Short and M. M. Heller, Heat Exchange in a Commercial Heat Exchanger.

ECONOMIC ASPECTS OF INDUSTRIAL DEVELOPMENT IN THE STATE OF TEXAS DURING THE PAST TWENTY-FIVE YEARS

W. B. TUTTLE[1]

I have lived in Texas more than a quarter of a century, and during that period I have seen great changes in the business activities and financial resources of the people of the State.

My first visit to Texas was as a constructing engineer, and it was necessary for me, in the construction work in which I was engaged, to look in some detail into the manufacturing facilities which then existed. At the same time, due to the fact that I had been raised in a rural community, I was greatly interested in the ranching and agricultural conditions which then existed, and I spent some time in traveling around the State and in seeing these conditions.

As an example of the manufacturing facilities which then existed, it might be interesting to know that I had to go from San Antonio to Beaumont to find a place where heavy steel tanks could be constructed. And the facilities at Beaumont existed only because of the early developments of the Beaumont oil field, which called for the fabrication of heavy metal tanks.

This does not mean that the machine shops and little factories of the State were behind the times. They were not—and such work as they were equipped to do was very efficiently performed—but the manufacturing industry had not yet called upon men for many forms of construction work. Engineering work in the State was a good deal in its infancy. Commonly when people spoke of engineers they meant surveyors, and while there were some very good civil engineers in the State, there was very little opportunity for men in any specialized line of engineering to make a living; and even as late as the time of the opening of the Rice Institute at Houston, I recollect that I was designated as representative of the American Society of Mechanical Engineers to attend this celebration, largely, I believe, because there were no other members of the Society in the southern part of Texas.

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[1] Chairman of Board, San Antonio Public Service Company, San Antonio, Texas.

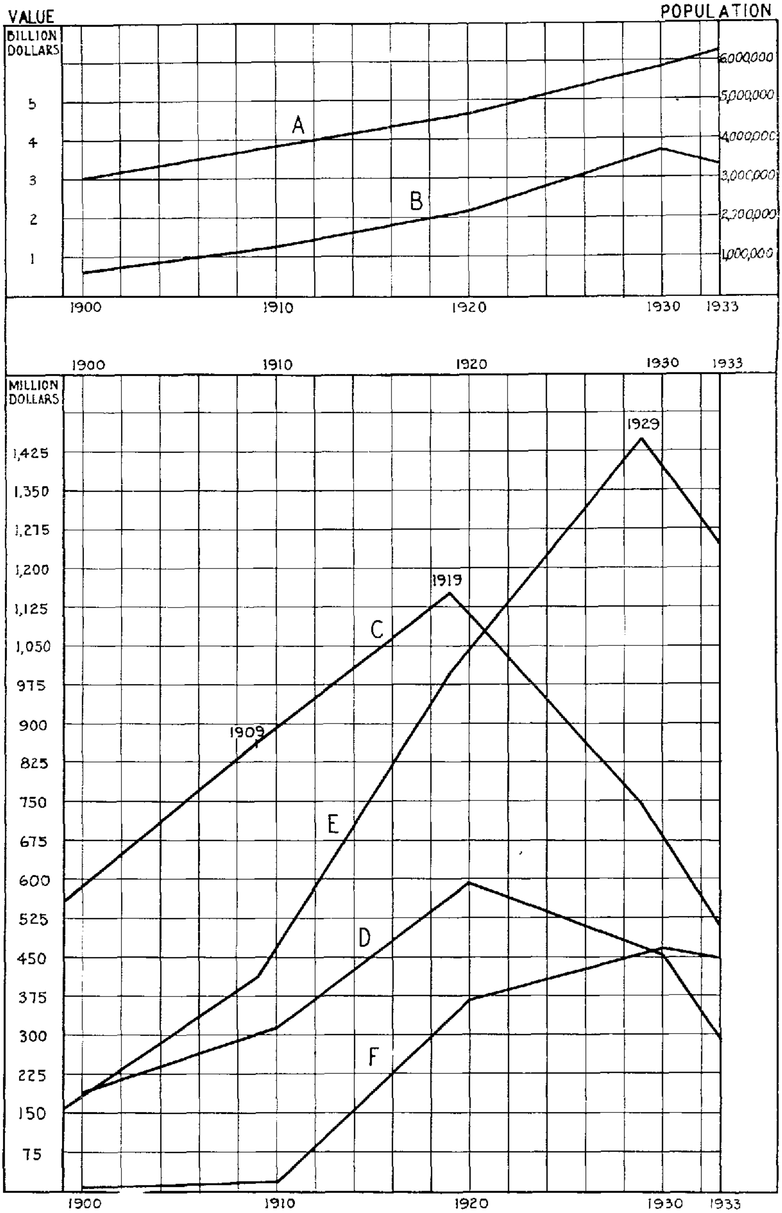

Fig. 1. Graphic representation of statistical data for Texas, 1900 to 1933, as follows: A, population; B, effective purchasing power; C, value of crops and livestock products; D, value of livestock on farms and ranches; and E. value of manufactured products.

The subject assigned me for this talk is "Economic Aspects of Industrial Development in the State of Texas During the Past Twenty-five Years."

In assembling the data to present this subject, we found that since it was necessary to use census statistics which had been taken in ten-year periods, it was desirable to treat the entire period from 1900 to 1933 inclusive.

In order to set out more easily the data which have been assembled, several charts have been prepared. Chart I (fig. 1), the first of these, covers conditions over the entire State of Texas for the period hereinbefore mentioned. Curve A on this chart shows the increase in population from about 3,100,000 in 1900 to approximately 6,300,000 in 1933. It will be noted that through the entire period there has been a steady increase in population.

Curve B on this chart shows the effective purchasing power for the same period, ranging from approximately $700,000,000 in 1900 to a maximum of $3,700,000,000 in 1930 and dropping back to $3,400,000,000 in 1933. This comparison is of interest because it shows that, while there has been a considerable drop in the purchasing power of the population, there is still an enormous purchasing power in the State even under the recent depressed business conditions, this purchasing power actually being more than 50 per cent greater now than it was in 1920, when business conditions were supposed to be fairly favorable. This fact warrants the conclusion that in spite of bad business conditions there is an inherent reserve strength in this State which will surely lead to an ultimate recovery.

Passing now to Curve C, which shows the value of crops and livestock products, we find a constant upward trend from a total of $555,000,000 in 1899 to a peak of $1,152,000,000 in 1919, with a decline back to $745,000,000 in 1929, and a sharper drop back to $510,000,000 in 1933.

In like manner Curve D, which shows the value of livestock on the farms and ranches, indicates a total of $190,000,000 in 1900, with an upward trend to $320,000,000 in 1910, a sharper rise to $590,000,000 in 1920, a drop to $450,000,000 in 1930, and a sharp drop to $290,000,000 in 1933.

Comparing these two curves, it will be seen that they are quite similar, except that the livestock curve, which really represents potential wealth rather than income, does not lead to quite as low a level as the crops and livestock products curve. Now it will be noted that through the entire period of time, from 1920 down to 1930, there was a continued decrease in the value of crops, livestock products, and livestock on the range. At the same time, it will be seen that there was a steady increase in purchasing power. Something was manifestly responsible for the increase in purchasing power, and this something was the manufacturing industry and the development of minerals and other resources.

If we turn to Curve E, which shows the value of manufactured products, we find that beginning in 1899 with a value of $155,000,000, there is a steady increase up to $415,000,000 in 1909, and then a sharp increase to $1,000,000,000 in 1919, when the value of manufactured products almost reached the value of crops and livestock products. And while the value of crops and livestock products was falling through the next ten years, there was a still further increase, so that in 1929 the value of manufactured products had reached a total of $1,450,000,000. From 1929 to 1933 there is a sharp decline to $1,250,000,000, but the value of manufactured products is still more than twice as great as the value of crops and livestock products.

The increase in purchasing power was also made possible by the development of minerals and other resources, as shown by Curve F. This was not a material factor until 1910, when the total was about $20,000,000. This source of wealth, however, increased to a total of $370,000,000 in 1920, and still further increased, as agricultural and livestock products went down, to a total of $470,000,000 in 1930, with a decrease to $450,000,000 in 1933.

From a study of these curves, it is apparent that while two components, crops and livestock products and mineral resources, are important, the most important place at this time in this State is held by industry which produces and distributes manufactured goods.

A further demonstration of the relative importance of industrial development may be found in a comparison of the statistics from various sections of the State. For the purpose of this comparison the State has been divided into five areas, which have been designated by the name of the principal city in each area. The boundaries of these areas have been fixed so as to embrace what may be called the trade territory of these principal cities, and this in turn has been determined in some measure by the physical characteristics of the territory and in some measure by the rail transportation facilities available. Some question may be raised as to the correctness of this subdivision of the State, but inasmuch as a change in the boundary lines would affect mainly the agricultural and livestock statistics in more or less thinly settled territory, the exact location of the boundaries is not of great importance. Chart 2 (fig. 2), the map of Texas, shows these boundaries graphically.

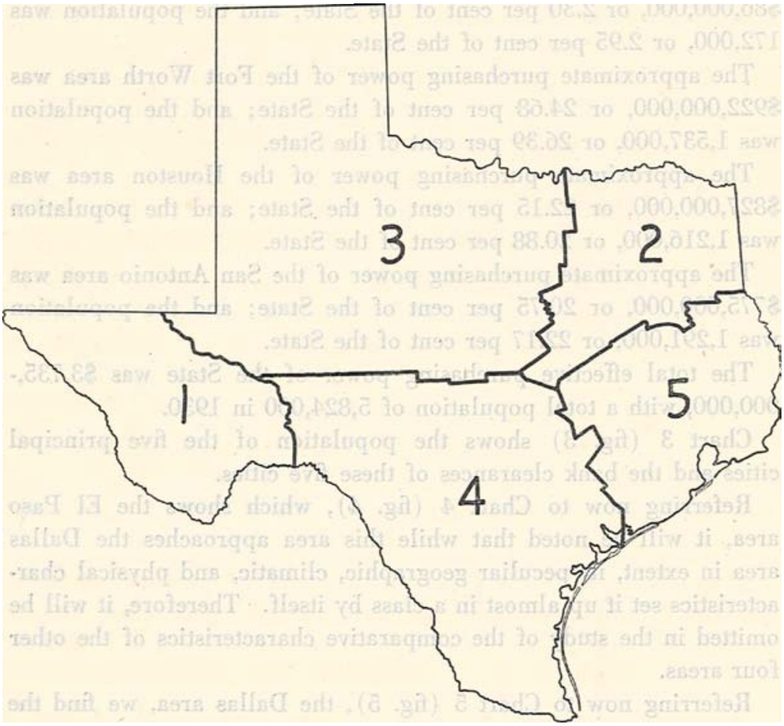

Fig. 2. Subdivision of Texas, for purpose of presenting statistical data, into five areas designated according to the principal city in each area as follows: 1, El Paso area; 2, Dallas area; 3, Fort Worth area; 4, San Antonio area; and 5. Houston area.

The Dallas area embraces 28,770 square miles, the El Paso area 30,891 square miles, the Fort Worth area 101,436 square miles, the Houston area 31,673 square miles, and the San Antonio area 69,628 square miles. The total trade area of the State of Texas approximates 262,000 square miles. Stated in percentages, the relative areas are as follows: Dallas area, 10.1; El Paso area, 11.7; Fort Worth area, 38.6; Houston area, 12.1; and San Antonio area, 27.5.

The effective purchasing power and the population of these areas are not at all in proportion to their relative sizes. The purchasing power of the Dallas area in 1930 was approximately $1,125,000,000, or 30.12 per cent of the State. The population was 1,608,000, or 27.61 per cent of the total State.

The approximate purchasing power of the El Paso area was $86,000,000, or 2.30 per cent of the State; and the population was 172,000, or 2.95 per cent of the State.

The approximate purchasing power of the Fort Worth area was $922,000,000, or 24.68 per cent of the State; and the population was 1,537,000, or 26.39 per cent of the State.

The approximate purchasing power of the Houston area was $827,000,000, or 22.15 per cent of the State; and the population was 1,216,000, or 20.88 per cent of the State.

The approximate purchasing power of the San Antonio area was $775,000,000, or 20.75 per cent of the State; and the population was 1,291,000, or 22.17 per cent of the State.

The total effective purchasing power of the State was $3,735,000,000, with a total population of 5,824,000 in 1930.

Chart 3 (fig. 3) shows the population of the five principal cities and the bank clearances of these five cities.

Referring now to Chart 4 (fig. 4), which shows the El Paso area, it will be noted that while this area approaches the Dallas area in extent, its peculiar geographic, climatic, and physical characteristics set it up almost in a class by itself. Therefore, it will be omitted in the study of the comparative characteristics of the other four areas.

Referring now to Chart 5 (fig. 5), the Dallas area, we find the same general characteristics which existed throughout the entire State; that is, a gradual increase in the value of crops and livestock products from approximately $200,000,000 in 1900 to a little more than $370,000,000 in 1919, with a sharp decline to approximately

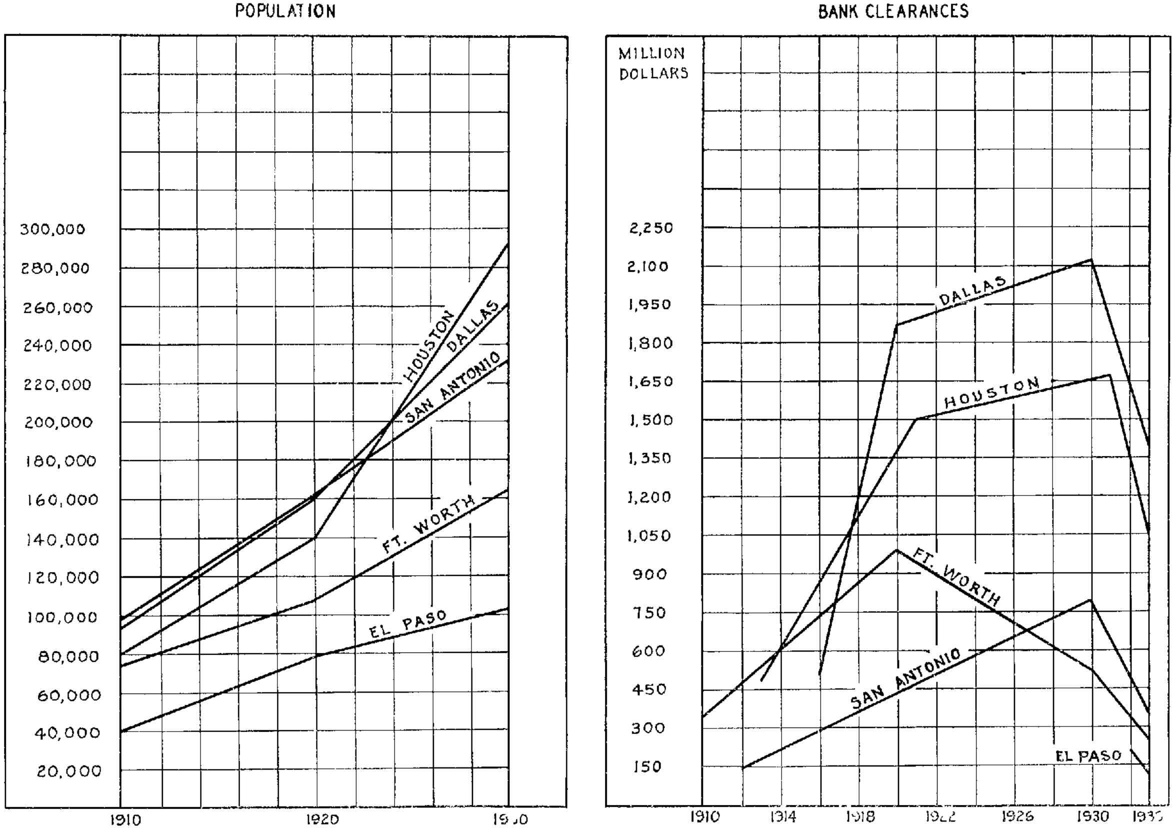

Fig. 3. Graphic representation of the population and of bank clearances, 1900 to 1933, of five principal cities of Texas.

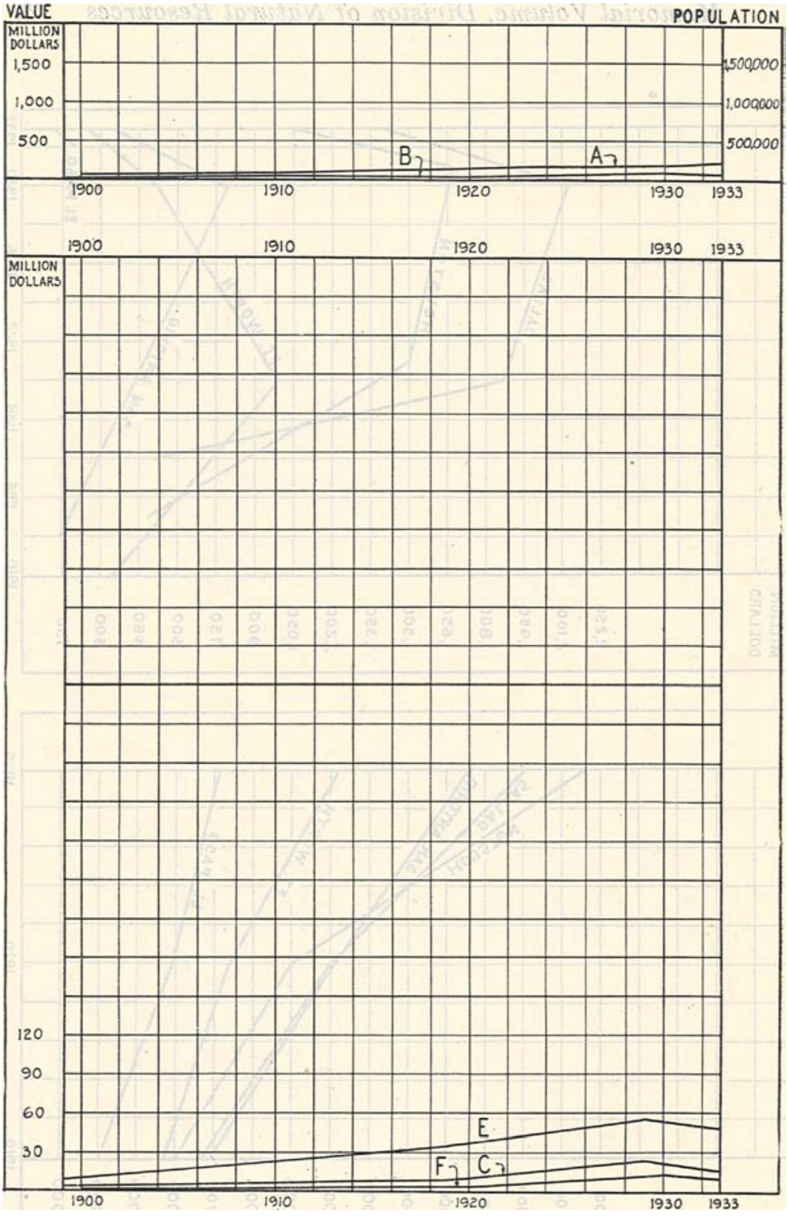

Fig. 4. Graphic representation of statistical data for the El Paso area, 1900 to 1933, as follows: A, population; B, effective purchasing power; C, value of crops and livestock products; E, value of manufactured products; F, value of mineral and other resources. This area includes 30,891 square miles.

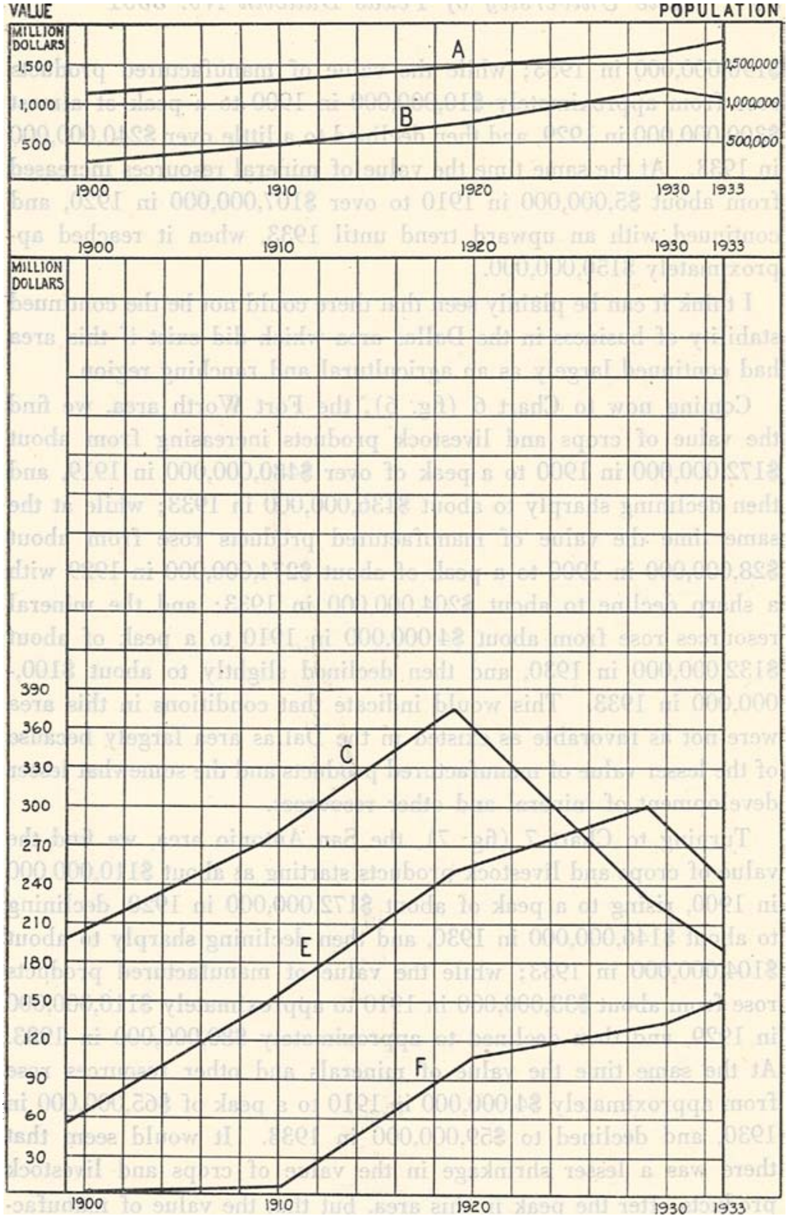

Fig. 5. Graphic representation of statistical data for the Dallas area. 1900 to 1933, as follows: A, population; B, effective purchasing power; C, value of crops and livestock products; E, value of manufactured products; F, value of mineral and other resources. This area includes 28,770 square miles.

$190,000,000 in 1933; while the value of manufactured products rose from approximately $10,000,000 in 1900 to a peak of almost $300,000,000 in 1929, and then declined to a little over $240,000,000 in 1933. At the same time the value of mineral resources increased from about $5,000,000 in 1910 to over $107,000,000 in 1920, and continued with an upward trend until 1933, when it reached approximately $150,000,000.

I think it can be plainly seen that there could not be the continued stability of business in the Dallas area which did exist if this area had continued largely as an agricultural and ranching region.

Coming now to Chart 6 (fig. 6), the Fort Worth area, we find the value of crops and livestock products increasing from about $172,000,000 in 1900 to a peak of over $480,000,000 in 1919, and then declining sharply to about $136,000,000 in 1933; while at the same time the value of manufactured products rose from about $28,000,000 in 1900 to a peak of about $274,000,000 in 1929 with a sharp decline to about $204,000,000 in 1933; and the mineral resources rose from about $4,000,000 in 1910 to a peak of about $132,000,000 in 1930, and then declined slightly to about $100,000,000 in 1933. This would indicate that conditions in this area were not as favorable as existed in the Dallas area largely because of the lesser value of manufactured products and the somewhat lesser development of mineral and other resources.

Turning to Chart 7 (fig. 7), the San Antonio area, we find the value of crops and livestock products starting at about $110,000,000 in 1900, rising to a peak of about $172,000,000 in 1920, declining to about $146,000,000 in 1930, and then declining sharply to about $104,000,000 in 1933; while the value of manufactured products rose from about $33,000,000 in 1910 to approximately $110,000,000 in 1929. and then declined to approximately $80,000,000 in 1933. At the same time the value of minerals and other resources rose from approximately $4,000,000 in 1910 to a peak of $65,000,000 in 1930, and declined to $59,000,000 in 1933. It would seem that there was a lesser shrinkage in the value of crops and livestock products after the peak in this area, but that the value of manufactured products, while increasing throughout a greater part of the period, is in no way equal to that of either the Dallas or the Fort Worth areas.

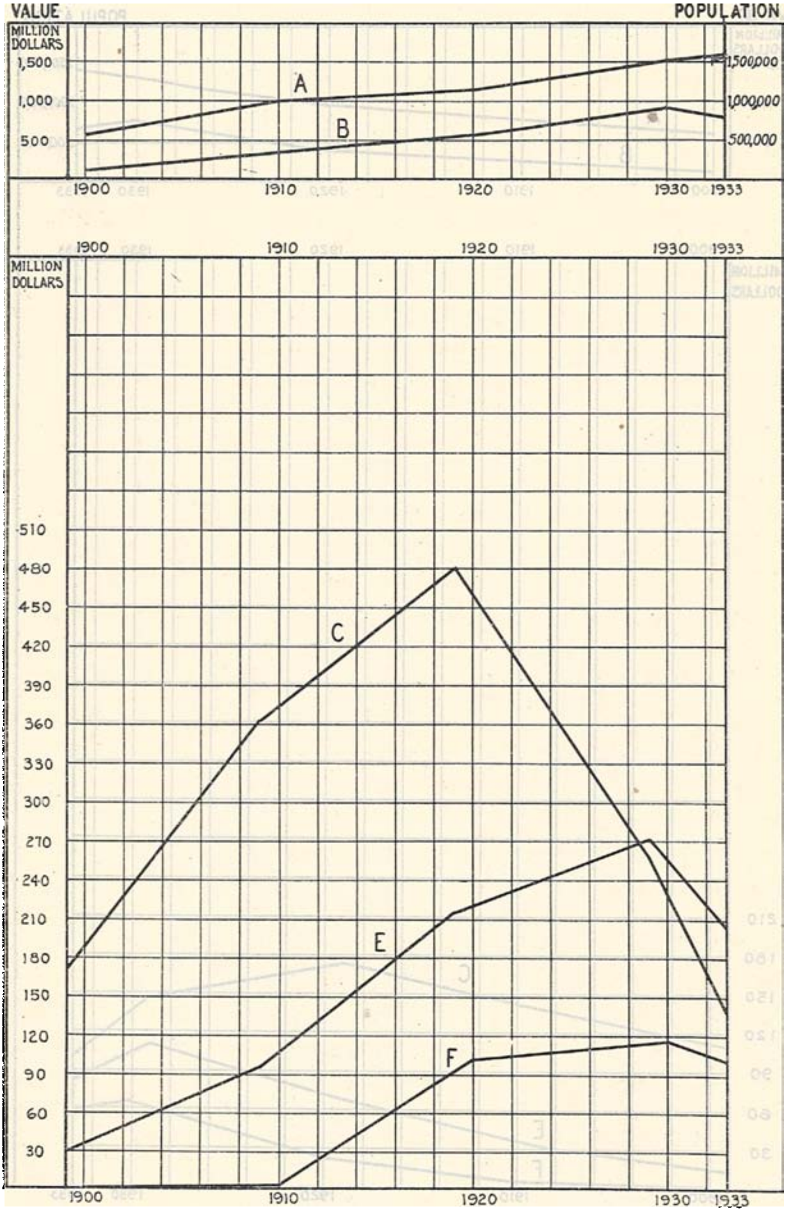

Fig. 6. Graphic representation of statistical data for the Fort Worth area, 1900 to 1933, as follows: A, population; B, effective purchasing power; C, value of crops and livestock products; E, value of manufactured products; F, value of mineral and other resources. This area includes 101,436 square miles.

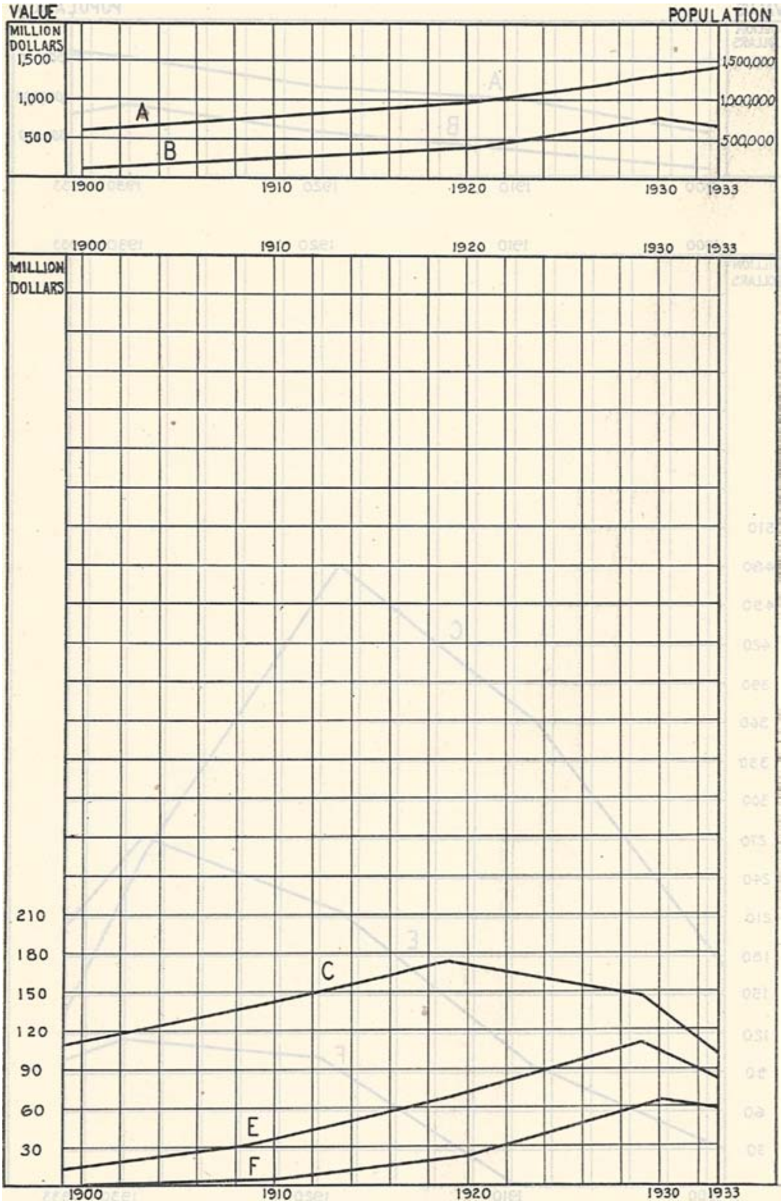

Fig. 7. Graphic representation of statistical data for the San Antonio area, 1900 to 1933, as follows: A, population; B, effective purchasing power; C, value of crops and livestock products; E, value of manufactured products; F, value of mineral and other resources. This area includes 69,628 square miles.

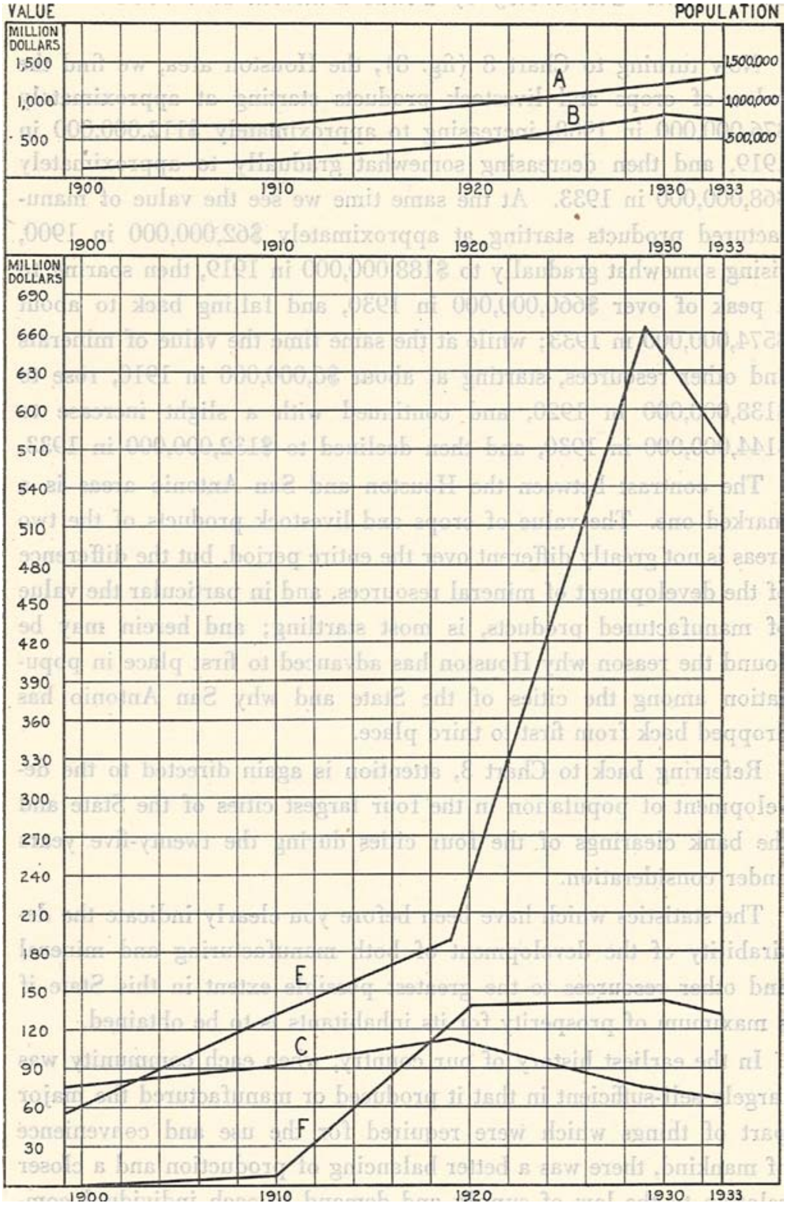

Fig. 8. Graphic representation of statistical data for the Houston area, 1900 to 1933, as follows: A, population; B, effective purchasing power; C, value of crops and livestock products; E, value of manufactured products; F, value of mineral and other resources. This area includes 31,673 square miles.

Now turning to Chart 8 (fig. 8), the Houston area, we find the value of crops and livestock products starting at approximately $76,000,000 in 1900, increasing to approximately $112,000,000 in 1919, and then decreasing somewhat gradually to approximately $68,000,000 in 1933. At the same time we see the value of manufactured products starting at approximately $62,000,000 in 1900, rising somewhat gradually to $188,000,000 in 1919, then soaring to a peak of over $660,000,000 in 1930, and falling back to about $574,000,000 in 1933; while at the same time the value of minerals and other resources, starting at about $6,000,000 in 1910, rose to $138,000,000 in 1920, and continued with a slight increase to $144,000,000 in 1930, and then declined to $132,000,000 in 1933.

The contrast between the Houston and San Antonio areas is a marked one. The value of crops and livestock products of the two areas is not greatly different over the entire period, but the difference of the development of mineral resources, and in particular the value of manufactured products, is most startling; and herein may be found the reason why Houston has advanced to first place in population among the cities of the State and why San Antonio has dropped back from first to third place.

Referring back to Chart 3, attention is again directed to the development of population in the four largest cities of the State and the bank clearings of the four cities during the twenty-five years under consideration.

The statistics which have been before you clearly indicate the desirability of the development of both manufacturing and mineral and other resources to the greatest possible extent in this State if a maximum of prosperity for its inhabitants is to be obtained.

In the earliest history of our country, when each community was largely self-sufficient in that it produced or manufactured the major part of things which were required for the use and convenience of mankind, there was a better balancing of production and a closer relation to the law of supply and demand to each individual community. At a later period, when there was a tremendous concentration of agriculture and livestock products in some sections and a tremendous concentration of manufacturing and the development of resources in other sections, the action of the law of supply and demand was not so obvious, particularly as to agriculture, and some of our present financial and business difficulties can be attributed to this fact.

It may be that a regional readjustment of the relation between agriculture and manufacturing and the development of mineral and other resources throughout the country would lead to a sounder and more satisfactory economic condition.

THIRTY-FIVE YEARS OF PROGRESS IN THE KNOWLEDGE OF THE GEOLOGY OF TEXAS

ALEXANDER DEUSSEN[1]

INTRODUCTION

On the occasion of the Quarter-Centennial Celebration of the founding of the Bureau of Economic Geology of The University of Texas, it seems appropriate to review the progress in the knowledge of the geology of Texas since the turn of the century. This is the period of the greatest advance in this knowledge. In no other previous one in the history of the State has there been recorded the same degree of advancement. In this interval, oil became the dominant industry of the State, replacing in this respect the cotton industry in the decades before the eighties and the cattle industry in the decades of the eighties and nineties.

It is often stated, and the geologist is prone to further the delusion, that the oil industry is indebted for its great progress during the past thirty-five years to the aid which the geologist has been able to render, but on this occasion I wish to acknowledge the debt which geology owes to the oil industry and to the oil driller. Much of the remarkable progress that has been achieved during this interval has been made possible by the activity of the driller. The drill has been the means of uncovering facts that without it may never have been uncovered, or at least facts, the discovery of which might not otherwise have been made until sometime far distant in the future.

The story of geologic progress in Texas is largely the story of oil since the discovery at Spindletop in 1901. It has been the information disclosed by the drill during this period which has contributed to the remarkable advance in the geologic knowledge of the State, the salient features of which I propose briefly to review on this occasion.

STATE OF KNOWLEDGE PRIOR TO 1900

When the task of preparing this paper confronted me, it became necessary to visualize the state of knowledge of the geology of

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[1] Consulting Geologist, Houston, Texas.

Texas prior to the Spindletop discovery. When one reflects on the state of this knowledge in 1900 one is at once profoundly impressed with its paucity, as compared with the present state. We had, of course, the contributions made by the early explorers, such as William Kennedy,[2] and by the early geologists of Texas, Dr. Ferdinand Roemer and the Shumards, aided by the contributions of the geologists associated with the military explorations, boundary and railroad surveys of the earlier days, such as Captain Marcy, Pope and others.[3]

These pioneers gained some idea of the geology of the State, but in the main this picture was dim and very meager. They recognized the presence of Cretaceous and Tertiary rocks in Texas and attempted a subdivision into formations of these rock groups, but, as it developed later, their studies, while extremely valuable, proved in a number of respects to be erroneous.

GEOLOGICAL SURVEY OF TEXAS, 1888–1892, UNDER E. T. DUMBLE

Prior to the time covered by this review, the greatest advance in the knowledge of the geology of the State was that contributed by the Geological Survey of Texas, established under the leadership of E. T. Dumble, in 1889.

Dumble brought to Texas and to the study of the geological problems of the State at that time a number of enthusiastic and brilliant young scientists, who in their later careers distinguished themselves as outstanding investigators and scholars, amongst them R. T. Hill, R. A. F. Penrose, Jr., G. D. Harris, Wm. Kennedy, W. F. Cummins, J. A. Taff, Ralph Tarr, and others. It would be difficult to name another group of men in the United States either then or since whose attainments in the field of geology have exceeded those of this particular and distinguished group.

With the aid of these enthusiastic investigators, Dumble made important contributions to the knowledge of the geology of the State, during the four short years of the life of this Survey. The

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[2] Not the William Kennedy connected with the Geological Survey of Texas from 1888 to 1892.

[3] The state of knowledge of the geology of Texas in 1887 is accurately summarized in the paper by R. T. Hill on "The Present Condition of Knowledge of the Geology of Texas," Bulletin 45, U. S. Geological Survey, 1887. Hill reviews carefully the history of the surveys and explorations prior to 1887, gives the list of publications resulting from these surveys and outlines the state of knowledge of the geology of Texas as of 1887.

studies established the surface distribution of the main rock groups—Tertiary, Cretaceous, Pennsylvanian, and the earlier Paleozoics. The main subdivisions of some of these rock groups were established, many of them valid at this date. The geologic features of the Staked Plains and some of the features of the Trans-Pecos country and the Central Mineral region of Llano and Burnet counties were developed. Likewise, at that time some considerable information was gained concerning the mineral resources of the State, particularly the iron ores and the lignite deposits, and some of the precious ores, mainly silver. However, it is interesting to note that the significance of oil and its future rôle in the State was not at all visualized by the men of the Dumble Survey. Some note had been made of the occurrence of oil in the Nacogdoches field in Nacogdoches County,[4] but apparently the significance of this occurrence and its implications did not register on the consciousness of these investigators. At least to their minds it was of subordinate importance. The iron ores and lignite deposits were considered the things of value that would contribute to the future industrial supremacy of Texas, and not oil.

It is likewise interesting to note that in the reports of the Dumble Survey attention was called to the salines of east Texas. Their unusual geologic features were commented on, but their true significance was not at all visualized. They were interesting, it appeared, mainly from the standpoint of salt production. The salt dome concept as known today likewise did not register on the consciousness of these geologists. The geologic survey under Dumble suffered an inconvenient demise in 1892, due to political considerations.

RISE OF OIL

Oil came to be of commercial importance in the State for the first time in the interval between the demise of the Dumble Survey in 1892 and the turn of the century in 1900, when oil was discovered and produced at Corsicana and at Powell in Navarro County (in 1894).

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[4] Dumble, E. T., and others, Reports on the iron ore district of east Texas: Texas Geol. Surv., 2d Ann. Rept., pp. 271–276, 1891.

SPINDLETOP DISCOVERY

The momentous discovery at Spindletop by Captain Lucas was on January 10, 1901. I still have a vivid recollection of the impression this discovery made at the time and of the tremendous boom which immediately followed. However, as is usual in these cases, its significance and importance were little realized at the time. Viewed in retrospect it was an event of outstanding importance in the history of Texas—one that compares with such major episodes as the adoption of the Texas Declaration of Independence, the Battle of San Jacinto, annexation to the United States, building of the first railroad, secession from the Union, and final conquest of the Indian. In the history of oil it must be ranked as of importance almost as great as the original Drake discovery in Pennsylvania in 1859. The Lucas discovery, of course, immediately stimulated intensive study of the geology of the Coastal Plain. It marked the beginning of that important branch of geology now referred to as salt dome geology—a branch not within the vision or expectation of any of the earlier investigators.

It it interesting to note in this connection that in this same year, 1901, there appeared R. T. Hill's classic on the Cretaceous of Texas, in the Twenty-first Annual Report of the United States Geological Survey, the paper being entitled "The Geography and Geology of the Black and Grand Prairies of Texas, with detailed description of the Cretaceous Formations and Special Reference to Artesian Waters." This publication remains one of the notable and outstanding contributions to the geology of Texas, and it has not been possible since that time to add very much to Hill's classification, definition, and description of the Cretaceous deposits of Texas.

THE UNIVERSITY OF TEXAS MINERAL SURVEY. 1901

One of the immediate and direct results of the Spindletop discovery was the passage by the Texas Legislature of an Act dated March 28, 1901, providing for the organization of The University of Texas Mineral Survey, under the direction of the Board of Regents of the University. The University of Texas Mineral Survey was organized May 4, 1901, and Dr. Wm. B. Phillips was appointed Director, assuming his duties shortly after his appointment. The first contribution of this new organization was a paper on Texas petroleum, published as Bulletin 1.[5]

Note that while the Dumble Survey was in existence from 1888 to 1892, the mineral resource publications of that Survey concerned themselves almost entirely with iron ore and lignite, whereas now—with oil in the industrial picture—the first publication of the Mineral Survey was devoted to this resource. Studies by Adams, Harris, Veatch, Hill, Kennedy, and Fenneman on the geology of the Gulf Coast, and notably on the salt domes, in the interval from 1901 to 1910, were the first contributions to our knowledge of the salt dome structures and marked the beginning of salt dome geology.

RED RIVER UPLIFT AND MUENSTER ARCH

Since Spindletop the story of geologic advance is likewise the story of continuing oil discoveries in Texas. Following the discovery of the salt dome fields in the Coast—Spindletop, Sour Lake,

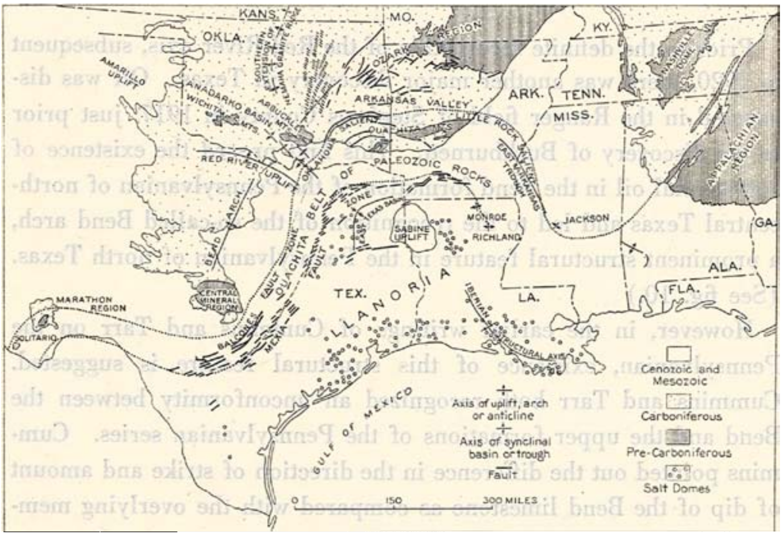

Fig. 9. Geologic map of Texas and adjacent regions showing structural features. (After Miser, Bull. Amer. Assoc. Petr. Geol., vol. 18, fig. 2, p. 1064, 1934.)

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[5] Phillips, W. B., Texas petroleum: Univ. Texas Bull. 5 (Min. Surv. Ser., Bull. 1), 102 pp., 1901.

Batson, Saratoga, and others—the oil operator rapidly turned his attention to other localities in Texas, and in 1904 commercial oil was discovered in Clay County, in connection with the Petrolia gas field.

As the Lucas discovery had given the first inkling of those numerous salt dome structures now known to exist beneath the Gulf Coast, so this discovery, due to the activity of the driller, gave us the first inkling of these important structures in north Texas known as the Red River uplift and the Muenster arch, with which the oil fields of Electra, Burkburnett, and Montague and Cooke counties are now known to be associated. (See fig. 9.) The existence of this uplift and arch was, of course, not recognized back in 1904. It was not until after the important discoveries at Electra in 1911, followed by additional discoveries at Burkburnett in 1919, and of deep oil at Electra in the same year, that this axis was finally recognized and identified.

BEND ARCH

Prior to the definite recognition of the Red River axis, subsequent to 1920, there was another major discovery in Texas. Oil was discovered in the Ranger field of Stephens County in 1917, just prior to the discovery of Burkburnett. This find proved the existence of commercial oil in the Bend formation of the Pennsylvanian of north-central Texas and led to the recognition of the so-called Bend arch, a prominent structural feature in the Pennsylvanian of north Texas. (See fig. 10.)

However, in the earlier writings of Cummins and Tarr on the Pennsylvanian, existence of this structural feature is suggested. Cummins and Tarr both recognized an unconformity between the Bend and the upper formations of the Pennsylvanian series. Cummins pointed out the difference in the direction of strike and amount of dip of the Bend limestone as compared with the overlying members of the Strawn group.[6] M. G. Cheney published the first map of the Bend arch, as we now know it, in the May, 1918, issue of the *Oil Trade Journal,* page 75. In the following month, June, 1918, a

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[6] Cummins, W. F., Report on the geology of northwestern Texas: Texas Geol. Surv., 2d Ann Rept., pp. 360–367, 1891.

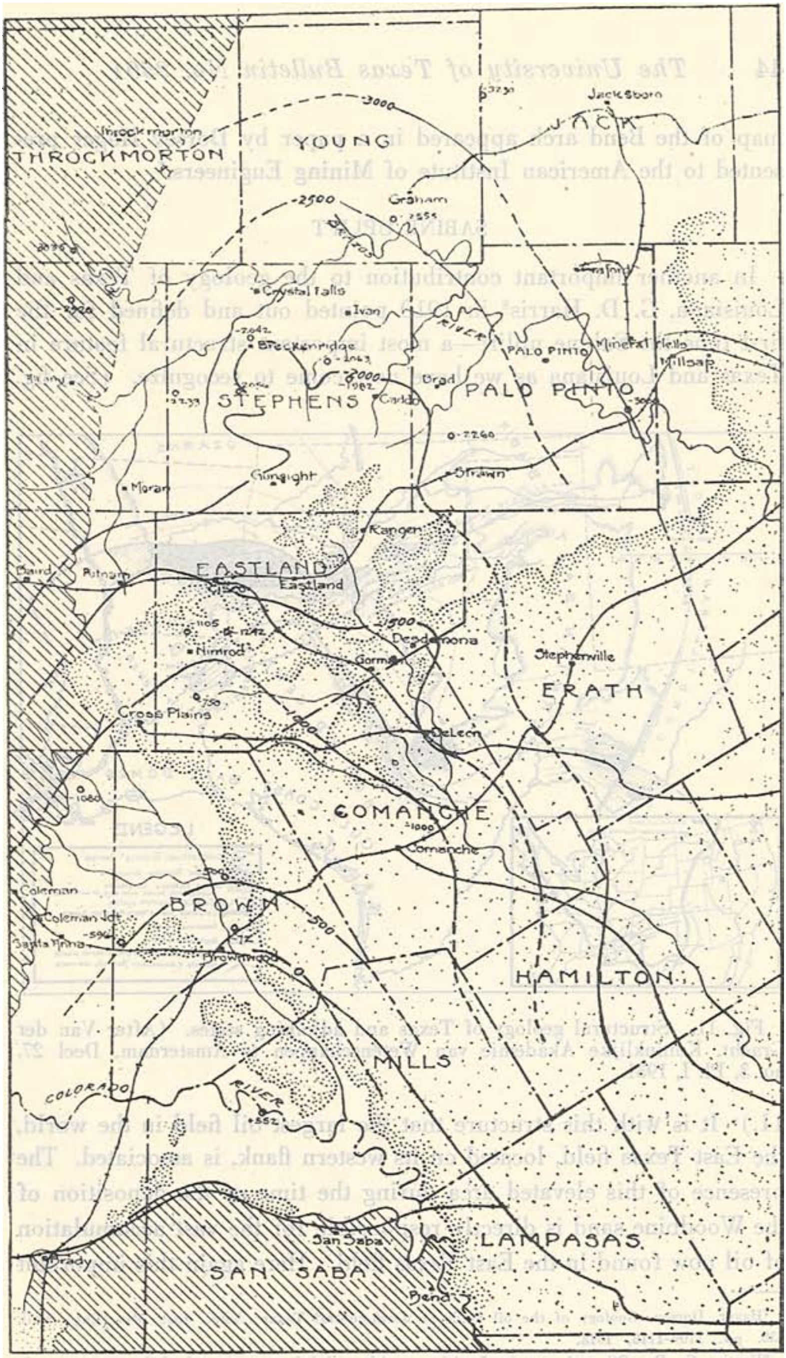

Fig. 10. Map of the Bend arch in Eastland, Stephens, and adjoining counties of north-central Texas. (After Plummer and Moore, Univ. Texas Bull. 2132, fig. 17, p. 199, 1921 [1922].)

map of the Bend arch appeared in a paper by Dorsey Hager presented to the American Institute of Mining Engineers.[7]

SABINE UPLIFT

In another important contribution to the geology of Texas and Louisiana, G. D. Harris[8] in 1910 pointed out and defined for the first time the Sabine uplift—a most important structural feature in Texas and Louisiana as we have now come to recognize. (See fig. 11.) It is with this structure that the largest oil field in the world, the East Texas field, located on its western flank, is associated. The presence of this elevated area during the time of the deposition of the Woodbine sand is directly responsible for the vast accumulation of oil now found in the East Texas field. Here again this important

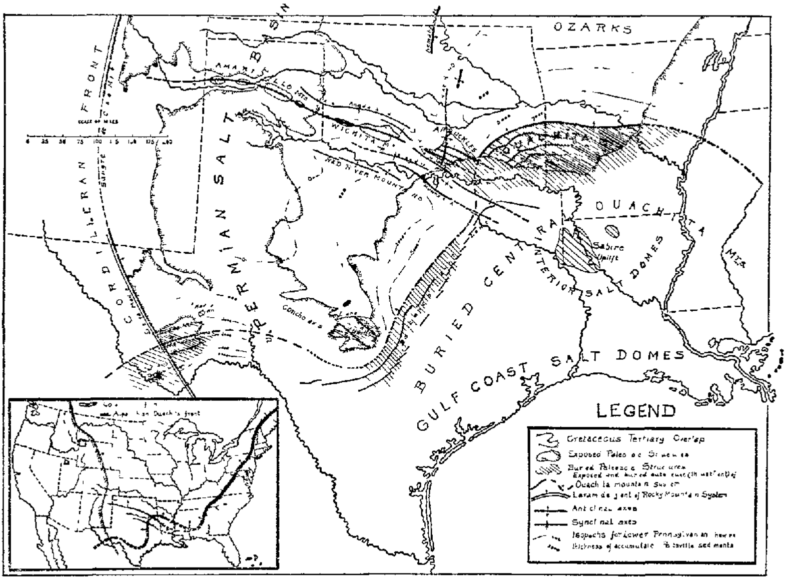

Fig. 11. Structural geology of Texas and adjoining states. (After Van der Gracht, Koninklijke Akademie van Wetenschappen te Amsterdam, Deel 27. no. 3, Pl. I, 1931.

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[7] Hager, Dorsey, Geology of the oil fields of north-central Texas: Amer. Inst. Min Eng., Bull. 138, pp. 1109-1118, 1918.

[8] Harris, G. D., Oil and gas in Louisiana, with a brief summary of their occurrence in adjacent states: U. S. Geol. Surv., Bull. 429, pp. 26-29, 1910.

contribution to the knowledge of the geology of Texas was made possible by the work that the driller had done, following the discovery at Spindletop.

Curiously enough, however, the original mapping of the Tertiary formations in east Texas by Penrose, Kennedy, and Dumble in the years before 1900 gave suggestion of this uplift, though the feature was not definitely recognized until described by Harris. The north Texas embayment or Tyler syncline on the west flank of the Sabine uplift is indicated on the original map published by Kennedy in 1895.[9] Lower Claiborne formations are shown on this map to extend as a protruding arm through Rusk, Gregg, and the western portion of Harrison and Marion counties into Cass County from the main exposed belt of these formations, which roughly parallels the present Gulf shore line. Prospecting on the Sabine uplift in Caddo Parish, Louisiana, started in 1904, and oil was definitely discovered in that year, but production in commercial quantity was not obtained until the year 1908 (499,937 barrels).

AMARILLO AXIS

In east Texas we have what is probably the largest oil field in the world, and in the Panhandle of west Texas we have what is probably the largest gas field. Associated with this enormous gas field is likewise an oil field, the gas and oil occurring at different levels in the Amarillo anticline. This anticlinal axis is located on top of a buried granite ridge which is an extension into the Panhandle of Texas of the Wichita-Arbuckle axis or mountains of Oklahoma. (See fig. 11.)

These are the facts as we now know them. We knew nothing of these conditions prior to 1906. Credit for the discovery of the Amarillo axis, and eventually of the Amarillo oil and gas field, must be given to Chas. N. Gould of Oklahoma, but in unravelling the picture, as we now know it, the drill as usual has played a very prominent rôle. In this case, as of course in many others, geologic investigation antedated actual drilling.

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[9] Kennedy, William. The Eocene Tertiary of Texas east of the Brazos River: Acad Nat. Sci. Philadelphia Proc. 1895, pp. 89–160, 1896.

In 1906 and 1907 appeared two papers by Gould[10] on the geology of the Panhandle of Texas, based on field work done for the U. S. Geological Survey in prior years. Gould's investigations were not concerned with oil but were undertaken primarily for the purpose of gaining some knowledge of the conditions of the occurrence of underground water in the Panhandle of Texas, a matter of transcendent importance then as now. In the history of oil, however, during the past thirty-five years, the driller has ever been eager to follow the slightest suggestion or intimation on the part of the geologist as to localities which might possibly produce oil, and he has always been eager to test out any and all areas that offered the slightest prospect of producing oil.

In Gould's paper on the geology of the western portion of the Panhandle of Texas, he called attention for the first time to the existence of the anticline exposed in the valley of Canadian River in Potter County, north of Amarillo.[11] It happens that the exposures noted by Gould on Canadian River are at the western extremity of the large anticline, 120 miles long, which we now know extends across four counties in the Panhandle, including Potter, Carson, Gray, and Wheeler. Canadian River cuts across the western end of this axis. However, at that time, and probably as late as 1917, there were very few geologists conversant with conditions in Texas who would have conceded the possibility of the existence of oil deposits in the Panhandle. It was considered that the Permian and Triassic rocks known to occur there were unfavorable for oil accumulation, and that these sediments representing the dessication of enclosed interior salt basins contained no source beds from which oil might have been derived.

At this stage the driller entered the scene. Though the geologists were not optimistic concerning the prospects for oil in the Texas Panhandle, the driller was willing to take a chance on whether or not there were source beds and oil sands in the section on the anti-

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[10] Gould, C. N., The geology and water resources of the eastern portion of the Panhandle of Texas: U. S. Geol. Surv., Water-Supply Paper 154, 64 pp., 1906; and The geology and water resources of the western portion of the Panhandle of Texas: U. S. Geol. Surv., Water-Supply Paper 191, 70 pp., 1907.

[11] Gould, C. N., The geology and water resources of the western portion of the Panhandle of Texas: U. S. Geol. Surv., Water-Supply Paper 191, pp. 14, 18, 1907.

cline mapped by Gould.[12] Accordingly, in 1918, in the days of the Ranger boom, a well was started on the anticline discovered by Gould in Potter County which resulted in the discovery of a 15,000,000-cubic foot gas well.

This discovery was followed three years later (in May, 1921) by the discovery of oil on this structure in Potter County. It was about this time that these exploratory wells drilled into granite wash and the granite core underlying this axis, a startling and most important discovery from the standpoint of geology. Again at first the importance of the oil was minimized, but with the intensive development that occurred in 1925 and 1926, a field of major proportion was uncovered and with it the true and complete picture of the geological conditions in the Panhandle as we now know them.

BUREAU OF ECONOMIC GEOLOGY

It is well to pause here for a moment to call attention to the work fostered by The University of Texas in the meanwhile. The University of Texas Mineral Survey, organized in 1901, as previously indicated, was of short duration, due to political difficulties. It came to an end in 1905. One important incidental effect resulting from the activities of The University of Texas Mineral Survey was the bringing of another eminent man to Texas in connection with this work, Dr. J. A. Udden. He began work with Dr. Phillips in the year 1903.

Dr. Phillips returned to the University in 1909 to assume the directorship of the newly organized Bureau of Economic Geology which was to take the place of the defunct University of Texas Mineral Survey. The financial support of this new organization was contributed by The University of Texas, without specific legislative appropriation. Dr. Phillips remained with the newly organized Bureau only a short time and later was succeeded by Dr. Udden, who continued with the Bureau until his death a few years ago.

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[12] Gould actually recommended and suggested the drilling of the original well that resulted in the discovery of gas in the Amarillo field. It was through his influence that the first exploration was undertaken

MEXIA-LULING FAULT ZONE

The next chapter in the development of knowledge of the geology of Texas—and likewise in the history of Texas oil—deals with the Mexia-Luling fault zone and oil in the Woodbine sand.

The Balcones fault, well exposed at the surface, from Del Rio to Waco, via Uvalde, San Antonio, New Braunfels, San Marcos, Austin, and Belton, was of course known to the geologists of Texas prior to 1900.

Hill and Vaughan[13] had mapped it with accuracy, little improved since, in their reports which appeared in 1898 and 1901.

We now know of another fault zone—the Mexia-Luling fault system, which extends from Titus County to Medina County, roughly following the Cretaceous-Tertiary boundary and paralleling the Balcones system from Waco south. (See map, fig. 9.) There is a downthrown block or fault graben between the two.

We now likewise know something of the underground conditions beneath the Cretaceous and between these two fault systems. The belt marks the site of a buried mountain axis connecting the Ouachita Mountains of Oklahoma with the Marathon-Solitario region of Trans-Pecos Texas. This axis represents the extension into Texas of the Appalachian Mountain system of the eastern United States. (See fig. 11.) It marks the site of a large geosyncline which became pronounced in Carboniferous time. Miser[14] has described it as the Ouachita geosyncline. In this geosyncline were deposited sediments of Ordovician, Devonian, Mississippian, and early Pennsylvanian age.[15] In late Permian time this series of sediments was compressed into a mountain range, of which the Ouachita and Marathon mountains are remnants still exposed at the surface. The greater portion of this ancient mountain system in Texas is now buried beneath the Cretaceous.

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[13] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas, with reference to the occurrence of underground waters: U. S. Geol. Surv., 18th Ann. Rept., pt. 2, pp. 193–321, 1898.

Hill, R. T., The geography and geology of the Black and Grand Prairies of Texas, with detailed description of the Cretaceous formations and special reference to artesian waters: U. S. Geol. Surv., 21st Ann. Rept., pt. 7, 666 pp., 1901.

[14] Miser, H. D., Relation of Ouachita belt of Paleozoic rocks to oil and gas fields of Mid-Continent region: Bull. Amer. Assoc. Petr. Geol., vol. 18, p. 1061, 1934.

[15] Van der Gracht, W. A. J. M. van Waterschoot, The Permo-Carboniferous orogeny in the south-central United States: Proc. Royal Acad. Sci. Amsterdam, vol. 28, no. 3, p. 9, 1931.

We knew nothing of the Mexia-Luling fault system, of the oil traps that accompany the faults, of the oil productive nature of the Woodbine sand and the Edwards limestone, and of the Ouachita axis in the years prior to 1914. Again it was the drill that made possible this advance of geologic knowledge.

As has been previously pointed out, the first oil of commercial importance in the State was that produced at Corsicana and Powell, discovered in 1894. Production was from the Nacatoch sand of the Navarro formation of the Upper Cretaceous. Showings of oil in water wells in that vicinity led to the original drilling which resulted in the discovery. Gas was found in the vicinity of the present Mexia field by the Mexia Oil and Gas Company in 1912. Production was from the Nacatoch sand at a depth of approximately 687 feet.

This writer[16] in a paper published in 1914 noted the fault at Mexia and pointed out the relation of the gas accumulation in the Mexia gas field to it. Later, Matson[17] published a paper on this gas field. He considered the gas to be associated with an anticline. Matson[18] suggested in this paper the advisability of testing the Woodbine sand in this Mexia structure for oil and gas. However, at that time there were few geologists and fewer operators who viewed this prospect with favor. The Woodbine sand, which at the time was considered to be the producing sand in the Caddo field on the Sabine uplift,[19] was known to carry fresh water at Corsicana, and was the source of water supply for many water wells in the Cretaceous area east of the outcrop, and for this reason many geologists were skeptical of its oil producing possibility.

However, as is usual in these instances, there is always someone willing to gamble on these prospects, the rewards in the way of oil, if successful, being sufficient to justify the hazard. In 1920, on the advice of F. Julius Fohs, a geologist, Colonel A. E. Humphreys took over a well previously drilled to a depth of 1800 feet by the Mexia

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[16] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Surv., Water-Supply Paper 335, p. 301, 1914.

[17] Matson, G. C., Gas prospects south and southeast of Dallas: U. S. Geol. Surv., Bull. 629, pp. 77–119, 1916.

[18] *Idem*, p. 104.

[19] It is now known that the Woodbine sand is not present on top of the Sabine uplift. The earlier correlation of the producing sand in the Caddo field with the Woodbine is now known to have been erroneous.

Oil and Gas Company on the L. W. Rogers tract on the Mexia structure and drilled the well into the Woodbine sand at a depth of 3100 feet, completing it as a pumper producing 150 barrels of oil per day and proving for the first time the existence of oil in the Woodbine sand in the fault structures of the Mexia-Luling fault system. Currie, Richland, Powell, and Wortham fields followed in rapid order. In 1922, oil was discovered in the Edwards limestone on the southern extension of the fault system on a fault structure identical in type with that with which the oil is associated at Mexia and Powell. It was not, however, until the Mexia field was actually drilled that the true structural conditions obtaining in this field and the rôle which the faults played were actually realized.

With the intensive period of geologic exploration which followed Mexia and the drilling that accompanied it, the distribution, type, and character of these faults became known, and the picture of the Mexia-Luling fault system, as we now know it. came within the scope of knowledge of the geologists of Texas. Likewise, the drilling that has accompanied the development of these fault fields has given to the geologist the knowledge of the buried Ouachita axis beneath this fault zone, previously referred to.

PERMIAN BASIN

We come now to the chapter of the Permian basin. For many years Udden had been engaged in a study of the geologic features of Trans-Pecos Texas and particularly of the area included in the Glass Mountains and Marathon basin. The results of these studies, and of those fostered under his direction, appeared in a number of publications issued by the Bureau of Economic Geology.[20]

I quote from his paper on the Glass Mountains published in 1917.[21]

> From my observations on all parts of the Glass Mountains it appears that the formations from the Vidrio up, are much less tilted and folded than the Gaptank and the other formations of probable Pennsylvanian age. It would seem, therefore, that most of the folding of the Marathon mountains antedated the deposition of the latest Permo-carboniferous sediments. I believe that the

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[20] Among these publications the following may be listed: Udden, J. A., A sketch of the geology of the Chisos country, Brewster County, Texas: Univ. Texas Bull. 93 (Sci. Ser., Bull. 11), 101 pp , 1907; and Notes on the geology of the Glass Mountains: Univ. Texas Bull. 1753, pp. 3-59, 1917.

[21] *Op. cit.*, pp. 57-58.

redbeds exposed in the Pecos Valley overlie the Tessey formation. These and the overlying Comanchean have therefore probably been very little disturbed by the Marathon uplift. So that there should exist, under the Comanchean and under the redbeds, some places northeast of the Marathon uplift where the Pennsylvanian and probably some of the Permo-carboniferous lie folded under the relatively undisturbed redbeds and the Comanchean limestones. The redbeds are entirely impervious and would make an excellent cover for an oil pool. How far such covered places of tilted petroliferous formations of the Pennsylvanian may be found away from the exposures in the Marathon country no one can say, but it would be no surprise to find them at a distance of at least fifty or a hundred miles beyond the Brewster-Pecos county boundary. The trend of the Marathon mountains would run through the southeast part of Pecos county into Upton and Reagan counties, or even farther east than this.

It will be remembered that on the west flank of the Glass Mountains, the Comanchean limestones have been slightly tilted and that outliers of this formation occupy some of the highest points on the mountains. This cannot be altogether due to an overlap. It certainly represents a slight uplift in post-Comanchean times. From what is generally known of the geologic history of the mountain-building forces, it is quite reasonable to suppose that post-Comanchean disturbances should have taken place over more than one part of a buried mountain system, such as that of the Marathon uplift. It ought for this reason to be practicable to find out how far in a northeast direction this uplift probably extends, for it can be expected to be marked by at least some slight elevation in the later Comanchean sediments. We have here a geologic problem, the solution of which may be of decided economic significance. In the distribution of the Comanchean along the North Concho and the Colorado rivers, there is nothing to especially suggest such an uplift. The conditions in the country to the northeast of the Glass Mountains, along the Pecos river, are singularly favorable for the testing of such a theory. The Comanchean limestones contain several sharply marked horizons that can be followed for long distances in the southwest part of Pecos county, and in most of Upton, Reagan and Crockett counties. Quite accurate measurements of any structure present can certainly be made. It is, however, a region where very little work has yet been done, and in the absence of any accurate knowledge of the conditions involved, further speculations seem unprofitable. We can only see that in the buried unconformity which certainly must exist between the lower folded series and the overlying merely gently folded or quite undisturbed sediments, there are natural chances for finding accumulations of gas as well as oil.

I am of the impression that the results of these studies have had far reaching effects. Casually I should mention that this splendid University plant which it is my privilege to enjoy today is in large measure the direct result of the fruitful labor of this untiring investigator. I seriously question whether The University of Texas has as yet given adequate recognition to the work that he has done. The statement I have quoted was published in 1917. At that time there was no oil of commercial importance in this area which we now know as the Permian basin, and as yet no oil or gas had been discovered in the Panhandle.

Again in this instance, as has been previously pointed out, suggestions of favorable structural conditions from the standpoint of oil accumulation in publications by the geologist were eagerly seized upon by the wildcatter and operator. The latter, in the later period of this history, when the structural control of oil accumulation came to be definitely recognized and commonly accepted, had by now become very keen to test out any new area that offered even the remotest chance of success.

When the activity that followed the discovery of the Mexia, Powell, and Luling fields in the Mexia-Luling fault zone subsided, the operator turned his attention to new areas, and the more venturesome among them at this time turned to the Permian basin, seeking for oil on extensions of the Marathon fold as suggested by Udden. Again, as often happened, the more cautious operators were skeptical of commercial oil deposits in this area.

In 1921, after leases had been assembled in Reagan County on the trend suggested by Udden, drilling started in the area of the present Big Lake field, which resulted in the completion of the discovery well in May, 1923. Again an intensive period of geologic investigation and oil exploration followed in this new area. Yates (in 1926), Winkler (in 1926), Hobbs, New Mexico (in 1928), as well as McCamey, McElroy, Church-Field, and Ector and Powell fields followed in rapid order.

As a result of these developments, of information that came to be available from drill holes, and of the intense geologic investigation that followed we have learned:

1. The geologic section, starting with Triassic at the surface (in the mid-portion of the basin in Midland County), followed by the Permian with the salt series at the top and the "big lime" near the bottom. followed by Pennsylvanian, resting unconformably on the Ordovician.
2. We have in a measure been able to correlate this section with the exposures at the surface farther east and with the exposures in the Delaware and Guadalupe mountains farther west.

3. We know the exact sub-surface position of the "big lime" at numerous points.
4. We have gained intimate knowledge of the main formational subdivisions of the larger units underground and have determined the petrographic and paleontologic characteristics of these units so they can be recognized in wells.
5. We have determined the position and location of the main structural axes in this basin, including the Fort Stockton "high," the McCamey-McElroy-Church-Field axis, and the Big Lake-Powell axis, with the intervening synclinal depressions. (See fig. 12.)
6. We have learned that the "big lime" of the Permian contains enormous deposits of oil and that the Ordovician underneath contains similar deposits, wherever favorable structural conditions exist.

None of these facts were within the scope of knowledge of the geologist in the years prior to 1900.

GULF COAST SINCE 1921

This history started with Spindletop in the Gulf Coast. The concluding chapter requires return to the Coast. The Gulf Coast is a featureless flat plain with low relief and only an insignificant amount of dissection. Clean-cut exposures upon which the geologist ordinarily relies for interpretation are few. The beds have only low and gentle dip, which means that over a wide expanse of territory the formation is identical. The terrigenous and alluvial deposits making up the surface formations are without diagnostic fossils. There is no definite and persistent stratification so that close correlation of definite horizons is not possible over any extended area. There are few regions in the United States where geologic work, by methods commonly applied, is more difficult.

Yet beneath this all-pervading and featureless mantle is a structural picture not simple or regular as the surface implies and a geologic story of intriguing episodes and stores of fabulous wealth, which might well excite the cupidity of an ancient Midas.

Vastly different today is the conception of the Gulf Coast to that which it must have been at the time when Penrose, Kennedy, and Dumble did their pioneering work. Certainly their vision did not embrace the important happenings that materialized in the decades that followed. Now we know that instead of simple and regular

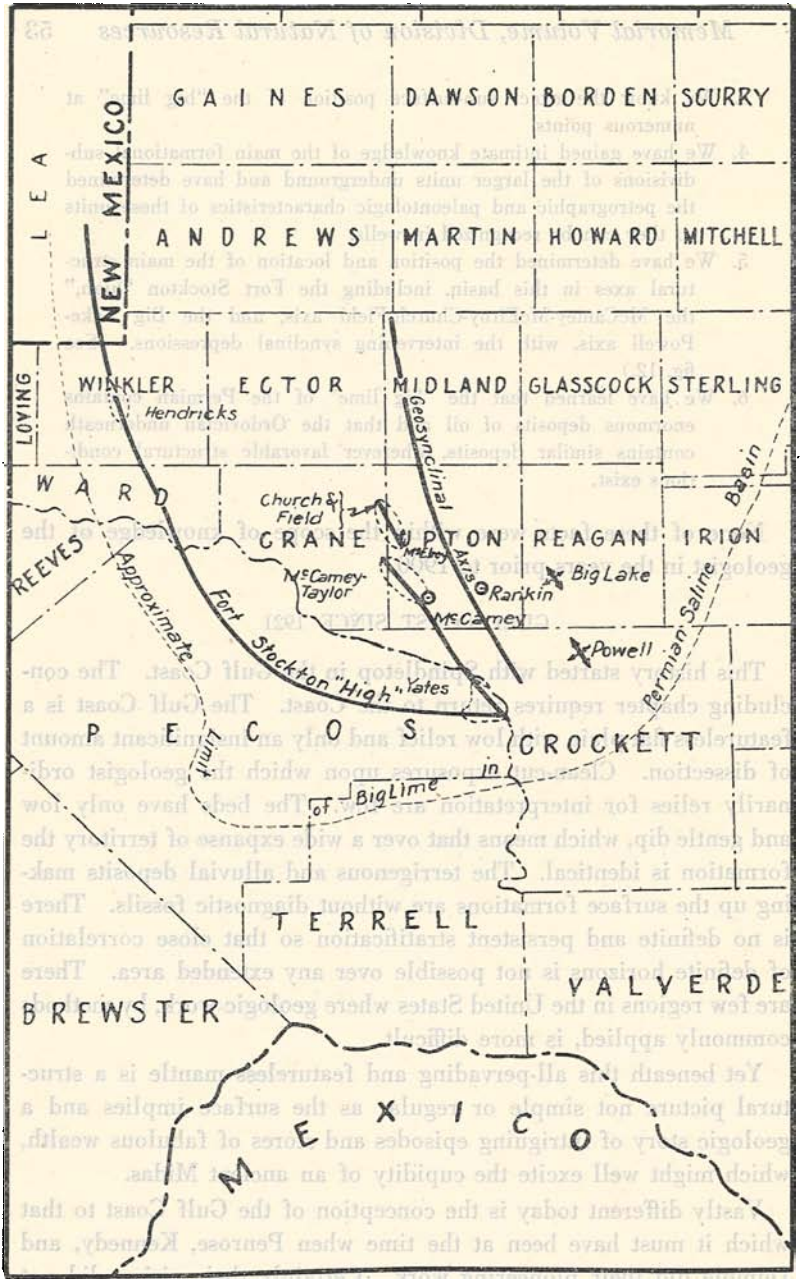

Fig. 12. Map of west Texas salt basin showing location of major structural axes. (After G. C. Gester and H. J. Hawley, Structure of Typical American Oil Fields, Vol. II, fig. 1, p. 483, 1929.

structure the reverse is true. There are buried folds and faults which date back to the oldest rocks. Many of these are axes along which movement has occurred at intervals almost to Recent time. There are deeply buried layers of rock salt. There are innumerable stocks of salt far above the level of the original bed, some reaching almost to the surface, while others lie at greater depths below. These stocks have punctured the older beds and deformed the overlying beds into domes and anticlines. And in these various structures have been stored millions of barrels of oil and millions of tons of sulphur.

How came these facts to be known? There are, of course, some faint intimations at the surface. These escaped the eye of the early observers, but to Lucas, after he became aware of salt and sulphur deposits at Jefferson Island and at Sulphur in Louisiana, the slightly elevated topographic mounds on this flat prairie were significant. When it was proven that similar deposits of salt existed in Texas and that oil was accumulated in connection with them, it was observed that gas seepages and mineralized water occurred in many places on this plain, and the drill quickly proved numerous other salt stocks.

Until 1922, drilling had revealed something like 44 of these obscure structures. By this time, however, it was becoming increasingly difficult to locate favorable spots for testing, most of the localities where there was gas or topographic expression having been tested to the depths to which it was possible to drill at the time. There was urgent need for improving methods then in vogue. In 1922 an important forward step was made. This was micropaleontology. Laboratories for the study of microfossils, mostly foraminifera, were established in Houston at about this time.[22] It was quickly ascertained that definite correlation by microfossils was possible, especially for the formations older than Miocene, and the drill was beginning to reach these older formations at a constantly increasing number of localities. Micropaleontology has made rapid strides since then and has been of inestimable value in determining structure underground in the Coast. It has multiplied many times

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[22] Rio Bravo Oil Company under the direction of E. T. Dumble established the first laboratory in Houston. However, in California correlation by microfossils was being successfully done before the work started in the Gulf Coast of Texas.

the effectiveness of the drill as an exploratory agent in locating new structures and new oil deposits. As a result it has been possible to determine with accuracy at many points the exact subsurface position of the several Oligocene and upper Eocene formations and to interpret structure accordingly.

Improved methods did not stop with micropaleontology. At about the same time geophysics was introduced to the Coast, starting with the torsion balance. In 1924 the first seismograph explorations were conducted in the Coast, using the refraction method. In 1928, seismograph exploration by reflection was started, and this method has now completely superseded the older method. Exploration by both torsion balance and seismograph made rapid strides and continues unabated at the present time. Much of the area of the Gulf Coast of Louisiana and Texas has been surveyed by either one or the other, or both, of these devices.

At least 34 new oil or gas fields have been discovered since 1922, following the introduction of geophysical surveys, including such major fields as Sugarland, Thompsons, and Iowa; and many new prospects, as yet either untested or not yet proven for production, have been found. Dozens of new salt domes have been discovered, and deeply buried structures of the salt dome type, with no salt as yet proven, such as Manvel, Thompsons, and others, have been revealed.

The latest improvement in the exploratory art, introduced into the Coast, is the method of electrical logging, that is, of determining the electrical resistivity of the several beds encountered in drill holes, as well as relative porosity of these beds by electrical methods. These surveys permit differentiation of oil-bearing and water-bearing sands and give accurate and mechanical record of the beds penetrated, permitting exact correlation in many instances, more accurate and better completion of oil wells, and more exact tests of oil-bearing sands in wildcat wells. These electrical surveys have only come into use during the past year. Important results may be expected to follow.

The geologists of the Gulf Coast have taken the leading part in the development and application of these new methods in determining underground structure and in conducting explorations for oil and have led this advance. These featureless young rocks at the surface offered a challenge. Lucas, a geologist, answered with his drill and found Spindletop. Others following in his footsteps have answered with micropaleontology, torsion balance, seismograph, and electrical logs and have found, amongst numerous others, Boling and Conroe. Spindletop, the first, discovered in 1901, contained 120,332,417 barrels of oil. Conroe, among the latest, discovered in 1932, contains 600,000,000 barrels.

The record of thirty-five years is, I believe, an imposing one.

THE ALCHLOR PROCESS

A. M. McAFEE[1]

I thank you, Mr. Chairman, for your generous introductory remarks. I would rather direct your thought to the fact that my training was received at The University of Texas, particularly in the School of Chemistry. In after years we are apt to feel that we are getting along on our own strength, when in fact we are largely putting into practice the ideas and ideals of those who taught us during that formative period. As I reflect, there stand out three men of this University to whom I owe a debt of gratitude which can not be adequately paid. I refer to Dr. Harper, Dr. Schoch, and Dr. Bailey. They are still in harness for Texas, carrying on their good work now with the second generation—your and my sons and daughters. May they be here to take on the third generation!

When Dr. Schoch invited me to take part on this program, my first impulse was to say no. I have appeared on such occasions only twice before, once in 1915 in San Francisco at a meeting of The American Institute of Chemical Engineers and again at a similar meeting in Philadelphia in 1929. These appearances were 14 years apart; hence to maintain the record I was not due to appear again until about the year 1943. But Dr. Schoch pointed out that this meeting was to commemorate the twenty-fifth anniversary of the Bureau of Economic Geology and Technology, started by Dr. William B. Phillips. Then I counted and found that I had graduated from Texas twenty-five years ago. That coincidence won me. So I am here to celebrate our Twenty-fifth Anniversary.

The next question was what I should talk about. The Alchlor Process was suggested, meaning by Alchlor, anhydrous aluminum chlorid. That would be an easy subject for me. But as this is a patented process, owned and operated exclusively by Gulf Refining Company, we have felt that the public is interested only in the products of that process. The thoughtful motorist has learned that the most important item in the proper operation and upkeep of an automobile engine is the quality of the lubricating oil used. Hence,

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[1] Gulf Refining Company, Port Arthur, Texas.

it seemed appropriate and timely that I should talk about the Alchlor Process as applied to the refining of motor oils. Now, I doubt if many of you ever heard of this process, but from the number of Gulf service stations I have observed in and about Austin, it is fair to assume that Gulfpride oils are well known to many of this audience. So, when I tell you that Gulfpride oils are made entirely by the Alchlor Process you will know better what I am talking about.

A lubricant has been defined as an agent that decreases friction between moving surfaces. Such a definition classifies a large number of substances as lubricants. Water, graphite, soap, vegetable oils, and petroleum are used to decrease friction between moving surfaces and are therefore lubricants by definition. There is no one agent which can be called a universal lubricant, one that can be used between all moving surfaces under all operating conditions. A compressor compressing oxygen into steel cylinders to 2200 pounds pressure must use a lubricant which is non-reactive with oxygen. Water containing a small amount of soap is a satisfactory lubricant in this case; vegetable and petroleum oils can not be used on account of their great reactivity with pure oxygen, more especially so under pressure. Certain hydrocarbon constituents of petroleum, commonly known as lubricating oils, come nearest nowadays to being the universal lubricant. This discussion will be limited to that class.

Petroleum is composed of compounds of the element hydrogen and the element carbon, and these compounds are called hydrocarbons. There are other elements and compounds in small amounts in petroleum such as sulphur, oxygen, and nitrogen, which are generally looked upon as impurities to be disposed of in refining. A discussion of these impurities is not here necessary. The number of different hydrocarbon compounds constituting petroleum amount to several thousands. Comparatively few individual hydrocarbons have been isolated from petroleum, and to date there are fewer practical uses for them. But, in the form of gasoline, kerosene, and lubricating oil, the consumption of these petroleum hydrocarbons is enormous. The petroleum refiner separates these hydrocarbons as they come to him in the crude into the desired groups by taking advantage of differences in boiling points of successive groups.

Gasoline boils at a lower temperature than kerosene; kerosene boils at a lower temperature than lubricating oil. The first essential step therefore is to distill the crude petroleum in order to make a separation of the hydrocarbons into the desired groups. This being accomplished, each group is further refined to meet the uses for which the finished products are desired.

Each of these groups is characterized by certain physical properties. Gasoline must be volatile—not too much or too little—in order to be used in an internal combustion engine. There are other important properties which gasoline must possess, but correct volatility is of first importance.

The largest consumption of kerosene is in the household lamp. Of course, kerosene must give light on burning in a lamp, but first it must be safe. The flash point, the temperature to which the kerosene must be heated to give off sufficient vapor to form an inflammable mixture with air, may be said to be the most important physical property of this product. Certainly there has been more legislation on this point than on any other.

The property which characterizes petroleum lubricating oil is viscosity. To be a lubricant it must be viscous enough to maintain a fluid film between the moving surfaces under all operating conditions. While it is true that lubricating oil must have viscosity it does not follow that any oil which has viscosity is a good lubricant. Many crude oils as they come from the ground are viscous, but few, if any, are used in the natural state as lubricants. Now we are in a position to consider what are the properties which motor oils should possess. Let us not confuse our thoughts by use of technical terms. I could talk about sludging value, Conradson carbon, and viscosity index of motor oils, but why do that if the desired properties can be expressed in language which all of us can understand from our daily experience. When it became popular to refer to the anti-knock quality of gasoline by octane number, I am reminded of the motorist who wanted gasoline containing 70 octanes per gallon. What do you want of the motor oil in the crankcase of your automobile engine? I expect the first thing you would say is that you want it to last a long time. Then you want to feel that during this time the oil is flowing freely through the lubricating system to all moving parts. Then, you want any oil which passes the piston rings and enters the combustion chamber to volatilize and get out without leaving behind a solid to clean out by hand. And finally, you want adequate viscosity at the highest as well as the lowest operating temperature of your engine. Now we can say what the motor oil should do in the modern, high-speed automobile engine:

1. Resist oxidation as much as possible.
2. Leave as little carbon on volatilizing as possible.
3. Change as little in viscosity with change in temperature as possible.

The ideal motor oil would be one which can not be oxidized, one which leaves no carbon on volatilizing, and one which has the same viscosity at all operating temperatures. Why? Because such an oil would not oxidize to form sludge to clog the lubricating system and would certainly last a long time, would leave no carbon in the combustion chamber to clean out, and would have the same viscosity on a cold morning when starting up the motor as it would have after the motor has been driven, say, 100 miles at top speed. Such an ideal motor oil has never been produced from petroleum. All petroleum lubricating oils are subject to oxidation, deposit carbon on volatilizing, and become less viscous with rise in temperature. The best we can do, therefore, is to recognize the qualities of the ideal motor oil and approach these qualities as near as possible.

In my course in organic chemistry under Dr. Bailey, there was one reaction which he particularly stressed, called the Friedel and Crafts' synthesis, discovered in the year 1877. The textbook which we used then was Holleman's "Organic Chemistry." I still have that textbook, which I prize highly, because on the margin of page 363 I wrote in the year 1907 the words "exceedingly useful." These were the words used by Dr. Bailey during his lecture that year on the Friedel and Crafts' synthesis. On this page Holleman says, "Friedel and Crafts' synthesis is peculiar to the aromatic series and depends on a remarkable property of aluminum chlorid." Five years later when I took up the study of petroleum hydrocarbons it was not surprising that I should question why aluminum chlorid is peculiar to the aromatic series.

I found that crude petroleum when heated with anhydrous aluminum chlorid undergoes profound internal changes. There is a rearrangement of the various hydrocarbons and removal of unstable bodies. The San Francisco paper given by me was entitled

"The Improvement of High Boiling Petroleum Oils and the Manufacture of Gasoline as a By-Product therefrom by the Action of Anhydrous Aluminum Chlorid." In that paper I showed that when crude petroleum is distilled in the presence of aluminum chlorid, lower boiling hydrocarbons are produced, leaving a residual oil free of asphaltic and resinous constituents. Thus a dual role was played by this remarkable chemical, one of conversion and one of refining. Both actions can be made to take place simultaneously or separately depending upon the temperature employed. At boiling temperatures all the high boiling constituents of crude petroleum can be converted into gasoline, gas, and carbon, but at lower temperatures the lubricating constituents are freed of those bodies which are more easily oxidized, deposit excessive carbon on volatilizing, and which are more susceptible to change in viscosity with change in temperature. Not until several years later was the quality of these products required by industry. As the automobile engine was improved in respect to higher compression and higher speed, anti-knock gasoline became important and improved motor oil was required. It was then that lubricating oils refined by aluminum chlorid came into their own because they more nearly approached the qualities of the ideal motor oil. Gulfpride oils by the Alchlor Process were then made available, first in small amounts and then in larger quantities each succeeding year as their merits were recognized through actual performance and not by fanfare of trumpets. Within the last few months sulphuric acid has been largely replaced by organic solvents for refining lubricating oils. Undoubtedly solvent refined oils are superior to those by sulphuric acid, but there is none which can not be made to approach nearer the ideal motor oil by refining with aluminum chlorid.

I am glad these products were ahead of their time, because the hard job ahead required a concentration of effort unhampered by the desire for immediate production. That job was how to make aluminum chlorid. Long before my time Von Baeyer had said that the uses of aluminum chlorid sound like a fairy story. I had added more fairy stories unless this chemical could be made from basic raw materials cheaply and in thousands of tons. There was no precedent to follow. It was easy to make it from metallic aluminum and chlorin, but for industrial uses metallic aluminum as a starting material was out of the question on account of its cost.

The story of the years of work at Port Arthur and the large amount of money required to solve what seemed at times insurmountable obstacles in this difficult chemical engineering problem was contained in my Philadelphia paper in 1929 and widely published; hence it need not be repeated here. Suffice it to say that paper told how Gulf was making aluminum chlorid from bauxite, the same ore from which metallic aluminum is made, at the rate of 75,000 pounds daily and at a cost such that it could be sold in carload lots at 5 cents per pound. Contrast this with the fact that in 1913 I purchased 100 pounds of aluminum chlorid at $1.50 per pound, waiting six weeks to get it, and it is not surprising that some of the fairy stories to which Von Baeyer referred took on industrial significance immediately after that paper.

Thus, I have given a running account to date of the founding and development of an enterprise which has been conceived and developed in Texas during the past twenty-five years. To Gulf Refining Company goes the credit for making these developments possible.

SECTION II—CHEMISTRY AND ENGINEERING

RESEARCHES IN ROCK WOOL RESOURCES

MORRIS M. LEIGHTON[1]

In view of the fact that the insulation industry is a rapidly growing industry, that rock wool is one of the important insulating materials, and that the discovery of large deposits of woolrock in Illinois would probably provide the basis for a new industry in the state, the Illinois State Geological Survey, in 1931, undertook to determine whether or not such deposits existed within the state. The Upper Mississippi Valley clearly affords large market possibilities because of the presence of six large cities—Chicago, St. Louis, Kansas City, Omaha, St. Paul-Minneapolis, and Milwaukee—and many smaller ones. The following table shows the number of non-farm homes in this area:

Table 1.—Number of non-farm homes in the Upper Mississippi Valley, in cities of more than 100,000 (U. S. Census).

	Owned homes	Rented homes
Illinois	765,546	906,619
Wisconsin	296,457	218,059
Minnesota	227,336	182,857
Iowa	233.509	172,445
Missouri	300,093	357,810
Total	1,822,941	1,837,790

Besides its being a very satisfactory insulating material for homes and office buildings, rock wool is also a valuable material in the industrial field. The maintenance of high and low temperatures is receiving increasing consideration by industry, and rock wool will find extended uses in the insulation of heating and cooling units, pipes and furnaces, and in various other ways.

Rock wool is a light-weight, fluffy material composed of thin fibers, made by blowing molten rock with steam or air. Under the microscope, each fiber is found to be an extremely small glass rod. A tangled mass of these fibers serves to entrap a large number of small air pockets which impart the property of low heat conductivity

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[1] Chief, Illinois State Geological Survey. Urbana.

to the aggregate. In addition to this property, it provides protective qualities against fire and vermin; it conforms easily to the space into which it is placed; it will withstand alternate wetting and drying and heating and cooling; it can be fabricated into boards, mats, or bricks to suit the particular use to which it may be put. In the case of house insulation, it can be blown through a hose into the space between the inner and outer walls, and it can be placed by hand into the wall space during the building operation. It will insure both summer and winter comfort and will materially lower the cost of fuel or electrical energy for either heating or cooling units.

The problem of finding rock wool resources requires the research methods and technique of geology, chemistry, and physics, and the problem of determining the most economically favorable areas requires the services of a mineral economist. Our Geological Survey was particularly well fitted to undertake the problem because it had adopted the group research plan, and its full-time staff is composed of specialists in geology, chemistry, physics, and mineral economics. The geological studies and the field sampling, together with the preparation of laboratory samples, were carried on by Mr. J. E. Lamar, Geologist and Head of the Non-fuels Division, and Dr. H. B. Willman, Associate Geologist, and their assistants. The chemical research was under the supervision of Dr. F. H. Reed, Chief Chemist, and was executed by Dr. C. F. Fryling, Physical Chemist, and his assistant. The analytical work was done under the direction of Dr. O. W. Rees, Associate Chemist. The assembling of the economic data and the drawing of conclusions regarding the most favorable areas were assigned to Dr. W. H. Voskuil, Mineral Economist.

The project was highly successful. Six major areas of woolrock were found, three in southern Illinois and three in northern Illinois, all close to lines of transportation and large markets. Many deposits of sub-woolrock were also found which require the addition of only small amounts of other material that, in each case, is available near by. In addition to these discoveries, the chemical studies revealed the effect of various chemical compositions and operating variables on the quality and color of the rock wool.

The work was started during the summer of 1931 and a complete report was published and distributed in the fall of 1934. The information given is of a fundamental nature which can be used by any competent engineering organization as a basis for determining the location of a plant and working out the design and plan of operation of the same. The report is perhaps the most complete of any thus far issued in this country and has created nation-wide interest. We fully expect that it will result in the state's possessing a new industry.

CONTROLLING FACTORS IN THE STUDY

The following were the controlling factors limiting the scope of the studies:

1. The extent of economically favorable areas of production as shown by economic studies:
2. The range of chemical composition of the rocks of Illinois as shown by geological research;
3. The permissible composition range for woolrocks and operating variables as shown by chemical research; and
4. The requirements of present manufacturing practice for consolidated raw material, with the possibility of an extension in practice by which unconsolidated materials (gravel and clay) may be used.

By far the greater portion of Illinois rocks are of sedimentary origin. This limits the materials commonly available for rock wool production to those substances which are to be found in limestone, dolomite, shale, siliceous sandstone, or in the various naturally occurring mixtures of these rocks.

The particular substances available in Illinois rocks that are useful for rock wool production are silica, alumina, lime, and magnesia. Since rocks are not found in Illinois with a molecular ratio of magnesia to lime greater than that of pure dolomite (1 to 1), nor of a molecular ratio of alumina to silica greater than that of pure kaolinite (1 to 2), our research was confined to compositions which fell within the limits indicated by these ratios.

It is obvious that not all of these rock formations are of a composition suited to the production of rock wool. Therefore, one very important phase of our research was concerned with the determination of the limits of suitable composition, expressed in terms of the four substances to which I have just referred. I shall consider this subject in more detail later.

However, we can summarize our results on composition limits in a very simple, yet reasonably accurate, manner. Rocks which contain from 20 to 30 per cent carbon dioxide were found to be close to or within the composition range suitable for rock wool production.

LOCATIONS OF THE ECONOMICALLY FAVORABLE AREAS

The choice of areas within the State which were selected for an intensive investigation of woolrock possibilities was determined largely by the economic factors involved in rock wool production and distribution, *i.e.*, size, location, and probable growth of the market; site cost; delivered cost of fuel; cost of quarrying raw materials; and freight rates.

The most important potential market area for rock wool to be produced in Illinois extends mainly into the states of Wisconsin, Minnesota, Iowa, Missouri, and the eastern portions of the Dakotas and Nebraska (fig. 13). East of Illinois the market is more economically supplied by production in Indiana and Tennessee.

Within the area outlined above, the market possibilities vary because of unequal distribution of population and concentration in or near urban centers. Two-thirds of the potential market, as indicated by number of homes, is in the Chicago, St. Louis, St. Paul-Minneapolis, and Milwaukee market areas.

Since the insulating market is a highly competitive one, plant location must be selected which will result in the lowest cost of assembling raw materials and fuel and of delivering the finished product to the market. In accordance with this principle, geologic exploration was concentrated in areas which were accessible to the most important market areas by railroad transportation. Obviously areas near railroads received the most attention. The market demand for rock wool, in terms of tonnage, is not large enough to warrant the building of long railroad spurs or other special transportation lines to a deposit, which in itself is of suitable composition and extent, solely for this traffic. Therefore, the studies of woolrock resources, with some qualifications, were restricted largely to three general districts, the Chicago, East St. Louis, and northwestern Illinois districts, within which deposits are considered to be

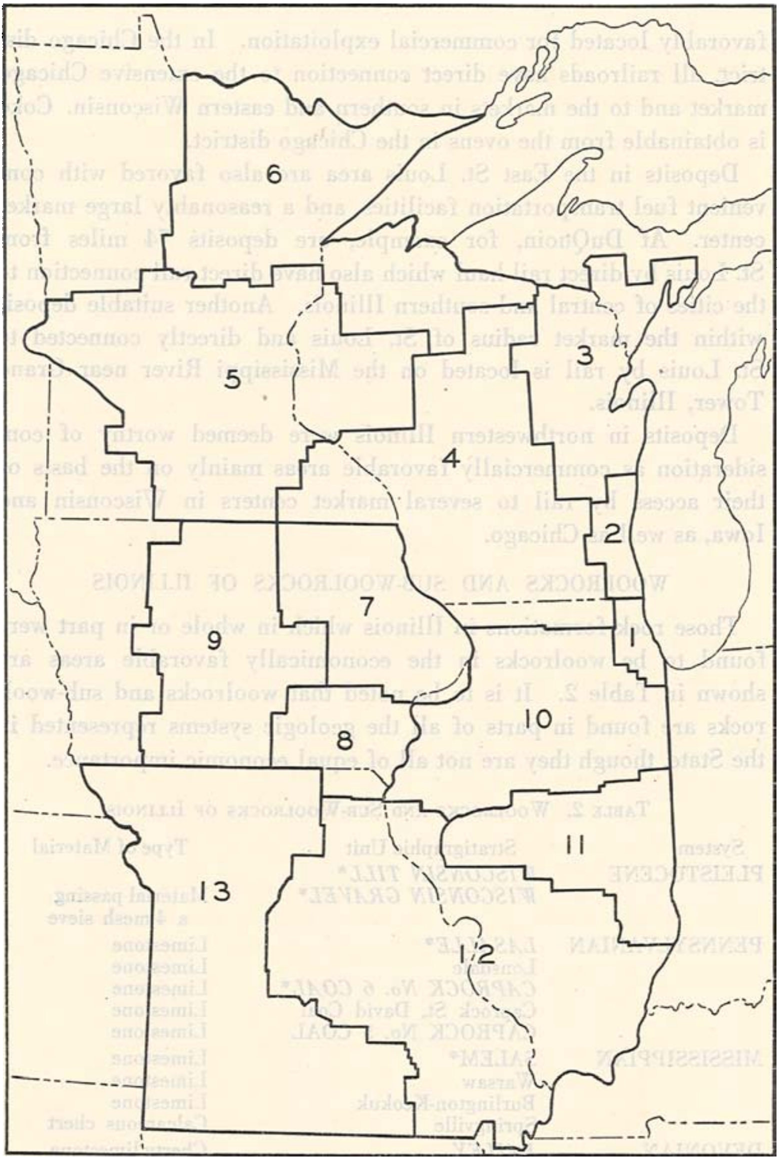

Fig. 13. Illinois market area showing potential markets for Illinois rock wool.

1. Chicago
2. Eastern Wisconsin
3. Green Bay
4. N. Illinois-Central Wisconsin-Winona, Minnesota
5. St. Paul-Minneapolis
6. Duluth
7. Davenport
8. Burlington
9. Des Moines
10. N. Central Illinois
11. Central Illinois
12. St. Louis-Southern Illinois
13. Western Missouri

favorably located for commercial exploitation. In the Chicago district, all railroads have direct connection to the extensive Chicago market and to the markets in southern and eastern Wisconsin. Coke is obtainable from the ovens in the Chicago district.

Deposits in the East St. Louis area are also favored with convenient fuel transportation facilities, and a reasonably large market center. At DuQuoin, for example, are deposits 74 miles from St. Louis by direct rail haul which also have direct rail connection to the cities of central and southern Illinois. Another suitable deposit within the market radius of St. Louis and directly connected to St. Louis by rail is located on the Mississippi River near Grand Tower, Illinois.

Deposits in northwestern Illinois were deemed worthy of consideration as commercially favorable areas mainly on the basis of their access by rail to several market centers in Wisconsin and Iowa, as well as Chicago.

WOOLROCKS AND SUB-WOOLROCKS OF ILLINOIS

Those rock formations in Illinois which in whole or in part were found to be woolrocks in the economically favorable areas are shown in Table 2. It is to be noted that woolrocks and sub-woolrocks are found in parts of all the geologic systems represented in the State, though they are not all of equal economic importance.

TABLE 2. WOOLROCKS AND SUB-WOOLROCKS OF ILLINOIS

System	Stratigraphic Unit	Type of Material
PLEISTOCENE	_WISCONSIN TILL_*	
	_WISCONSIN GRAVEL_*	Material passing a 4-mesh sieve
PENNSYLVANIAN	_LASALLE_*	Limestone
	Lonsdale	Limestone
	_CAPROCK No. 6 COAL_*	Limestone
	Caprock St. David Coal	Limestone
	CAPROCK No. 5 COAL	Limestone
MISSISSIPPIAN	SALEM*	Limestone
	Warsaw	Limestone
	Burlington-Keokuk	Limestone
	Springville	Calcareous chert
DEVONIAN	_BAILEY_	Cherty limestone
	“Middle Devonian”	Limestone
SILURIAN	_“NIAGARAN”_*	Dolomite and cherty dolomite
ORDOVICIAN	_MAQUOKETA_*	Dolomite
	DECORAH(?)	Cherty limestone
	SHAKOPEE*	Cherty dolomite

Capitals = woolrocks. * = also sub-woolrocks in places.
Upper and lower case = sub-woolrocks only.
Italics = of major importance.

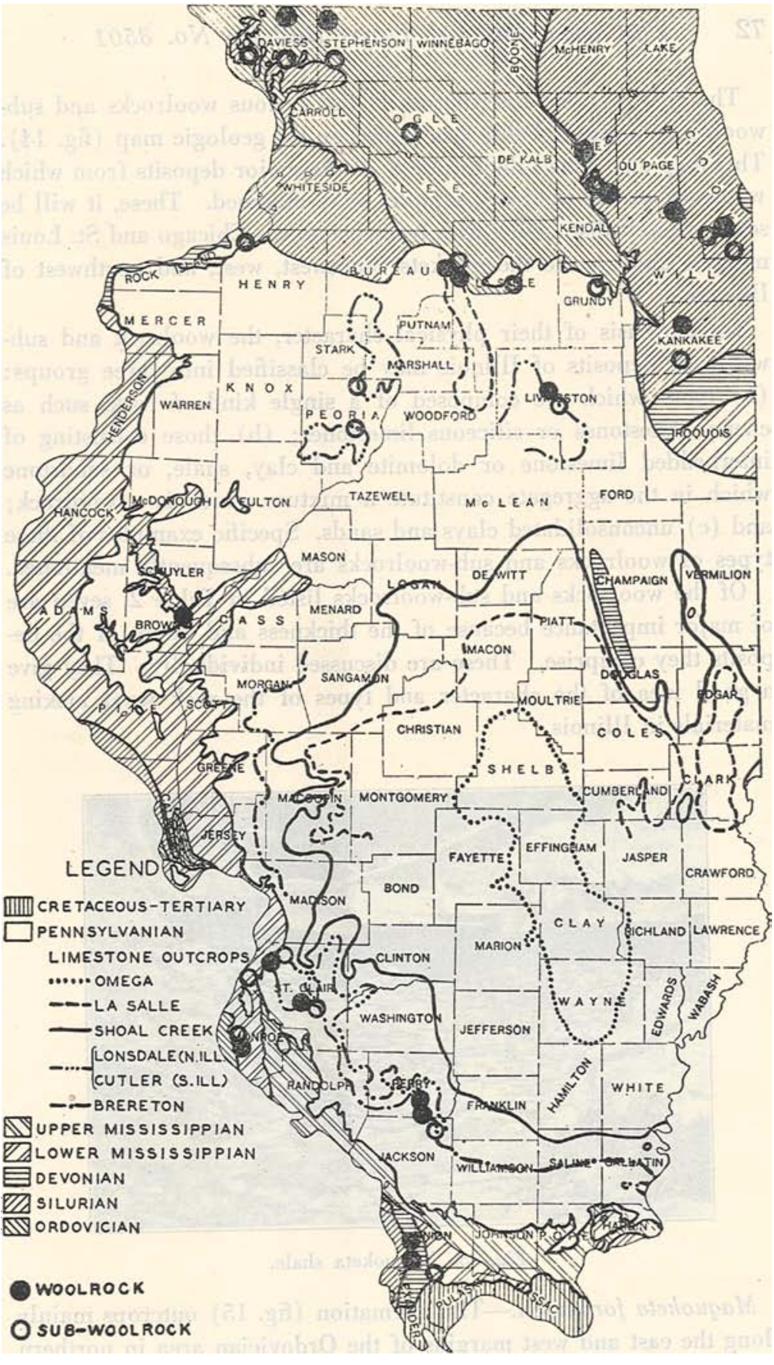

Fig. 14. Geologic map of Illinois showing major deposits of woolrock.

The general areal distribution of the various woolrocks and sub-woolrocks listed in Table 2 is shown on the geologic map (fig. 14). This map also shows the locations of the major deposits from which woolrock or sub-woolrock samples were obtained. These, it will be seen, are well distributed with reference to the Chicago and St. Louis markets and also to the markets southwest, west, and northwest of Illinois.

On the basis of their physical character, the woolrock and sub-woolrock deposits of Illinois may be classified into three groups: (a) those which are composed of a single kind of rock, such as cherty limestones or siliceous limestones; (b) those consisting of interbedded limestone or dolomite and clay, shale, or sandstone which in the aggregate constitute a mixture which is a woolrock; and (c) unconsolidated clays and sands. Specific examples of these types of woolrocks and sub-woolrocks are subsequently mentioned.

Of the woolrocks and sub-woolrocks listed in Table 2, seven are of major importance because of the thickness and extent of the deposits they comprise. These are discussed individually. They give a good idea of the character and types of the rock wool making materials in Illinois.

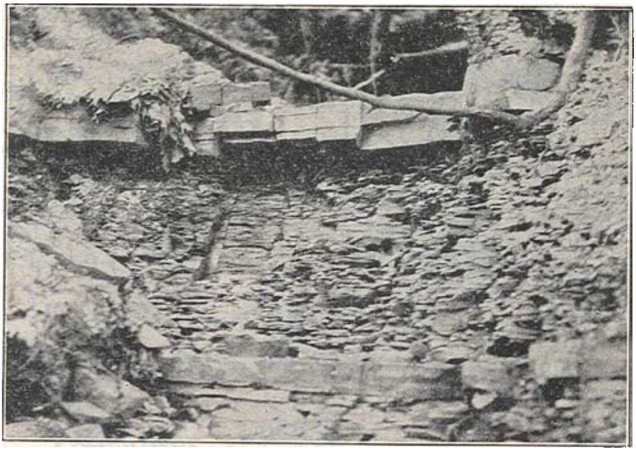

Fig. 15. Maquoketa shale.

Maquoketa formation.—This formation (fig. 15) outcrops mainly along the east and west margins of the Ordovician area in northern

Illinois. The woolrocks and sub-woolrocks of this formation belong to both groups (a) and (b) mentioned above and include deposits as much as 35 feet thick of interbedded shale and comparatively pure limestone or dolomite and also deposits of impure dolomite of fairly uniform lithologic character 20 feet or more thick. The impurities are principally clay and fine silica.

"Niagaran" formation.—The woolrocks and sub-woolrocks of this formation belong to group (a) and are of two kinds, first, dolomites containing clay and fine silica as impurities, and, second, highly cherty dolomite (fig. 16). Locally a thin dolomitic shale is a sub-woolrock. Thick deposits of Niagaran woolrock or sub-woolrock are known in southern Cook County near Chicago where both impure and cherty dolomites are present and in Jo Daviess County of northwestern Illinois where a cherty dolomite is a sub-woolrock.

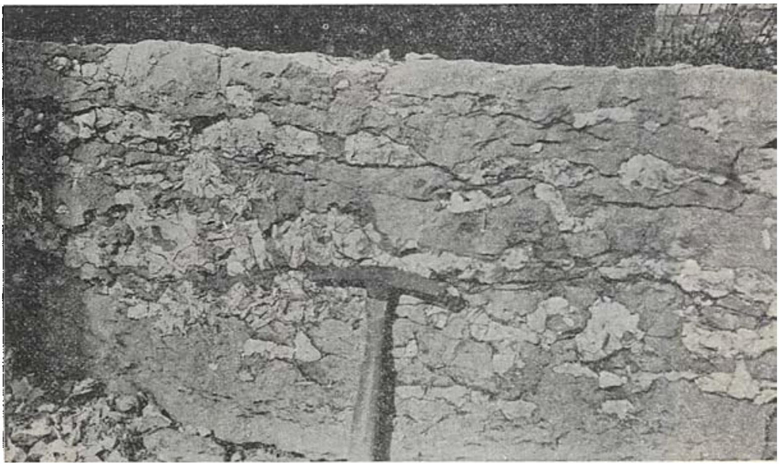

Fig. 16. Cherty Niagaran dolomite.

Bailey formation.—The outcrop of this formation (fig. 17) is restricted to Jackson, Union, and Alexander counties of extreme southern Illinois, where it is 100–150 feet thick and forms conspicuous bluffs 50 to 100 feet or more in height along Mississippi Valley. It is a siliceous cherty limestone, the chert occurring both as nodules and as beds up to about 6 inches thick (fig. 18). Despite the disseminated silica and chert present, the formation as a whole is quite uniform. Analysis of five samples each taken from 30 feet or more of the formation and scattered over a 14-mile stretch showed a maximum variation in CO_2 content of but 5 per cent.

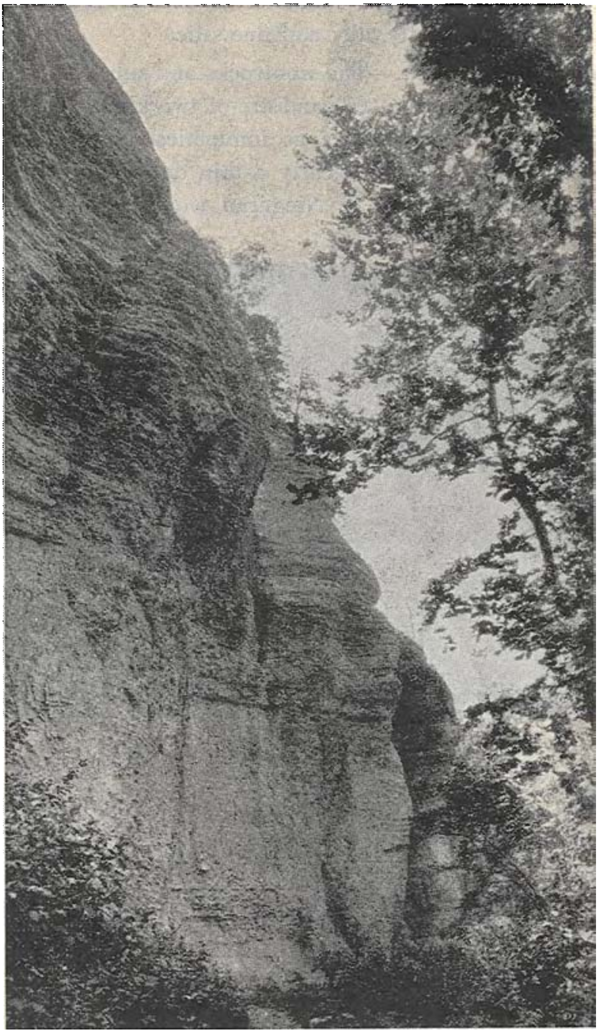

Fig. 17. A typical cliff outcrop of about 125 feet of Bailey limestone. (Photograph by J. E. Lamar.)

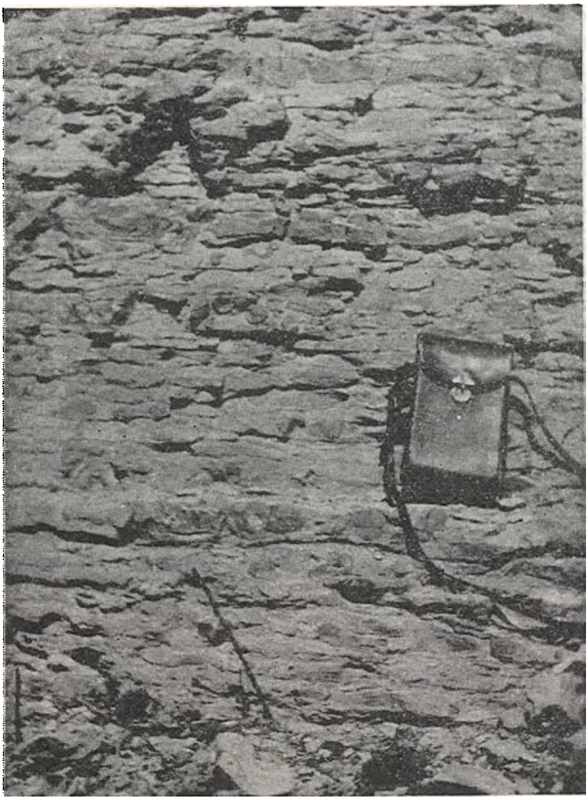

Fig. 18. Typical Bailey limestone. The thin-bedded character of the rock and the chert nodules and layers, which appear darker than the limestone beds, are well shown. (Photograph by J. E. Lamar.)

The Bailey limestone and the cherty Niagaran dolomite mentioned above are rather unique woolrocks in that the impurities present are largely silica which ranges from 31 to 41 per cent in the woolrocks, whereas alumina and magnesia are very low, neither one exceeding 4 per cent in the samples analyzed.

Caprock No. 6 coal (Brereton limestone).—This limestone (fig. 19) outcrops in several parts of the State but is best developed in St. Clair and Perry counties of southwestern Illinois, where it locally reaches thicknesses of 15 to 23 feet but is subject to pronounced

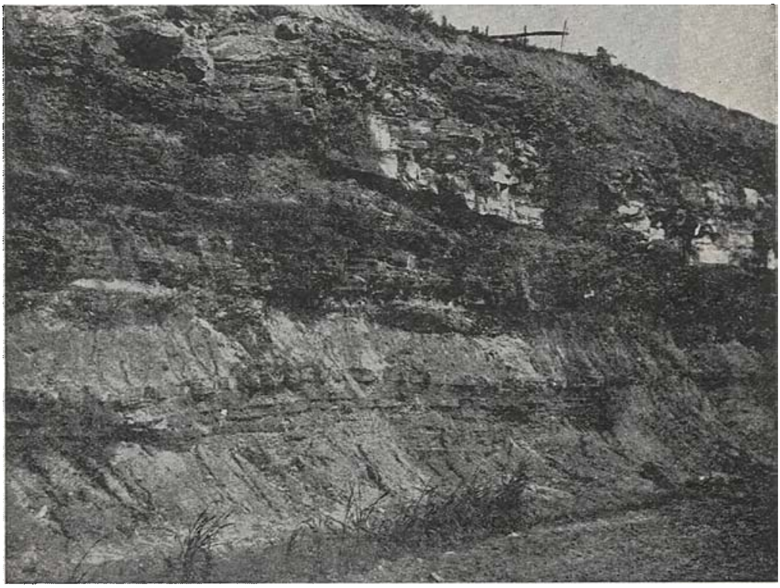

Fig. 19. Caprock of No. 6 coal.

lateral variations in thickness. As coal No. 6, which it overlies, is being stripped at several places in these counties, large quantities of the limestone can be secured in connection with coal mining. The limestone is commonly dark gray to almost black, due to included carbonaceous material. It occurs in layers 6 inches to 3 feet thick and is overlain and usually underlain by shale. The typical woolrock phase of the Brereton formation is an impure limestone containing clay and finely divided silica. The underlying and overlying shales are a potential source of material for addition to the caprock, where it is a sub-woolrock, in order to yield a mixture having the chemical composition of woolrock.

LaSalle limestone.—Although outcropping in many parts of Illinois, the LaSalle limestone (fig. 20) is known to be important for rock wool only in LaSalle and Bureau counties of northern Illinois. Here the formation is 10 to 30 feet thick and is usually a sub-woolrock, though locally it is a woolrock. The formation consists of limestone of varying degrees of purity interbedded with thin

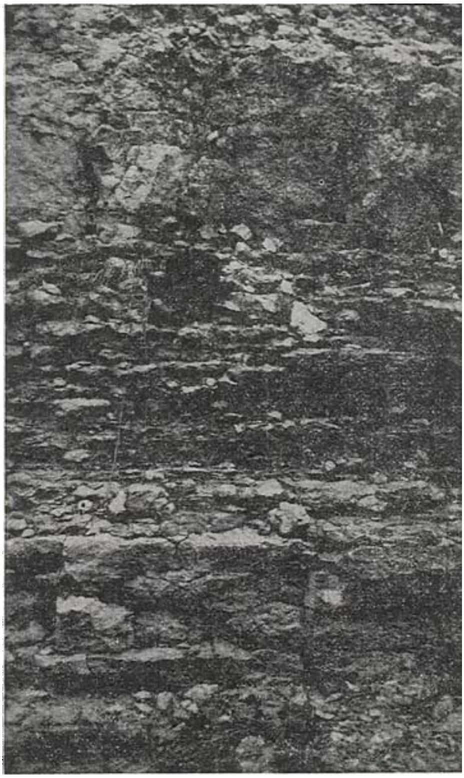

Fig. 20. LaSalle limestone.

layers of shale or clay. The impurities in the limestone are clay and silica. It is commonly overlain by shale and underlain by thin, interbedded strata of shale and limestone, some of the latter being woolrocks. Both the overlying and underlying materials serve as a potential source of material to be added to the LaSalle limestone to yield a suitable mixture where the formation is a sub-woolrock. In the LaSalle-Bureau County area the LaSalle formation is characterized by a low $MgCO_3$ content, usually less than 5 per cent.

Wisconsin gravel.—Diverse types of gravel deposits (fig. 21) laid down by waters from the melting Wisconsin glacier, the last to enter Illinois, are particularly prevalent in northeastern Illinois. Because

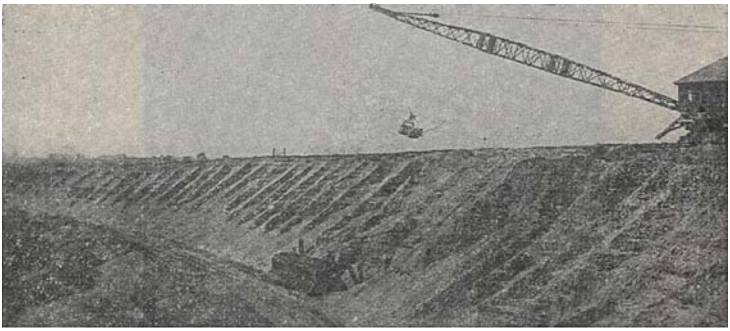

Fig. 21. A mammoth sand and gravel pit in northeastern Illinois.

of the extent of these deposits and their occurrence in economically favorable areas for rock wool manufacture, a preliminary study of Wisconsin gravels was undertaken in anticipation of engineering progress which may make unconsolidated materials usable for rock wool manufacture. Seventeen samples of gravel were secured from representative deposits. The samples were screened to four different grades and the CO_2 content of each grade was determined. The results of these studies indicated that in general that part of the gravels retained on a 1-inch screen was too high in carbonates to be sub-woolrock and the material passing the 1-inch screen but retained on a 4-mesh sieve was too high in carbonates to have the composition of woolrock though many samples were within the sub-woolrock limits. The minus 4-mesh fraction was generally within the woolrock limits or very close to them. This fraction, constituting 31 per cent by weight of the samples, had an average CO_2 content of 26 per cent.

Wisconsin till.—Thirty-two samples of Wisconsin till, which is a pebbly clay, were tested. Of these, four were woolrocks and 14 were sub-woolrocks requiring additional carbonates. The fact that tremendous quantities of till exist in northern Illinois and are in many places associated with large, readily accessible deposits of dolomite or limestone capable of supplying the necessary carbonate for addition to sub-woolrock till, suggests that some of these deposits may become of commercial importance when engineering research reveals economical methods for utilizing such materials for making rock wool.

RESEARCH TO DETERMINE THE COMPOSITION LIMITS OF WOOLROCKS

The first step in our research on determination of composition limits of rock wool, and hence woolrocks, was concerned with the construction of experimental equipment capable of producing a material as good as or better than products already on the market. Figures 22, 23 and 24 show the equipment which was employed in our blowing tests. Figure 22 shows the transformer, the high frequency induction furnace, and the tilting device.

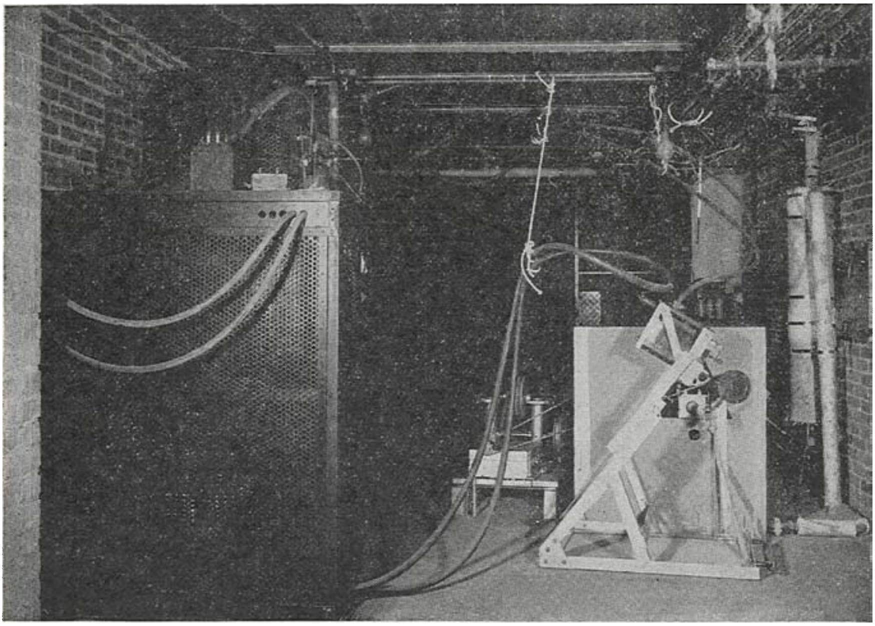

Fig. 22. Transformer, induction furnace, and tilting device.

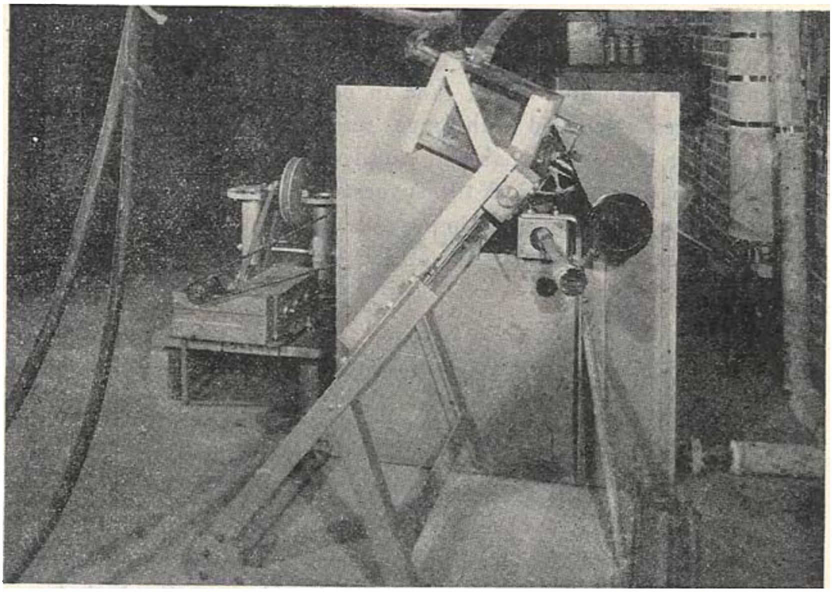

Fig. 23. View of crucible in pouring position showing arrangement of steam gun and pressure gauge.

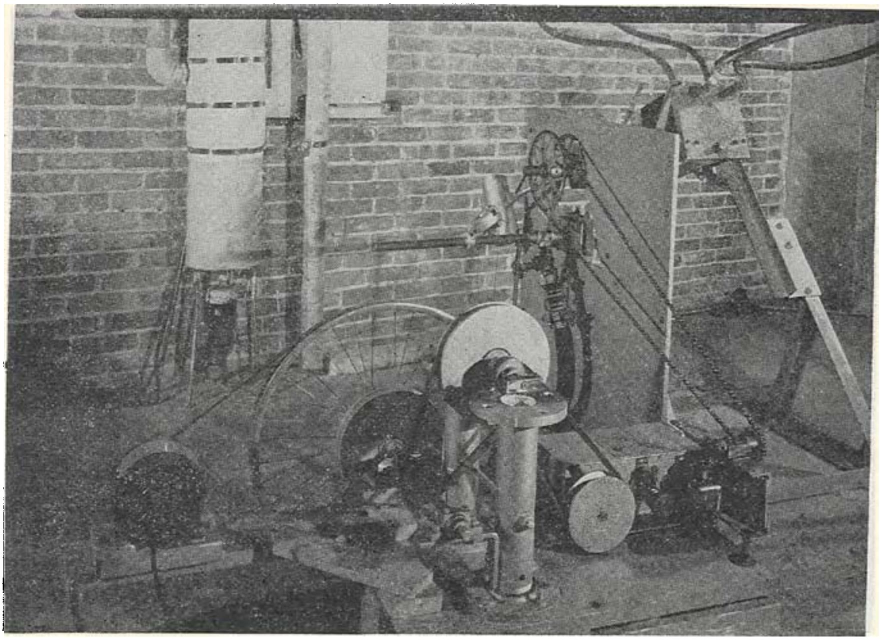

Fig. 24. Side view of tilting mechanism and controls on steam gun.

The operation of this equipment was spectacular. The rock was melted by induced high frequency current acting on a graphite crucible. This part of the apparatus is shown in the position tilted for pouring. A temperature of 1500° C. could be reached in 20 minutes. One kilogram of calcined rock was used in each experiment.

The blowing operation was started by tilting the furnace mechanically by means of the motor and reduction gear shown in Figure 23, and in the background of Figure 24. The stream of molten rock was subjected to a 70-pound pressure blast of steam directed from behind the safety screen. The impact of the steam blast with the molten rock reduces the liquid to small droplets which are propelled at high velocity through the air. During their flight, these droplets spin out the fine threads which make up rock wool (fig. 25). The wool is deposited in billowy masses on the floor in about the position occupied by the camera used for making these photographs.

The whole blowing operation required only 35 seconds per kilogram of calcined rock. During this time it is estimated that 4000

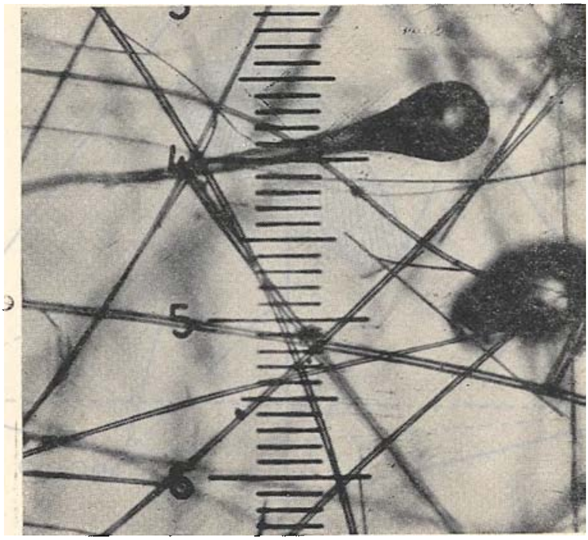

Fig. 25. Droplets and threads of rock wool.

miles of fiber are produced. Calculations based on the velocities attained by expanding steam indicate that about 300 fibers are produced simultaneously.

The range of compositions suitable for rock wool was determined by experimental blowing tests conducted on 108 synthetic mixtures made up to predetermined compositions. These were all blown under the same conditions, namely, 1500° C., 70-pound blast pressure, and 35 seconds pouring time per kilogram of melt. These conditions are closely comparable to those used in industry. It was found that subjecting commercial wools to this treatment yielded products which, under the microscope, could not be differentiated from the materials from which they were blown.

In plotting results, use was made of plane sections of an equilateral tetrahedron (fig. 26). In this tetrahedral figure each apex

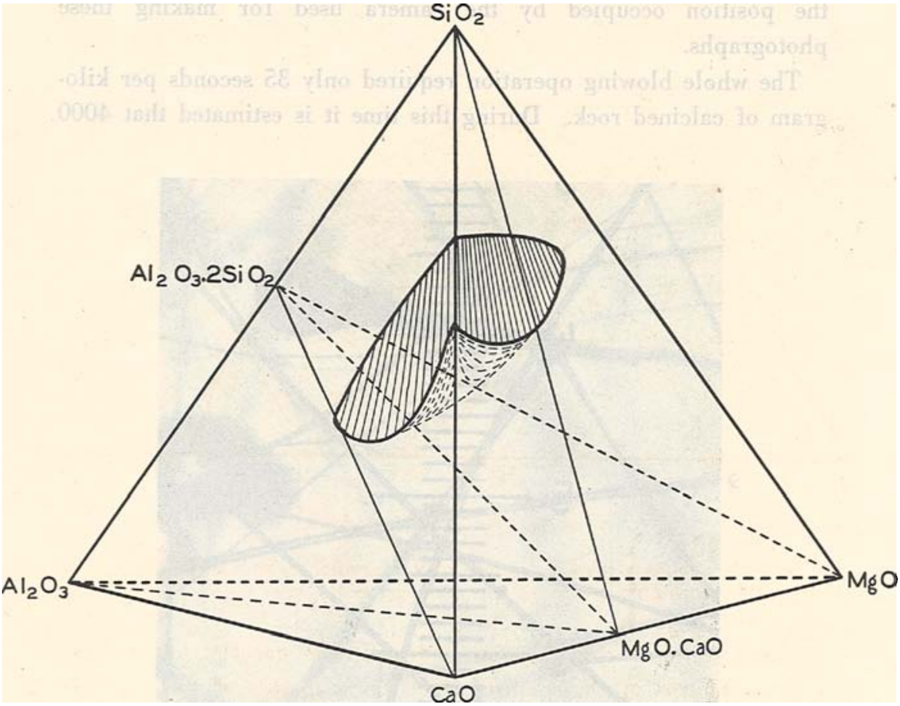

Fig. 26. Diagrammatic representation of composition range suitable for rock wool production.

represents 100 per cent of the component indicated. Each edge is representative of compositions of but two of the four components; each face, of three of the four components; while any given point within the figure is representative of a certain definite composition involving all four of the components.

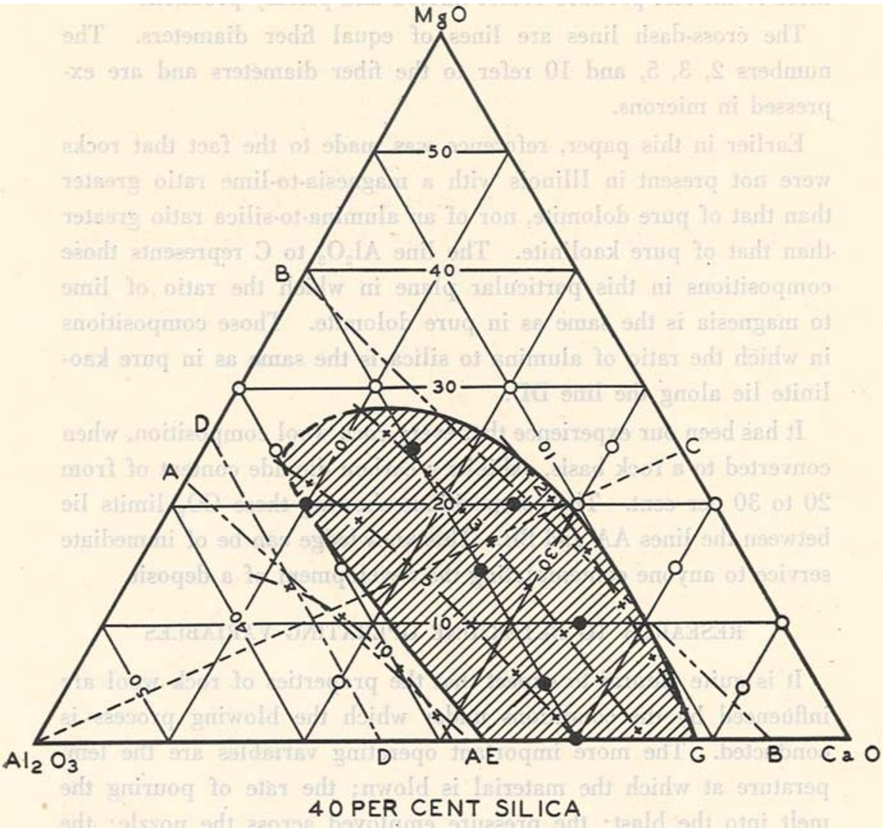

Fig. 27. Diagram showing range of compositions suitable for rock wool production in the quaternary system at 40 per cent silica.

Plane sections from this tetrahedron, taken parallel to the base, give us figures of this nature which, as a matter of fact, are the actual type on which the results were plotted during the course of the work. This particular diagram (fig. 27) shows such a section containing 40 per cent silica. The solid circles represent experimental wools which we consider satisfactory for insulation. The area delineated by the heavy line indicates a range of composition suitable for the production of rock wool. Unsatisfactory compositions are represented by the open circles. Compositions falling to the right of the shaded area yield fine, short-fibered wools; while those to the left produce coarse-fibered and prickly products.

The cross-dash lines are lines of equal fiber diameters. The numbers 2, 3, 5, and 10 refer to the fiber diameters and are expressed in microns.

Earlier in this paper, reference was made to the fact that rocks were not present in Illinois with a magnesia-to-lime ratio greater than that of pure dolomite, nor of an alumina-to-silica ratio greater than that of pure kaolinite. The line Al_2O_3 to C represents those compositions in this particular plane in which the ratio of lime to magnesia is the same as in pure dolomite. Those compositions in which the ratio of alumina to silica is the same as in pure kaolinite lie along the line DD.

It has been our experience that every rock wool composition, when converted to a rock basis, exhibits a carbon dioxide content of from 20 to 30 per cent. The compositions showing these CO_2 limits lie between the lines AA and BB. This knowledge can be of immediate service to anyone contemplating the development of a deposit.

RESEARCH TO DETERMINE OPERATING VARIABLES

It is quite natural to expect that the properties of rock wool are influenced by the conditions under which the blowing process is conducted. The more important operating variables are the temperature at which the material is blown; the rate of pouring the melt into the blast; the pressure employed across the nozzle; the direction of the blowing jet; and, finally, the medium used for blowing, *i.e.*, air or steam.

With regard to pouring temperature (fig. 28), it was found that an increase of this variable was accompanied by a decrease in shot and fiber diameters, by lighter color, higher bulk density, and increased softness of the wool to the touch.

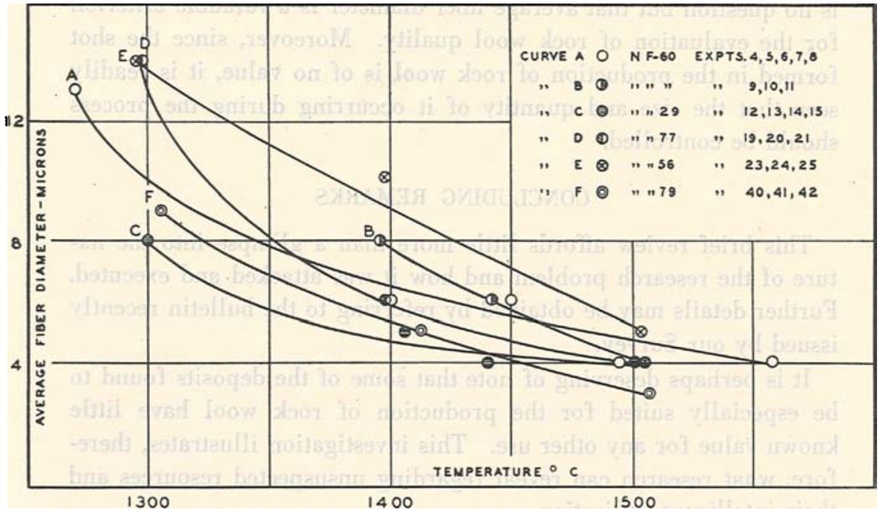

Fig. 28. Variation of fiber diameter with pouring temperature.

Steam pressures within certain limits did not influence the shot and fiber diameters appreciably. There is reason to believe, however, that the number of shot is increased by conducting the blowing operation at lower pressures. In some of our preliminary experiments, such a condition gave rise to the production of heavy wools containing excessive amounts of shot.

Within a limited range, little influence was noted on fiber and shot diameters by variation in the rate of pouring the molten material into the steam blast. An increase in the number of shot produced, however, was found to accompany an excessive increase in the pouring rate. It is believed, however, that careful design of the steam nozzle would be of great importance in decreasing the number of shot.

The fiber characteristics of rock wool determine the important properties of heat conductivity and bulk density. Wools of high bulk density and with probable high heat conductivity are found to consist of extremely fine fibers. Coarse-fibered wools are not effective in entrapping air pockets of sufficient smallness to prevent convection. Those rock wools which we considered of satisfactory bulk showed fiber diameters lying between 2 and 10 microns. There is no question but that average fiber diameter is a valuable criterion for the evaluation of rock wool quality. Moreover, since the shot formed in the production of rock wool is of no value, it is readily seen that the size and quantity of it occurring during the process should be controlled.

CONCLUDING REMARKS

This brief review affords little more than a glimpse into the nature of the research problem and how it was attacked and executed. Further details may be obtained by referring to the bulletin recently issued by our Survey.

It is perhaps deserving of note that some of the deposits found to be especially suited for the production of rock wool have little known value for any other use. This investigation illustrates, therefore, what research can reveal regarding unsuspected resources and their intelligent utilization.

ELECTRICAL DEVELOPMENT IN TEXAS DURING THE PAST TWENTY-FIVE YEARS

S. M. UDDEN[1]

In the world in which we are living, whether this world be our home, our work, our city, our state, or our nation, our every act reflects the advances in the arts and sciences since the beginning of time, and Texas, as we see it today, is the result of the labors of its present inhabitants and those who have gone before them. The arts and sciences have made our present state of civilization possible and as we see approaching Texas' one-hundredth birthday and the Centennial, we are becoming more conscious of its achievements and greatness. Rich in resources and rich in its heritage of men, Texas has accomplished much in her lifetime and today looks back on its industrial and political history with pride.

During this 100 years several distinct periods of development have occurred; namely, the early settlement era, the cattle era, the railroad building era from about 1870 to 1900, and, lastly, the period from 1900 to date, which we might term as the industrial era.

We have around us everywhere evidence of the foresightedness of the pioneers and evidence of Texas' industrial greatness, and our school books today tell our children that Texas produces more cotton, more oil and gas, more cattle, more sulphur, more wool and mohair than any other state in the Union. We have, I am informed, the only antimony smelter in the United States and it is interesting to note that the first electric street railway built west of the Mississippi River was placed in operation at Laredo, Texas. Fort Sam Houston at San Antonio is Uncle Sam's largest army post. Kelly Field and Randolph Field, the "West Point of the Air," are Uncle Sam's largest air fields. The resources and developments in Texas are rapidly bringing our State to the front.

Among the industries which have helped enormously both in agricultural and industrial growth is the electrical industry in its many phases. Many of us may think of the electrical industry in terms

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of light and power, but equally important branches of this industry are to be found in our telegraph and telephone developments and in the radio.

The electric light and power industry, I am told, had its inception in Texas fifty-two years ago, which takes us back to 1882 while Thomas Edison was planning the famous historical Pearl Street Station in New York City. At that time a company was formed in Houston, then a city of about 20,000 population, to construct and operate an electric light plant. This plant, consisting of five ten-light Weston Arc Machines driven by a 125-H.P. Armington and Sims high speed engine, was completed and placed in operation on December 17, 1882, giving arc light service in a few stores, houses, and hotels.

During the next twenty-five years electric plants were installed in the larger towns and cities throughout the State. Historical records of these plants are on the whole very meager, making difficult any attempt to make a concise statement of development.

Should the occasion present itself, some time and effort could be very profitably devoted to compiling an accurate history of electrical development in this State. A student of electrical engineering so inclined would find the preparation of such a history very interesting and a pleasant study which might be acceptable as a thesis for a master's degree. Much of this history is still available because many are yet living who pioneered in the development of our early electric light and power service.

We find, however, that some electrical statistics for this State are available for as early as 1907. In that year 68,447 homes and commercial establishments were using electric service. In 1933 electric service had been extended to 675,572 homes and establishments. In a period of twenty-seven years, service has been increased to ten times the number in 1907.

In 1907 the total installed capacity of all electric plants in the State was 48,558 kilowatts, which is no more than the capacity of many modern power plants today. In 1933, installed power plant capacity totaled 935,200 kilowatts, approximately twenty times the capacity of 1907.

Probably the greatest development in the electric light and power industry during the past twenty-five years has been the construction of electric transmission lines, which transmission lines have made electricity available to practically all cities, towns, and villages within the State. Few people, even in this audience, realize that the innocent electric clocks which are found in homes at Brownsville or Houston, Dallas, or Amarillo, though miles apart, are receiving their electricity from electric lines connected with each other, and that these same clocks are all keeping exactly the same time.

Twenty-five years ago, I am told, the only transmission lines operated as such in the State were between Houston and Galveston, and Dallas and Fort Worth used to supply the interurban railroad with electric power. These lines gave electric service to a few communities through which they were built but were primarily for furnishing power from a central power plant for the operation of the interurban cars. At that time all other electric customers received their electric service from their local isolated electric plant.

Coincident with the construction of the electric transmission lines came the construction of larger and more efficient power plants with the result that these power plants made transmission lines economically possible. There came the full realization that the combination of transmission lines and a few large power stations were more economical than individual stations, besides having the added advantage of giving electric service to the smaller communities not yet supplied with electricity.

By generating energy in large central plants, economies were effected in fuel, labor, and other expenses which reduced generating costs. The addition of many new customers to electric lines resulted in lower costs and placed a greater supply of energy in the small communities than could be obtained from individual plants. With this realization in mind the electrical industry in Texas began formulating plans for transmission systems, and the first transmission line was built by the Texas Power and Light Company between Fort Worth and Waco in 1912 with branch lines to Hillsboro and Waxahachie and Ferris. In 1913 this line was extended to Temple and the following eight or nine years the system was very rapidly extended in the northern and central part of the State.

The development in that area was only natural as that section was the more densely settled at the time. As other sections of the State grew, companies serving those areas built similar lines until the major portion of the complete transmission system in the State was finished in 1931 with the completion of a line to Brownsville and the lower Rio Grande Valley connecting with San Antonio. During this period of nineteen years, transmission lines had been constructed and connected with each other so that today practically all lines could be operated as one power system.

The first transmission lines constructed in north Texas were built on steel towers, but during the war period steel became very expensive and difficult to obtain. As a result of this condition creosoted pine poles, which had been used first in 1913–14, came into general use for transmission line service with a resultant lower ultimate cost.

The value of the various transmission systems to the State of Texas is readily apparent from the fact that in 1917, 195,148 customers were using electric service, whereas today there are approximately 700,000 electric customers in the State. These customers are being served through a network of 27,000 miles of major transmission lines, 22,000 of which have been constructed during the past twelve years.

The first lines constructed in this State used copper wire as a conductor. This, of course, is an excellent conductor but heavy, thus requiring a close spacing of poles or supports. Aluminum wire has been developed which permits greater spacing between poles and thus substantially reduces transmission line cost.

The majority of lines operate at 66,000 volts or less, but the last several years have seen the construction of trunk lines between major power stations which operate at 130,000 volts.

Power plant development in the State paralleled the development of the transmission system. The first large plant was constructed at Fort Worth; however, the first complete new and modern plant was built in Waco in 1913 as the main central station of the North Texas Transmission network. This plant was built on the Brazos River and had a capacity of 12,000 kilowatts. Since that time many other modern and efficient plants have been built, such as the 75,000-kilowatt plant at Trinidad, the 110,000-kilowatt plant at Houston, and the 60,000-kilowatt plant at New Braunfels and other smaller, highly efficient plants at various locations.

The Trinidad plant was, and is still, of particular interest in that it was the first large power plant in Texas to use powdered lignite for fuel. This plant was built at the mouth of the Lignite Mines; lignite is delivered through conveyors to the plant, where it is powdered and then burned much the same as is natural gas.

Likewise the plant of the San Antonio Public Service Company at New Braunfels originally burned lignite for fuel, but, as in many other plants, this fuel has been discontinued due to the great abundance of natural gas for fuel.

The production of electric energy is, however, not limited to the use of fuel-burning power plants. In areas where there exist dependable supplies of water from lakes and rivers, hydro-electric power can be produced. If such water supplies are reasonably close to those points where electricity is consumed, the construction of hydro-electric plants may be economically possible. In Texas, however, suitable streams of consequence traverse flat and prairie country, thus limiting their fall and making them less attractive for power development, or the best sites for development are at points sufficiently distant from the load centers that the cost of transmission lines renders their construction economically unsound. Texas has, however, eleven hydro-electric plants, all of which I believe have been constructed during the past twenty-five years. The total capacity of these plants, with a normal flow of water, is about 20,000 kilowatts. There are two plants on Devils River north of Del Rio, one on the Rio Grande just above Eagle Pass which has a capacity of 8,000 kilowatts, two small plants on San Marcos River, and eight on Guadalupe River having a capacity of about 10,000 kilowatts.

In the foregoing I have outlined the electric light and power development in the past twenty-five years. We have seen electricity march steadily forward with a result that electric service is now available to practically all small communities in spite of the fact that in this State distances are great and the density of population per square mile is smaller than that in the majority of other states of the Union.

What our future developments along these lines will be remains to be seen. We are sure, however, that both industry and agriculture will continue to expand for as yet we have but scratched the surface.

Telephone and telegraph as well as electric light and power have made very rapid advances in this State during the past twenty-five years. Neither the present Southwestern Bell Telephone Company nor the Southwestern Telegraph and Telephone Company had been organized in 1909, so in reality our telephone service consisted of a large number of individually owned local and long distance telephone companies. I have been unable to find any record of the actual number of telephones in operation in 1909; however, it may be fairly safe to estimate that in that year there were probably fifty thousand telephones in the entire State, about equal to the number in the city of Dallas today.

Local exchanges in the larger cities were of the so-called common "battery" type and in the smaller communities of the so-called "magneto" or hand-ringer type. In a few of our larger cities the telephone lines in the congested parts had been placed underground but by far the majority of the lines were carried on the very familiar telephone poles. Long distance as well as the telegraph circuits were likewise carried on poles overhead.

Today practically all long distance telephone circuits in the State are owned or operated by the American Telephone and Telegraph Company or the Southwestern Bell Telephone Company. As a result of this there has been built a vast communication system until now it is only a matter of a minute or so to obtain connections which enable us to talk to the far corners of this State or to almost any city in the United States.

There are now approximately 533,000 telephones in service in Texas, approximately ten times the number that were in use in 1909. This short space of twenty-five years has seen the majority of the overhead exposed telephone wires replaced with overhead and underground cables in all except our smaller communities, with the result that our conversations are now much clearer and less subject to interruptions.

This same practice has been extended to the long distance telephone circuits and we now have between Saint Louis, Dallas, Fort Worth, and on to Cisco a continuous underground telephone cable, which in turn can be connected to similar cables to Chicago and New York.

Along with voice communication over the telephone lines have come other interesting developments: Teletype, a printing telegraph machine, was first placed in general operation in Texas in 1931, less than four years ago, with the result that today 258 such machines are in actual operation in the State. With the use of these machines it is possible for one business house to obtain direct connection with another business house having a similar machine installed in the same way that one obtains connection with a distant party on a telephone connection.

The vacuum tube, as commonly seen in our radio, has made possible many of the improvements in telephone or voice communication. It is this tube which is used as a repeater on the long distance telephone circuits which steps up the weakened electric current and sends it along its journey. A similar vacuum tube has also made it possible to place additional voice or telegraph circuits on existing wires. This together with multiple telegraph has made possible a maximum utilization of existing telephone lines, and today one pair of two-wires at any one instant can carry four separate telephone conservations, twelve to fifteen telegraph circuits, and an additional carrier telephone circuit.

Probably the most familiar improvement to our ordinary telephone service in this State during this period is the installation and use of the so-called "automatic" or machine switching telephone exchange. This equipment is a very definite advance in telephone service, both from the standpoint of the telephone company as well as for the user.

The first automatic telephone equipment installed in Texas was put into operation in Dallas in 1912. For a good many years no further installations were made, but at the present time Dallas, Fort Worth, Houston, San Antonio, Austin, Amarillo, and probably several other towns are completely equipped with automatic switching equipment. This equipment is successful and we may except within the next twenty-five years to see automatic telephones in the majority of our Texas cities.

As a result of this rapid and extensive development we find that in both industry and government the telephone and telegraph services are practically indispensable.

The infant of the electrical industry probably is the radio but this is fast becoming one of the important functions of electricity. Twelve years ago the radio was just emerging from the commercial code stage to the experimental broadcasting stage. Since that time radio has developed at an unbelievable rate and we now have a total of thirty-two broadcasting stations in Texas with a total rated output of 169,915 watts. The telephone lines in connection with the broadcasting stations have made this development possible and today we may be in our home in the mountains in west Texas, on the plains of north Texas, or along the coast in southeast Texas and listen in on a two-way conversation between New York City and the South Pole, or we may hear the hourly emergency broadcast of our county or city police department, or we may hear periodic reports from the planes along the numerous air lines to their headquarters.

Great though these developments have been, in my mind probably the most valuable and greatest development in the electrical field in the past in Texas has been the training of its men, and our development in the next twenty-five years will be largely in the hands of those now beginning their careers in the engineering and allied lines. Texas has provided for the training of its people. It has insured its future development and progress by providing educational facilities which are recognized throughout the Nation. The State University, as well as other public institutions everywhere, is sending forth men prepared to meet the problems of tomorrow and to carry forward the progress of this State.

I do not have a record of the number of graduates from all of the engineering and scientific schools in the State, but those of the College of Engineering in the University will illustrate this progress. In 1909 there were 237 students enrolled in the Engineering Department. During this year a total of 914 students are enrolled in the various branches of engineering. In the past thirty years a total of 1509 engineering degrees have been conferred by the University, which includes 112 graduate degrees.

It is true that there is a far greater number of engineers actually employed in the State today than is represented by the above figures, but we must remember that these are figures of graduates from the University alone and that there are five or six other schools contributing to the total number of technically trained men. Many of this number have found their field of work in other states but by far the larger portion remain within the State and have become active leaders both in industry and in civic organizations.

Much of our future, both political and industrial, is in the hands of the various schools making up our educational system. Today probably more than ever before do we need a well-balanced school. In my opinion a student should be taught to study and to reason for himself. He should not be taught ideas and theories which probably represent only the mind of some individual. The ability to investigate, to analyze, and to reach sound conclusions on any problem is, I believe, more valuable for the success of an individual than almost any other training that might be received.

It is my pleasure to say that I consider my years as a student in this school the most valuable part of all of my training, and I wish at this time to voice my appreciation, and I am sure the appreciation of many others, for the work of those men both young and old who so unselfishly devote their labors in the training of the younger generation in preparation for their life work.

SOME PROBLEMS IN FOUNDATION DESIGN; THE SOIL LABORATORY AS AN AID IN THEIR SOLUTION

W. E. SIMPSON[1]

In the field of building construction I cannot help but feel that there is generally a very careless attitude taken towards the details of the foundation of the building; a more or less hit-or-miss method of drawing the foundation plans, indicating a very evident careless, "don't-care" attitude towards this important part of the building.

In the smaller buildings foundation engineers are rarely employed while in the larger buildings structural engineers seem invariably to give more attention to the superstructure than they do to the foundation. In the former case the foundation is apt to be inadequate and in the latter case it is apt to be overdesigned and expensive. A very apparent point of view taken in many of these plans is that a foundation is the amount of concrete and steel shown on the plans, very little consideration having been given to the soil on which this concrete and steel rest. The depth to which a foundation footing is extended is very often determined by guesswork in an office without any reference to or examination of the soils under the structure through means of test pits.

The problem of foundation engineering is not so much to design a certain foundation in such a way that the stress in the concrete and steel is not more than the allowable amount already established as it is,

First, to determine the nature of the soils which lie under the proposed structure;
Second, to select out of these that suitable stable soil which will remain in the state found throughout the life of the structure; and
Third, to determine the carrying capacity of the soil selected.

We have certain stresses established and laboratory tests which determine the strength and therefore the size of all the building materials used structurally in the superstructure. Throughout many years these tests have been carefully carried on by laboratories, much attention being given to determining the allowable working stresses. And these working stresses are generally known and followed. In the case of the soil on which the structure rests, tests

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have also been established, although not generally known nor followed, which enable us to determine the nature or condition—the structure—and the allowable working stresses in the soil.

One of the first of the perplexing phenomena of soils found in the testing laboratory is that certain soils exist in a natural or undisturbed state and also others in an unnatural or disturbed state; that there is a great difference in the action of soils in these two states; and also that a soil in an undisturbed state can be entirely altered by man or by nature. In the undisturbed state the soil is stable and is capable of resisting well-defined stresses without undue strain, while in the disturbed state just the opposite is true.

The measure of the disturbed condition of a soil is largely a matter of determining the amount and condition of moisture in the clays.

One of the greatest natural disturbing factors of soils is the evaporation of capillary water which is constantly rising towards the surface. Natural clays are filled with capillary water, and when this water is driven out no human being can restore the clay to its original structure nor its original ability to carry loads. As this capillary water rises towards the surface of the ground, the heat from the sun's rays starts evaporating the capillary water as fast as it rises. This evaporation is complete down to a certain point; then it continues with gradually diminishing effect until at a certain depth below the surface the natural capillary water has not been disturbed.

The question might be asked, how do these points bear on the selection of a foundation? When the capillary water has been driven out of a clay it becomes dry and coarse in structure containing visible voids and is of a crumbly nature and filled with air. It can readily be conceived that such a soil in the first place is very easily compressed under load, and in the second place the subsequent addition of water to the soil will easily flow into it and instead of becoming capillary water will simply break down the soil into a mud entirely unsuitable for a foundation. On the other hand the clay which is undisturbed contains its original capillary moisture and will not receive any additional moisture and can be relied upon to remain in the condition found.

Of course, an experienced foundation engineer can within certain limits by sight and feel pretty well segregate the disturbed soils from the undisturbed but there is always a transition layer where there is doubt and it is here that the laboratory instruments step in to determine very accurately the depth where the undisturbed soil is reached.

Therefore, through these tests in the laboratory which are intended to determine the nature and conditions of the soil we really arrive at the solution of our second problem. We are enabled to select by elimination the stable soil which will remain in the state found throughout the life of the structure.

I believe that most all of the foundation failures I have ever noted are due to the improper selection of the soil on which to rest the structure. There seems to be a most determined resistance on the part of everyone connected with building construction, more especially in the smaller buildings, to spend an adequate amount of money on the foundation. This leads to the foundation of a building being placed at too shallow a depth directly in the porous disturbed top soils. No amount of reinforcing steel or tie rods or bracing will prevent the porous crumbly loamy soil from becoming saturated with water either from rains or leaky pipes, thereby being transformed into such a state that it is not capable of carrying any load at all. I think this point is most generally misunderstood.

We then reach the third part of our problem: to determine the bearing capacity of this stable soil. Here is where I think the greatest service is being rendered to the foundation engineer by the soil laboratory. Assume that we have found a stable clay and all that is desired for our foundation. All stable soils or clays compress or flow under load and they continue to compress or flow through the years depending upon the intensity of the load applied, their plastic state,. and their depth. We are assuming that the loads on the foundation can be so carefully calculated that the intensity of pressure on the foundation clay throughout our structure is exactly the same, which would therefore mean that all footings would settle a like amount. Any variation in this intensity of pressure will always mean a differential settlement in the different parts of the foundation. Assuming that we have selected a foundation soil at, say, 20 feet below the surface, this soil has had on it by reason of the weight of the earth above 2300 pounds per square foot of pressure. Under this pressure it has reached a point of equilibrium so far as further consolidation or settlement is concerned, that is, the resistance to water being driven out under pressure is just balanced by the weight of the soil above. If now a structure is placed on this soil at this depth which increases the pressure, further consolidation will occur and a settlement of the structure will result until the soil again reaches a point of equilibrium. This is a real conception of our problem of determining the carrying capacity of the soil selected.

It will take longer for the second point of equilibrium to be reached when the additional load is very high than when the additional load is comparatively low, while if the additional load is very excessive for the particular soil in question the soil may never reach a state of equilibrium and the settlement of our structure continue indefinitely and un-uniformly.

Our real problem is, then, not what bearing capacity the soil in question has, but how much additional weight can be placed on the soil above that which has already been put on it due to the surcharge load of the earth above the foundation level. In some structures the total additional load is the total weight of the structure and its live load; in others, like buildings with deep basements, it is the total weight of the building and its live load less the weight of the soil which has been excavated for the basement.

When an additional load beyond that under which it has been deposited is placed on the clay, settlement immediately begins and continues at a rapid rate through a certain period of time and then gradually diminishes so that after a certain total period of time there is practically no further settlement.

If on a structure built on clay, levels were taken over a period of years at regular intervals of time and a curve plotted indicating the amount of settlement at each interval of time, it would result in what is called a time settlement or time consolidation curve, starting off steep and gradually flattening out. While such time settlement curves taken of an actual building are probably the best form of measurement by which to determine this time settlement curve for a certain clay, still it can be readily seen that there would be quite an expense involved and years and years of time spent before any valuable information could be accumulated.

However, there has been developed a little testing apparatus which may be used in a laboratory which will determine this time settlement curve for us in the matter of a few days, which is just about as accurate as measurements over the actual building over many long years. A small disk of the foundation soil in question is placed into this little machine and a constant load applied. Due to the very delicate measuring dials the consolidation of this 1-inch sample can be determined over a period of days and this record, by the proper mathematical calculations, transferred into the total amount of consolidation of our clay bed whose thickness we know.

But before you can determine what additional weight may be placed on your clay you must determine the total settlement which your structure will stand and the length of time in which you want that total settlement to be reached.

It has been found that there is a relation between the total settlement of a foundation and the differential settlement of its different parts. At least it can be said that a very large total settlement will generally result in an excessive differential settlement. This differential settlement in some types of buildings cannot be even one-fourth inch. For instance, in residences, if two adjacent footings of a residence have a differential settlement of one-fourth inch to one-half inch destructive cracks will occur. In a two-story school building a larger differential settlement can be allowed, which makes a larger total settlement of the foundation to be allowed. In a very tall structural steel and reinforced concrete frame office building sometimes as much as 2 inches of differential settlement can be allowed, which would mean that 4 or 5 inches total settlement in the foundation can be allowed before this 2-inch differential settlement would be reached.

After you have selected a suitable clay for a foundation, then from the time settlement curve of that clay the total settlement which can be allowed for the type of structure contemplated must be determined and from this the allowable soil pressure chosen. How different this method is from the old haphazard way still used by some—in guessing at the so-called soil value at no matter what depth the foundation. I see many today designing a foundation under certain predetermined pressure for a certain depth and then after starting construction increasing that depth two or three times without decreasing the design pressure in proportion to the added overburden at the new depth.

There is another very perplexing problem encountered in the design of foundations, particularly of buildings and highways, and that is the swelling tendency of certain soils practically throughout Texas and more especially immediately surrounding San Antonio.

It is practically certain that if a basement slab or a first floor slab or a sidewalk is placed directly on any soil in this locality which has stood exposed for a number of years the original level of this slab will change. The soil swells due to moisture getting into it from several sources and this swelling occurs with a great deal of force. At one time the writer attempted to measure the intensity of the swelling tendency of some of our soils and it was found that a certain yellow clay, that is often found in this territory, in which are concretions of lime or chalk and which has been disturbed, will swell with a force of over 8000 pounds per square foot. I have noted that the point of maximum swelling is not at the surface but at a point 3 to 6 feet below the surface. Basement slabs of buildings placed just 3 feet below the surface, if there is no drainage provision made, have been known to swell as much as 18 inches. We are now making studies of methods of preventing this swelling in a particular building in San Antonio where the basement slab is about 6 feet below the surface of the original ground. This basement slab has already swelled in the last four years to an extent of 12 or 14 inches and has completely wrecked all of the partitions in the basement by forcing these partitions up against the first floor and causing damage there.

The swelling of the soil immediately on the surface is not as great but is equally as troublesome. It is known that when certain natural undisturbed plastic clays are dried they will shrink and then as moisture reënters afterwards they will again swell until the moisture reaches a certain state where the soil is saturated.

There are two sources of this moisture to cause the swelling. Probably the most common source is the capillary water from some reservoir forcing its way up from below. This is kept down previous to the construction of the building by evaporation due to the sun's heat, but since the building offers shade and prevents to a great extent the evaporation of the capillary water, it again starts to rise and reaches the soil immediately under the slabs and swelling results. Another source of water is from leaky mains or leaky pipes. They will invariably be found under your buildings. The swelling soil will break the pipes and the leaky pipes will cause more swelling.

I have been trying for several years to provide a method of preventing this swelling and I feel that I have almost arrived at a solution of it. When capillary water gets into the soil the only way to get it out is through air ventilation or heat combined with air ventilation. It might be well to note that we have had considerable success in placing a series of drain tile trenches under slabs which should otherwise have been expected to swell. These drain tile trenches are generally dug about 4 feet deep and an open tile drain placed in the bottom. The function of the tile in the bottom is to keep the reservoir of underground water which might come under the slab at any point at least 4 feet below the slab. The trench is then filled not with small gravel, which would form an obstruction to the flow of air, but with very large stones about 6 inches in diameter and all practically the same size in order that a free flow of air can take place in the trench. These trenches are placed at a depth of 4 feet and not over 12 feet apart. At intervals along their length open grates are placed in the floor in order that the circulation of air might be produced. Of course, the tile drains are connected to sumps with pumps which keep the water below the 4-foot level. In several buildings where we were allowed to place these sub-drainage systems in floors that would otherwise have swelled, there has been no swelling of the basement floors. But the most striking results have been obtained in buildings where the slabs have already started to swell—and with a great deal of force; immediately the drains are placed, the swelling stops. In fact, in some instances where the floor is in a display room on the first floor level, tunnels have been dug under the slab for this drainage system and immediately after the tunnels were dug and before the drain tiles or large stones were placed, the lifting of the slab was stopped.

I feel that it is useless to put in any such drainage system, however, unless there is allowed a free circulation of air. It is the capillary water which causes the soil to swell, and it is only the air that will draw this capillary water out of the soil and prevent it from rising. Simply the old type of tile drain placed in a back-filled trench of earth will be of no value. This tile drain system might be considered rather expensive and it is. However, at the first floor levels it is not quite as expensive as the suspended floor over the entire area. Unquestionably a suspended floor is the proper method of preventing the swelling conditions at first floor levels. At basement level it is impracticable to suspend the floor and the tile drain system outlined can be resorted to. I have encountered this swelling of soils in many localities throughout the State, more particularly in numerous school building sites where there seems to be a habit of placing a ground floor 3 feet below ground level. I have often inspected such buildings while the owners or those in charge of them felt quite sure that their buildings were settling in a very pronounced manner while, as a matter of fact, their slab on fill was simply lifting. I mention this as one of our real problems here and in the territory immediately adjacent to San Antonio. Swelling can be expected wherever a disturbed plastic clay is encountered on which the slab is to be poured.

PRODUCTION AND UTILIZATION OF TEXAS BLEACHING CLAYS[1]

D. M. PHILLIPS[2] AND L. V. PHILLIPS[3]

INTRODUCTION

The term "bleaching clays" has been carefully selected as including both the natural and activable bleaching and filtering materials of Texas. By "fuller's earth" is generally meant the natural bleaching material with which we have been familiar for years —in fact even since the King James Version of the Holy Bible, in which reference is made to the bleaching action of "fuller's earth" by name. More recently, and more officially, this same distinction has been drawn in the Code of Fair Competition for the Fuller's Earth Producing and Marketing Industry, which as originally approved uses the words "natural clay-like mineral substance."

So far as I am aware, no one definite term is universally accepted to designate the more recently developed group of bleaching materials prepared in various methods from raw substances which require activation to reach maximum efficiency. The general method of preparation is to treat with an acid—commonly sulphuric acid—a raw mineral substance which is of little or no natural bleaching efficiency but which, when processed, customarily reaches a much higher efficiency than the average fuller's earth. Such finished materials are marketed under various trade names, and some raw materials are marketed as crude clay. All are in effect used for the same purpose, as fuller's earth, and, without touching on the various commercial controversial features, will be included in this discussion of the bleaching earths of Texas.

HISTORY

Fuller's earth has been produced commercially in Texas since 1907, but the industry became of real importance in 1920. For years, almost all of our domestic consumption—particularly in the petroleum industry—came from Florida and Georgia. Up until

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[1] Read by D. M. Phillips.

[2] Producing Engineer, The Texas Company, Riverside, Texas.

[3] Refining Engineer, The Texas Company, Port Arthur, Texas.

1920 these two states practically held a monopoly on fuller's earth, though large deposits were known to exist in Texas, and at least two small companies were pioneering under great difficulties. It is gratifying to note that these pioneers through many lean years and under various guises have prospered and are today the basis of one of the larger producers of Texas.

The petroleum industry became really interested in Texas fuller's earth about 1920, and by 1923 two small but thoroughly modern plants were in operation. These plants, located at Riverside, Walker County, have been in continuous operation, one since 1921 and one since 1923. Taking full advantage of favorable freight rates, they have established the industry on a stable basis as one of the important minor mineral industries of Texas, and they give every indication of continued progress.

About 1926 activated clay became of major importance. The process had been known in Europe but had been little used here until intensive development took place in California using clays now most commonly classed as bentonites. Death Valley clay and Otay Valley clay became well known, and investigations were begun in Texas to locate similar materials. I believe I started the ball rolling when I wrote to Dr. J. A. Udden, then Director of the Bureau of Economic Geology, asking him to tell me where in Texas to start looking for bentonite. It is a fitting tribute to Dr. Udden's knowledge of the mineral resources of Texas that he sent me to Fayette County, where the first and largest production of bentonite in Texas took place.

Since then bentonite or similar substances, by whatever name called, have become of considerable importance in quite a few portions of Texas. In addition to the Fayette County development, in which several companies are interested, one large plant has already been built and another is proposed. Much prospecting is being done, and the outlook is bright for continued development of this steadily growing industry.

OCCURRENCE

Present commercial production of bleaching earths in Texas is confined to a long, comparatively narrow, belt running southwest from Walker County, through Grimes, Brazos, Washington, Burleson, Fayette, Gonzales, and Guadalupe counties, to Bexar County.

Deposits are known farther northeast and farther southwest, and some occurrences have been reported at considerable distances from this general region, but approximately 95 per cent of Texas production now comes from these nine counties. With the possible exception of some deposits near San Antonio, practically all production comes from formations ranging from Pliocene to Eocene. According to the 1933 geologic map of Texas, these bleaching earths seem to predominate along the line between the Oligocene and the Eocene, in the Fleming, Gueydan, Jackson, Claiborne, and Wilcox groups.

PRODUCTION

Mining of these bleaching earths in Texas is a very simple operation, being entirely open pit. Overburden is generally thin and soft, rarely exceeds 10 or 12 feet, and frequently ranges down to 6 feet. Rock hard enough to require blasting is quite unusual, particularly if stripping is done with heavy shovels instead of light draglines or by hand. In general it can be said that overburden on fuller's earth is harder and denser, while on bentonite it is usually soft and sticky. Some deposits of fuller's earth run up to 16 feet thick, though the average is not over 10 feet, and bentonite is generally less even than this—about 6 feet would be a fair average. Deposits of fuller's earth are generally uniform vertically, that is, they exhibit few signs of stratification and show little variation of color or texture in a vertical section. Bentonites usually do exhibit distinct stratifications and frequently show sharp lines of demarcation as to color and texture. These characteristics must be considered in mining, to the extent that production of a high-grade uniform bentonite to be used for activation requires careful selective mining and frequent sampling. In some few rare cases, the gradation from fuller's earth to bentonite is very gradual so that some materials have been classified by some as fuller's earths and by others as bentonites. There is really no hard and fast distinction—the final test is one of bleaching efficiency, raw or activated.

PREPARATION

Fuller's earth.—Texas fuller's earth normally contains from 25 to 30 per cent of free moisture. Under favorable seasonal conditions this will air dry down to about 20 per cent. Moisture specifications on finished materials vary from 3 to 8 per cent for most purposes, though in some cases moistures down to 1 per cent and up to 12 per cent are preferred. Moisture removal at the plant is accomplished by passing earth crushed to minus 3/4 inch through rotary kilns generally held at shell temperatures below 1000° F. From 25 to 30 minutes are required for the earth to pass through the kiln, and some cooling takes place before the earth is discharged to storage bins from which it is fed to screens and mills. Most kilns are equipped with recording pyrometers, and the most efficient are gas fired, while some use hard cord wood.

In general there are three primary commercial sizes of fuller's earth: 16/30 or "coarse mesh"; 30/60 or "fine mesh"; 100 plus or "fines." These various grades are prepared in a series of mills and screens so arranged as to permit of what might be called "progressive crushing," that is, we crush the earth several times instead of just once and screen out sized particles between each crushing. By this method we are able very closely to control the yield of various grades and to reduce the amount of fines produced. Since fines are priced at only one-half the price of coarse mesh, and at times can hardly be disposed of at all, this is probably the most important single feature of plant operations. Screen specifications are usually very close as to the amount of coarse or fine earth above or below limits, though within the limits not a great deal of attention is paid to particle size. For the hard heavy Texas earths, which crush to a distinct sharp-edged grain, metal screens are used almost exclusively. This is the greatest difference in milling technique between Texas and Florida, since in Florida, on account of a soft, light, flakey earth, silk cloth is used on bolting machines. Roller mills are used for intermediate crushing, and either attrition, impact, or roller mills are used for the final reduction to fines.

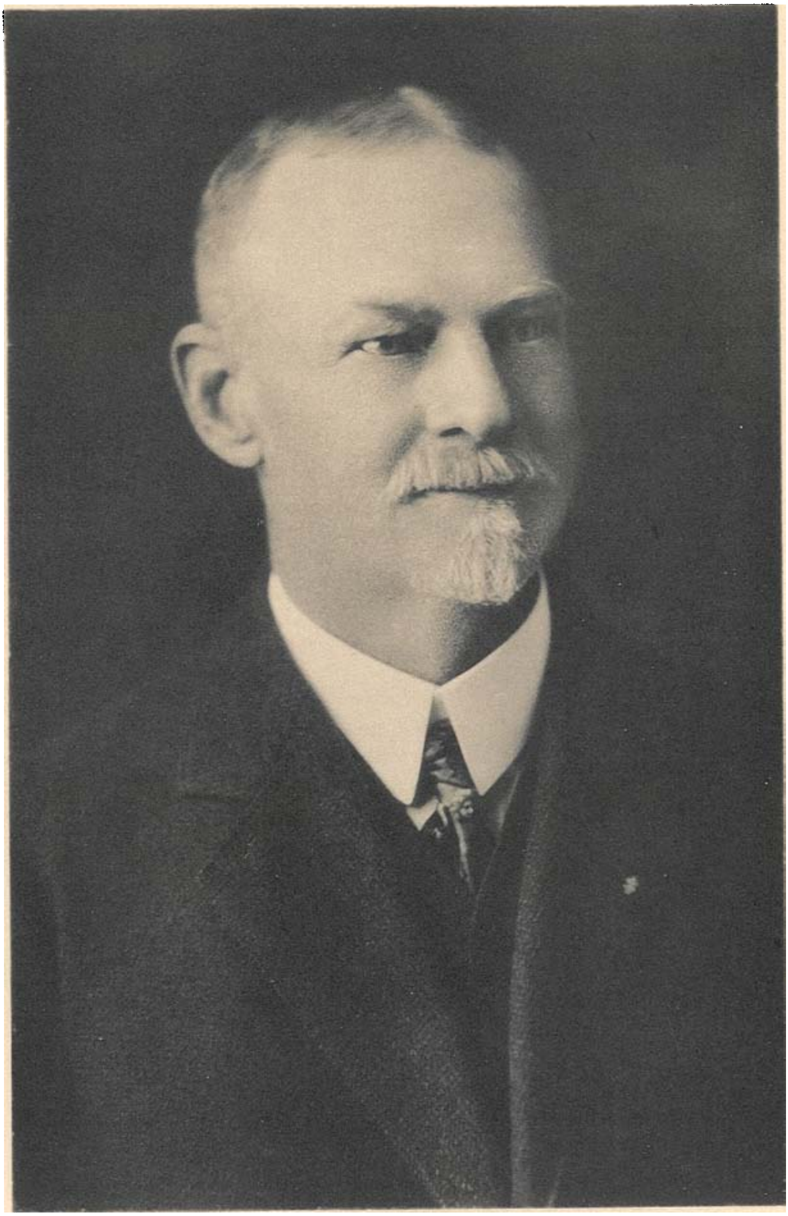
Bentonite.—The activation of bentonites is a subject which could itself be discussed at great length. Initial work was done in Europe many years ago and in this country in California within the past decade. There have been some patent controversies, but the basic principle is well known and of general application. To an accurately proportioned mixture of clay and hot water, fluid enough to be pumped, is added a definite amount of sulphuric acid. The resulting slurry is agitated for several hours at a temperature of approximately 210° to 212° F., using low pressure steam for both heat and agitation. Washing, either by settling and decantation or in continuous counter-current thickeners, produces a thick, almost neutral pulp.

Raw bentonite contains from 25 to 35 per cent of free moisture, and it pulps with great difficulty. Once it has been dried down to 10 per cent or less it pulps readily. To save paying freight on water, and to insure easy uniform pulping, bentonites are either air dried or kiln dried at the mine. Atmospheric drying is purely a seasonal affair in Texas—it works excellently well in parts of California and Nevada most of the year in the open—but in Texas open drying is out of the question and drying under sheds is not at all satisfactory. As a result, rotary dry kilns are used in which shell temperatures are held as low as possible to prevent incipient fusion, to which bentonite is more susceptible than fuller's earth. Moisture contents ranging from 5 to 10 per cent are easily secured with very little fuel and with very satisfactory savings in freight rates.

This kiln drying constitutes the greatest difference between Texas technique and that of California, Nevada, Arizona, and Utah, from which states comes the bulk of our bentonite for activation. It is considered probable by some that kiln drying, however carefully controlled, has some injurious effect on the ultimate efficiency of the activated material, but this point has not been proven. The bulk of present Texas production is probably somewhat less efficient than the high-grade California treated materials, but deposits are known in Texas fully as efficient as those in California, and it is only a question of time until we are producing here in Texas as good an activated bleaching material as anywhere in the world.

UTILIZATION

There are so many ways of using bleaching materials in the modern petroleum refinery that no hard and fast distinction can be drawn between natural and activated media. Almost any rule will have numerous exceptions. We do not know of any uses of granular activated material, but on the other hand much fine fuller's earth is used. Possibly as close as one can come is to state rather hesitantly that all activated earths are used in some variation of the



WILLIAM BATTLE PHILLIPS
1857—1918

so-called "contact process," and hope that no one knows of a case to the contrary.

Fuller's earth—certainly in the production of lubricating oils—is primarily a "percolation proposition." By percolation we mean the process of forcing oil, either by gravity or by pressure, through bodies of granular earth at very slow rates, thus giving the earth ample time to absorb the coloring matter and other impurities. In general, the process is most applicable to neutral oils and results in the production of a whole series of colors in the filtered oils. The "first through" is very light; color darkens with increased thruput; finally the yield goes "off color," when the earth has become saturated. The method involves large quantities of earth in process and requires large stocks of numerous oils. The earth can be recovered efficiently and reused several times by additions of small amounts of "make-up" and in general gives entirely uniform results over a period of time.

Activated earth, by comparison, is primarily a "contact proposition." By contact we mean the process of mixing fine dry earth, or the thick pulp previously referred to, with oil, agitating the mixture to secure thorough contact, and then separating the earth with its absorbed impurities in some form of filter press. In general, the process is most applicable to acid stocks, in that the activated earth, while itself still slightly acid, possesses the very valuable characteristic of thoroughly neutralizing the acid oil. The entire thruput is of a predetermined color, dependent upon the dosage of earth; stocks of earth and of oil can be smaller; and the entire plant is more flexible. So far as we are aware there are no satisfactory commercial methods of recovering the spent earth, though here again we can but hope no one knows of a case to the contrary.

In the production of gasoline and kerosene, the two types of bleaching earths more nearly overlap. It is true that in the various vapor phase processes, granular fuller's earth—the 30/60 fine mesh previously referred to—seems to predominate, but this may be attributed more to mechanical factors than to the earths themselves. Fines, either natural or activated, would promptly set up abnormal pressures through the packed towers which prohibits their use, even though the absorbing efficiency was much higher. If the texture of the activated earths was such as to permit manufacture of fine granular grades, it seems probable that they would replace fuller's earths in the vapor phase processes, which at present seem to offer the best opportunity for increased markets.

Fine fuller's earth and fine dry activated earth, however, come into sharp competition in the treatment of gasoline not manufactured by vapor phase processes and in the treatment of kerosene. Not all gasoline nor all kerosene is clay treated, but when it is, both fuller's earth and activated earth are available. Some plants use agitation and decantation, while some use agitation and filtration. In either process, measured minute amounts of earth are added to the liquid for removal of color, moisture, or "floc," with resulting improvement, particularly as regards stability. The choice between natural and activated media is largely one of cost, fuller's earth being naturally much cheaper and activated earth being naturally much more efficient.

VEGETABLE OIL INDUSTRY

So far consideration has been given only to the petroleum industry, primarily because over 90 per cent of the bleaching materials are used in this industry. Here in Texas, however, we have another home industry well worth our close attention, namely, the cottonseed oil industry. We have no outstanding single center of this industry such as Cincinnati, Chicago, Philadelphia, or New Orleans, but we have numerous smaller plants using appreciable amounts of bleaching earths. For many years only English fuller's earth was acceptable to the edible oil industry, and today some refiners still import all their earth, but Texas earths have made much progress, both in Texas and elsewhere in the United States.

In the edible oil industry, particularly as regards cottonseed oil and cottonseed lard, four factors are of prime importance. Earth must bleach well, have a low retention and a high rate; it must not fire in the press when blown with air to remove entrained oil; it must decrease, or at least leave unaffected, the free fatty acid content; and it must not impart an "earthy taste" to the bleached oil. The first three of these factors are susceptible to exact determination: you can read color on a Lovibond glass and rate on a flow meter; you can tell how hot a press gets when you blow it; free fatty acid can be read to fractions of a per cent; but you actually have to taste the oil to find out if it tastes earthy. Texas earths meet the first three tests very satisfactorily, and we are making progress in the education of expert Texas tasters.

CONCLUSION

In concluding this brief review of the development of one of our important minor mineral industries we want to express our appreciation of the efforts and accomplishments of the various Bureaus which comprise the Division of Natural Resources of The University of Texas. The steady progress of Texas as a mineral producer is due in no small measure to the work of this Division.

With all the progress that has been made, however, the mineral resources of Texas, aside from petroleum, natural gas, and sulphur, have really but been touched. This bleaching clay industry can well serve as an example of what has been accomplished and as an indication of what may be achieved.

SECTION III—GEOLOGY

SYMPOSIUM ON THE MAJOR UNCONFORMITIES IN THE TEXAS GEOLOGIC SECTION

PRE-CAMBRIAN UNCONFORMITIES

PRE-CAMBRIAN UNCONFORMITIES IN THE TRANS-PECOS REGION

C. L. BAKER[1]

On the Van Horn uplift the lowest rocks exposed are the Carrizo Mountain series of basement complex—highly deformed, strongly metamorphosed, originally sedimentary and igneous rocks. Although the normal contact between these and the Millican series is not visible, the break between the two is apparently as great as any which exists in the Lake Superior region or in any other pre-Cambrian shield area. The Millican is practically non-metamorphic, is less strongly deformed than the Carrizo Mountain, and its conglomerate contains schist pebbles. Both G. B. Richardson and P. B. King think that the Millican succession is conglomerate at the base, fine-grained, somewhat shaly sandstone in the middle, and cherty limestone at the top. The thick conglomerate contains large abundant limestone boulders which would appear to have been derived from some older, ordinary sedimentary limestone unless the conglomerate is at least in part a thrust-breccia.

An unconformity of great angularity separates the Millican from the Van Horn formation. The Van Horn has been referred to the Upper Cambrian, but it is certainly not the glauconitic marine Upper Cambrian found in other districts in every direction from the Van Horn area. One can merely state that the Van Horn is pre-Ordovician, it being separated by an unconformity of some angularity from the El Paso limestone of Beekmantown or Lower Ordovician age.

Therefore, three distinct epochs of mountain making are evident in pre-Ordovician time in the Van Horn area.

In the Franklin Mountains north of El Paso the Lanoria quartzite and shales begin with the oldest visible rock being a fine-textured

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[1] Geologist, Bureau of Economic Geology of the Division of Natural Resources.

conglomerate. The Lanoria is topped by an erosional unconformity upon which is deposited a volcanic agglomerate with boulders of the quartzite and acidic igneous rock. The agglomerate is followed by a thick succession of rhyolitic lava flows. The intrusive granite, considered by Richardson as post-Carboniferous, is clearly intrusive into the rhyolite-porphyry volcanic flows but from Richardson's mapping may prove to be pre-Bliss in age, because it is everywhere, except where faulting is conjectured, overlain by the Bliss sandstone. There possibly is also a granite of later age. The Bliss sandstone lies with an erosional unconformity upon the volcanic series. No pre-Pennsylvanian angular unconformity is known in the Franklin Mountains. The Lanoria may be the equivalent of the Troy quartzite of Arizona which A. A. Stoyanow proved to be Middle Cambrian.

PRE-CAMBRIAN UNCONFORMITIES IN THE LLANO REGION

H. B. STENZEL[1]

Only one pre-Cambrian rock group of sedimentary derivation is known from the Llano region. This is the group of the Packsaddle schists. All other pre-Cambrian rocks are intrusive and of igneous origin. The Packsaddle schists are conformable among themselves and do not have any visible stratigraphic breaks. Either the schists are an originally conformable sequence or such unconformities as may have existed once were obliterated by the metamorphic processes.

Therefore, there are no stratigraphic sedimentary breaks to report. However, if we apply the term "unconformity" loosely and include structural or intrusive breaks there are large breaks to report.

It is possible to establish in this region an intrusive sequence. It was reported by the writer[2] as follows:

III. Dike Intrusions
    6. Opaline quartz porphyry and felsites
II. Massive Intrusions
    5. Sixmile granites
    4. Oatman granites
    3. Town Mountain granites
I. Folded Frame=Llano series
    2. Valley Spring orthogneiss
    1. Packsaddle schists

How large are the time intervals between the different intrusions? This is difficult to ascertain. The approach to this question is indirect. One example might suffice in this discussion.

In the quarries at Sixmile are several exposures of inclusions of coarse-grained Town Mountain granite included in the gray, fine-grained Sixmile granite. The inclusions are large and angular, their outside boundaries are sharp, and obviously they are clean-cut breaks. The coarse-grained Town Mountain granite inclusions have also aplite dikes that belong to the sequence of the Town Mountain granite. These aplites are also cut off together with their parent rock in a clean-cut fashion by the fine-grained Sixmile granite.

It takes a long time for a large intrusion to solidify and crystallize as a coarse-grained granite. And in this example it was cooled

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[1] Geologist, Bureau of Economic Geology of the Division of Natural Resources.

[2] Stenzel, H. B., Pre-Cambrian of Llano uplift, Texas (abst.): Bull. Geol. Soc. Amer., vol. 43, pp. 143–144, 1932.

sufficiently so that the granite and its aplite could be broken into angular fragments that were engulfed by the younger granite. Therefore, one must assume that the time intervals between some, if not all, intrusions of different structural type were large.

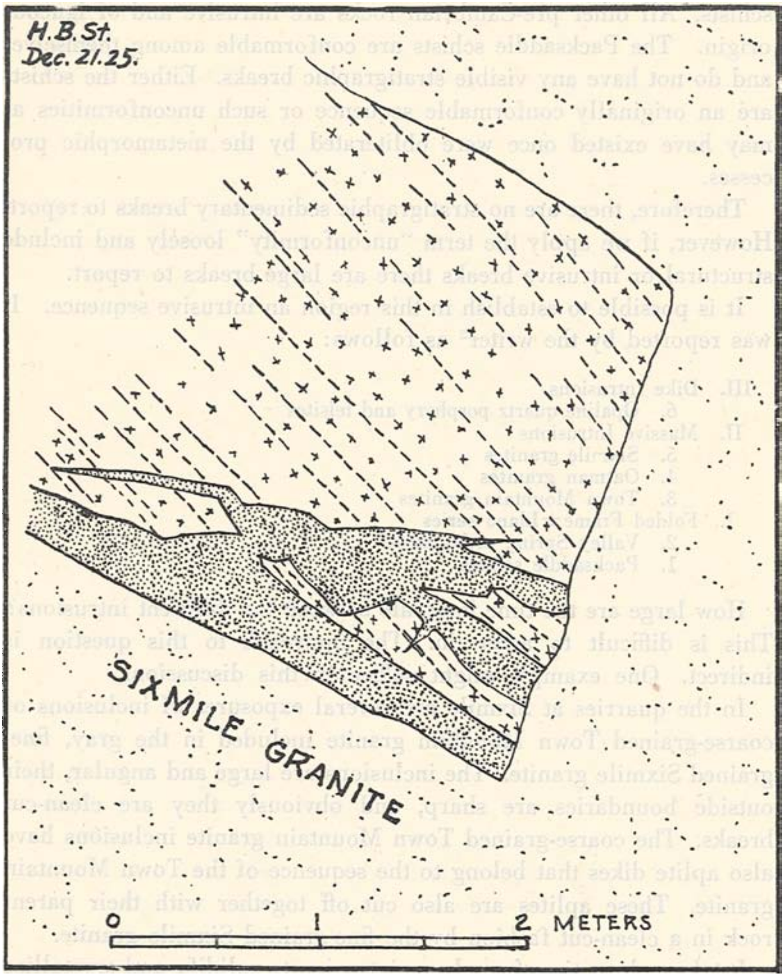

Fig. 29. Inclusion of coarse-grained Town Mountain granite and its aplite in fine-grained Sixmile granite in quarry at Sixmile near Llano, Llano County, Texas. Explanation of symbols: loose stipples = Sixmile granite; dense stipples = aplite; crosses and dashes = Town Mountain granite.

PALEOZOIC UNCONFORMITIES

EARLY PALEOZOIC UNCONFORMITIES IN TRANS-PECOS TEXAS

(Cambrian to Devonian Inclusive)

M. B. ARICK[1]

Trans-Pecos Texas is conveniently subdivided into several districts in discussing the unconformities in the early Paleozoic sediments exposed within its confines. These districts are as follows:

(1) The El Paso district, comprising the Franklin and Hueco mountains;
(2) The Van Horn district, comprising the Beach, Baylor, and Sierra Diablo mountains;
(3) The Marathon district, comprising the Marathon basin folds; and
(4) The Solitario district, comprising the Solitario basin folds.

EL PASO DISTRICT

In the Franklin and Hueco mountains the Upper Cambrian Bliss sandstone rests unconformably upon the pre-Cambrian schists and igneous rocks. The duration of the time interval expressed by this unconformity is not known. It included all of Middle and Lower Cambrian time and probably some part of the upper Proterozoic period. The Bliss passes without a perceptible break into the El Paso limestone above, which carries a Lower Ordovician Beekmantown fauna. Above the El Paso limestone another formation of Ordovician age, the Montoya limestone, occurs. This limestone carries an Upper Ordovician fauna which is correlated with the Fernvale-Richmond of the eastern United States and with the Viola limestone of Oklahoma. These correlations indicate an hiatus of considerable importance between the El Paso and the Montoya, as the equivalents of the Buffalo River, Chazy (Simpson), and Mohawk are missing. This hiatus is expressed by a thin bed of shale in parts of the Franklin Mountains and by a zone of sandy limestone containing rounded, frosted sand grains in the Hueco Mountains.

Above the Montoya, the Fusselman dolomitic limestone of middle Silurian age occurs. This hiatus is expressed by a change in deposition with locally a few limestone pebbles imbedded in the basal

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[1] Geologist. Humble Oil and Refining Company. Midland. Texas.

Silurian. No apparent divergence of dip between these formations has been noted.

Resting on the Fusselman with an angular unconformity ranging from 3° to 7°, a cherty shale of supposed Devonian age occurs in the northern Franklin Mountains. This shale is considered to be the equivalent and southern extension of the Percha formation of New Mexico and to be of Upper Devonian age. In the Hueco Mountains, this shale has been replaced by a basal white chert and an upper gypsiferous shale. The duration of the unconformity between this chert and shale and the Fusselman is from middle Silurian to Upper Devonian. No conglomerate was seen on the contact but, as noted above, there is angular discordance.

VAN HORN DISTRICT

The degree of unconformity between the Upper Cambrian sandstones and the pre-Cambrian beds is probably somewhat less in the Van Horn district than at El Paso. At Van Horn, a wedge of red, coarse-grained sandstone and conglomerate occurs at the base of the Paleozoic section. This member, which is known as the Van Horn sandstone, has a discordant and in at least one place a slightly angular contact with the overlying fine-grained gray sandstone which has heretofore been considered as the upper part of the Van Horn, but which is considered by the writer to be very probably the age equivalent of the Bliss sandstone discussed above. The duration of the unconformity between these two sandstones is not known but is thought to have been of short duration. The Van Horn is exposed and is overlain by the gray sandstone in the Beach and Baylor mountains. In both of the above-mentioned mountains El Paso limestone and Montoya limestone occur and have almost identical relationships as in the El Paso district; the only difference worthy of notice being the presence of more sand between the formations. The Fusselman recently discovered by P. B. King in the Baylor Mountains has not been seen by the writer, and its relationships are unknown.

In the northern Sierra Diablo the Montoya limestone is exposed. Here the section is either thicker than that exposed elsewhere in Trans-Pecos Texas or is repeated by closed folding or faulting. A quartzose sandstone occurs at its base and a conglomerate occurs at about the middle of the exposure. No El Paso limestone is known for certain but some exposures of what may be El Paso limestone occur at the base of the escarpment about 80 feet below the quartzose sandstone noted above. In the issue of the Bulletin of the American Association of Petroleum Geologists for November, 1934, P. B. King has interpreted this 80-foot interval as Devonian and the limestone as Silurian faulted down below the level of the Montoya. The writer, however, did not note any evidence of faulting here and did note exposures of soft marly material lying apparently conformably beneath the basal Montoya in the stream reëntrant to the south of the hogback formed by the basal Montoya sandstone and therefore questions King's interpretation and wonders if the fossils were not mislabeled. If this material is older than Montoya and the limestone at the base of the hill represents the top of the El Paso, then the unconformity here between the El Paso and the Montoya is less than that in the El Paso district and that in the Beach and Baylor mountains located from 20 to 25 miles to the south. The other Paleozoics of this area are present in disconnected exposures, and their exact relationships were not ascertained. It is conjectured that these relationships are the same as those found in the other exposures discussed above.

MARATHON DISTRICT

The oldest Paleozoic formation exposed in the Marathon district is a sandstone of supposed Cambrian age which has been named the Dagger Flat sandstone. This sandstone is highly folded and is overlain by the Marathon limestone of Beekmantown Ordovician age. The two formations appear to be folded in conformity and the contact is not discordant. However, as the meager fauna of the Dagger Flat is considered to be Upper Cambrian and that of the lowest part of the overlying Marathon limestone as Lower Ordovician Beekmantown, some degree of disconformity is indicated.

The Alsate[2] shale overlying the Marathon limestone has a conglomerate at its base and carries a high Beekmantown fauna. The conglomerate and the change in fauna from a lower Beekmantown to a highest Beekmantown age indicate that the unconformity here represents the middle and the lower part of the upper Beekmantown beds.

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[2] Misspelled. The formation was named for Alcate, an Apache Indian chief.

The Fort Peña formation and the Woods Hollow shale are conveniently considered together as they are apparently conformable and gradational to each other. A conglomerate occurs at the base of the Fort Peña, and the fauna and stratigraphic relations suggest that its age is probably uppermost Chazy or Black River. The Woods Hollow shale has a more abundant fauna which, however, is indecisive other than to place the formation as of Middle Ordovician age. Many conglomerates occur within the Woods Hollow. Evidence is lacking as to the amount of time represented by these detrital beds. It is thought that they are somehow related to the hiatus between the El Paso and the Montoya noted farther west and in a general way to the widespread pre-Cincinnatian unconformity. The unconformity at the base of the Fort Peña possibly includes most of the Chazy or Simpson.

Above the Woods Hollow in the Marathon area another Ordovician formation, the Maravillas chert, occurs. The fauna of this formation is correlated with the Richmond, and it is considered to be the age equivalent of the Montoya of western Trans-Pecos Texas. A conglomerate occurs at the base of the Maravillas, and there are intraformational conglomerates in the lower part. The unconformity represented by the basal conglomerate is from middle to uppermost Ordovician.

Above the Maravillas the Caballos novaculite occurs. No diagnostic fossils are known from this formation but, on account of its position in the section and more particularly because of its lithologic resemblance, it is considered to be the equivalent of the Arkansas novaculite and is therefore assigned to the Devonian. If this age designation is correct, a considerable time interval is represented by the contact between the Caballos and Maravillas. This contact, wherever seen, shows no evidence of conglomerate or erosion. A radical change in deposition is indicated, however, since at most places where the top of the Maravillas was seen, the uppermost member of that formation consisted of a brown, arenaceous shale, upon which the white novaculite, or greenish chert, rests with no apparent divergence in dip. However, if the novaculite is Devonian in age, the unconformity represented by the contact includes all of Silurian time and possibly some of the Ordovician and the Devonian.

SOLITARIO

The early Paleozoic unconformities of the Solitario are not known with certainty. The same lithologic facies is present here as that at Marathon discussed above. Certain differences, however, are indicated. It was noted above that at Marathon the Chazy is apparently only partially represented and that even this is doubtful. Recent fossil determinations from the slabby limestone present in the northern part of the Solitario show that this formation is at least in part Chazy. This indicates that the unconformity between the Lower and Middle Ordovician equivalents is not as great in the Solitario as at Marathon. Also, in the northeastern part of the Solitario a white, slabby limestone occurs beneath the Maravillas, which at this point does not appear to be overthrust. The possibility that it is in overthrust contact with the limestone member, however, is not denied. Should the contact be normal, a member that does not appear to occur at Marathon is present here. This member will fit into a part of the interval between the Woods Hollow shale and the Maravillas present at Marathon.

A supposed shale, present between the Maravillas and the Caballos in the Solitario, upon examination proved to be a layer of bentonite. Similar bentonite layers interbedded with the black chert and limestone occur within the Maravillas, and it seems certain that the uppermost bentonite belongs to the Maravillas formation so that the unconformity here between the Maravillas and the Caballos is the same as that at Marathon.

Fossiliferous limestone boulders found in a stream channel in the northern part of the Solitario proved to contain a Cambrian fauna. The lithology is different from any known elsewhere in Trans-Pecos Texas of similar age. The exposures from which these boulders were eroded were not found, and the relationships are not known.

LATE PALEOZOIC UNCONFORMITIES IN NORTH-CENTRAL TEXAS

M. G. CHENEY[1]

The information concerning late Paleozoic unconformities in north-central Texas is no doubt very incomplete at the present time. Many difficulties are involved in exact determinations because of the low angularity, the difficulty of definite correlation, and limited areas of exposure. However, the general relationships and major controlling structural features are fairly well known, and these will be briefly discussed, reserving detailed cross sections, thickness and structural maps of this area for a prior commitment.

The dominating positive structural features of the region during much of the late Paleozoic were the prominent Muenster and Electra arches at the north, related to the Wichita Mountain system, and the broad Concho axis at the south, along which the Llano uplift is at present a conspicuous development. Prior to later Pennsylvanian times these southeastward trending axes resisted more successfully than areas about them the prevailing subsiding tendencies of this region, and at times experienced vertical uplift as evidenced by several hundred feet of truncation occurring from Chester to Canyon times. These positive areas must have repeatedly appeared as islands or as peninsulas projecting southeastward toward the great geosynclinal area which apparently developed as continuous troughs from the Ouachita area of Arkansas and southeast Oklahoma around the Concho axis to the Marathon area of southwest Texas. This may be interpreted quite logically as a part of the great Appalachian geosynclinal development which seems to have crossed the Continent in a meandering trend from northeast to southwest. The abundant conglomerates of the Strawn and later Pennsylvanian beds of north-central Texas and the boulder beds and conglomerates of the Haymond beds and extensive pre-Permian thrusting of the Marathon area give adequate evidence of extensive orogeny of Pennsylvanian age along a southwest trend not far beyond the east and south margins of north-central Texas.

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[1] Geologist, Coleman, Texas.

This orogeny during middle and late Pennsylvanian times doubtless represents an important and probably major part of the Appalachian revolution as it affected this region. Extensive uplifts developing during late Pennsylvanian times in the Arbuckle-Wichita-Amarillo mountain areas to the north and the Permian basin and Marathon areas to the southwest are in contrast to the broad minor movements along the Concho axis of central Texas during pre-Canyon time.

The problem of unconformities in this region might be attacked by starting from the major axes of uplift heretofore mentioned and attempting to identify the more outstanding losses of section which permit upper Strawn or lower Canyon beds to rest upon pre-Mississippian beds along these uplift areas. No doubt these major unconformities are divisible into several smaller ones, the more important of which will be mentioned in turn.

MISSISSIPPIAN UNCONFORMITIES

The Mississippian sediments of this area are probably nowhere more than 400 feet thick, and as these are assigned to three or possibly four of the Mississippian epochs, it is evident that great hiatuses exist. These time breaks do not seem to be accompanied by the development of noticeable angular unconformities.

The basal Mississippian deposit transgresses a truncated pre-Mississippian surface representing a considerable erosion of Ordovician beds as the Concho axis is approached from either the east or west. However, it is probable that very little of the structural relief involved in this broad movement need be assigned to the early Mississippian.

PENNSYLVANIAN UNCONFORMITIES

If the Bendian[2] beds are considered a series rather than a system (until more final decision is made as to their proper rank) they may properly be treated as "Pennsylvanian," according to present general practice. The enormous thicknesses of this series in the Ouachita and Ardmore districts of Oklahoma and in the Marathon district of southwest Texas are lacking in north-central Texas. It is apparent that the rather inconspicuous unconformity between the Marble Falls limestone (upper Bendian) and the underlying

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[2] Harlton, B. H., Carboniferous stratigraphy of the Ouachitas with special study of the Bendian: Bull. Amer. Assoc. Petr. Geol., vol. 18, pp. 1018–1049, 1934.

Mississippian Barnett group represents a great unconformity when considered regionally.

Doubtless the most conspicuous unconformity to be observed over most of this area occurs between the Bendian and later deposits. This statement is subject to challenge unless certain sandstones and shale exposed in the vicinity of Smithwick are included in the Bendian rather than post-Bendian epoch, for these beds have the character of Strawn deposits but are as strongly folded as the underlying Bend. Nearness of this locality to the overthrust zone of the Ouachita trend and absence of diagnostic fossils make difficult the proper interpretation of this evidence.

Much of north-central Texas experienced erosion during some part or all of the time from Bend to upper Millsap Lake times. The truncated Bend beds in the area from the Bend flexure westward are overlapped by not more than a few hundred feet of the Millsap Lake beds as against several thousand feet in the deeper part of the Strawn basin to the east. Many unconformities may be involved in this great loss of section.

The upper Millsap Lake, Garner, and Mineral Wells beds seem to have had a much wider area of deposition than earlier Strawn deposits. The conglomerates of the Garner and Mineral Wells beds, especially the Brazos, Lake Pinto, Ricker, and Rochelle conglomerates, doubtless represent important disconformities and possibly appreciable unconformities. The replacement of *Fusulina* by *Triticites* and other fossil evidence developed by White,[3] Henry Morgan and others support the view that the unconformity between the Des Moines and Missouri series of the northern Mid-Continent area must lie within the Mineral Wells formation of the Brazos River area and the Brownwood shale of the Colorado River section. The major positive areas received either very thin or none of these upper Strawn deposits, while the central area between the Concho and Electra arches accumulated a thickness varying from 2500 to 800 feet, as measured in Stephens to Jones counties, respectively. The loss of section is more rapid from Stephens to Brown County than from Brown County to Menard County. The most rapid losses. however, are close to the Electra and Muenster arches.

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[3] White. M. P., Some Texas Fusulinidae: Univ. Texas Bull. 3211, 105 pp., 1932.

Most of the Canyon beds, though somewhat thinner than normal, are present over these three arches, and, except for occasional conglomerates which may represent channels and non-conformities, this epoch seems to have passed without marked disturbance. However, there is scattered evidence that the unconformity between the Missouri and Virgil series of Kansas and Oklahoma may fall within the Graford formation of lower Canyon age.

The Graham beds, lower Cisco, show a marked thinning near their most eastward exposures, both in the northern and southern parts of the region, suggesting renewed uplift along the Ouachita-Marathon trend. The Concho, Muenster, and Electra arches seem to have received nearly normal thicknesses of Cisco deposits. Repeated channeling is evident in the Cisco beds and for several hundred feet above, but as the various losses of section appear to be local they need not represent unconformities within the area discussed herein. The Graham and Thrifty formations show more marked changes of thickness than do the overlying Cisco beds, and there are evidences of a minor unconformity at the base of each of these two lowest Cisco formations. In general, the Cisco shows a gentle southeastward thinning in contrast to the thinning in Canyon and upper Strawn beds toward the Concho axis on the south and the Muenster and Electra arches to the north.

The writer is not aware of evidence of other unconformities in the section until the Double Mountain beds of west Texas are reached.

UNCONFORMITIES IN THE HUMBLE WHITE AND BAKER DEEP TEST, PECOS COUNTY, TEXAS

J. BEN CARSEY[1]

From the surface downward the Humble Oil and Refining Company No. 1 White and Baker well is presumed to have encountered the following formations:

System	Formation or Group	Thickness *Feet*	Depth *Feet*
Comanche	Fredericksburg	235	0– 235
	Trinity (?)	80	235– 315
Triassic	Dockum (?)	335	335– 650
Permian	Red beds	90 cor.	650– 740
	Salt	290 cor.	740–1030
	Anhydrite	491 cor.	1030–1521
	Dolomite	1929	1521–3450
	Limestone	2910	3450–6360
Pennsylvanian	Cisco	530	6360–6890
	Canyon	400	6890–7290
	Mineral Wells	215	7290–7505
	Millsap Lake	465	7505–7970
Unknown age	Oolitic limestone	42	7970–8012
Ordovician	Simpson	1373	8012–9385
	Ellenburger	426 plus	9385–9811

The first unconformity penetrated is that at the base of the Comanche. The Comanche is resting upon a sand of uncertain age which we are tentatively assigning to the Triassic because of the presence of heavy minerals. Heavy minerals are a common feature of the Triassic of the Permian basin but are also present, though somewhat more sparingly, in the Upper Permian sand. The interval represented by the basal Comanche unconformity is from lower Fredericksburg, or uppermost Trinity, to Upper Triassic or Upper Permian. The basal Comanche sands of this area correlate with the Paluxy of north-central Texas and are a continuation of the so-called Maxon sandstone of P. B. King which occupies a position in the Comanche section of the Marathon basin area corresponding to that of the Paluxy in the north-central Texas section.

If the 335 feet of sandstone and red beds beneath the Comanche is regarded as belonging to the Dockum series of Upper Triassic

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[1] Geologist, Humble Oil and Refining Company, Midland, Texas.

age then an unconformity representing the interval from Upper Permian to Upper Triassic is present at its base.

Owing to the fact that this well was drilled by rotary methods, the exact thickness of the salt section and consequently that of the red beds and anhydrite is uncertain. The thicknesses given are assumed by correlations with nearby cable tool holes.

No major unconformities are known for the Permian section and it is believed to be fully represented in the well. The top of the Permian dolomite was penetrated at 1521 feet, or at plus 1194 feet, and 1929 feet of dolomite was encountered. At 3450 feet the section became limestone, which material persisted to the base of the Permian section and proved to be 2910 feet thick. At 6360 feet shale was introduced into the section, and this is taken as the contact point between the Pennsylvanian and the Permian, since Cisco fusulinids were found in the shale and limestone section a short distance below this point, and the character of the lithology changed here from a brownish dolomitic limestone to a brown crystalline limestone.

The Permian dolomite and limestone section is considered to belong to the Word, the Leonard, and the Wolfcamp formations. The term Leonard has been construed by the West Texas Division offices of the Humble Company since 1929 as including both the Leonard and the Hess, and the term Wolfcamp as that portion of the Wolfcamp above the first limestone above the *Uddenites* zone, and these terms are so used here.

The degree of unconformity between the Permian and Pennsylvanian is apparently slight. The meager fauna which was recovered indicated that the interval of non-deposition extended only from Wolfcamp (upper Cisco) to lower Cisco. Insufficient faunal evidence was found to ascertain what part, if any, of the Cisco is missing.

Beneath the Permian, the Pennsylvanian is represented by Cisco, Canyon, Mineral Wells, and Millsap Lake equivalents. Five conglomerates are present in this section.

The Cisco is apparently conformable on the Canyon, but at the base of the latter division is a zone of detrital material 30 feet in thickness.

The next 215 feet of material has been called Mineral Wells, this term being used here to include Mineral Wells and Garner undifferentiated. A minor break, represented by a thin conglomeratic zone, occurs at the base of this interval.

The next 465 feet carry *Fusulina* sensu stricto, *Chaetetes milleporaceus*, and *Mesolobus mesolobus*. This interval represents the Millsap Lake formation. There are two thin conglomeratic zones within the formation representing minor breaks and nearly 200 feet of limestone and chert conglomerate at the base.

Underlying the Millsap Lake, and separating it from the Simpson, is a heavy bed of oolitic white limestone of uncertain age. However, it is believed to be Pennsylvanian and probably is the only representative of the Bend group in this well.

The oolitic limestone is separated from the Simpson by a thin zone of red sandy shale containing chert pebbles.

A rather thick section of Simpson is present and a basal sandstone occurs with each of the five divisions.[2] It is supposed that there is very little, if any, break within the formation as the basal sandstones are not believed to denote interrupted deposition.

The Simpson rests upon the Ellenburger with no apparent break. In fact, the contact is difficult to pick as the Simpson limestone gradually becomes more and more dolomitic until it attains the characteristics of typical Ellenburger. The contact was placed at 9385 feet. It is admitted that it could be above this point but certainly not below it. A minor break represented by 5 feet of chert and dolomite conglomerate occurs at 9600 feet. No hint as to the duration of this break was found.

The well tested 900,000 cubic feet of gas at 1521 feet from the top of the Permian dolomite section and encountered flowing sulphur water at the same horizon. At 9668 feet 100 barrels of briny sulphur water per hour was tested. As the hole was drilled with rotary tools, it is possible that water in small quantities between the two horizons noted above was passed without its presence being known.

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[2] See Decker, C. E., The stratigraphy and physical characteristics of the Simpson group: Oklahoma Geol. Surv., Bull. 55, 112 pp., 1931.

UNCONFORMITIES IN THE LATER PALEOZOIC OF TRANS-PECOS TEXAS[1]

PHILIP B. KING[2]

Trans-Pecos Texas, like other districts in the Southwest, was subject to considerable crustal unrest in the later part of Paleozoic time. This is expressed partly by unconformities of greater or less importance and partly by a considerable variation in the thickness and lithologic character of the sediments.

Unconformity at the base of the later Paleozoic.—The oldest strata of the later Paleozoic, either of late Mississippian or early Pennsylvanian age, rest with great hiatus on the older Paleozoic rocks. The underlying beds in most places are probably of Devonian age, but the fossil evidence is meager, characteristic Devonian fossils having been obtained in only one area, the Franklin Mountains.

The beds which rest upon the Devonian of the Franklin Mountains belong to the upper Mississippian, being of Chester age. Upper Mississippian (Chester) fossils are also found in the upper or fossiliferous part of the Helms formation of the Hueco Mountains and in the Sierra Diablo, in both of which areas the strata beneath the fossiliferous Mississippian beds may also be of Devonian age. There is no marked physical evidence of a break at the base of the Helms formation, but the fossils indicate that the lower part of the Mississippian is not represented.

In the Marathon region the break appears to be greater, since here the Tesnus formation rests on the Caballos novaculite. The Caballos is presumably of Devonian age, and the Tesnus, as dated by fossil plants found in its upper part, seems to be in greater part at least of early Pennsylvanian age. At many places the base of the Tesnus contains beds of conglomerate derived from the underlying formation. Moreover, it thins in a remarkable manner, from 7000 feet or more in the southeast part of the Marathon basin, to a few hundred feet in the northwest. Various lines of evidence suggest that this thinning is chiefly the result of an overlap on the Caballos novaculite.

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[1] Published by permission of the Director, U. S. Geological Survey.

[2] Associate Geologist, U. S. Geological Survey.

Mississippian-Pennsylvanian unconformity.—In northwestern Trans-Pecos Texas, where both the Mississippian and Pennsylvanian series are represented, there is probably a hiatus between them in places. In the Sierra Diablo, shales and limestones of Smithwick and Marble Falls age intervene between the Mississippian rocks and the Magdalena limestone (early Pennsylvanian), and here the separation in time may not be great. In the Hueco and Franklin mountains, however, these shales and limestones are not recognized, and there is probably a hiatus representing the time of their deposition. There is no important physical evidence of such a break in these two areas, and the Magdalena limestone rests on the even upper surface of the Mississippian.

During Pennsylvanian time itself, deposition appears to have been continuous. No breaks are evident within the Magdalena limestone. The great succession of sediments at Marathon, from the Tesnus through the Dimple, Haymond, and Gaptank formations, seems from plant and invertebrate fossil evidence to represent the greater part of Pennsylvanian time. No important physical evidence for a break is to be found anywhere in the section. In the upper part, however, in the Haymond and Gaptank formations, are conglomerates and boulder beds which contain rocks that normally should lie deeply buried beneath them. The inclusion of such fragments in the conglomerates indicates that marked uplift and profound erosion had taken place in regions nearby.

Unconformity near base of Permian.—Probably the greatest unconformity within the later Paleozoic of Trans-Pecos Texas is that which lies near the base of the Permian series. The oldest rocks above this break contain species of *Schwagerina* at all places, and if, as some geologists advocate, the zone of *Schwagerina* is considered the base of the Permian, the unconformity marks the boundary between the Pennsylvanian and Permian series. The unconformity was brought about by folding and mountain building which took place in the Llanoria geosyncline and by the slighter deformation to which the foreland area was at the same time subjected.

The results of this movement are most evident in the Marathon basin, where the rocks of the Llanoria geosyncline are exposed. In the northwestern part of this district, fossiliferous middle Pennsylvanian strata have been overriden by thrust sheets and profoundly disturbed, and the basal Permian beds (Wolfcamp formation) with *Schwagerina* and with coarse conglomeratees at the base rest on the eroded surfaces of the Pennsylvanian formations. Elsewhere in the same district, however, the relations are not so clear. At Wolf Camp, in the northeast part of the area, the beds with *Schwagerina* are underlain by beds that contain a sequence of fossiliferous zones that extend downward from upper into middle Pennsylvanian. One finds it hard to escape the inference that there was little or no break in sedimentation from Pennsylvanian into Permian time at this locality.

In northwestern Trans-Pecos Texas the unconformity below the zone of *Schwagerina* is very well marked. In the Hueco Mountains the Hueco limestone as now restricted, which contains this fossil at the base, lies on the upturned edges of the Pennsylvanian (Magdalena limestone), as is well shown in Powwow Canyon, on the El Paso-Carlsbad highway. Here the Hueco has at its base a coarse conglomerate (Powwow member). Farther southeast the Hueco overlaps across progressively older beds and at the south end of the range overlies the Ordovician. In the Sierra Diablo the relations are similar, save that the overlap is from the Magdalena down to the pre-Cambrian. Strata of Permian age rest upon the latter over extensive areas in the southern Sierra Diablo and in several adjacent mountain ranges to the south. In places in this district, as in the Baylor Mountains, the pre-Permian floor was rugged, and several steep faces of the older rocks, against which Permian strata have been deposited, may be observed.

Unconformities within the Permian.—Following this time of disturbance and erosion, there was nearly continuous deposition during Permian time. What breaks occur in the succession appear to have been local in their extent, and in most areas each formation seems to have been deposited directly on that which preceded it.

In the Marathon region, however, some movements in the Llanoria geosyncline must have continued into Permian time, for the Wolfcamp formation at the base is overlain by the Leonard with a well marked unconformity, expressed by slight divergences in dip, erosion of the older beds, and a persistent conglomerate at the base of the younger formation.

In northwestern Trans-Pecos Texas, the Wolfcamp formation finds its equivalent in part of the Hueco limestone, and the Leonard formation finds its equivalent in the Bone Spring limestone. Regarding these two formations, Dr. G. H. Girty writes: "I know of no more profound faunal change or faunal unconformity than that which is encountered on passing from the Hueco to the Guadalupian" (of which the Bone Spring is a part). Diligent search in the field has, however, failed to reveal any physical evidence for such a break, although it may be discovered by later work. The writer is, however, inclined to believe that a part of the difference between the two faunas is the result of markedly different environments of deposition, rather than separation by a long time interval.

A later unconformity is well developed in the Guadalupe Mountains farther north, and lies between the Bone Spring limestone (of Leonard age) and the Delaware Mountain formation. The unconformity was caused by an uplift of the Bone Spring beds in the northwest part of the area, so that they have been somewhat eroded, and so that local coarse, thick conglomerates have been laid down at the base of the succeeding formation. The Delaware Mountain beds overlap northwestward against the uplifted Bone Spring, so that the lower 1000 feet of the Delaware Mountain formation as represented at Guadalupe Point disappears entirely 5 miles to the north. The unconformity is said to continue some miles to the north, into New Mexico, but to the south, in the Delaware Mountains, there appears to have been little or no break between the two formations, and the character of the strata at the contact suggests a gradation.

Higher in the section, in the Delaware Mountains, an unconformity was at one time thought to exist between the Delaware Mountain formation and the overlying Castile anhydrite. Such a relation was suggested to account for the absence in this area of the Capitan limestone, which overlies the Delaware Mountain formation at its type section in the Guadalupe Mountains. It is now known, however, that most if not all of the Capitan limestone is replaced by rocks of Delaware Mountain facies in the Delaware Mountains so that the need for assuming a break no longer exists. Where the Delaware Mountain-Castile contact is examined, it is seen to be a gradation from thinly laminated sandstone and limestone into laminated calcareous anhydrite and finally into laminated pure anhydrite. The physical conditions during the deposition of the two formations were radically different, the first having been laid down in a sea connected directly with the ocean and the second in a body without free communication with the ocean, but no great time interval need have separated them.

The relations toward the margins of the Delaware basin, or region in which the Castile and Delaware Mountain formations were deposited, are somewhat different. These relations cannot well be observed on the surface, and most of the evidence has been obtained from subsurface work. Along the margins of the Delaware basin the Capitan limestone, which is equivalent to the upper part of the Delaware Mountain formation, rises in a steep face, and the Castile anhydrite passes out by overlap against it. Beyond the limits of the Delaware basin the succeeding formation, the Salado halite (also known as upper Castile), rests directly on beds of Capitan age.

The steep face of the Capitan limestone against which the Castile overlaps is probably in part a depositional surface. At the beginning of Castile time, it may have been that the sea bottom was markedly irregular, with the surface in the Delaware basin considerably lower than that of the surrounding areas. The steep face was probably caused in part, however, by later movements. During the time of Castile deposition the Delaware basin may have subsided gradually, and the boundary between it and the more stable surrounding areas may have been a zone of downward flexing. Such a structural feature would resemble that in the Bone Spring limestone, against which the lower beds of the Delaware Mountain formation pass out by overlap.

Toward the end of Permian time, or perhaps a little later, the Permian rocks of the Glass Mountains were tilted and eroded, and the products were laid down to the northwest to form the Bissett conglomerate. This formation is probably of Triassic age.

Where beds younger than the Permian lie above this series, they are unconformable on it. In the Glass Mountains and the Sierra Diablo the Permian is gently tilted and worn down to an even surface and is overlain by the Cretaceous. The movements by which this was accomplished took place in the Mesozoic, and the unconformity is only a part of a widespread one, which extended over the whole of Texas, and into adjacent states.

MAJOR UNCONFORMITIES IN THE WICHITA FALLS DISTRICT OF NORTH-CENTRAL TEXAS

NORTH TEXAS GEOLOGICAL SOCIETY[1]

Older Formations	*Overlain by*	*Locality recommended for observation. No surface exposures.*
Pre-Cambrian	Canyon to Cambrian	Thalia, Foard County: Canyon on pre-Cambrian. Johnson Pool, Foard County: Strawn on pre-Cambrian. Nocona, Montague County: Strawn on pre-Cambrian. Petrolia, Clay County: Cambrian on pre-Cambrian.
Cambrian	Canyon	Continental on Beach farm well, Wichita County: Canyon on Cambrian.
Ellenburger		
Ozarkian	Canyon	Bulcher, Cooke County: Canyon on Ozarkian.
Canadian	Comanche to Mississippian	Pilot Point, Cooke County: Trinity on Canadian. Cooke County: Strawn on Canadian. Swenson well, Throckmorton County: Mississippian on Canadian. Young County: Mississippian on Canadian.
Ordovician—absent		
Silurian—absent		
Devonian—absent		
Mississippian	Strawn to Bend	Phillips No. 2-N Waggoner well, Wilbarger County: Bend on Mississippian. Chalk Hill, Archer County: Bend on Mississippian. Humble well, Childress County: Strawn on Mississippian.
Strawn	Comanche	Cooke County: Trinity on Strawn.
Canyon	Comanche and middle Cisco	Cooke County: Trinity on Strawn. Thalia, Foard County: Middle Cisco on Canyon. Sunshine Hill, Wichita County: Middle Cisco on Canyon.

Older formations	*Overlain by*	*Locality recommended for observation. May be observed in surface exposures.*
Cisco	Comanche	Montague County: Trinity on Cisco.
Within Cisco		At or below Gunsight there is a regional unconformity characterized by a change in fauna, channeling, red beds, and coal deposits.[3]
Permo-Pennsylvanian		Paleontological evidence.[2]
Cisco		Overlying the Coleman Junction limestone is a widespread horizon, marking the base of the beds of anhydrite and dolomite with limestones below.[2]
Double Mountain	Whitehorse facies	The contact of the Double Mountain-Whitehorse facies marks a pronounced lithologic change in the Permian red beds.
Double Mountain	Comanche	Double Mountains, Stonewall County: Trinity on Double Mountain.
Permian to Cisco	Pleistocene	Terrace and channel deposits along Wichita River.

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[1] Statement made by John A. Kay, Virgil Pettigrew, Robert Roth, and R. S. Powell, Committee representing the North Texas Geological Society, Wichita Falls, Texas.

[2] This unconformity is of small vertical magnitude but is widespread laterally.

[3] This unconformity is of unknown vertical magnitude and is widespread laterally.

MAJOR UNCONFORMITIES IN THE GEOLOGIC SECTION OF THE TEXAS PANHANDLE

PANHANDLE GEOLOGICAL SOCIETY[1]

1. Unconformities in and at the top of the pre-Cambrian.

There is no direct information available in this area, but it is assumed that there is an unconformity at the top of the pre-Cambrian.

2. Early Paleozoic unconformities, Cambrian to Devonian inclusive.

A deep test recently completed in Moore County is conceded to have stopped in Lower Ordovician (Ellenburger or Arbuckle) lime. There was possibly no section of Silurian or Devonian present and certainly not a full section of formations of these ages. There is, therefore, at least one unconformity between the Ordovician and Mississippian in this area, and there is probably more than one. Whether such unconformities as are present are structural and erosional or non-depositional is not yet known.

3. Late Paleozoic unconformities, Mississippian to Permian inclusive.

In the above-mentioned well there was unconformity material present at the top of the Mississippian and below beds interpreted to be lowest Pennsylvanian, or Bend, in age; thus indicating an erosional unconformity at this horizon.

The general opinion is that the major uplift in this region, resulting in the Amarillo Mountains, or Granite Ridge, occurred in early Pennsylvanian time (probably in late or post-Bendian) and that erosion continued into the Permian, at least through Wellington time.

There is a major erosional unconformity of considerable magnitude in this region between the Quartermaster (at the top of the Permian) and the Triassic.

4. Mesozoic unconformities to and at the top of the Comanche Cretaceous.

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[1] Statement submitted by W. W. Rusk, Secretary, Panhandle Geological Society, Amarillo, Texas.

Comanche outcrops in place on top of the Triassic are known in this area, indicating at least a disconformity which cuts out the Jurassic. It is also known that there is an unconformity between the Comanche and the Gulf Cretaceous.

5. Later unconformities.

The Tertiary overlap in this area covers all pre-Tertiary erosion features. The oldest formation known to be in contact with the Tertiary is the Blaine.

MESOZOIC UNCONFORMITIES

UPPER CRETACEOUS UNCONFORMITIES IN TEXAS

W. S. ADKINS[1]

The stratigraphic evidences of various types of lack of conformity have been listed by many writers and are well known. However, this line of approach to the problem of recognition and evaluation of stratigraphic unconformities is not the only one. Another approach to the problem is the study of fossil faunas. The following are some of the paleontologic signs of lack of conformity.

1. An unconformity sharpens the ranges of the fossils on both sides of it.

   (a) For example, two fossils, whose ranges in a complete section overlap, will fail to overlap if the overlapping portion is cut out by the unconformity.
   (b) Two fossils the ranges of which do not meet will be caused to meet, if the intervening section is cut out.
   (c) A group of fossils which became extinguished at various times will appear to have become extinct at the same time. Similarly,
   (d) A group of fossils which originated, or which entered the region at different times, will appear to originate or enter the region at the same time. The sudden extinction or sudden appearance of several or many species should suggest an unconformity of greater or less magnitude.

2. Intercalation of a barren series of sediments in a fossiliferous series produces the same effects as an unconformity. Many so-called cryptogenic forms are not cryptogenic, but their appearance follows an unrecognized unconformity.

3. An unconformity recognized by paleontologic signs may or may not be accompanied by distinct physical evidences.

Breaks in the stratigraphic (physical) sequence are called by various names, such as unconformity, disconformity, non-conformity, et cetera. A break in the paleontologic series is called nonsequence.

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[1] Geologist, Shell Petroleum Corporation, Houston, Texas. Published by permission.

4. Whence, it follows that the paleontologic criteria of non-conformity are fully as important as the stratigraphic, especially for small breaks. Every paleontologic non-sequence requires some sort of explanation.

The Cretaceous, both upper and lower in Texas, contains many unconformities of diverse types, recognizable by both stratigraphic and paleontologic signs.

COMANCHE-WOODBINE UNCONFORMITY

At the outcrop in north and central Texas, southwards to the Johnson-Hill County line, the uppermost Comanche formation is Grayson, thence intermittently Grayson and Buda to a point 2 miles east of Salado, Bell County; thence southwards and westwards to El Paso it is the main body of the Buda. It should be mentioned that on the Hill-Johnson County line the writer found an outlier of solid Buda, similar to those at Bosqueville and in Bell County, intercalated between the Grayson and the Upper Cretaceous. From Fink, Grayson County, eastwards to southwestern Arkansas, the top of the Comanche is bevelled off so that the Woodbine rests successively on Main Street, Weno, Fort Worth, Duck Creek, Goodland, and finally on thinned marginal overlapping units of the Trinity group. On the Sabine uplift and on other sharp uplifts in northern Louisiana, the Washita and Fredericksburg have been bevelled, and Upper Cretaceous rests on Trinity. Locally in Nacogdoches County, Austin directly overlies Georgetown. Near Zwolle, Fredericksburg may be absent, Washita resting directly on Trinity. Likewise, in the northern Panhandle of Texas, Woodbine rests on Duck Creek, and the area between the Oklahoma Panhandle and the Davis Mountains doubtless contains an overlap over a bevelled Washita surface similar to that just described. Throughout the East Texas embayment southward to the Buda margin passing through central Limestone County, southern Leon County, and central Houston County, the topmost formation of the Comanche is Grayson black shale containing a typical microfauna.

The basal formation of the Upper Cretaceous is Woodbine shale or sandstone or possibly Pepper shale as far west in Texas as Denton County; thence southwards to at least San Antonio it is a black shale which may be referred to the Pepper shale. The typical Woodbine, *i.e.*, sands and sandy clays, is absent south of a line passing on the outcrop from southern Hill County to near Tokio, McLennan County, thence underground through central Limestone, southern Leon, central Houston, and southern Cherokee counties, and turning thence northwards through western Rusk and central Gregg counties, skirting the southern part of the Sabine uplift.

On the outcrop west of San Antonio and in Trans-Pecos Texas the Eagle Ford, in either its Boquillas flag facies or its Chispa Summit clay facies, directly and unconformably overlies the top of the Lower Cretaceous which is Buda limestone at all places where it has not been subsequently removed. Hence the unconformity is a northern marginal phenomenon; it disappears southwards into Mexico and with it disappears the distinction between Comanche and Gulf series. It is significant that in a magnificent suite of ammonite-bearing samples identified by the writer from a 15,000 foot section of the Cretaceous at the Peñoles Company's mines near Sierra Mojada, western Coahuila, some limestone samples from near the contact of Lower and Upper Cretaceous contained a mixture of ammonites which in Texas would be referred to Grayson and to Eagle Ford flags, thus leading to the distinct inference that the age of the rocks may be between the two, that is, in the Woodbine interval represented by the Comanche-Gulf unconformity in Texas or, in other words, marine Woodbine limestone. Laborious search has failed to reveal any such condition in the East Texas embayment.

It will be recalled that it has already been demonstrated that the actual age gap between Buda and Eagle Ford flags is slight, only a small part of the Middle Cenomanian. The deposition of the Pepper and Woodbine did not occupy much of Cenomanian time. The age of the Pepper is a question which will soon be solved. The writer was fortunate in discovering, in addition to the ammonites at the type locality, an excellent marine seam at a McLennan County locality, with abundant and well preserved fossils.

The tentative suggestion is made that the Pepper climbs in the geologic column on going south, and that from Waco southwards it is of Eagle Ford age. If this hypothesis of transgressive overlap were correct, this black colloidal noncalcareous shale would show the relations of a transgressive basal conglomerate. It is also suggested from the ammonite evidence that the Eagle Ford flags are younger south of McLennan County than north of that area.

UNCONFORMITY AT BASE OF EAGLE FORD

At the north Texas outcrop there is only a slight physical evidence of unconformity between the Woodbine and the Eagle Ford; furthermore the ammonite zonation is imperfectly known, a fact which prevents a proper estimate of the size of the unconformity. However, two facts stand out in north and central Texas. First, the Eagle Ford disappears in the East Texas embayment east of a line running from northwestern Red River County southwards through central Upshur, eastern Smith, and east-central Cherokee counties, this line being west of and parallel to the East Texas oil field. Secondly, on crossing the San Marcos arch in Travis and adjacent counties, the middle and upper Eagle Ford are represented by a condensed zone of only a slight thickness, in which ammonite markers of various Eagle Ford ages are indiscriminately mixed. Underground on the San Marcos arch the Eagle Ford is even thinner, and it is probably even more condensed. How much basal Eagle Ford this thinning removed is unknown.

West of Uvalde, where the Eagle Ford is taken up by the Boquillas flag facies, ignorance of the zonation permits no statements except that there is an unconformity at the base of the Boquillas. In the Chispa Summit area the Upper Cenomanian *Acanthoceras* level appears to be missing, or at least has not been found. The same statement holds for the two Turonian basins in the lower Conchos Valley, Chihuahua, El Alamo, and San José de Cacahuatál, investigated by Dr. Robert King and the writer, but in a third basin farther west, at Rancherias, the basal Turonian, in the Chispa Summit facies, is already beginning to be affected by incursions of the western sandy marginal facies, and here the Eagle Ford is approaching a western shore line.

In summary, nowhere has a complete sequence been observed in Texas at this contact. Indeed it requires some research to know what the complete sequence is, because our section is fully as complete as in France and England, where also a zone of *Metoicoceras pontieri* and *Neocardioceras* occurs at the contact.

There are probably smaller non-sequences within the shaly or clayey Eagle Ford, both in north Texas and in the Chispa Summit-Conchos Valley region, which have never been properly investigated.

At many places in the East Texas embayment the determination of the top of the Woodbine is attended with much difficulty. Hence, whatever the size of the unconformity there, the physical conditions must have been somewhat similar on either side of it.

EAGLE FORD-AUSTIN UNCONFORMITY

Physical evidence of this unconformity has been published by several writers. Here the European zonal sequence is more nearly ideal, but it has never been properly applied to the Texas zones. However the writer ventures the judgment that the zonal break will be found to be slight in both Texas and northern Mexico. In the Terlingua and Chispa Summit areas the physical break is insignificant, if indeed any exists. In Travis County the condensed zone already mentioned includes the highest known Eagle Ford zones and is succeeded by the Austin, with, however, physical evidences of unconformity in both the top Eagle Ford and the basalmost Austin. At some places in the East Texas embayment the materials near the contact appear to be alternating, and the contact may be gradational. At the north Texas outcrop, although physical signs of minor unconformity occur, there is no general overlapping of Eagle Ford zones by the basal Austin, except that down Red River valley, the situation has not been properly investigated.

So far as can be judged at some places, as west of San Antonio, the expected basal zones of the Austin occur. Whether their absence elsewhere is because of insufficient collecting remains unknown.

AUSTIN-TAYLOR UNCONFORMITY

The writer long ago pointed out that the same ammonite zone which occurs in Travis County 125 feet above the base of the Taylor occurs near Emhouse, Navarro County, about 700 feet above the base of the Taylor. Geologists of the Humble Oil and Refining Company collected a mass of stratigraphic and microfaunal evidence showing that at the central Texas outcrop, on passing south, the Gober and Pecan Gap equivalents approach the top of the restricted Austin by a constantly decreasing interval of the basal Taylor marls. Thus it is the base, not the top, of the Taylor which is reduced or else unrepresented on the south-central Texas outcrop. In Bexar County the Pecan Gap directly and unconformably overlies the restricted Austin.

In spite of much effort the Taylor ammonite zonation still remains unsatisfactory. The best starting point for a Taylor correlation is probably the Pecan Gap equivalents. The Taylor below the Pecan Gap contains the zone of *Scaphites hippocrepis* and other zones. In or near the Pecan Gap are the zones of *Hoplitoplacenticeras vari, Parapachydiscus travisi* and others. Just above the Pecan Gap are probably the main zones of *Mortoniceras delawarense, Placenticeras guadalupae* (with *P. planum, P. meeki, Pseudoschloenbachia, Submortoniceras,* and others) and the undivided zone of *Bostrychoceras polyplocum, Parapachydiscus* large species (like *P. gollevillensis* and *P. wittekindi* in Europe), and finally near the top of the Taylor the zones of *Placenticeras intercalare* and *Sphenodiscus lenticularis.* The Pecan Gap is represented west of San Antonio in the Anacacho limestone, and farther southwest in the Upson clay; the upper Taylor zones are represented in the Big Bend in the Aguja formation. Until these zonal details are clarified we will be unable to estimate the extent of the unconformities involved in the section.

In summary, the unconformity at the base of the Taylor is less conspicuous at the outcrop in north Texas, very prominent at the outcrop in central Texas, and uninvestigated in west Texas and underground. Whether it represents transgressive overlap, submarine erosion, or what sedimentary conditions accompanied it, has not been clarified.

It should be mentioned in this connection that at widely separated places in the East Texas embayment short sections of various Upper Cretaceous groups occur. Thus, aside from the eastward regional thinning and disappearance of Woodbine and Eagle Ford near the East Texas oil field, locally thinned sections of Austin, lower Taylor, the entire Taylor and Navarro are known. Some of these may occur in connection with sharp local uplifts and suggest the situation on local uplifts in northern Louisiana, but this connection is by no means invariable. In Sabine Parish, Louisiana, Midway and Annona are separated by only 20 to 100 feet of "Zwolle marl" containing an intermixture of fossils of upper Taylor, Saratoga, Nacatoch, and Arkadelphia ages. Although there is some brecciation and reworking, especially near its base, the thinned "Zwolle marl," in the main, is a condensed zone. South of Zwolle, Midway directly overlies Annona. Near the Sabine uplift, as in Cherokee and Nacogdoches counties, Navarro and/or upper Taylor may be absent, and Midway may directly overlie Pecan Gap.

TAYLOR-NAVARRO UNCONFORMITY

Lack of good zonation does not permit a statement of how much uppermost Taylor is removed in most parts of Texas, except that the upper Taylor in Medina County is very high in the zonation, and is, according to Dr. Spath and the studies of the writer, definitely higher than the top Taylor marl in the Big Bend. In the Terlingua and San Carlos areas the upper Taylor zones occur in the Aguja. Near Austin, as in southern Arkansas, the upper Taylor appears to be high in the zonation.

Authors have cited evidences of unconformity at this contact on the outcrop in southern Arkansas, questionably in Texas as far south as Cameron, and thence south and west to the Rio Grande embayment, where the nonmarine Olmos beds are supposed to indicate a break in lower Navarro sedimentation. In the region of Lampazos, Nuevo Leon, no prominent break is indicated, nor at the well known locality at Barroterán in the Sabinas basin, where Taylor and Navarro fossils occur practically together. Farther south no prominent break is indicated at Tula, Tamaulipas, or at Cárdenas. Some micropaleontologists consider that the Mendez includes basal Navarro equivalents.

In summary, the evidence so far is insufficient to permit accurate judgment as to the size of this unconformity. It should be noted that in using well records, many micropaleontologists include Saratoga or Neylandville equivalents in their Taylor. The youngest Taylor, as now defined in Texas, includes ammonite zones which must be placed in the basal Maestrichtian.

UNCONFORMITY AT TOP OF CRETACEOUS

We will omit repetition of the great quantity of material which has been written on this unconformity. A few species of Ostracoda and Foraminifera survived the break, practically no megafossil did, and characteristic plants and large Mesozoic groups of Reptilia and Cephalopoda became extinct. Physical and sedimentary conditions in Texas likewise changed greatly; for example, little limestone was deposited in the Tertiary. The zonation at this boundary is very unsatisfactory for the entire world, so that it is difficult to estimate the size of the break. The following are a few pertinent lines of evidence for the Texas area:

1. Incursions of brackish or nonmarine conditions occurred at different times near the end of the Cretaceous at different places.

2. Varying amounts of uppermost Cretaceous have been removed at different places in Texas.

3. When the Tertiary sea returned, it did so locally with large overlaps, so that, for example, the Wilcox was deposited on the eroded top of the Cretaceous. It would be necessary to go downdip under these overlaps to discover both how much uppermost Cretaceous is absent and how much basal Tertiary is absent. To date, drilling has not clarified these matters.

4. It is improbable that Texas west and north of the Balcones fault was ever covered by much if any Tertiary or even high Cretaceous deposits. If it had been, we would expect large amounts of reworked Cretaceous material in the early Tertiary formations. No such situation exists. Reworked Cretaceous is uncommon in Tertiary beds older than the Oakville; except for locally reworked material in the basal Midway, it is rare in the Yegua, Jackson, Frio, *Discorbis* zone, and Catahoula, common in the Oakville and in the Lagarto, locally common in the Lissie, rare or absent in the Beaumont, and occasional in Recent shore sands.

In the Yegua and Jackson, Cretaceous *Gümbelina* and *Globigerina* occur. In the middle and upper Frio and in the *Discorbis* zone of the marine Oligocene, reworked Cretaceous Foraminifera are occasional. In the down-dip Catahoula in Wharton County, reworked Cretaceous occurs.

In the Oakville, many Cretaceous fossils occur, some of them in such quantity and good preservation that it has been surmised that they were transported in large chunks of their matrix by means of torrential floods, induced by heavier rainfall than exists at present. It is unknown whether the rather sudden uncovering of Cretaceous beds can be correlated with major tectonic events, the uplifting of the central Texas Cretaceous, the subsidence of the coastal plain; at any rate the Miocene in the Gulf and Caribbean region was a time of intense earth movements and vulcanism.

The writer has heard of a locality near Brenham in which great heaps of *Exogyra ponderosa* and other Cretaceous fossils occur as well preserved as on their original outcrop and abundant enough to be crushed for road material. From a locality in Duval County quantities of well preserved Paleozoic crinoid stems were collected.

The Oakville has yielded:

Gryphaea mucronata (mis-named marcoui, from the Fredericksburg)
Exogyra arietina (from the Grayson)
Exogyra ponderosa (Taylor)
Inoceramus prisms (Upper Cretaceous)
Anomalina navarroensis (Navarro)
Kyphopyxa (from the Taylor)
Anomalina taylorensis (Taylor)
Globotruncana (Upper Cretaceous)
Gümbelina (Cretaceous)
Globigerina (Cretaceous)

The Lagarto has yielded:

Exogyra arietina (Grayson)
Gryphaea
Dictyoconus walnutensis (Fredericksburg)
Gümbelina
Globigerina
Anomalina
Nodosaria
Cristellaria

From Recent shore sands on Galveston Island and near the mouths of the Brazos and Colorado, there have been collected numerous easily recognizable Cretaceous foraminifera.

In conclusion it should be mentioned that much more work is in order on the Cretaceous unconformities in Texas. In both the Lower and Upper Cretaceous, the types of physical and faunal breaks called *Dachbänke* and *Sohlbänke* by Brinkmann, Arkell, and others are known to exist. But most particularly a much more expert and detailed knowledge of the zonation is imperative for any real understanding of the Cretaceous unconformities.

SECTION IV—MIDDAY AND EVENING GENERAL SESSIONS

THE TREND OF OIL PRODUCTION AND PETROLEUM ENGINEERING

W. W. SCOTT[1]

Mr. Toastmaster, Ladies and Gentlemen:

It is a real pleasure to me to take part in this program. Although it was not my good fortune to attend Texas University, I think I can appreciate the pride and satisfaction manifested by the faculty, alumni and students in the activities of the associated Departments of Geology, Chemistry, and the College of Engineering in the completion of the wonderful program for this celebration. I am sure you are all disappointed that Mr. Suman was not able to be with you today and, although it is a pleasure to "pinch-hit" for him, I fully realize I am a very poor substitute.

When Mr. Plummer wrote me regarding this meeting, he suggested that I say whatever I desire about petroleum engineering and the oil business. After reviewing the program for your meeting and keeping in mind the suggestions of Mr. Plummer, I have prepared a discussion on "The Trend of Oil Production and Petroleum Engineering." I therefore assume that you are interested in at least some branch of the oil industry.

I am sure you are all informed as to the inception of the oil industry and its history does not require repetition at this time. However, I desire to present some of the statistics about the oil industry in order to clarify or build a background for some of the remarks I will make later on, and perhaps it will be the means of causing some of you to become oil minded for the moment.

The industry now has approximately 330,000 wells, producing in the neighborhood of 2,400,000 barrels of oil per day. Of this total amount of production in the United States, the State of Texas produces approximately 1,050,000 barrels per day, or 44 per cent from approximately 53,129 wells. Seventy-four per cent of the Texas production is produced from 38 per cent of its wells at

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Paper presented at midday session of Quarter-Centennial Celebration of the Division of Natural Resources, The University of Texas.

the average rate of 35 barrels per well per day, while the remaining 26 per cent of the total production is produced from 62 per cent of the wells at an average rate of 4.5 barrels per well per day.

In order to maintain the supply of crude to take care of the demand of 800 million to 1 billion barrels of oil annually, it has been estimated that it is necessary to complete 20,000 wells per year at a cost of $500,000,000. The investment in the industry since its beginning in 1859 has amounted to 13 billion dollars, with a production of more than 16 billion barrels of oil. There are more than 2 million employees in constant service within its various departments. Since its beginning, the petroleum industry has been exceptionally hazardous for investors, with the price of crude oil ranging from $20 a barrel in 1859 to 10 cents a barrel within a few years after that time and fluctuating at a wide range up to the present time.

Since 1859 the oil industry has been faced with an over supply, with the exception of the years during the World War when there was considerable demand for the production of the United States, but many times it has appeared that the reserves of petroleum were limited to the supply necessary for the following few years, when new discoveries, such as East Texas and Conroe, would be added to extend this time by several years. As large and important as the East Texas field is, its total recoverable oil probably would not furnish the requirements for the United States for more than a period of 5 years if all other production were shut in. The estimated oil reserves at present are from 10 to 12 billion barrels for the United States. Of the total reserves for the United States, the State of Texas has from 40 to 50 per cent. During the last ten years, production has exceeded new reserves found in every year except 1926, 1928, 1930, and 1931. Since January 1, 1931, reserves have decreased by 1,300,000,000 barrels.

	Reserves discovered			Production		
	1933	1934	Total	1933	1934	Total
Texas	121,000,000	159,000,000	280,000,000	410,760,000	381,232,000	791,992,000
Total United States	184,000,000	400,000,000	584,000,000	911,743,000	908,277,000	1,820,020,000
Per cent Texas	65.76	39.75	47.94	45.05	41.97	43.51

The importance of the oil industry to the State of Texas is readily seen when the value of its production is compared with its strongest competitor—cotton. The wholesale value of Texas oil production in 1933, at a price of 60 cents per barrel, was $237,872,000, as compared to $204,040,000 for the value of cotton. It has been observed that during the past ten years the percentage of successful oil producing wells has fluctuated between 60 per cent to 70 per cent of the total number drilled, and in 1934 the percentage of successful wells is estimated to be 70.5, but there has been no definite trend towards either an increase or decrease in the percentage of successful wells. During the life of the industry, a total of 825,135 wells have been drilled, of which number 191,095 have been dry holes.

With reference to the economics of drilling and producing oil, needless to say there is much confusion. By that I mean that there is no basis of comparison between the costs of companies because of different methods of accounting and also between different areas because of variations in conditions. A recent report of the Petroleum Administrative Board showed the cost per barrel for producing oil in the United States during the period 1931–1933. This report is of interest because of the fact that the costs arrived at are on the same basis.

Average Cost per Barrel

	1931–1933
California	$ .65
Texas	.66
Oklahoma	.99
Kansas	1.03
Eastern states	1.65
Average United States	.806

These costs represent the over-all costs. That is, they include overhead, leases, taxes, depreciation, cost of drilling, and operating. The average cost was 80.6 cents per barrel while the average price was 72 cents per barrel.

During the past ten years the industry has changed from uncontrolled to controlled operation, or from unrestricted operation to development under proration. In this I refer to the rational development programs in most all our recently discovered fields, with particular reference to wider spacing of wells and the recognition of production rates that will better utilize reservoir energy in recovering oil and gas. Although figures and statistics are tiresome, I feel sure that the following will demonstrate the point I desire to make more convincingly than I can state it. The following costs reflect only drilling and lifting cost.

Unrestricted Fields	Well Density Acres per Well	Ultimate Drilling Cost per Barrel	Ultimate Production Cost per Barrel
Refugio	8	$ .539	$ .864
Powell	8	.242	.543
Orange	1	.527	.906
Goose Creek	1	.393	.813
Luling	4	.252	.556
Prorated Fields			
Conroe	18	.050	.20
Hobbs	40	.110	.245
Yates	37	.012	.114
Van	7	.043	.178
Sugarland	14	.043	.143
Thompsons	18	.033	.133
East Texas	5	.158	.293

To carry the case of the Conroe field further: Where the drilling cost is 5 cents of the total ultimate development and producing cost of 20 cents, if spacing in that field should go to a pattern of one well to 300 feet, or 2.2 acres, instead of a spacing of one well to 20 acres, which is now in effect, there would be a total of more than 8000 wells drilled in the Conroe field instead of the approximate total 970. The field would not be drained any more efficiently and the investment in wells and producing equipment would be increased by approximately $200,000,000, or about 35 cents per barrel of oil recovered.

The present trend is towards wide spacing of wells, and in many cases it is believed that the ultimate recovery will be greatly increased by wide spacing due to the fact that in some instances reservoir energy may be better utilized in the fields where wide spacing is in effect. In new fields in the west Texas area and in New Mexico, the trend is towards 40-acre spacing, whereas the new fields in the Gulf Coast area are being developed more on the 20-acre spacing pattern. This is a considerable variation from development of one well per acre as exists at Orange and Goose Creek, one well to 3 acres at Powell, and one well to 4 acres at Luling.

The factor of increased recovery is only one of those which make wide spacing favorable. Another factor which is more and more making wide spacing a necessity is that from year to year the depth of production is increasing, and the cost of such wells makes it necessary that spacing be on a wide pattern. The effect of depth on the cost of wells is shown in the case of several fields which are now being developed such as the following: East Texas, in which the wells are approximately 3700 feet deep and cost approximately $14,000; Tomball, in which the wells are approximately 5500 feet deep and cost approximately $28,000; Roanoke, in which the wells are approximately 8600 feet deep and cost from $75,000 to $100,000. An example of unnecessary drilling with no increase in recovery is that of the world's most important field, the East Texas field, in which it had been hoped that the well density would not exceed one well to 10 acres, giving a total of approximately 11,600 wells to the field. The drilling density in the field has a possibility of reaching one well to 5 acres, which gives an additional 11,600 wells that will not increase the recovery of the field and which will cost the operators an additional $162,400,000 for drilling development costs. For this additional expenditure there will be no return. On the contrary, the excessive number of wells will tend to cause disorderly or overproduction which in turn will damage the field to such an extent that recovery will not be equal to that on 10-acre spacing under more orderly producing conditions.

I think it would be in order to discuss some of the trends in drilling and production practice with particular reference to the part the technical man has in them. It may be pertinent to inquire, "What has the engineer taught the practical oil man?"

My answer is "To think, to plan, and to coördinate his work." Your immediate reply to that statement is that I have dealt in generalities and that I should be more specific. First I will discuss some of the contributions of the geologists and second those of the engineer.

In my estimation the geologist has made a real contribution to more efficient development in the correlation of formations from well logs. No operator can successfully carry on without this valuable service. As many of you know, the geologist's recommendations involve the practical problem of determining the depth to set casing in wells, depth to take cores to obtain most beneficial data, and the depth to complete wells. The correlation of well data also results in an early estimate of the size and extent of new oil fields which is invaluable to the executives whose duties are to deal with the financial aspect of development work. Also, in this connection, the geologist aids in keeping the number of dry holes down to a minimum. The elimination of dry holes results in the saving of money.

The development of geophysical methods has also influenced drilling and development in the industry to a very great extent. As you all know, the geophysicists have speeded up discovery of new structures which has made the drilling business literally "hum" during the past few years. However, it may be observed that if the geologist does not get busy and find some new method or improve present technique there may be a decided "lull" in the discovery of new oil fields. At the same time, I am mindful of the fact that it is the function of the geologist not to permit such a condition to come to pass.

So much for the geologist. Now let us inquire, "What has the engineer contributed?" To this inquiry I believe I can say he has contributed a great deal.

With reference to the actual producing of oil, perhaps the greatest accomplishment has been the recognition of the principles relating to the efficient utilization of reservoir energy in the operation of wells and pools. By reservoir energy I refer to (1) gas energy in the free gas in the higher portions of the reservoir and to gas dissolved in the oil and (2) the hydrostatic pressure of edge and bottom water in the lower portions of the reservoir below the oil. The most efficient utilization of these factors results in the greatest ultimate recovery of oil. In the past, it has been generally recognized that the recovery of oil in the average field amounted to about 25 per cent of the oil in place, when little or no attempt was made to utilize reservoir energy, but now it is believed that most efficient utilization of reservoir energy will result in recoveries amounting to from 50 to 75 per cent of oil originally in the reservoir.

Further consideration of the benefits to be derived from the utilization of reservoir energy in producing oil brings out that there is a certain balance between investment, recovery, rate of recovery, and cost of producing which must be determined in order to operate most successfully a given oil pool, and the technical man is much better prepared to render this service than anyone else.

I am sure the advantages to be gained by rational development programs and then by producing at rates of withdrawal in keeping with reservoir conditions is obvious to all of us. Many of you recall the discovery of the deep pools in the Los Angeles basin some ten years back, and later Seminole in Oklahoma, and then the Oklahoma City pool. It was often remarked, "Why discover deep oil pools when the cost of producing them will be prohibitive?" In those days, 20 to 25 per cent of the ultimate production was recovered by flowing and the balance by pumping. Today, with our new fields developed under proration and with proper attention given to utilization of reservoir energy, it is not unreasonable to expect a recovery of 80 to 100 per cent of the recoverable oil by flowing. Thus depth has ceased to be as great a factor in lifting costs. Likewise, drilling costs have been materially reduced during the past few years. For instance, the shallow sands of the Raccoon Bend oil field were drilled during 1928 and 1929. The average depth was 3327 feet. It required 72 days to complete a well at a cost of $32,000. During 1934 a deeper sand was discovered in this same field where the depth is over 4100 feet. It now requires about 25 days to complete a well, and even with the depth 800 feet greater, the cost is $25,000, or approximately $7,000 less per well. Likewise, drilling to depths of 9000 feet to 10,000 feet will not be prohihibitive since drilling costs can yet be further reduced. I do not hesitate to predict that drilling costs will be cut in half during the next ten years.

The oil industry offers a fertile field for research, probably more so than any other industry. The sciences of geology, physics, chemistry, and mathematics are all used in some phase of the oil industry and to a very considerable extent in the production division which embraces the geological, drilling, and producing departments, which fact is sufficient to demonstrate that the field is large. In drilling and production alone, there are research programs of considerable magnitude being carried on at this time, and no doubt the future will see a great deal more of this kind of work. For instance, equipment for drilling in itself offers a big field. We are now drilling wells to a depth of about 2 miles. Thirty-five years ago a well 3500 feet deep was considered to be of a great depth. Research in equipment will require much work to be done in the study of alloys for the purpose of manufacturing equipment that will stand abuse and be of much greater strength. The mechanical engineer will be called upon to design new equipment, whereas the drilling technician will be obliged to improve methods and technique in drilling and producing. During the past five years, the chemistry of mud fluid control has received a great deal of attention, but all of those in close contact with this problem will admit that they have only begun their work. Also research on cement is necessary when wells are drilled to great depths. Large quantities of cement are used in oil well drilling.

In the field of production there is yet unlimited possibility for work with one outstanding problem—increased ultimate recovery. It is generally accepted, and in numerous instances it has been proved, that for every barrel of oil produced there are approximately two barrels of oil left in the ground. In connection with this problem, additional work must be done on the physical properties of oil and gas as they occur in a reservoir, together with their behavior under various reservoir conditions. A solution of these problems will give a better understanding of the proper methods to adopt in the drilling for and the producing of oil. Repressuring and water flooding are old methods which are familiar to most of us, yet they still require further study and research for much needed greater improvements.

Technicians have constructed their own special instruments for obtaining the knowledge that we now have of reservoirs and their contents, and these instruments are much in need of improvements and accessories. For instance, there is the pressure bomb, which is used to take subsurface pressures in oil wells. Then there is gas and fluid sampling equipment which still needs to be perfected. Laboratory equipment used in any of these problems needs to be perfected, and the technique of handling most of these problems in the laboratory will be improved as additional time and effort are given to them.

In conclusion, I would say that the technical man today has greater opportunities in the oil industry than have ever been presented to him in the past.

RELATION BETWEEN GEOLOGY AND ENGINEERING IN WATER CONSERVATION

TERRELL BARTLETT[1]

Mr. Chairman, Ladies and Gentlemen:

It is indeed an honor to be asked to address this distinguished assemblage, particularly on the occasion of the celebration of the Quarter-Centennial of the three bureaus which make up the Division of Natural Resources of our University. It is difficult for me to use and think of these institutions in terms of their impersonal titles. We are really here to do honor to the great personnel that has inspired and made those organizations of so great value to the people of Texas and more directly to the engineers of our State.

The thought of the lapse of the twenty-five years, the expiration of which forms the anniversary we celebrate, naturally induces a reminiscent attitude of mind. It is rather risky for a young man to reminisce for fear he appear to be coming to—what shall I say—years of discretion. But lest any get a false impression, I would have it distinctly understood that my start into engineering work was at a very young and tender age.

My subject relates more to the work of the Bureau of Economic Geology and its relation to that of engineers. Better than any other way, I believe, to give a picture of the value of the geologist's work to the engineer will be to recount a few typical experiences.

In 1908 I was sent to the Army Maneuver Reservation at Leon Springs to report upon the possibilities of increasing the water supply which was then secured from a number of small yield wells into the sand strata of the bottom of the Cretaceous. That is anticipating, because "Cretaceous" was then merely a word out of a textbook. But I got hold of a copy of Dr. Hill's paper on the Cretaceous formations of southwest Texas. My method of locating my geological horizon was at least somewhat novel. Our distinguished geologists should listen carefully for instructive information. The surface outcrops were in the alternating beds of the Glen Rose, but I was not even sure of that. I platted to scale

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[1] Consulting Engineer, San Antonio, Texas; Consultant, Texas State Planning Board.

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a section through the whole Lower Cretaceous taken by Dr. Hill on the Colorado River, 80 miles away. Then, on another strip, I platted a section from stream bed to hilltop which I had taken, noting the thickness and sequence of hard and soft layers. Then by sliding the two strips until the strata matched, I discovered I was deep down in Glen Rose, and, by further reference to Hill, that the water horizon the wells were already in was the only one beneath us.

On the occasion of the investigation of the Medina project, one of the questions was whether the reservoir, which was in limestone, would hold water—but the beginning of that story is back in school days. We had a course in lithology, under Prof. W. O. Crosby. The professor had, unfortunately, become quite deaf. The lecture room was rather wide and not very deep, with doors at both of the two front corners. Between the doors was a long table full of specimens. Prof. Crosby, in his kindly way, took the roll at the beginning of the hour, then began his lecture. When he turned to one end of the long table three or four students would disappear through the opposite door. When he turned to find a specimen at the left hand, out would go several at the right door. When the hour was over the class had shrunk more than perceptibly. Prof. Crosby never appeared to realize that any had left. We thought of him as tottering on the verge of the grave.

Well, five or six years later Mr. John R. Freeman came to report on the Medina project, and who should he bring for the geological investigation but Prof. Crosby. My partner and I accompanied him on his field examination, both of us used to hikes and believing ourselves to be in the pink of condition. After two days there were two sadder and wiser young men. They could not have been more weary and footsore if they had been trailing the most agile goat known to natural history. There is one piece of professional advice I would like to give to the engineers present. If a geologist is to pass on one of your projects you should not attempt to influence his opinion by dogging his footsteps. It is better form to permit him entire freedom to make his field examination alone.

The importance of water supply problems to the continued development of Texas is but little appreciated by the public. As compared with such states as Illinois, Pennsylvania, New York and the New England group, our surface water supply is only four or five per cent as much in proportion to area. Our underground waters and the quantitative measure of possible continued draft on a given horizon in a given zone, which can be sustained by normal replenishment, will become increasingly important, and we are greatly dependent on the geologist for our facts concerning outcrops and underground conditions. The early summary of information concerning wells, as made by Dean Taylor, the important original work of Dr. Hill, and the later works of Mr. Deussen on the geology of the Coastal Plain, have been indispensable to engineers in connection with water supply and irrigation problems.

Another allied problem has to do with the losses of surface waters from our streams. We have had occasion to study the losses in a certain stream, together with the question of developing storage reservoirs near the zones of loss. For this study we developed a diagrammatic profile showing below the outcrops and depths of the various geologic formations in the stream bed from a published geological map, and above this showing to scale the volume of stream flow as measured from point to point along its course. This diagram gives a very clear picture of what becomes of the water and why.

Mother Earth! I like that term—Mother Earth. Next to the study of mankind itself, the most important thing for man to know and understand is this shell on which we live and from which we draw all the fruits of the soil and the treasures of the mind. Even a full understanding of the life of man himself demands a knowledge of geologic history.

I often wonder why the students in our academic courses do not more frequently elect geology as their scientific study. It is so much more fundamental than botany or zoology or even chemistry or physics. My amateur acquaintance with geology provides me with a never-failing source of interest and pleasure. It tells me why these soils are here and others there; why this valley is rugged and narrow and another broad and alluvial; why these farmers are dependent on earth tanks for their water—and have had to haul during the past year—and why this other region is dotted with merrily spinning windmills; why this prairie is treeless and another wooded; why the mesquite growth disappears and scrub oak and tough shrubs replace it. Differences in the nature and appearance of our cities even may be due to the varied geologic conditions which surround them.

If I may be permitted to digress, I would like to inject a brief word about the Texas Planning Board and its purposes. This Board of eleven members, including three from the faculty of the University, was appointed in the early summer by Governor Miriam A. Ferguson at the suggestion of the National Resources Board. That is a Federal Planning and Coördinating Agency, composed of five of the Cabinet members, with Mr. Ickes as Chairman. There is an active Advisory Committee under the chairmanship of Mr. Frederic A. Delano; Chas. W. Eliot, 2nd, is executive officer.

The Texas Planning Board views its function in this new field as coördinating and suggestive. The broad thought back of the planning idea can best be expressed, as respects Texas, in this way: Here are six million people bound together by many common interests, but all going helter-skelter about their various endeavors, individually and through a host of corporations and governmental units and agencies. There has been no one in a position to consider the relation of these various endeavors one to the others, nor with the duty of applying a reasonable and manifestly possible degree of foresight to the common problems. That, briefly, is the field and purpose of state planning.

In conclusion I wish to express on behalf of engineers generally, as well as personally, our sense of obligation to and appreciation of the work of the late Dr. Udden and to the administrative officers of the University who created these three organizations and who have sustained their continued existence, and also to my friends, Dean Taylor, Dr. Schoch, and Dr. Sellards, and their able staffs, who have been and are providing us with a great wealth of basic information, of ultimate value as yet unknown to any of us, and who are at all times so gracious and helpful on specific problems.

A MODEL STATE RESOURCE SURVEY

MORRIS M. LEIGHTON[1]

Mr. Toastmaster, Ladies and Gentlemen:

I am glad for this opportunity to extend, on behalf of the Illinois State Geological Survey, our congratulations to the Bureaus of Economic Geology, Industrial Chemistry, and Engineering Research of The University of Texas on their splendid record of achievements during the past twenty-five years of service to the State of Texas and to society in general.

This period of time has probably brought the greatest industrial development to this and other countries, in all their history. This development was not accidental. It came as a direct outgrowth of what man put into it, and I dare say that the most potent part of this was his research and experimentation. In the State of Texas, your bureaus have played their part, and therefore this Commonwealth is indebted to them.

I desire also to take this privilege of paying high tribute, on behalf of the geologists of Illinois, to the late Dr. Johan A. Udden, who contributed so greatly to the development of your State. We of Illinois can join hands with you of Texas in gratefully acknowledging the gifts of his mind and spirit to our respective states, for he devoted many of his younger years to the geology of Illinois.

May I also take this opportunity to pay my highest respects to your revered Dr. R. T. Hill, who is your honored guest on this notable occasion. I would have been willing to make this journey to Texas for no other reason than to express my regard and my admiration for him, if I had known that he was to be here.

I have been requested to speak this evening on the subject, "A Model State Resource Survey." I infer from this that the directors of these bureaus and their governing board are ever alert to ways of increasing the effectiveness of these bureaus for the welfare of the State and of society, that they cultivate an open mind as to how best they can achieve their main objectives, and that they are seeking various points of view for their own consideration. I

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[1] Chief, Illinois State Geological Survey, Urbana.

Paper presented at evening session of Quarter-Centennial Celebration of the Division of Natural Resources, The University of Texas.

wish to thank you for the compliment which you have paid me in asking me to discuss this subject, but I must confess that I undertake to do so with considerable misgivings of the appropriateness and value to your situation of what I may say.

THE IMPORTANCE OF STATE RESOURCE SURVEYS

State Resource Surveys are concerned with the natural resources of a state. The importance and value of these resources up to the present are in part potential—they remain to be more fully and more perfectly developed.

Every reason exists as to why these resources should be fully investigated. The entire volume of the world's business always has been and always will be based on natural resources—the resources of the land, of the rocks beneath the surface, of the water, and of the air. The materials in these resources provide the basis—the starting point for all employment—for labor, skill and management in the development and extraction of all their products, in their preparation and refining, in their conversion into consumers' goods, in their use in construction, in their transportation and distribution, in providing various forms of communication, in marketing by wholesalers, jobbers and retailers, in financial institutions, in all the trades and professions, in the world of education, art, and religion, and in governmental administration and control. In other words, natural resources form the basis upon which and out of which the physical framework of society is erected. They are the original source for the satisfying of man's economic wants, whether those wants be in the form of food, construction materials, surgical services, educational opportunities, or valet service. All other activity is, at every point, dependent upon and sequential to the recovery of materials from the primary natural resources. Man creates nothing; he merely changes the form, content, and position of materials whose ultimate source is in Nature. He uses the materials and forces of Nature to achieve his natural-born aspirations to higher and higher standards of living.

This development of the natural resources of the State and of the Nation, and likewise their conservation, is dependent upon a knowledge of what these resources are, how they can best be recovered, and for what they can be used. The more abundant these resources are, the greater is man's opportunity for better living conditions and the greater also is the opportunity for employment in diverse occupations. The more perfect and thorough this knowledge, the greater will be the development of a region and the sounder will be the basis for wise and practicable measures for conservation. This is the field for natural resource surveys. Their place is fundamental. They are essential to a high civilization.

THE GROWING NEED FOR BETTER NATURAL RESOURCE SURVEYS

Our Nation is young. Many of our states are younger. The development which has taken place in the early part of the cycle, by reason of the youth of the country, has been marked by exploitation. Capital and labor were scarce in the early days; natural resources were abundant. The latter were used liberally and even wastefully in attempting to satisfy the most elemental wants. Those resources most easily found and recognized and most easily drawn upon have been exploited. Wholesale extraction and inefficient and wasteful methods of utilization have marked this period. Our soils have been depleted, our forests have been largely destroyed, billions of tons of our best coal have been wastefully mined and used, our oil and gas reservoirs have been unscientifically tapped and uneconomically developed, reservoir pressures have been dissipated, our underground water supplies have not been properly husbanded, our fish and game have been massacred, our streams have been polluted, and many other resources have been mistreated or destroyed.

All of this is characteristic of the exploitation stage of development. The time has come, however, when we are entering the next stage, the stage of putting our resources to their highest uses in harmony with economic principles. Those states which take cognizance of this will become the more progressive and the welfare of their people will be more secure.

An integrated and practical program, based on an appreciation of the powers of science and technology and on sound principles of economics, should be formulated and set in motion in every state for the purpose of making as complete an inventory of its resources as is possible, of making studies that will point the way to the correction of wasteful practices of recovery, of finding more efficient methods and forms of utilization, and of determining wise and effective means of conservation and development. These, I believe, are the objectives of a Natural Resource Survey, particularly along mineral lines.

Many of our Natural Resource Surveys in their organization, objectives, and methods are nearly identical to what they were in the early days when they were founded. Times, conditions, public responsibilities, opportunities, and methods of practice have changed, and every natural resource organization should conscientiously face the question as to whether or not it is *now* properly organized to meet the new needs. The increasing draft upon exhaustible natural resources which a growing society demands must be accompanied by authoritative and detailed knowledge of the most effective methods by which these resources can be used and conserved. Our present society must have Natural Resource Surveys adequately equipped to cope with modern conditions and problems. To this end, those in political authority must lend an intelligent ear.

WHAT WOULD BE A MODEL NATURAL RESOURCE SURVEY?

My discussion of this question must be limited to general basic principles. The authorities in each state, in my opinion, are the ones best fitted to adapt these principles to the conditions therein existing, for I believe that no one idealistic plan can be set up in detail that would fit more than one state. I could hold no other view when I observe that the natural resources of any two states are not alike, that the opportunities for development of these resources in any two states are dissimilar, that the institutions and traditions of any two states are different, and that the needs of the industries and of the people of any two states are not the same. Therefore, it is not to be expected that the Natural Resource Surveys of any two states can be alike, in detail.

But there are certain basic principles affecting the functions of probably most, if not all, State Natural Resource Surveys which, if recognized and heeded, will go far towards making them successful. I shall now speak with particular reference to surveys dealing with geological resources.

WHAT A MODEL SURVEY SHOULD HAVE

I realize that there may be different points of view with regard to the points which I choose to mention. However, I offer them in the spirit of endeavoring to make a contribution to this question as to what would be a model Survey, believing that they deserve careful and constructive study.

(1) A Survey should have a proper motivating viewpoint. Someone has said, "Tell me what your resources are and I shall tell you what your society is." The term "resources" is used here in the broadest sense.

The more we ponder this statement, the more we become impressed with its force. Our minds immediately reflect upon those regions which differ in their resources of basic materials, of geographic location, of topography, of climate, and of human talent and skill. We recall those regions which have much, and those which have little. We picture their wealth, or their poverty; their attraction for men of ability on the one hand, or men who are content to live on small margins on the other hand; their high development of all of those features which make for a progressive type of civilization with ready means of extraction and conversion of resources into energy, construction, transportation, communication, educational facilities, and human character; or the lack of such development, which keeps mankind in the primitive state. It seems indeed true that the sum total of the resources of a region determine the state of society existing there.

But, upon second thought, we remind ourselves that a society may cease to progress. It may become static; it may retrograde. This is likely, especially if the individuals which make up that society are content with conditions as they are, if they feel that no new knowledge lies ahead, and no new and better ways of accomplishment. Instead, therefore, of saying, "Tell me what your resources are and I shall tell you what your society is," it is perhaps desirable that we adopt another more dynamic point of view—namely, "Tell me what can be done with your resources and I will tell you what your society can become."

This viewpoint may well serve as the cardinal principle of a model Survey working in the mineral field. The kind of a society that you and I can hope for for Texas and Illinois and the rest of the Nation will depend very much upon what can be done with their resources.

(2) A model Survey must, of course, have a program of research aimed at both basic knowledge and applied knowledge, and shaped

and reshaped against a background of continuously improved information concerning the possibilities of the geological resources of the State. Having shaped such a program, it is for that organization to see that it is carried through, inviting and taking advantage of such coöperation as related organizations can give.

(3) A model Survey should have a staff of personnel of advanced and varied training and experience in the basic sciences of geology, physics, and chemistry, and in mineral economics—a staff of persons whose personalities and resourcefulness will enable them to do group research along sound economic lines. This, I believe, is the minimum requirement. Such group research by geologists, physicists, chemists, and mineral economists, should be closely knit under one administrative head in order to facilitate planning, insure maximum coöperation, and expedite the work. The staff, as a general rule, should give full time to the work and should have limited or no teaching schedules to interfere with field conferences or conferences with persons coming to the office for inquiry. There will also be needed men for technological work in mining engineering, ceramic engineering, petroleum engineering, combustion engineering, materials testing, and the like. If the survey organization is located where these personnel and facilities are available in other organizations, advantage should be taken of these services, thereby saving unnecessary duplication of expense and preserving solidarity; but the work should be done as an integral part of the program of the Resource Survey.

(4) The Survey should have a non-political method of appointing its Director and its staff so that their positions are permanent as long as they are productive, coöperative, and in sympathy with the proper Survey policy. Such specialists should receive adequate compensation, because a staff which changes too frequently cannot make satisfactory progress on the research projects nor maintain the contacts with industry necessary to visualize and become thoroughly acquainted with its problems. It is also to be remembered that an investment in a poorly trained man may be much more serious than the total loss of the investment, because his work will stay progress for a long time. The Survey should also have liberal provision for field work and consultation with the industries and adequate and appropriate apparatus and equipment.

(5) The Survey should have an adequate clerical staff for the purpose of providing prompt replies to inquiries from citizens and all others who are interested in the industrial development of the State.

(6) An efficient filing system for all scientific and technical data, specimens, and maps should be provided.

(7) The Survey should have the means for prompt publication and distribution of the results of its investigations.

WHAT A MODEL SURVEY SHOULD DO

(1) A model Survey, dealing with geological resources, should carry on basic studies on the geologic framework of the State. Only by an intimate knowledge of the stratigraphy and structure of the sedimentary formations and of the nature, character, mode of occurrence, and structural relations of the igneous and metamorphic formations can the applied researches be soundly based. A part of this work will deal with problems of geologic systems, a part with areal geological surveys, and a part with subsurface problems based on well records, mine data, and geophysical information. This work will bring to light the extent, nature, and occurrence of the mineral resources and the geological conditions which affect the works of man.

(2) These basic researches should give rise to and be accompanied by researches aimed at applying this basic knowledge to economic problems. They should be directed towards the discovery and recovery of the commercial occurrence of new resources or needed additional resources and should seek new or better uses of known materials in which investments have already been made.

An important phase of this work, which I mention because it is relatively new, is the microscopic and X-ray study of the constitution of clays, shales, and coal. Such studies offer great possibilities of finding new uses for these materials and of improving their products.

(3) The Survey should furnish technical and scientific information on the results of its researches to all who are interested. It should furnish it in a way that bears directly on the particular problem in hand or with respect to a given industrial plant. The specifications which producers must meet for various kinds of mineral products are increasingly more exacting. Therefore, the giving of specific information is highly important.

(4) If a base map has not been made, the Survey should prepare an accurate base map of the State, suitable for the mapping of the resources, for the study of problems of land and water utilization, and for other uses too numerous to itemize here. Such base maps should be completed at as early a date as possible.

(5) Through an educational extension program, the Survey should make available to the citizens, industrialists, consumers, and teachers, and through them the next generation, facts regarding the results of the researches, the resources of various parts of the State, and the possibilities of improved or new utilization. Such educational work will meet what the citizens have a right to require, will create interest in investment circles in the State's resources, will create State pride, and will bring enthusiastic support to the work of the organization.

CONCLUDING REMARKS

In closing, I wish to reiterate that the security and happiness of the people are dependent upon what the natural resources are and what can be done with them. We have passed through the exploitation cycle of industrial development. Much benefit has come out of this cycle in producing wealth, but there has also been incomplete and inefficient development and conservation of our resources. Unnecessary waste of an exhaustible resource steers the nation towards calamity. Cheaper production of power and other materials necessary for manufacturing will bring widespread benefit. New and higher uses for materials now serving lower purposes will bring both added wealth and higher standards of living. In this day, haphazard exploitation appears to be giving way to a more scientific and rational form of development in which research will be increasingly looked to for new uses, or improved uses, for materials. The need for fully organized Natural Resource Surveys is greater than it has ever been, especially for those who are in position to employ the newer and the more powerful tools of science in the light of economics. New opportunities await discovery from creative research, and more general happiness for man is impending if the social and economic dangers that accompany periodic fluctuation in business can be avoided in ways that will preserve the opportunity for man's initiative. A forward step will be taken in this direction by researches embracing the various aspects of our resources, production volume, market capacity, and market trends.

Finally, permit me to express the opinion that if your bureaus of research will succeed in meeting the new needs of the next twenty-five years as constructively as they have the needs of the past, their service to the State and their reputation will be admirably glorified.

ADDITIONAL PAPERS

DIMORPHISM IN PERMIAN FUSULINES

CARL O. DUNBAR,* JOHN W. SKINNER,† AND ROBERT E. KING‡

INTRODUCTION

It is now well known that sexually produced foraminifera commonly grow larger than asexually formed individuals of the same species, and that they also differ in other shell features, notably the size and arrangement of the early chambers. As a result many species are represented by shells of two distinct forms.

This phenomenon of dimorphism was first suspected by students of the Eocene nummulites who found repeatedly an association of a large and a small species as, for example, *Nummulites laevigata,* with a diameter of 20 mm. and *N. lamarcki,* with a diameter of only 3 to 4 mm. Eventually no less than sixteen such pairs of large and small "species" were known. When these shells were sectioned it was found that the larger form invariably possessed a much smaller proloculum, whence it was termed *microspheric,* while the small form, because of its large proloculum, was termed *megalospheric.* The large shells were therefore characterized as *microspheric* and the smaller ones as *megalospheric.* Believing that so general an association of a microspheric and megalospheric form could not be fortuitous, Munier-Chalmas in 1880[1] advanced the idea of dimorphism, stating that each such pair represents merely two forms of a single species. He did not then know the reason for this difference and, not having observed any young microspheric individuals, made the mistake of thinking that the two forms began alike, the one adding small chambers at the center of its shell during later growth. De la Harpe[2] and de Hantken soon discovered young microspheric shells and corrected this error. They were inclined to doubt the hypothesis of dimorphism but suggested that if it were

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[1] Munier-Chalmas, Sur le dimorphisme des Nummulites: Bull. Soc. Géol. de France, vol. VIII, p. 300, 1880.

[2] De la Harpe, P., Sur l'importance de la loge centrale chez les Nummulites: Bull. Soc. Géol. de France, vol. IX, p. 171, 1881.

really true the two forms might represent different sexes. It was not until 1895 that the true relation was found experimentally by Lister[3] and Schaudinn[4] while working independently on the living foraminifera. The explanation was first fully set forth in 1903 by Lister[5] who had coined the terms *micro-* and *megalospheric* in 1895.

He showed that in normal reproduction the protoplasm of the adult subdivides into a few amoebulae which leave the parent shell and take up their independent existence, each immediately secreting a subspherical test, the proloculum, to which chambers are added as growth proceeds. This gives rise to a megalospheric shell. Such asexual reproduction may be repeated generation after generation; but on occasion the protoplasm of an individual divides into a very large number of minute flagellate zoospores, known as flagellispores, which conjugate in pairs before starting to grow. By this sexual

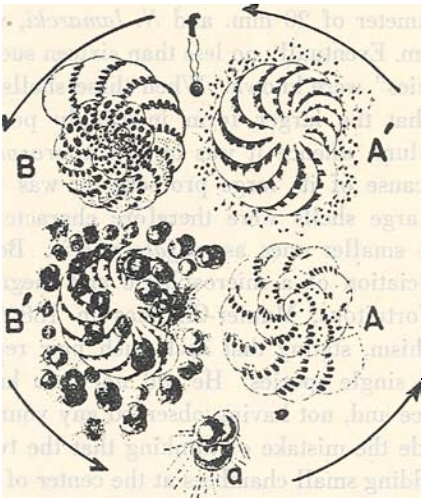

Fig. 30. The life cycle of *Polystomella crispa* (after Schaudinn). At the right is shown a decalcified megalospheric shell (A,A′) surrounded by flagellispores which have just emerged and will conjugate in pairs (f) to form a microspheric individual (B,B′) which, in its turn, will produce amoebulae (a) that will grow into megalospheric individuals, completing the life cycle.

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[3] Lister, J. J., Contributions to the life-history of the Foraminifera: Royal Soc. London, Philos. Trans., Ser. B, vol. 186, p. 401, 1895.

[4] Schaudinn, F., Ueber den Dimorphismus der Foraminiferen: Sitzungsb. d. Gesell. Naturforsch. Freunde zu Berlin, no. 5, pp. 87–97, 1895.

[5] A Treatise on Zoology, edited by E. Ray Lancaster Pt. I, Introduction and Protozoa, fasc. 2, pp. 69–78.

act each pair of flagellispores becomes a very tiny individual which secretes its microspheric proloculum and eventually grows to relatively large size, repeating in its ontogeny more or less of the phylogenetic history.

Similar observations have since been made on other living species by Hofker.[6] Cushman, and Myers,[6a] so that the principel of dimorphism now rests upon a secure basis. Its importance in the study of fossil foraminifera has been emphasized by Cushman[7] and by Hofker[6] and dimorphism is now recognized in so many fossil genera that it may be expected in any group of the foraminifera. Heretofore, however, no striking cases have been described in the *Fusulinidae.*

It is true that the proloculum varies considerably in size in many species of the fusulines, and specimens with the smaller proloculi have been considered by some to be microspheric. Staff[8] and Hayden,[9] indeed, have both written briefly on dimorphism in this group, but the supposed microspheric and megalospheric shells which they mention do not differ appreciably except in the size of the proloculum and earliest volutions. Dimorphism is apparent in some of the *Neoschwagerininae,* but in the described *Fusulininae* variations in the size of the proloculum fall into graded series and appear to indicate only individual variation.

However, in our study of the Permian fusulines for the Texas Bureau of Economic Geology, we have encountered undoubted dimorphism of the most spectacular sort in the genera *Parafusulina* and *Polydiexodina,* and it is our purpose here to present this interesting discovery.

This is but a detail of a monographic report on the Permian fusulines now in preparation. The extensive collections before us for this study have been made by a number of geologists to whom we are much indebted. The investigation was begun originally by Dunbar on collections at Yale made by Robert E. and Philip B.

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[6] Hofker, J., The Foraminifera of the Siboga expedition, Part II, pp. 79–104, 1930.

[6a] Myers, E. H., The life history of *Patellina corrugata,* etc.: Bull. Scripps Inst. Oceanogr., Tech. Ser., vol. 3, pp. 355–392, pls. 10–16, 1935. Myers found the gametes not to be flagellispores. He also found the details of the life cycle to be more complicated than that described above.

[7] Cushman, J. A., Foraminifera, their Classification and Economic Uses, p. 357, Sharon, Mass., 1928 Also in Second Edition, p. 50, 1932.

[8] Staff, Hans von, Ueber Schalenverschmelzen und Dimorphismus bei Fusulinen: Sitzensb. Gesellsch. Naturforsch. Freunde zu Berlin, pp. 217–237, 1908.

[9] Hayden, H. H., Fusulinidae from Afganistan: Records Geol. India, volume 38, p. 252, 1909.

King[10] during their survey of the Glass Mountains, the Sierra Diablo and the Hueco Mountains in 1925–28. Skinner began independently a study of a large collection made by Robert Roth in the Glass Mountains, the Delaware Mountains and the Guadalupes, and when the duplication of effort was discovered a coöperative study was undertaken. Robert E. King later made important collections in the vicinity of Las Delicias, Mexico,[11] and Skinner revisited the Delaware Plateau and the Guadalupe Mountains and collected more material. The U. S. Geological Survey has also placed at our disposal the important collections of Philip B. King and J. Brookes Knight made in the Hueco region and the Sierra Diablo in 1933, and of Philip B. King and H. C. Fountain in the Delaware Mountains and the Guadalupes in 1934. The Texas Bureau of Economic Geology has also provided some material and has given every encouragement to the study.

NATURE OF THE DIMORPHISM IN *PARAFUSULINA* AND *POLYDIEXODINA*

In the Middle and Upper Permian collections occasional giants are found among abundant fusulines of much smaller size. These we have found to be truly microspheric individuals. In the following pages such dimorphism is presented in three species of *Parafusulina.* Each is represented by a plate of illustrations in which both microspheric and megalospheric individuals are shown in natural size, with sections magnified five times, and details at the center enlarged fifty times. The use of the same magnification for both forms makes it simple to contrast the megalospheric and microspheric shells, and similar arrangement in the three plates will facilitate comparison of the species. In each of these species the micro- and megalospheric shells differ greatly in four respects.

(1) The proloculi are of a different order of size, those of megalospheric shells having about ten times the diameter, hence 1000 times the volume, of corresponding microspheric proloculi.

(2) The juvenile volutions are much the more numerous in the microspheric shells, four or five having formed before the young

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[10] The Geology of the Glass Mountains, Texas, Part I, Descriptive Geology, by P. B. King: Univ. Texas Bull. 3038, 1930; Part II, Faunal summary and correlation of the Permian formations with description of Brachiopoda, by R. E. King: Univ. Texas Bull. 3042, 1930.

[11] King, R. E., The Permian of southwestern Coahuila, Mexico: Amer. Jour. Sci., vol. 27, pp. 98–112, 1934.

shell had attained a diameter equal to that of the proloculum in the megalospheric form; and growth continued longer so that the giant shells attained about twice the total number of volutions and twice the length of the corresponding megalospheric shells.

(3) The megalospheric individuals are bilaterally symmetrical from the start, but the microspheric shells possess an endothyroid juvenarium of about two volutions coiled nearly at right angles to the plane of the later whorls. In these juvenile volutions the chambers are narrow, apparently subspherical, and coiled in a low spiral as in *Endothyra.* Since the axial section, cut at random, may coincide with the plane of coiling of the juvenarium or may intersect it at any angle up to 90°, the appearance will vary, of course, in different sections. We have been fortunate in securing several which coincide with the plane of coiling of the juvenarium.

(4) The microspheric shells lack a tunnel at all stages of growth or at best show only a small subcircular orifice in the septa of the first two or three volutions surrounding the juvenarium, whereas all other shells of all the genera of the *Fusulininae* show a tunnel in all but the last volution or the last several chambers. The lack of a tunnel appears to be distinctive of these big microspheric shells so that they can be recognized even without sectioning to the center. Even in the genus *Polydiexodina* microspheric individuals show no tunnels, either normal or supplementary.

EVIDENCE OF DIMORPHISM

In the preceding paragraphs we have assumed that the microspheric and megalospheric shells thus paired really belong together as dimorphic forms of a single species. This assumption rests on the following lines of evidence:

(1) The paired forms are literally megalo- and microspheric. The distinction is of the nature and degree observed experimentally in cases of dimorphism in modern foraminifera.

(2) The field association suggests dimorphism here just as it did in the case of the nummulites over fifty years ago. In each of the three species described, many megalospheric shells of a single type are found with rare specimens of a single microspheric form. In the case of *Parafusulina deliciasensis* a single chunk of siliceous limestone dissolved in HCl yielded some two hundred megalospheric shells and a single microspheric individual.

(3) Two anomalous features of these giants—the lack of a tunnel and the spiral juvenarium—indicate that if not physiologically specialized individuals they represent a new generic type which does not even fit well within the family *Fusulinidae* as now understood. Yet in many other features—as the wall structure, the character of the septa, the septal pores, and septal fluting—they show a close alliance with the other fusulines which invariably possess a slit-like tunnel and bilateral symmetry.

(4) Finally, the occurrence of these rare microspheric giants finds a remarkable parallel in the modern *Alveolinella quoyi,* the striking dimorphism of which has been described by Chapman[12] and Hofker.[13] The parallelism not only affords a strong support for the belief in dimorphism in *Parafusulina* but at the same time is one of the most remarkable illustrations of homeomorphy yet seen among invertebrate animals.

TAXONOMIC SIGNIFICANCE

The taxonomic significance of this discovery is two-fold. First, the microspheric giants must be identified with their megalospheric counterparts through their field occurrence, and obviously should not be given distinct names.

In the second place, the endothyroid juvenarium strengthens the alliance of the large fusulines of the Upper Pennsylvanian and Permian with such primitive genera as *Schubertella, Boultonia, Fusiella* and *Yangchienia* which clearly indicate their endothyran ancestry. There has been a tendency on the part of some students of the fusulines to stress the distinction between those types which have an endothyroid juvenarium and those which are bilaterally symmetrical from the start. The persistence of the endothyran characters in such marked form in these microspheric shells, even to the end of the Permian, suggests a common ancestry for all the fusulines, and, at the same time, gives rise to more than a suspicion that the bilaterally symmetrical shells as seen in *Fusulina, Fusulinella, Triticites, Schwagerina,** etc., represent only asexually

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[12] Chapman, F., On dimorphism in the Recent Foraminifera, Alveolina Boscii Defr.: Jour. Royal Microscopical Soc., pp. 151–153, pls. 2–3,, 1908.

[13] Hofker, J., Foraminifera of the Siboga expedition, Part II, pp. 163–170, pl. 41, figs. 6–7, and pl. 64, 1930.

*The name *Schwagerina* is used throughout this volume in the current sense, *i.e.*, for shells with a tightly coiled juvenarium followed by inflation.

formed individuals. If so, however, it seems strange that no microspheric individuals have been found in the genera just mentioned. In any event, there can be no doubt that *Parafusulina* has descended through *Pseudofusulina, Triticites* and *Fusulina* in which shells with a spiral juvenarium have not yet been found. Does this mean that sexual reproduction did not occur in these genera throughout most of Pennsylvanian and early Permian time but was reverted to by their descendants in the later Permian, or is it possible that forms now described as *Schubertella, Boultonia, Fusiella* and *Yangchienia* are but the microspheric counterparts of other genera? The latter suggestion now seems improbable but deserves study.

SYSTEMATIC DESCRIPTIONS

We present herewith three new species of *Parafusulina* in which dimorphism has been critically studied. In our collections there are a number of other large microspheric forms which will be described in our completed report. Among the *Polydiexodinas* of the Capitan limestone there are several microspheric giants in our collections. It now appears that such extreme dimorphism is to be expected in any of the species of *Parafusulina* or *Polydiexodina.*

PARAFUSULINA DELICIASENSIS Dunbar and Skinner n. sp.

Pl. I, figs. 1-9

Megalospheric form.—An elongate, slightly fusiform species of moderate size, tapering gradually from the equator to subacute poles. Adult megalospheric shells include 7 to 8 volutions, attaining a length of 15 to 18 mm. and a diameter of 2.8 to 3.0 mm.

The proloculum is large, commonly measuring 500 to 600 microns in diameter, and is usually not spherical, being much flattened on the apertural side or even subrectangular in section. Its aperture is a round pin-hole, about 50 microns in diameter, with its margins invaginated into the form of a short collar, with a flange like a bottle neck, directed into the proloculum.

The equatorial expansion is slow, the volutions being low at the middle, though increasing in height toward the poles so that the shell becomes more nearly cylindrical as it approaches maturity. The ratio of length to thickness increases from 2 or 3 to 1 in the early whorls up to 6 or rarely 7 to 1 in the adult shells. The specimen shown as figure 2, Plate I, is more bluntly rounded at the poles, hence somewhat shorter, than the average shells; that of figure 1, Plate I, is normal.

The wall is thin, increasing from 30–40 microns in the early volutions up to 70–80 microns in the outer whorls. It shows clearly the tectum and keriotheca. The septa are regularly and intensely fluted in the form typical of *Parafusulina, i.e.*, the folds extend almost to the top of the septum and the opposed folds of adjacent septa meet, except near the top, subdividing the meridional chambers into regular cell-like chamberlets, while near the base the tips of opposed folds meet without touching the floor of the volution, leaving a series of arch-like basal foramina, and the basal sutures of the septa run spirally about the shell.[14] In their present completely silicified condition, the septa do not clearly show pores. In a typical sagittal section the septa number 12, 22, 28, 33, 33, respectively, in the first five volutions.

Statistical measurements are given in the following table for four specimens.

Table of Measurements

	Half Axial Length				Half Diameter				Form Ratio			
	1	2	3	4	1	2	3	4	1	2	3	4
Proloc	.30	.23	.30	.27	.250	.15	.24	.27	—	—	—	—
Vol. 1	.45	.75	.9	1.0	.370	.23	.35	.35	1.21	1.50	2.60	2.9
2	1.28	1.50	1.8	1.8	.480	.32	.45	.47	2.66	3.26	4.0	3.8
3	2.20	2.40	3.0	2.8	.635	.45	.58	.58	3.50	5.33	5.0	4.8
4	3.40	3.70	4.3	4.2	.805	.61	.78	.72	4.25	6.0	5.6	5.8
5	4.75	5.20	—	5.6	1.000	.81	—	.91	4.75	6.4	—	6.1
6	6.08	7.40	—	6.8	1.236	1.03	—	1.11	5.0	7.0	—	6.1
7	7.30	—	—	7.7	1.435	1.27	—	1.33	5.1	—	—	6.0
	Wall Thickness				Tunnel Angle							
	1	2	3	4	1	2	3	4				
Vol. 1	40	30	35	50	23	—	25	30				
2	50	35	50	45	34	—	35	36				
3	50	40	?	45	41	—	51	40				
4	60	50	70	60	45	—	58	43				
5	—	?	—	70	53	—	60	43				
6	80	70	—	80	—	—	—	60				
7	—	80	—	—	—	—	—	—				

Microspheric form.—We have a single adult microspheric individual (Pl. I, figs. 3 and 4) and about 200 megalospheric individuals, all completely silicified, which were etched from a small chunk of dark gray siliceous limestone. This microspheric shell has a length of 33.2 mm. and a diameter of 2.5 mm., its form ratio of 13:1 exceeding any other fusuline known for its extreme slenderness. The shell comprises 11 volutions of which the first two constitute a minute endothyroid juvenarium. The proloculum is not very clearly shown but is certainly less than 50 microns in diameter. Unfortunately, we have not dared to cut this unique specimen as thin as necessary for a good photomicrograph, but, with proper illumination, the slide shows a structure closely similar to that of the microspheric shell of *P. rothi* (Pl. II, fig. 7). As shown in Plate I, figure 8, there is no evidence of a tunnel at any stage of growth.

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[14] See Dunbar and Skinner, New fusulinid genera from the Permian of west Texas: Amer. Jour. Sci., vol. 22, p. 259 and Plate II, 1931.

The spiral juvenarium has a diameter of about 130 microns, including the minute proloculum and about two volutions. The half diameter of the shell is .1 mm. in the third volution, increasing in succeeding whorls to .16, .25, .34, .46, .62, .77, .96, 1.18 mm. respectively. In Plate I, figure 9 shows this specimen at natural size along with young and adult megalospheric shells. Figure 3 shows it, enlarged 5 diameters, before sectioning, and figure 4 shows the axial section at the same magnification, which may be compared with a megalospheric specimen, figure 2, equally enlarged. In figure 8 the center of this specimen is shown at 50-diameter enlargement and may be compared with figure 7 which shows the center of a young megalospheric shell. The absence of a tunnel in the microspheric shell and its prominence in the megalospheric shells is noteworthy.

Discussion.—This species is not closely similar to any heretofore described in America. *Fusulina verneuili sapperi* [= *Parafusulina sapperi*] Staff, from Guatemala, has about the same length and the same number of volutions, but it is almost twice as thick and differs entirely from our shell in its proportions at all stages of growth. The megalospheric form more closely resembles *P. rothi,* described on the following pages, but that species is not quite so slender, is less pointed at the poles and has a much smaller proloculum. In spite of the small proloculum which would tend to result in more early volutions, the rate of expansion is such in *P. rothi* that it tends to have one less volution than *P. deliciasensis.* The microspheric shells differ more than the megalospheric, that of *P. rothi* being a little shorter and much thicker than that of *P. deliciasensis.* The specific name is given for the locality Las Delicias, in western Coahuila, Mexico.

Occurrence.—The types were etched from a single chunk of dark siliceous limestone collected by Robert E. King from the Middle Permian beds south of El Tordillo, near Las Delicias, province of Coahuila, Mexico.

The types are in Peabody Museum, Yale University.

PARAFUSULINA ROTHI Dunbar and Skinner n. sp.

Pl. II, figs. 1–8

Megalospheric form.—A short, stubby, subcylindrical species of medium size, attaining 7½ to 8 volutions and having a length of 15 to 16 mm. with a corresponding diameter of 3.7 to 3.9 mm., the ratio of length to thickness being about 5:1 in the adult. The poles are bluntly rounded and the equator not inflated.

The proloculum ranges between about 300 and 450 microns in diameter. It is subspherical, or more commonly cardiform, being flattened or slightly invaginated on the side which bears the aperture and somewhat inflated on the opposite side.

The equatorial expansion is rather slow. The ratio of length to thickness is about 2 or 3 to 1 in the juvenile whorls but increases to about 5 to 1 at maturity.

The wall is rather thin, increasing from a thickness of 30 to 40 microns in the early whorls to about 90 in the outer volutions. It consists of a thin tectum and a well defined keriotheca. The septa are intensely fluted and in tangential slices show the typical characters of the genus. The tunnel is slit-like and well marked in the first five volutions but is commonly missing in the outer whorls. The tunnel angle ranges from 40° to 50° and, in contrast to the condition in *P. deliciasensis,* does not increase markedly in the outer whorls. There is no trace of chomata at any stage of growth.

In the following table statistical data are given for three axial sections and the septal count is given for two additional specimens numbered 4 and 5.

Table of Measurements

	Half Axial Length			Half Diameter			Form ratio		
	1	2	3	1	2	3	1	2	3
Proloc.	.14	.215	----	.14	.215	.15	----	----	----
Vol. 1	.34	.67	.6	.21	.31	.21	1.6	2.2	2.9
2	.83	1.19	1.2	.28	.42	.30	3.0	2.8	4.0
3	1.47	2.08	1.8	.43	.58	.43	3.4	3.6	4.2
4	2.28	3.39	2.8	.61	.79	.64	3.7	4.3	4.4
5	3.61	4.74	4.2	.90	1.10	.90	4.0	4.3	4.7
6	5.61	6.42	6.0	1.22	1.41	1.25	4.6	4.5	4.8
7	7.93	7.72	7.5	1.54	1.77	1.61	5.1	4.3	4.7

	Wall Thickness			Tunnel Angle			Septal Count		
	1	2	3	1	2	3	4	5	
Proloc.	.033	.033	.040	----	----	----	----	----	----
Vol. 1	.028	.028	.030	----	35	----	15	17	----
2	.039	.047	.045	52	50	----	23	20	----
3	.039	.056	.045	45	45	----	23	23	----
4	.056	.067	.050	50	53	----	26	24	----
5	.075	.070	.065	----	49	----	31	25	----
6	.083	.094	.082	----	----	----	----	28	----
7	.095	----	.090	----	----	----	----	30	----

Microspheric form.—Large, elongate, subcylindrical, attaining 16 volutions, with a length of 34 mm. and a diameter of 4.7 mm., the ratio of length to thickness being approximately 7.2:1 at maturity. The proloculum has a diameter of only about 40 microns and the first two volutions constitute an endothyroid juvenarium coiled approximately at right angles to the axis of the adult shell. The juvenarium consists of about 18 rounded chambers of which 6 constitute the first, somewhat spiral whorl and the remainder form a little over one volution. There is then an abrupt rotation of the axis of coiling through 90° and the typical fusulinid growth begins. There is apparently a very narrow tunnel in the first two volutions outside the juvenarium, the openings appearing almost circular, but if so it is lost in the later volutions which, as shown in figures 4 and 6 of Plate II, were without a trace of a tunnel.

We have several microspheric individuals of this species, and two of the axial sections show the endothyroid juvenarium as in Plate II, figure 7. In these the juvenarium is coiled approximately in the plane of the slice. If the section had been cut at a high angle to this, the appearance would obviously differ and the true form of the juvenarium would not be so clearly shown. In the specimen shown as figure 7 on Plate II, the proloculum has a diameter of 40 microns and the half diameter of successive volutions measures, in millimeters, .045, .070, .095, .12, .18, .28, .39, .45, .61, .86, 1.14, 1.52, 1.89, 2.19. In the specimen shown as figure 4, the proloculum is 35 microns in diameter and the half diameter of the shell, in millimeters, measures, in successive volutions, .050, .075, .11, .15, .22, .32, .45, .58, .78, 1.02, 1.10, 1.39, 1.7.

A sagittal section of a young microspheric shell shows a septal count of 9, 11, 14, 19, 23, 28, 30, 34 and 35, respectively, in the first 9 volutions.

Discussion.—In shape this species most nearly resembles *P. wordensis* Dunbar and Skinner, both species having a stout, subcylindrical form with bluntly rounded polar extremities, but *P. wordensis* is almost twice as big, its megalospheric individuals, with only 8 volutions, reaching a length of 28 mm. Microspheric individuals of *P. rothi* are a little more slender than megalospheric shells of *P. wordensis* but otherwise closely resemble them superficially.

P. rothi is smaller and proportionately shorter than *P. kingorum* and has a much smaller proloculum. The species is named for Mr. Robert Roth.

Occurrence.—The figured types, except that of figure 7, were collected by Robert Roth at a locality near, but south of, Guadalupe Peak, in the Delaware Mountain Plateau where the Pasotex pipe line meets the trail to A J. Williams ranch. The horizon is a yellow sandstone in the lower part of Delaware Mountain formation not far above the top of the Bone Springs limestone. The species was also collected by John Skinner, from a limestone member of the middle Delaware Mountain formation at a locality below the airplane beacon, about 3 miles southeast of Guadalupe Point, and from the same horizon by P. B. King, one-half mile east of the west end of Getaway Gap. The specimen shown in Plate II, figure 7, is from the latter locality.

Figured types are in Peabody Museum, Yale University, except that represented by figure 7 which will be deposited in the U. S. National Museum.

PARAFUSULINA KINGORUM Dunbar and Skinner n. sp.

Pl. III, figs. 1–7

Megalospheric form.—Large, subcylindrical, tapering slightly toward the bluntly rounded ends, comprising about 8 volutions and attaining a length of 23 mm. and a thickness of 4.8 mm., the ratio of length to thickness being about 4.8:1 at maturity.

The proloculum is large, commonly measuring from 470 to 600 microns in diameter, and is normally subspherical, but in one sectioned specimen, figure 4 of Plate III, it is greatly flattened and measures 500 by 780 microns. Equatorial expansion is slow but the volutions increase considerably in height toward the poles. The half diameter in the specimen shown as figure 1,

Plate III, measures .35, .47, .60, .80, 1.05, 1.41 and 1.86 mm., respectively, in the first 7 volutions. The corresponding half axial lengths are 1.0, 1.4, 2.2, 3.0, 4.0, 6.0, 8.0, 10.0. Thus the ratio of length to thickness increases from 2.8 to 1 in the first volution to 3.7 to 1 in the fourth and 4.3 to 1 in the seventh volution. The septa are numerous and are intensely fluted in the manner characteristic of *Parafusulina.* In the sagittal section noted above, the septal count runs 13, 30, 38, 38, 45, respectively, for the first five volutions. No complete count can be made in the later whorls which are broken, but the last half volution shows 30 septa.

The tunnel is slit-like, rather narrow and apparently imperfectly developed since it appears well defined in some of the volutions, while in some intermediate ones there are remnants of the septa where the tunnel should exist. In the specimen shown as figure 1, Plate III, the tunnel angle measures 15° in the first volution, cannot be measured in the second, is 21° in the third, 32° in the fourth and is too indistinctly limited in later whorls to be measured. In another specimen it measures 17° in the first whorl, 23° in the second, 29° in the third, ? in the fourth, 31° in the fifth, but is only 27° in the seventh.

There is no trace of chomata at any stage of growth. Abundant septal pores are indicated wherever the preservation is suitable.

The wall is thin but somewhat thicker than in the preceding species. In the specimen shown as figure 1, Plate III, its thickness in the first seven volutions runs 30, 45, 55, 65, 90, 120 and 120 microns.

Microspheric form.—The microspheric shells of this species attain giant proportions for a Paleozoic foraminifer. the upper specimen shown in figure 7 of Plate III having a length of 51 mm. with both ends missing. It certainly exceeded a length of 60 mm. and has a diameter of 7.8 mm. The somewhat smaller specimen shown below it in figure 7 was sectioned and is shown, × 5, in figure 3. This specimen has a diameter of 6.2 mm. and the preserved half measures 22 mm. from proloculum to pole, indicating a complete length of 44 mm. In this shell there are 14 or more volutions. Apparently the juvenarium was coiled in a plane at right angles to the section and, unfortunately, the complete silicification has obscured the details here so that its form cannot be clearly demonstrated as in the previous species. The proloculum cannot have been much larger than that of *P. rothi* in any event. The specimen clearly had no tunnel at any stage of growth. Abundant septal pores are shown from the fifth volution outward.

Discussion.—The preparation of suitable sections and illustrations of this species has presented exceptional difficulties. All our material is in the form of fossiliferous chert in which fossils and matrix are completely silicified together so that specimens cannot be freed by etching. To cut the slice shown in figure 3 to transparent thinness alone required more than a day's careful work. The photographs also are somewhat unsatisfactory because of the unequal color of the silicified shell walls which in places appear opalescent and in others heavily clouded.

This species resembles *P. wordensis* superficially but the megalospheric shells of that species are considerably larger than in this and differ in proportions at all stages of growth. A sectioned specimen of *P. wordensis* having an equatorial diameter of 5.7 mm. and a length of 30.0 mm. has only eight volutions. In that species the shell tapers to more acute ends in the early whorls, the young shells having been more fusiform than in the species before us.

The name is given for the brothers Robert and Philip King, whose work in the Glass Mountains has made such an important contribution to the stratigraphy of the American Permian.

Occurrence.—This species occurs in the highest beds of the Word formation. The types were collected along the ridge from 2.7 to 4.7 miles northeast of the old Word ranch in the Glass Mountains, Texas.

Types in Peabody Museum, Yale University.

PLATE I

Parafusulina deliciasensis Dunbar and Skinner, n. sp.

Figures—

1. Adult megalospheric shell (× 5), also shown at natural size in the lower right quadrant of figure 9.
2. Axial section of another megalospheric shell (× 5) which is more bluntly rounded than the normal.

3, 4. Adult microspheric individual and axial section of same (× 5); the same shell is shown at natural size at the top of figure 9.

5. Axial section of a young megalospheric shell (× 5).
6. Antethecal view of a young megalospheric shell (× 5), also shown at natural size just below the microspheric shell in figure 9.
7. Enlarged view of the center of figure 5 (× 50).
8. Enlarged view of the center of figure 4 (× 50).
9. A group of cotypes, natural size.

All shells figured on this plate were etched from a single small chunk of limestone collected by R. E. King from the Middle Permian formations south of El Tordillo, near Las Delicias, province of Coahuila, Mexico.


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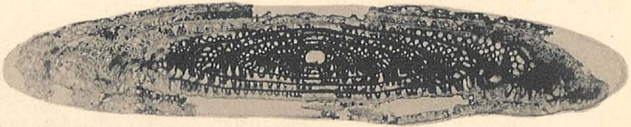
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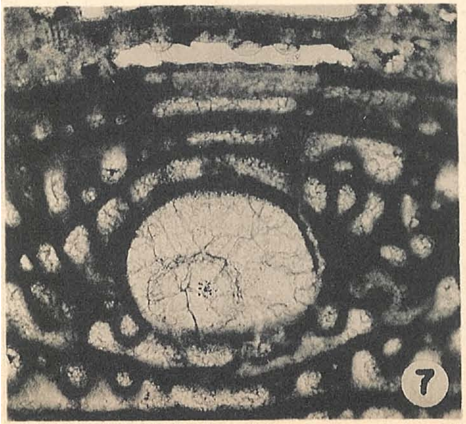
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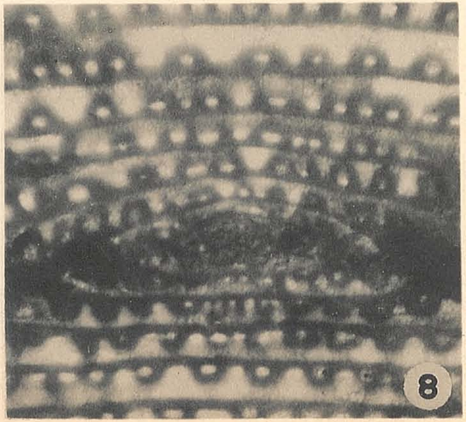
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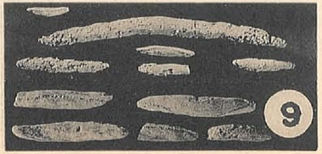
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PLATE II

Parafusulina rothi Dunbar and Skinner, n. sp.

Figures—

1, 2. Axial sections of adult megalospheric shells (× 5), with penciled sketches natural size to show the external form.

3. Sagittal sections of a similar shell (× 5).

4. Axial section of an adult microspheric shell (× 5) which is shown at natural size as figure 8.

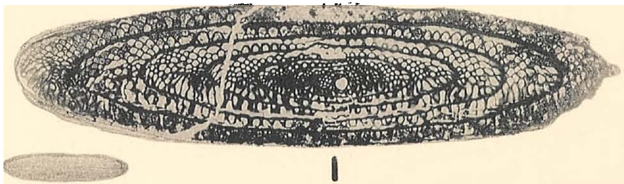
5. Enlargement of the center of figure 2 (× 50).

6. Enlargement of the center of figure 4 (× 50).

7. Center of axial section of another specimen (× 100) showing the endothyroid juvenarium of nearly two volutions.

8. Microspheric shell (× 1).

All specimens except number 7 were collected by Robert Roth from a yellow sandstone near the base of the Delaware Mountain sandstone as it is represented at a point south of Guadalupe Peak northeast of the junction of the Pasotex pipe line and the trail to A. J. Williams ranch. Specimen 7 was collected by P. B. King from the Getaway limestone member of the Delaware Mountain formation, at a horizon about "700 feet below the upper dark limestone" on the north rim of the canyon between one-fourth and one-half mile east of the west end of Getaway Gap, south of Guadalupe Peak.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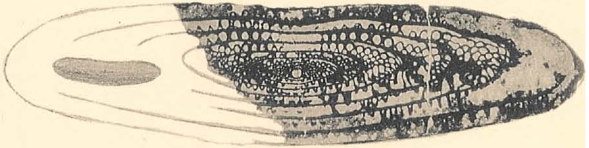
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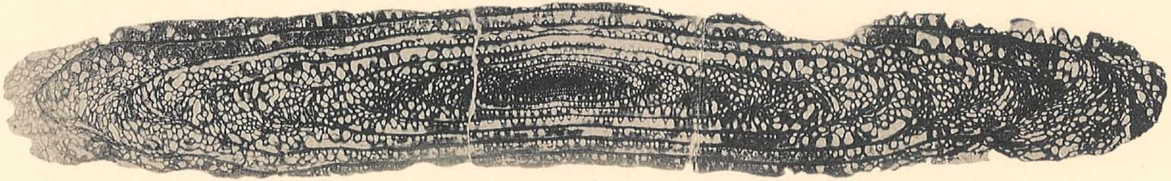
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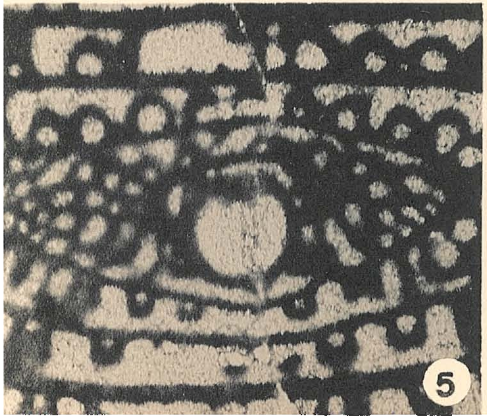
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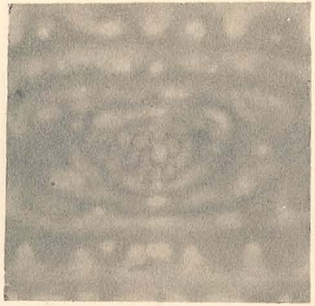
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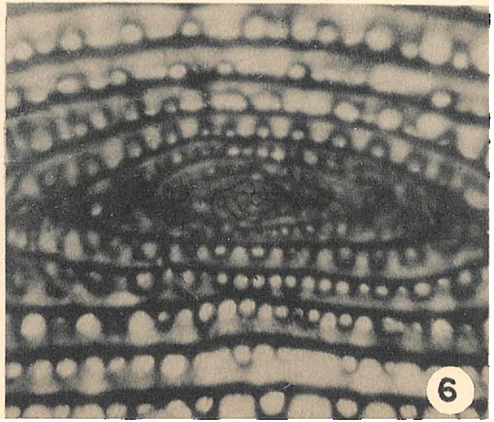
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PLATE III

Parafusulina kingorum Dunbar and Skinner, n. sp.

Figures—

1, 2. Axial sections of adult and young megalospheric shells (× 5) with pencil sketch (× 1).

3. Axial section of an immature microspheric individual (× 5). This is the specimen shown in the center of figure 7. Our largest specimen (top of figure 7) is one-third larger in diameter than this shell.

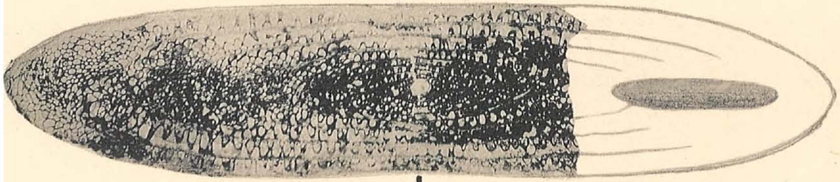
4. Sagittal section of a megalospheric shell with exceptionally large and flattened proloculum (× 10).

5. Enlargement of the center of figure 2 (× 50).

6. Pieces of chert with the megalospheric shells (× 1).

7. Two microspheric individuals (× 1) showing their association with the abundant megalospheric shells. (The lower piece is slightly enlarged.)

All these specimens were collected by Robert E. and Philip B. King from the uppermost part of the Word formation from 2.7 to 4.7 miles northeast of the old Word ranch, Glass Mountains, Texas.



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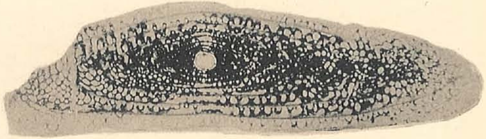

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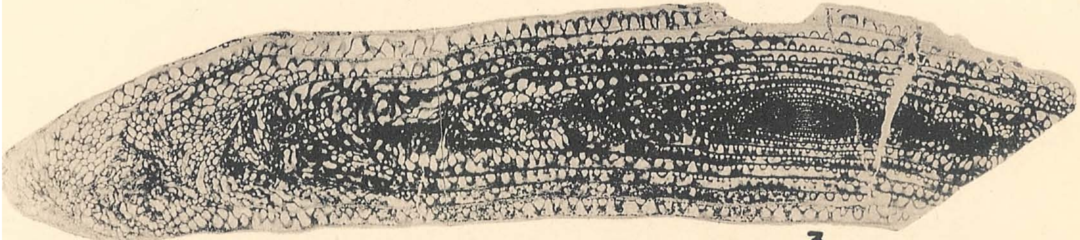

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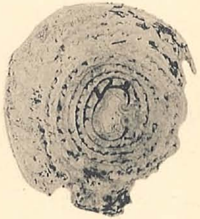

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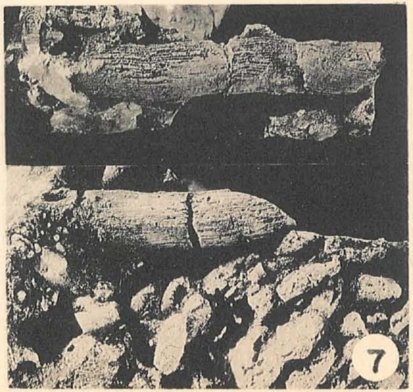

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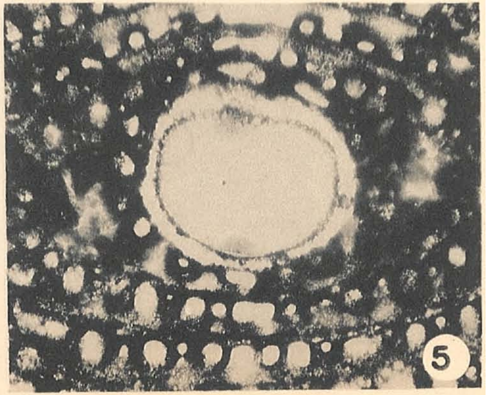

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THE UPPER PENNSYLVANIAN AND LOWER PERMIAN SECTION OF THE COLORADO RIVER VALLEY, TEXAS

FRED M. BULLARD[1] AND ROBERT H. CUYLER[2]

INTRODUCTION

The Colorado River of Texas takes definite form in the vicinity of Colorado, Texas, in the southern part of the Texas Panhandle. In this area several tributaries, some of which have their source in New Mexico, join, and Colorado River as such is formed. It flows in a general southeasterly direction across the central portion of the State, emptying into Matagorda Bay on the Gulf Coast. Its course is nearly at right angles to the strike of the various formations, and as a result it cuts through almost the entire geologic section in its course across the State. Beginning with the Tertiary and Triassic rocks near its source, it then crosses the Permian of Coke, Concho, and Runnels counties, the Pennsylvanian of McCulloch, Coleman, Brown, and San Saba counties, the older Paleozoics and pre-Cambrian rocks of the Llano uplift, the Cretaceous of Burnet and Travis counties, and a short distance to the east of Austin enters Cenozoic rocks over which it flows for the remainder of its course.

This paper deals with the stratigraphy of the Upper Pennsylvanian and Lower Permian rocks exposed along Colorado River. Most of the studies were carried on in northern McCulloch County.

McCulloch County is located in the central portion of the State. The Colorado River flows along the north side forming the boundary between McCulloch County on the south and Brown and Coleman counties on the north. Brady, the principal town and county seat of McCulloch County, has a population of about 4500. It is 75 miles east of San Angelo; 53 miles south by west of Brownwood; and about 150 miles northwest of Austin. Brady serves as a trading center for a rather extensive ranching and farming area.

The area covered by the geologic map (Pl. IV) accompanying this paper is a strip from 5 to 8 miles in width extending along

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the northern side of McCulloch County and with Colorado River forming the northern boundary. This area was selected because it is covered by topographic maps of the Mercury, Waldrip, and Stacy quadrangles, which have been recently issued by the United States Geological Survey in coöperation with the Texas Board of Water Engineers. These maps, on a scale of approximately 1 inch to the mile and with a contour interval of 20 feet, make an ideal base on which to map areal geology.

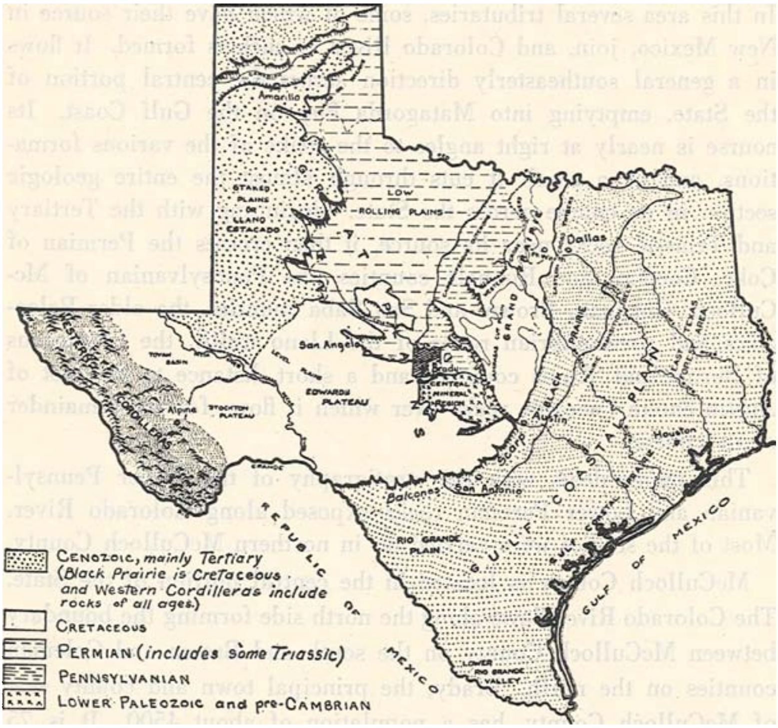

Fig. 31. Index map of Texas showing the area described in McCulloch County. Adapted from "Economic Survey of Texas," by Southwestern Bell Telephone Company, 1928.

The field work on which this paper is based was done in connection with the course in Field Geology offered each summer by the Department of Geology of The University of Texas. In this course an area is selected for study, a permanent camp established at some convenient place, and the advanced students in Geology are afforded an opportunity to do actual field work under close supervision. McCulloch County was the area selected for study during the field seasons of 1930, 1932, and 1934. McCulloch County is an excellent laboratory for field work. The proximity to the Central Mineral region gives ready access to pre-Cambrian rocks as well as to the lower Paleozoic section. Good exposures of the Pennsylvanian and Permian in the northern part of the county and the Cretaceous in the Brady Mountains are combined to make the area very suitable for student work. Also the fact that very little detailed information was available on McCulloch County made it desirable to carry on the work in this area. While studies have been made over much of the county the results presented in this paper are limited to the narrow belt along the northern boundary of the county.

Acknowledgments.—A permanent camp was established at Brady each of the three summers that work was carried on in McCulloch County. With automobiles and good roads all parts of the county are readily accessible. The writers wish to acknowledge the many courtesies extended to the students and faculty of the Geology Field Station by the citizens of Brady and McCulloch County. The work was under the direction of the senior author assisted by the junior author. While much of the work was done by advanced students it has all been carefully checked. The following students assisted in the field work:

Summer 1930.—E. Allerkamp, L. M. Bradfute, R. L. Breedlove, B. G. Bryan, R. Cady, J. C. Callihan, W. E. Cartwright, R. Coit, A. Durham, E. Flaxman, W. C. Gardiner, R. H. King, R. W. Loveless, P. W. Mattocks, G. R. McNutt, R. B. Newcome, Jr., S. D. Quay, B. Rutland, J. A. Slavik, O. J. Solcher, Jr., G. R. Sparenberg, R. D. Woods, F. Wright.

Summer 1932.—M. Body, R. T. Bonar, R. T. Booth, W. E. Cox, G. Fischer, D. Fisher, S. Laird, G. R. McNutt, D. F. Metts, A. J. Needham, R. B. Newcome, Jr., T. A. Pollard, T. H. Shelby, Jr., J. J. Simkins, J. Westheimer, J. B. Wheeler, J. C. Wilder, P. Wood, W. I. Woodson, R. H. Wright.

Summer 1934.—Katherine Archer, W. E. Brubeck, R. E. Brown, R. F. Campbell, R. R. Copeland, H. Corman, R. B. Curry, W. E. Dougherty, P. B. Fahle, T. Girdler, Marie Gramann, C. Holcomb.

C. E. McCarter, M. J. Moore, H. M. Morse, J. Pedigo, W. I. Mayfield, W. H. Marshall, D. F. Sandifer, T. H. Shelby, Jr., S. J. Taylor, R. D. Woods, Mildred Winans, H. E. Yates.

The writers wish to express their appreciation for the interest and efforts of these students.

Previous work.—Strangely enough the first work done on the Pennsylvanian rocks of Texas was done in this area and very little has been done in this immediate area since that time. The first work in this area was done by Tarr.[3] In this short paper Tarr recognizes the basal limestones (now Bend), to which he did not apply a name, and concludes that they are Lower Carboniferous in age. To the sandstones and shales above these limestones he applied the name "Richland sandstone" (Strawn) and he proposed also the name Rochelle for the conglomerate at the top of this series. Above the Rochelle, Tarr divided the section into the Milburn shales, the Brownwood division, and the Waldrip division which begins with the coal layers near Waldrip. The top division is called the Coleman which included the upper part of the Cisco and a portion of the overlying Permian. The next contribution to the geology of this area was by Cummins,[4] published in 1891. Cummins established the age of these beds as Pennsylvanian, gave a satisfactory description of the beds and classified them as follows: Bend, Millsap, Strawn, Canyon, and Cisco. Two years later, Drake[5] in a report on the "Colorado Coal Field" gave a rather complete account of this section. Drake adopted Cummins' classification, with minor modifications, and defined each unit more sharply by selecting a prominent limestone to mark the top. Drake then divided each group into members, to some of which he applied names while to others he simply gave a number. The detail in which he studied the area is indicated by the number of subdivisions that he recognized for each group: For the Strawn he recognized 19 subdivisions; 12 in the

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[3] Tarr, R. S., A preliminary report on the coal fields of the Colorado River: Texas Geol. Surv., 1st Ann. Rept., pp. 199–216, 1890.

[4] Cummins, W. F., Report on the geology of northwestern Texas: Texas Geol. Surv., 2d Ann. Rept., pp. 357–552, 1891.

[5] Drake, N. F., Report on the Colorado coal field of Texas: Texas Geol. Surv., 4th Ann. Rept., pp. 355–446, 1893.

Canyon; and 19 in the Cisco. In 1921 Plummer and Moore[6] published a very exhaustive study of the Pennsylvanian rocks of north-central Texas. The classification of Cummins, as modified by Drake, is adopted with a number of minor changes—chiefly in the nomenclature of the members of the groups. Drake's numbers are replaced by geographic names, derived largely from localities in the northern portion of the Pennsylvanian outcrop, and his names, such as "*Campophyllum* bed," are replaced also by geographic names. These members are then grouped into a number of formations. Practically no new information is introduced on the area covered by this paper, the discussion and the map of the Colorado River valley area being taken directly from Drake's report.

This area, then, in which Tarr, Cummins, and Drake carried on their studies is the type section of the Pennsylvanian for central Texas and for this reason a careful study of this section is desirable. This paper is a study of the stratigraphy of the Upper Pennsylvanian and Lower Permian rocks as exposed along Colorado River in northern McCulloch County. The stratigraphic sequence is established by detailed measurement of sections at the outcrop of the beds. The marked similarity between the various limestones in the section makes it practically impossible to recognize the various beds without actually tracing them through. For this reason it was necessary to trace most of the mappable limestones in order to complete the stratigraphic sequence. No attempt is made to include a study of the paleontology of the various horizons. Fossils are abundant in many places and extensive collections were made, although to date they have not been studied. It is hoped that an opportunity will be afforded to study these collections and if so the results will be reported at some future date. During the course of the work many fossils were noted, especially in measuring detailed sections. In most cases only the more common forms are listed, based on a field identification.

The sediments of this area are made up of alternating shales and limestones for the most part, with occasional sandstones, conglomerates, and coal beds. The limestones are usually much thinner

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[6] Plummer, F. B., and Moore, R. C., Stratigraphy of the Pennsylvanian formations of north-central Texas. Univ. Texas Bull. 2132, 237 pp., 1921.

than the shales. These sediments normally dip to the west or northwest at a rate of approximately 60 feet per mile. The alternation of the beds and the westerly dip usually cause the formations to weather into east-facing escarpments. The top of each escarpment is capped by a resistant limestone. Some of these escarpments attain a height of a hundred feet or more and may be followed without difficulty along the strike of the beds. In general, these escarpments trend in a north-south direction.

With a number of exceptions, the section of Pennsylvanian in the Colorado River valley is similar to the north-central Texas section as described by Plummer and Moore. There are many gradations from north to south. Many of the formations thicken and thin rapidly. Conglomerates grade into sandstones and sandstones into shales.

The Pennsylvanian and Permian in this area are underlain by Ordovicion, Cambrian, and pre-Cambrian rocks. In McCulloch County, there is an overlap of Lower Cretaceous sediments on the Pennsylvanian and Permian, forming an angular unconformity. This causes a constant change in the nature of the contact between the Cretaceous and the underlying rocks, inasmuch as the Pennsylvanian and Permian have a westerly dip and the Cretaceous normally dips to the southeast. The Cretaceous is present in this area as a rather extensive outlier, extending from east to west across the central part of the county. This outlier, or series of outliers, is the most prominent topographic feature in the county and is known as the Brady Mountains.

STRATIGRAPHY

The rocks of the Colorado River valley are divided into groups, formations, and members as shown in the classification given below.

In this paper the authors are following Sellards* in placing the Pennsylvanian-Permian contact at base of the Moran formation thus making the Camp Colorado limestone the top of the Pennsylvanian.

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*The University of Texas Bulletin 3232, The Geology of Texas, Vol. 1, p 140.

Permian	Wichita	Putnam	Coleman Junction limestone Santa Anna Branch shale
		Moran	Sedwick limestone Santa Anna shale Horse Creek limestone Watts Creek shale
Pennsylvanian	Cisco	Pueblo	Camp Colorado limestone Salt Creek Bend shale Stockwether limestone Camp Creek shale
		Harpersville	Saddle Creek limestone Waldrip beds Lower Harpersville
		Thrifty	Breckenridge limestone Avis sandstone
		Graham	Speck Mountain limestone Wayland shale Gunsight limestone Upper Bluff Creek shale Bunger limestone White Ranch limestone Lower Bluff Creek shale
	Canyon	Caddo	Home Creek limestone Hog Creek shale
		Brad	Ranger limestone Placid shale Clear Creek limestone Cedarton shale
		Graford	Adams Branch limestone Brownwood shale Rochelle conglomerate
	Strawn	Undifferentiated	
	Bend	Smithwick shale Marble Falls limestone	

PENNSYLVANIAN

BEND GROUP

The Bend group, the lowest division of the Pennsylvanian, consists of two formations: Marble Falls limestone and Smithwick shale. Although no detailed work has been done on these formations, a brief statement in regard to this group is included for the sake of completeness.

The Marble Falls limestone is a medium gray to black, massive, finely crystalline limestone with an average thickness of 400 to 500 feet. It is exposed north of the Central Mineral region, extending

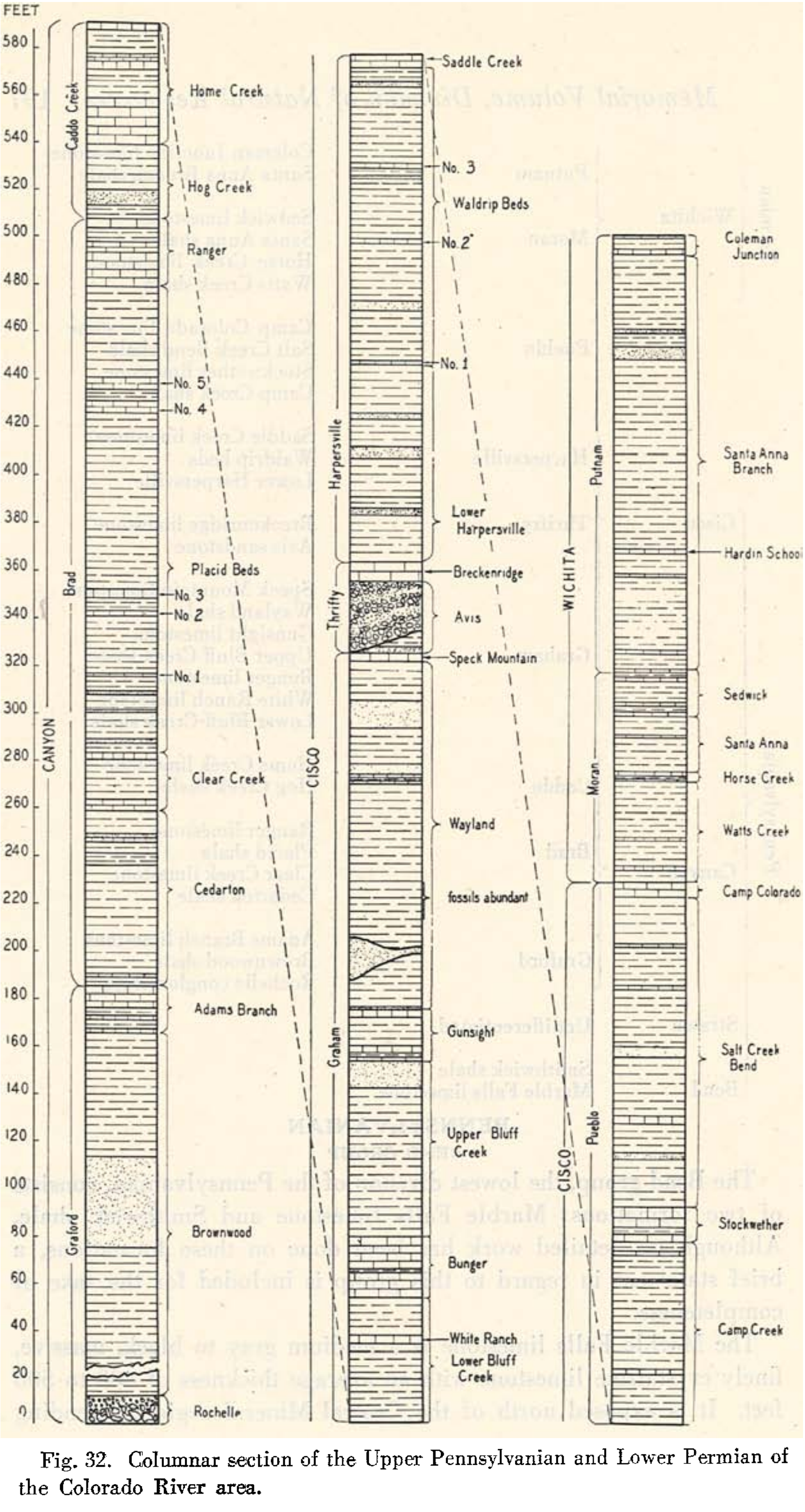

Fig. 32. Columnar section of the Upper Pennsylvanian and Lower Permian of the Colorado River area.

in a broad band from Brady to a point south of Rochelle and thence to San Saba.

The Smithwick in its typical exposure consists of 200 to 400 feet of dark gray to black shales. The lower phase is a black, carbonaceous, thinly bedded, fissile shale, with thin layers of limestone scattered throughout. The upper portion consists of dark to yellow-green, or brown, somewhat arenaceous shales and lacks the thin limestone layers characteristic of the lower portion. At a point 3 miles southeast of Rochelle, the upper part of the lower phase of the Smithwick is exposed. The upper part of the formation is covered by the Rochelle conglomerate.

The highest member of the Bend in this exposure is a medium gray limestone containing numerous fusulinids. Below the limestone is a thinly laminated blue-gray shale containing an abundance of selenite. There is about 15 feet of this shale exposed, and near the base of the exposure there is a ferruginous layer containing an abundance of fossils.

STRAWN GROUP

The sediments of the Strawn group of the Colorado River section were not studied in detail during the course of this work. However, to enumerate a few general observations may not be out of place. The Strawn consists almost entirely of coarse to fine-grained sandstones which are cross-bedded and lenticular and which persist for only short distances. Shale beds form a rather prominent part of the section, and a few relatively thin limestones have been observed near the eastern boundary of McCulloch County. The Strawn is limited on the south by the Llano uplift which was gently arched following the deposition of the Bend sediments. The Strawn varies greatly in thickness. In its eastern exposures it has its greatest thickness and thins rapidly to the west.

CANYON GROUP

The Canyon sediments lie unconformably on the Strawn and include all beds between the Strawn and the top of the Home Creek limestone. It is made up of a series of thick shales interstratified with thin beds of hard crystalline limestone. Lenticular sandstones, composed of very fine material are rather common. Many of the shale beds and limestone members are ferruginous. Cummins[7] first applied the name Canyon to this group of strata. The name is taken from the town of Canyon in Palo Pinto County. Drake[8] recognized 12 subdivisions of the Canyon. Plummer and Moore[9] divided the Canyon into three formations retaining some of Drake's subdivision names as members of formations. The three formations in the Canyon are:

Caddo Creek
Brad
Graford

GRAFORD FORMATION

The Graford is the basal formation of the Canyon group. It consists of three well defined members: Rochelle, Brownwood, and Adams Branch.

Rochelle conglomerate.—This member was named for the town of Rochelle, about 10 miles northeast of Brady, McCulloch County. The conglomerate varies in thickness up to about 25 feet. It is composed of subangular pebbles of chert and quartzite, frequently laminated. Many fragments of Ellenburger and Marble Falls limestones are present. Quartz pebbles also are present in abundance. A characteristic of the member is the presence of green chert pebbles. These green chert pebbles distinguish the Rochelle from most of the other conglomerates in the Pennsylvanian. Many of the cherts are banded. In many places, as east of Mercury, the conglomerate does not appear, but at its horizon a sandstone is present. To the south of the type locality, the conglomerate soon passes under the Cretaceous, and it has not been recognized definitely in the outcrops to the south of the Cretaceous ridge. To the north the bed thins rapidly and disappears in Brown County. Bay,[10] who has made a detailed study on the conglomerates of the Pennsylvanian, states that materials composing the Rochelle were stream

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[7] Cummins, W. F., *op. cit.*, p. 374.

[8] Drake, N. F., *op. cit.*, p. 387.

[9] Plummer, F. B., and Moore, R. C., *op. cit.*, p. 90.

[10] Bay, Harry X, A study of certain Pennsylvanian conglomerates of Texas: Univ. Texas Bull. 3201, pp. 149–188, 1932.

carried, having their principal source to the northeast. He estimates that the cherts in the conglomerate were transported approximately 250 miles before being deposited.

Brownwood shale.—The name Brownwood is applied to the shales lying between the top of the Capps lentil, or in some places the Rochelle conglomerate, and the Adams Branch limestone. It is exposed typically at the town of Brownwood, Texas, from which it takes its name. The shale varies in thickness up to approximately 150 feet. The member consists chiefly of a blue-gray shale which weathers to yellow. The shale contains several layers of sandstone and a small amount of limestone. Generally there are two persistent layers of sandstone—one near the middle and the other near the top. The middle portion of the member is decidedly sandy at the exposure east of Mercury. The shales, although bluish upon fresh exposure, weather to purplish or yellowish color upon long exposure.

In some areas, especially north of Colorado River, there occurs, near the base of the Brownwood shale, a thin lenticular limestone known as the Capps lentil limestone. The presence of this limestone south of Colorado River has not been established definitely. A good exposure of this limestone may be seen at its type locality on the Capps farm, 3 miles east of Brownwood, Brown County. Due to its lenticular nature, this bed is very irregular in its lithologic character and varies up to 4 feet in thickness.

The Brownwood shale is highly fossiliferous, especially in a zone near the base and a zone about 20 feet below the top. A good exposure of the upper fossiliferous bed may be seen about one-half mile east of Mercury. Among the many forms which are present here are *Spirifer cameratus* Morton, *Chonetes granulifer* Owen, *Spiriferina kentuckiensis* Shumard, *Hustedia mormoni* Marcou, and species of fusulinids. Immediately below the zone of abundance of these forms, there is a zone which consists chiefly of *Myalina* sp. and Bryozoa.

Section of upper Brownwood shale and Adams Branch limestone on bluff about 4 miles southeast of Mercury, McCulloch County.

	Thickness *Feet*
Adams Branch limestone:	
Massive beds, about 8 inches in thickness	18.7
Brownwood shale:	
Sand and shale covered by slump from overlying Adams Branch	21.0
Yellow shale containing an 8-inch bed of limestone near top	6.7
Limestone; contains *Myalina* and Bryozoa in great abundance	0.8
Sandstone, ferruginous, weathers dark red to yellow, and light-green shale	5.0
Sandstone, cross-bedded, grayish brown	23.2
	75.4

Adams Branch limestone.—This limestone, which is named for a creek in Brown County, forms the top member of the Graford formation. It caps a very prominent east-facing escarpment formed by the resistant limestone overlying the relatively soft Brownwood shale. The Adams Branch is typically a hard, light-gray limestone, massively bedded, and with the characteristic wavy bedding planes which are so common in the Pennsylvanian. Frequently the limestone cracks into large rectangular blocks. It is quite fossiliferous, but due to its hardness, fossils are not obtained easily. The limestone is often iron stained.

The Adams Branch is well developed on the escarpment just east of Mercury, but as it is traced southwards toward Rochelle, the Adams Branch dips under, and the next higher limestone, the Clear Creek, forms the crest of the escarpment. The characteristic heavy bedding of the Adams Branch may be seen at an outcrop on the south bank of Colorado River north of Morgan Mountain, near the town of Winchell. At Mercury, the Adams Branch does not appear to be so heavily bedded.

The Adams Branch, which forms the escarpment 4 miles southeast of Mercury, has a thickness of about 19 feet. On Colorado River, just east of the mouth of Corn Creek, the Adams Branch has a thickness of 21 feet. On the river north of Morgan Mountain, the Adams Branch is about 16 feet thick, as shown in the section of that locality, given under the heading of Cedarton.

Section of Adams Branch limestone, 0.5 mile east of Mercury, McCulloch County.

	Thickness *Feet*
Adams Branch limestone:	
Limestone, hard, massive, blue-gray, weathering to yellow; contains abundance of fusulinids	10.0
Shale, light-colored	3.0
Limestone, massive, blue-gray, weathering to yellowish gray	1.0
Shale, calcareous	4.0
Limestone, hard, blue-gray	1.0
	19.0

BRAD FORMATION

The Brad is the middle formation of the Canyon group. In this region it consists of approximately 335 feet of sediments which are divided into four well-defined members: Cedarton shale, Clear Creek limestone, Placid shale, and Ranger limestone.

Cedarton shale.—The Cedarton shale is named for the town of Cedarton, Brown County, Texas, where it is typically exposed. It consists of all beds lying between the top of the Adams Branch limestone and the base of the Clear Creek limestone. This shale is usually reddish brown in color and contains a few layers of sandy limestone. The shale weathers reddish to purplish, occasionally yellowish gray and is locally very fossiliferous. In a railroad cut 2.5 miles south of Mercury the following fossils were collected: *Lophophyllum profundum* Milne-Edwards and Haime var. *radicosum* Girty, *Archeocidaris* sp., crinoid stems, *Fistulipora nodulifera* Meek, *Polypora* sp., *Rhombopora lepidodendroidea* Meek, *Tabulipora* sp., *Chonetes granulifer* Owen, *Composita subtilita* (Hall), *Spirifer cameratus* Morton, *Spirifer* sp., *Spiriferina kentuckiensis* Shumard, *Euphemus carbonarius* Box, *Phanerotrema grayvillense* Norwood and Pratten, *Worthenia tabulata* Conrad, and *Pseudorthoceras knoxense* McChesney. Another locality where the Cedarton is well exposed and where fossils are abundant is on the east-facing bluff just west of the old Mercury-Brady highway, west of the railroad station and stock pens at Mercury. The Cedarton is usually made up of shale and marl and often has a drab olive-green color. Limonite concretions are abundant in this member. The Cedarton is characteristically fossiliferous and contains many well-preserved specimens. A species of *Griffithides* occurs frequently in two zones in the Cedarton, one near the middle of the member and the other near the top.

The Cedarton varies greatly in thickness. It appears to thin southward from Mercury and thicken to the north. East of Placid, the Cedarton is only 23 feet in thickness, whereas at Morgan Mountain it has a thickness of 73 feet. On the south side of Colorado River, east of the mouth of Corn Creek, the Cedarton has a thickness of 76 feet. At Morgan Mountain about 3 feet above the Adams Branch there is a fossiliferous limestone 1.5 feet thick. Specimens of species of *Composita, Spirifer,* and *Pustula* are abundant.

Section of lower Brad formation, from bluff on Colorado River north of Morgan Mountain to top of mountain, 1 mile southwest of Winchell, McCulloch County.

	Thickness *Feet*
Lower Clear Creek limestone:	
Limestone, hard, nodular, steel-gray, crystalline, weathering in irregular surface, fractured; bottom 8 inches rather massive	2.5
Cedarton shale:	
Slope, covered by blocks and boulders of slump material from lower Clear Creek	4.6
Shale, reddish, finely bedded, containing limonite	5.6
Sandstone, yellowish to brown, coarse grained, weathers into a pitted surface, very fossiliferous, contains *Composita subtilita* (Hall), *Marginifera lasallensis* Worthen, *Chonetes verneuilianus* Norwood and Pratten, *Productus semireticulatus* Martin, and crinoid stems	0.5
Shale, reddish, finely bedded, laminated, marly, contains profusion of limonite nodules, also *Hustedia mormoni* Marcou and *Spiriferina kentuckiensis* Shumard	5.1
Limestone, hard, light gray to brownish, weathers yellowish, densely crystalline, shows a conchoidal fracture, fine texture	0.5
Shale, dark blue to greenish, laminated, bituminous, finely bedded, somewhat arenaceous, weathers in characteristic laminae, few limonite concretions and fossils present	5.6
Shale and marl, drab olive-green, very finely laminated arenaceous, contains concretions of limonite in abundance, very fossiliferous, containing *Lophophyllum profundum* Milne-Edwards and Haime, *Ambocoelia planoconvexa* Shumard, *Marginifera*	

	Thickness *Feet*	
lasallensis Worthen, *Spiriferina kentuckiensis* Shumard, *Hustedia mormoni* Marcou, *Griffithides* sp., plates and spines of *Archeocidaris* sp., and crinoid stems in great profusion	39.8	
Covered slope, probably same as above	7.0	
Limestone, light tan to gray; contains calcite veins, marly in lower portions; weathers into nodules; contains specimens of *Composita*, *Spirifer*, and *Pustula*	1.4	
Shale, very light in color	3.0	
Total Cedarton		73.1
Adams Branch limestone:		
Limestone, upper portion light gray, thinly bedded, weathering into nodules and small blocks	3.6	
Limestone, lower portion hard, crystalline, massive, dark gray upon fresh fracture, weathering to a brownish gray, slumping into huge rectangular blocks	12.0	
Total Adams Branch		15.6
Total section at Morgan Mountain		91.2

Clear Creek limestone.[*]—This member consists of two limestone beds separated by a shale parting of variable thickness. The lower bed consists of a gray limestone which varies from 5.5 to 15 feet in thickness. Ordinarily this limestone is very hard, crystalline, massive, fossiliferous, and has many calcite veins through it. The weathered lower Clear Creek limestone is usually steel-gray in color and has a characteristic irregular surface and is distinguishable by the presence of long, parallel joint lines.

The shale interval between the lower and upper Clear Creek limestone consists of about 16 feet of variegated clays and marls which are usually reddish to yellow in color. The upper portion is usually arenaceous and in some places grades into sandstone. The shale is apparently nonfossiliferous.

The upper Clear Creek limestone is rarely more than 2 or 3 feet thick and is characterized by being a hard, massive, crystalline bed which contains a noticeable amount of iron and weathers to a very characteristic reddish-brown color. This limestone is well jointed and breaks up into blocks of fairly uniform size. The top of this bed contains numerous specimens of *Myalina subquadrata* Shumard.

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[*] Also known as Merriman limestone.

When struck with a hammer, this limestone produces a distinctive ringing sound. The upper Clear Creek is more uniform in its characteristics over the whole area where it outcrops than any other bed.

Section on bluff 1 mile east of Placid, McCulloch County.

	Thickness *Feet*	
Clear Creek limestone:		
Limestone, gray, weathering to yellow	2.0	
Shale, weathering to yellow	17.0	
Limestone, finely crystalline, gray, weathering to light gray	15.0	
Total Clear Creek		34.0
Cedarton shale:		
Shale, reddish brown, containing some layers of thinly bedded sandstone		23.0
		57.0

Section at road cut at side of hill 1.5 miles west of Corn Creek, due south of B.M. 1321, and 1 mile south of Colorado River, McCulloch County.

	Thickness *Feet*
Clear Creek limestone:	
Limestone (upper Clear Creek), hard, reddish brown, crystalline, weathering to a dirty yellowish tan	1.5
Shale, soft, grayish brown, marly, weathers to yellow	12.5
Limestone (lower Clear Creek), flaggy, thinly bedded, nodular, weathering unevenly. (Not all of lower Clear Creek present.)	3.0
	17.0

Section of portion of Brad formation at Sulphur well south of White ranch house, approximately 2.5 miles southwest of Mercury, McCulloch County.

	Thickness *Feet*
Placid shale:	
Limestone (Placid No. 1), dark gray; crystalline; weathers light brown, lower part softer and very fossiliferous; upper part hard, with many crinoid stems and with some shale partings, surface smooth	2.4
Marl, yellow, arenaceous	5.0
Sandstone, yellow to cream, soft, fine textured	1.4

	Thickness *Feet*
Marl, yellow, arenaceous	2.5
Sandstone, yellow to cream, fine, thinly bedded, soft	1.0
Marl, yellow to cream, sandy	1.5
Sandstone, yellow, fine grained, thinly bedded	1.0
Clay, variegated red and yellow, arenaceous, laminated near top, containing thin layers of sandstone	5.4
Sandstone, yellow with brown iron streaks, thin bedded, fine textured, weathers black in spots, composed of 2-inch layers, ripple marked on top	1.5
Shale (base of Placid), yellow, arenaceous	3.8
Clear Creek limestone:	
Limestone (upper Clear Creek), gray, very hard, crystalline, weathers a distinctive reddish brown; streaks of recrystallized calcite, iron stain, massive, smooth surface, not well jointed, very fossiliferous, containing chiefly *Myalina subquadrata* Shumard, crinoid stems	2.5
Clay, variegated red and yellow, grading upward into yellow sandy clay, apparently nonfossiliferous	16.3
Limestone (lower Clear Creek), gray, with yellow streaks, hard, crystalline, massive, 6-inch beds near base and thinner one toward the top, rather fossiliferous with many *Composita subtilita* (Hall); base not exposed	4.0
Total section	48.3
Total Clear Creek	22.8

Placid shale.—The Placid beds are typically exposed at the town of Placid, McCulloch County, Texas. This member separates the Clear Creek and Ranger limestones. It is made up of alternating beds of limestone and shale, with shale predominating. The member has a thickness of about 195 feet in northern McCulloch County. In the area southwest of Mercury the member consists of seven shale intervals separated by five limestones. For sake of convenience, these limestones will be referred to by number, one to five, from oldest to youngest.

Usually series of alternating shales and sandstones separate the lowest Placid limestone from the upper Clear Creek. The shales in this interval are usually gray in color and are nonfossiliferous. The presence of iron in large quantities is responsible for the weathering of the shales to a yellowish color. The sandstones which alternate with these shales are usually light-colored, are characterized by being covered with iron stains, and are usually thinly bedded; however, in the northern portion of this area the sandstones become massive, fine grained, highly indurated, and range from light tan to a deep reddish brown. In several localities the shale below the sandstone is absent, leaving the sandstone resting directly on the upper Clear Creek. The shale above the sandstone lenses is light gray to brown and is nonfossiliferous. These sandstones and shales together total a thickness of from 25 to 34 feet in the vicinity of the Pumphrey-White area southwest of Mercury. This thickness, of course, is quite variable.

The first limestone above the top of the upper Clear Creek, Placid No. 1, is hard and somewhat crystalline. It is usually light gray in color and contains many veins of calcite. The bed weathers into large, rectangular blocks and has a rough fracture. In the northern part of McCulloch County the limestone contains much iron which gives it a brown color. On fresh exposures small iron spots can be noticed and large iron spots are present on its weathered surface. This limestone remains about the same in thickness throughout the area, varying only from 1 to 3 feet.

Between Placid limestones No. 1 and No. 2, there is a shale interval. This shale is yellowish gray to reddish in color and is nonfossiliferous. In some areas there is a light-colored, fine-grained sandstone parting which divides the shale. This interval varies from 21 to 27 feet in thickness. The shale is usually covered by slumped fragments of Placid No. 2 limestone.

The second Placid limestone, Placid No. 2, is dark gray to brown in color, very hard, and weathers into large blocks, exposing large, yellow spots. Fragments of small crinoid stems are exposed frequently on weathered surfaces. The limestone appears massive but is sometimes thinly bedded. This bed is approximately 2.5 feet in thickness. Often Placid No. 2 consists of two beds separated by a very thin shale interval. The upper part, about 6 inches in thickness, is a hard, crystalline, gray limestone with some calcite veins. The lower part, about 1.3 feet in thickness, is brownish and contains iron stains; this is the more characteristic of the two beds. The large spots present in the lower part aid in distinguishing this limestone from the ones overlying and underlying it. Northwest of the White Company ranch house, toward Colorado River, the limestone changes a little, becoming thicker, more massive, and browner in color. The calcite veins give the weathered blocks a ridged appearance. This characteristics appearance may be seen on the limestones on the east bank of Corn Creek, 0.5 mile south of Colorado River.

The shale interval between Placid limestones No. 2 and No. 3 is usually from 7 to 11 feet in thickness. This shale is usually gray in color, sometimes having a reddish tint. It is arenaceous and non-fossiliferous. Usually there is a thin, light tan to reddish-brown sandstone dividing the shale. There is a bed in which there is an abundance of *Campophyllum torquium* (Owen) in this shale interval. This interval seems to thin northeast towards Colorado River where Placid No. 3 appears to rest directly on Placid No. 2.

The third Placid limestone, Placid No. 3, is a hard, dark to light gray, thinly bedded limestone containing an abundance of veins of secondary calcite. Iron is also present in many of the veins. *Lophophyllum profundum* Milne-Edwards and Haime and crinoid stems are abundant. The limestone weathers to a light-gray, chalky, nodular mass. In the vicinity of the White Company ranch house the limestone is about 3 feet in thickness, but thickens northward until along Colorado River this bed has a thickness of almost 20 feet and is quite massive, breaking off in huge rectangular blocks. It is often difficult to distinguish between Placid No. 2 and Placid No. 3. The fact that these limestones are very close together adds to the difficulty in distinguishing the two. Usually, however, the yellow spots which are so common on Placid No. 2 and the greater abundance of calcite veins on Placid No. 3 will help distinguish these two beds from each other.

Between Placid limestones No. 3 and No. 4 there is a shale interval of about 75 feet. This shale interval can be measured best along the line of strike, on a north-facing bluff, about 1 mile north of the water tank on the escarpment about 1 mile northwest of the White Company ranch house. The shale is arenaceous, non-fossiliferous, and varies in color from gray near the basal portion to red near the top. This shale, as measured west of the White Company ranch house, is divided by two sandstones of varying thickness. The shale directly above Placid No. 3 is covered. A thin, fine-grained, light-tan to reddish-brown sandstone with a large amount of iron present rests on this shale. Above the sandstone is a buff-colored shale containing a thin bed of *Myalina subquadrata* Shumard. The second sandstone is massive, highly indurated, fine grained, light gray to brown, and rests on this shale. On weathering it turns to a dark brownish red. Iron stains are present on its weathered surface.

The fourth Placid limestone, Placid No. 4, is light to dark gray in color and is of medium hardness. Usually the limestone is divided into a thinly bedded lower portion and massive upper portion. Because of the thin bedding, the lower portion takes on an appearance of being flaggy. Chert nodules are common in the upper part of this limestone. Weathered surfaces of the lower beds show a graphic pattern of secondary calcite veins. Fresh fractured limestones from Placid No. 4 show iron stains. Crinoid stems and *Composita subtilita* (Hall) are abundant. This limestone has a normal thickness of about 4.5 feet.

Between Placid limestones No. 4 and No. 5 there is a thin shale interval varying from about 5 to 8 feet in thickness. It is nonfossiliferous and yellowish in color. As was the case with the shale interval between Placid No. 2 and Placid No. 3, the shale between Placid limestones No. 4 and No. 5 thins as it is traced northward toward Colorado River.

The fifth Placid limestone, Placid No. 5, is a light-gray to tan, medium hard, crystalline, fossiliferous limestone, the lower half of which is massive and the upper half of which is thinly bedded. It contains a large number of secondary calcite veins, being comparable to Placid No. 3 in this respect. Upon weathering it is a light-gray, irregularly bedded mass, forming in most cases small nodular blocks which slump over the underlying formations. Upon complete disintegration it forms a white chalky mass. The limestone contains *Lophophyllum profundum* Milne-Edwards and Haime and *Composita subtilita* (Hall). Ordinarily Placid No. 5 forms a shelf just below the base of the Ranger limestone. The thickness of this limestone west of the White Company ranch house is about 5 feet, whereas on Colorado River it thickens to almost 20 feet. This thickening may be due to the lensing out of the shale interval between Placid No. 4 and Placid No. 5. Along the river, Placid No. 5 is quite massive and breaks in large rectangular blocks.

Between Placid No. 5 and the Ranger limestone there is a shale interval which varies from 16.5 to 45 feet in thickness. This shale grades in color from yellowish gray in the lower portion to a maroon color near the top. In the middle portion of the shale there is a calcareous sandstone about 6 inches in thickness. The bottom of the sandstone is covered with fucoids and crinoid stems. The shale interval has a thickness of 45 feet on the escarpment west of the White Company ranch house and thins northwestward until it has a thickness of only 16.5 feet on Tom Dean Creek. It is worthy of note that this shale interval is, like the others in the Placid, thinning from the exposures near the Pumphrey and White ranch houses toward Colorado River.

The sections which follow describe many of the characteristics of the Placid beds.

Section of a part of Brad formation on White and Pumphrey ranches about 3 miles southwest of Mercury, McCulloch County.*

	Thickness *Feet*
Ranger limestone:	
Limestone, hard, gray, massive, weathering dark gray and breaking in large blocks; contains much chert and nodules of iron oxide; crinoid stems present occasionally; amount exposed	10.0
Placid shale:	
Shale, grades in color from yellowish gray to maroon near top; characterized by 6 inches of calcareous sandstone 20 feet below top; bottom of sandstone covered with fucoids; crinoid stems present in small numbers	40.0
Limestone (Placid No. 5); medium hard, gray, having lower half thin bedded; crumbles into small pieces upon weathering; contains *Lophophyllum profundum* Milne-Edwards and Haime and *Composita subilita* (Hall)	5.0
Shale, yellowish, nonfossiliferous	5.0
Limestone (Placid No. 4), medium hard, light gray; lower 3 feet thin bedded, upper part massive; weathered surfaces of lower portion show graphic pattern of secondary calcite veinlets; fresh fractures show yellow iron stains; crinoid stems and *Composita subtilita* (Hall) abundant	4.5

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*Interval between upper Clear Creek and Placid No. 3 was measured on small hill east of road at east entrance to Pumphrey ranch. Interval between Placid No. 3 and Ranger was measured on escarpment west of White Company ranch house, 2½ miles southwest of Mercury.

	Thickness *Feet*	
Shale, varies in color from gray at bottom to reddish near top; nonfossiliferous. (Correction made for dip.)	75.0	
Limestone (Placid No. 3), hard, dark gray, thin-bedded, containing veinlets of secondary calcite; *Lophophyllum profundum* Milne-Edwards and Haime and crinoid stems abundant	3.0	
Shale, gray, no fossils found	6.0	
Limestone (Placid No. 2), dark gray, very hard; weathers in large blocks having a rough surface and showing large yellow blotches; fragments of small crinoid stems exposed on weathered surfaces; occasionally appears massive but often shows thin bedding	2.5	
Shale, yellowish gray to reddish; nonfossiliferous	25.0	
Limestone (Placid No. 1), massive, dark gray, resembling upper Clear Creek but weathering into smaller blocks and lacking the *Myalina* so characteristic of that bed; fusulinids present on weathered surface; underlain by a thin bed of very sandy limestone containing several species of *Productus*	1.0	
Shale, gray; no fossils found	5.5	
Sandstone, light colored, coarse grained, thin bedded, containing scattered iron stains	0.8	
Shale, gray; contains many flakes of iron oxide	6.0	
Sandstone, light-colored, very similar to one mentioned above	0.1	
Shale, yellowish gray; nonfossiliferous	12.3	
Sandstone, very fine-grained rock of light-buff color; contains iron stains and wood chips replaced by iron; thinly laminated	0.3	
Shale, gray; nonfossiliferous	3.0	
Total Placid		195.0
Clear Creek limestone:		
Limestone (upper Clear Creek), dark gray, hard, massive, weathering in large blocks with brown surface; fresh fractures show limonitic spots; fusulinids and *Myalina subquadrata* Shumard prominent on weathered surfaces	1.5	
Shale, varies in color from gray at bottom to reddish at top; crinoid stems, fragments of *Productus* forms present	18.5	
Limestone (lower Clear Creek), hard, gray; lower portion massive but shows three distinct layers; weathers into large blocks having pitted surface; upper 2 feet made up of thin massive beds and thin nodular beds in succession; *Composita subtilita* (Hall) abundant in upper thin massive bed	4.5	
Total Clear Creek		24.5

Section of Placid member, on hill 1 mile north and 1 mile west of Mercury, McCulloch County.

	Thickness *Feet*
Limestone (Placid No. 3), light gray, hard, massive, compact, weathers in nodular shapes	3.0
Shale, covered with slump material probably Placid No. 3; same as in shale below	14.5
Limestone (Placid No. 2), gray, weathers to gray-brown, the brown being in streaks; hard, massive, compact; jointed in top 22 inches, more solid in bottom 8 inches; weathers very smooth	2.5
Shale, covered with slump material probably Placid No. 2; full of iron nodules and containing few fossils including *Spirifer cameratus* Morton and *Composita subtilita* (Hall)	14.6
Limestone (Placid No. 1), gray-brown, weathers to light brown, holocrystalline, hard, compact, massive, and heavily bedded	1.3
Shale, mostly covered; much iron contained as limonite, same as in shale below	15.0
Sandstone, same as in sandstone below	1.4
Shale (Placid No. 1), reddish brown, profusion of limonite nodules ¼-inch in diameter	6.0
Sandstone, dark red, weathers to a much darker red-brown; heavily bedded, rather soft	2.0
	60.3

Section of portion of Placid shale on east bank of Corn Creek, 0.5 mile south of Colorado River, McCulloch County.

	Thickness *Feet*
Limestone (Placid No. 3), hard, crystalline, contains calcite veins, thinly bedded, weathering into nodular masses	7.37
Shale, ranging from brownish red in upper portion to light dirty gray in lower portion	18.6
Limestone (Placid No. 2), upper part gray, hard, crystalline, containing a few calcite veins	.5
Shale, covered	.3
Limestone (Placid No. 2), lower part brownish, containing iron stains, and horizontal veins of calcite giving a ridged appearance	1.3
Shale, covered	22.2
Limestone (Placid No. 1), bluish gray to light gray, hard, crystalline, massive, weathers into dark gray rectangular blocks, contains iron stains and calcite	1.25
Shale, light tan to light gray	8.0

	Thickness *Feet*
Sandstone, light yellowish tan weathering to brown	.7
Shale, light tan to light gray	16.0
	76.22

Section on north-facing bluff, about 1.5 miles northwest of White Company ranch house, and 1 mile north of water tank on escarpment west of ranch house, about 2.5 miles west of Mercury, McCulloch County.

	Thickness *Feet*
Placid beds:	
Limestone (Placid No. 5), light gray to tan, hard, crystalline, massive, with calcite; weathers to dark gray, has rough fracture; contains iron stains	5.0
Shale, covered	8.3
Limestone (Placid No. 4), dark gray, crystalline, hard, massive, calcite present, smooth fracture; weathers to dark gray	4.5
Shale, covered	28.3
Sandstone, very hard, fine grained, light gray to brown, weathers to dark brown; iron stains present	2.0
Shale, buff-colored, weathers to light brown, contains zone of *Myalina subquadrata* Shumard	12.4
Sandstone, light tan to deep reddish brown, fine grained, very hard, massive to thin bedded; iron stains present	.75
Shale, covered	22.0
Placid No. 3	
	83.25

Ranger limestone.—The top member of the Brad formation, Ranger limestone, is named for the town of Ranger, Eastland County, Texas. It is a very prominent horizon and usually forms an escarpment, second in height only to that made by the Adams Branch limestone. This escarpment is quite noticeable west of the White Company ranch house, approximately 2.5 miles southwest of Mercury. Much confusion has resulted in attempting to recognize the Ranger from early published descriptions. The characteristic usually assigned as peculiar to the Ranger is that it is cherty. This is misleading, however, inasmuch as chert is also found in the Home Creek limestone and some of the Placid limestones, especially Placid No. 4.

In general the Ranger is a hard, gray, massive limestone and locally is quite cherty and ferruginous. In the area west of Mercury the base of the Ranger is marked by a hard, dense, ferruginous limestone usually from 1 to 2 feet in thickness. On weathering this bed assumes a very conspicuous brownish-yellow color. In some instances the ferruginous stain is irregularly distributed giving the bed a spotted appearance. This ferruginous bed breaks into large slabs which are prominent on the slopes of the Ranger escarpment. The upper portion of this basal bed contains an abundance of chert nodules. Above the basal ferruginous bed is a hard gray limestone which contains an abundance of chert nodules. These masses of chert are usually whitish in color, irregular in shape, and range from a fraction of an inch to 2 feet in diameter. The upper part of the basal ferruginous bed and the gray limestone immediately above it is the zone of abundance of chert in the Ranger.

Fossils found in the Ranger include specimens of species of *Spirifer*, *Composita*, and *Productus*. In some localities fossils are common although they are never very abundant. The thickness of the Ranger is quite variable, ranging from 10 feet on the east side of Lost Mountain to nearly 50 feet at the mouth of Cedar Creek. On Tom Dean Creek, about three-fourths of a mile from its mouth, an excellent section of the Ranger is exposed which contains a zone of chert more than 10 feet in thickness. The Ranger at this point is about 30 feet in thickness.

Other details regarding the characteristics of the Ranger are given in the sections which follow.

Section of upper Brad and lower Caddo Creek formations, 200 yards east of first fork in Tom Dean Creek, approximately 0.5 mile south of Colorado River, McCulloch County.

	Thickness *Feet*
Home Creek limestone:	
Limestone, hard, massive, crystalline, buff to gray; weathers into large blocks having irregular surface, frequently with ferruginous stains; upholds prominent ridge	4.8
Hog Creek shale:	
Shale, buff-colored marly material with thin interbedded limestone and sandstone beds, covered in part by Home Creek slump	19.1
Sandstone, composed of loosely compacted cream to tan-colored quartz grains; ferruginous stains on fresh fractured surface	5.6
Shale. dark buff-colored marly material	6.8
Total Hog Creek	31.5

	Thickness *Feet*	
Ranger limestone:		
Limestone, hard, crystalline, cream to gray; forms low escarpment with narrow bench	3.3	
Shale, buff-colored sandy soil covering	6.1	
Chert, hard, white, fossiliferous, crinoid stems and fusulinids present	4.1	
Limestone, hard, massive to thinly bedded, gray, upper zone cherty, containing fusulinids, *Productus*, *Composita subtilita* (Hall), and *Spirifer cameratus* Morton	14.6	
Total Ranger		28.1
Placid shale:		
Shale and marl, with thin interbedded limestones		19.0
Total section exposed		83.4

Section at mouth of Cedar Creek, from water's edge on Colorado River to top of hill due east of the mouth of creek, McCulloch County.

	Thickness *Feet*	
Graham formation:		
Limestone (Bunger), gray, weathering to brown	6.0	
Shale (Bluff Creek), weathers brown, contains some sandstone	80.0	
Total Graham exposed		86.0
Caddo Creek formation:		
Limestone (Home Creek), light gray, weathering to dark gray	2.0	
Shale, yellow	11.5	
Limestone, white, soft, chalky	4.2	
Limestone, gray, regularly bedded, made up of layers about 6 inches in thickness	3.2	
Covered, probably shale	11.0	
Limestone (Home Creek), thick, massive, white, weathering to gray, forming large blocks of slump	19.5	
Covered (Hog Creek), probably shale	25.0	
Total Caddo Creek		76.4
Ranger limestone:		
Limestone, light gray, weathering brown, irregularly bedded	14.7	
Limestone, layers separated by shale parting	5.1	
Limestone, covered by sand	4.8	
Limestone, hard, regularly bedded, weathers brown	2.7	
Limestone, gray, massive, spotted with iron	4.8	

	Thickness *Feet*	
Chert, gray	0.5	
Limestone, massive, light gray, weathering dark gray	3.0	
Chert, blue	0.3	
Limestone, massive, gray, weathering blue	12.0	
Total Ranger		47.9
		210.3

CADDO CREEK FORMATION

The Caddo Creek formation takes its name from a creek by that name which is located at the town of Caddo, Stephens County, Texas. In this area the formation consists of approximately 75 feet of sediments and includes all the strata from the Ranger to the top of the Home Creek limestone. The Caddo Creek forms the top of the Canyon group. It consists of two members: Home Creek limestone and Hog Creek shale.

Hog Creek shale.—This member is named for Hog Creek, Brown County. It is made up of yellow shale containing, in places, layers of sandstone, conglomerate, and sometimes limestone lentils. The shale forms the large flat or terrace which is located just above the Ranger limestone in the vicinity of Lost Mountain. An exposure just east of the mouth of Tom Dean Creek shows a large amount of thinly bedded, yellowish-brown sandstone in the upper part of the member. The sandstone is loosely compacted, light brown in color, and weathers to a deep dark brown with iron stains present. Sections of Hog Creek on Cedar Creek and Tom Dean Creek are given under the discussion of the Ranger limestone.

At the mouth of McDowell Creek, on Colorado River, underlying about 20 feet of sandstone, a thick conglomerate is present in the position of the lower Hog Creek shale. On the south bank of Colorado River, opposite the mouth of Home Creek, there is a massive conglomerate which is fully 30 feet in thickness. The thickness, however, varies greatly in short distances, indicating that it is only locally developed. The conglomerate is composed of subangular chert of all colors, including much green chert. The size of the pebbles, the green, banded cherts, the general composition and appearance, causes this conglomerate to resemble the

Rochelle in many respects; the Hog Creek conglomerate, however, contains many pieces of Ranger limestone which have been reworked. The conglomerate rests in a channel which was cut into the Ranger limestone by streams subsequent to the deposition of the Ranger and preceding the normal deposition of the Home Creek limestone above. In the bluff on the south bank of Colorado River, clear-cut exposures of the base of the channel may be examined. The conglomerate rests on the Ranger limestone, with a somewhat uneven contact existing between them. The basal portion of the conglomerate contains many fragments of Ranger limestone. A short distance back from the top of the bluff, good contacts of the channel with the Ranger can be followed for a considerable distance. The Ranger extends to levels above that of the conglomerate and in many places the contact on the sides of the channel is sharply defined. The channel conglomerate may be followed westward along the bank of the river for a distance of 3 or 4 miles. It dips westward and becomes lower on the river bluff until near the mouth of Tom Dean Creek it is in the bed of Colorado River.

The Hog Creek shale varies in thickness from a minimum of about 15 feet east of Lost Mountain to 100 feet at the type locality.

Section on south bank of Colorado River, 1 mile upstream from Military Crossing, McCulloch County.

	Thickness *Feet*
Home Creek limestone:	
Limestone, fairly thinly bedded, contains many chain corals of the type *Syringopora* and *Michelinia,* also cup corals of the type *Zaphrentis* sp., and *Campophyllum torquium* (Owen)	7.5
Limestone, very massive, grayish, weathers to smooth surface, indistinct shale parting near center	8.5
Limestone, marly, grayish to brownish, irregular weathered surface, fossiliferous, containing *Astartella concentrica* McChesney, *Nucula ventricosa* Hall, *Squamularia perplexa* McChesney	5.0
Total of complete section of Home Creek	21.0
Hog Creek shale:	
Shale, yellowish gray, surface covered by limestone slump	34.0
Total thickness of Caddo Creek	55.0

Home Creek limestone.—This member is named for Home Creek in Brown County. Inasmuch as it lies between the Hog Creek and the Bluff Creek shales, it stands out as a rather prominent member. It is a hard, massive, thick-bedded, grayish limestone ranging in thickness from 15 to more than 30 feet. The lower beds of this member are thin bedded, uneven, and more or less lens-like, and weather into irregular slabs of a yellowish or brown color. The upper portion is harder, finely crystalline, massive, and weathers into large, smooth blocks of a grayish color. The slumping of large, massive blocks, due to the removal of underlying shale, is a characteristic feature of the Home Creek, as typically exposed on Home Creek, about 1 mile from its mouth, Brown County. The top of the Home Creek frequently contains *Campophyllum torquium* (Owen). The Home Creek contains occasional chert beds which tend to confuse the identification of this member with the Ranger. The chert of the Home Creek, however, is characteristically in irregular rough sheets on the bedding plane, whereas the chert of the Ranger is characteristically nodular. In the section at Lost Mountain, the Home Creek consists of two limestone layers separated by a shale parting. Northward from this point the shale parting disappears, and the limestone becomes thicker and more massive. In general, the Home Creek limestone outcrops between Tom Dean and Cedar creeks with excellent exposures along the banks of the latter.

Section of Home Creek limestone, south bank of Colorado River, 0.5 mile below mouth of Bluff Creek, McCulloch County.

	Thickness *Feet*
Home Creek limestone:	
Limestone, gray to bluish, crystalline, beds range in thickness from 18 inches to 24 inches; some iron stains	17.2
Limestone, light gray to gunmetal, soft lenticular beds ranging in thickness from 1 foot to 4 feet; fossils include *Campophyllum torquium* (Owen)	11.1
Alluvium	5.5
	33.8

CISCO GROUP

Following the deposition of the comparatively thick calcareous beds of the Canyon, conditions gradually changed and more clastic sediments were brought in; the limestones make up a smaller part of the sediments, and at least two coal beds were formed. The name Cisco was applied to these beds by Cummins[11] from the town of Cisco in Eastland County. Cummins included in the Cisco all the strata from the more massive limestones of the Canyon below to the limestones of the Wichita above. Drake[12] accepted Cummins' classification but defined the upper limit of the Cisco as the base of the Coleman Junction limestone. In 1921 Plummer and Moore modified Drake's definition of the Cisco by making the Coleman Junction the top of the Cisco. For a number of years the top of the Coleman Junction limestone was accepted as the Pennsylvanian-Permian contact. In 1932, Sellards, after carefully reviewing the problem, placed the base of the Permian at the top of the Camp Colorado limestone, thus placing the two upper formations formerly considered as Cisco in the Permian. Drake, who made the first detailed study of the Cisco, recognized 19 subdivisions. To some he applied names and to others simply a number. Plummer and Moore grouped Drake's subdivisions into six formations, using the more important limestones as formational boundaries. The classification of the Cisco established by Plummer and Moore is followed in this paper, with the exception of the two upper formations, which, in accordance with the usage of Sellards, are placed in the Permian. Drake's subdivisions are recognized as members of the formations insofar as possible. The formations of the Cisco are:

Pueblo
Harpersville
Thrifty
Graham

In the Colorado River valley, although the clastic sediments are more abundant in the Cisco than in the Canyon, they are not as prominent as they are to the north. Red clays and shales are more common in the Cisco than in the underlying Canyon, indicating a

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[11] Cummins, W. F., *op. cit.*, p. 374.
[12] Drake, N. F., *op. cit.*, p. 421.
[13] Plummer, F. B., and Moore, R. C., *op. cit.*, p. 22.
[14] *Idem.*

change in sedimentation towards the Permian type. The rhythmic alternation of limestone and shale is quite marked in the Cisco. As a rule each formation is bounded at the top and bottom by a thin impure limestone. The basal portion of each formation is usually marl or shale grading into typical "red beds" near the middle and then grading back into a marl and finally into an impure limestone at the top. This is repeated, in some cases, several times within a single formation.

GRAHAM FORMATION

The Graham formation is the basal member of the Cisco group. It was named from the town of Graham, the county seat of Young County. It is defined to include all the strata from the top of the Home Creek limestone to the first sandstone above the Wayland shale. In the Colorado River valley the following subdivisions of the Graham have been recognized.

Speck Mountain limestone
Wayland shale
Gunsight limestone
Upper Bluff Creek shale
Bunger limestone
Lower Bluff Creek shale

Bluff Creek shale.—This shale directly overlies the Home Creek limestone of the Caddo Creek formation. It was named by Drake[15] from its outcrop along Bluff Creek east of Mitchell Crossing on Colorado River. The Bluff Creek shale consists of yellow-brown shale and massive, brown to gray, medium-grained sandstones. The sandstones contain much iron and are easily recognized by the dark reddish-brown color. The sandstones are markedly lenticular, frequently increasing in thickness from a foot or so up to 20 feet or more in a few rods. The shales are fossiliferous in some places, carrying a fauna similar to that found in the Wayland shale.

Varying from 35 to 45 feet above the base of the Bluff Creek shale is a distinctive, impure, reddish-brown limestone about 2 feet

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[15] Drake, N. F., *op. cit.*, p. 400.

in thickness. This bed proved to be quite persistent and was valuable both in geologic and structural mapping. It is here designated the White Ranch limestone after the White ranch on which it is typically exposed along the west side of Bluff Creek. It is an impure, ferruginous limestone weathering to a yellowish-brown color. A shale bed with a thickness of 15 to 20 feet and with the same general character as the shale below the White Ranch limestone separates this bed from the overlying Bunger limestone.

Good exposures of the lower Bluff Creek shale occur along Bluff Creek, Drake's type locality, northeast of Cow Creek Tabernacle. Here a thickness of about 65 feet of Bluff Creek shale is found between the Home Creek limestone, in the bed of the creek, and the base of the Bunger limestone on top of the bluff. Good exposures occur also in the bluffs on the south bank of Colorado River between the mouth of Bluff Creek and Military Crossing.

Section of lower Graham formation from top of Home Creek limestone to top of bluff on Colorado River, 0.5 mile below mouth of Bluff Creek, McCulloch County.

	Thickness *Feet*
Bunger limestone:	
Limestone, beds thin and lenticular, steel-gray on fresh fracture, weathers gray with iron stains, contains many spines and plates of *Archeocidaris* sp. and *Chaetetes* sp.	8.7
Limestone, massive, heavy bedded, crystalline, fossiliferous, gray on fresh fracture, weathers gray	5.0
Covered slope, probably shale similar to lower bed	14.8
White Ranch limestone:	
Limestone, nodular, chalky, weathers yellow to light brown, erodes rapidly	1.5
Limestone, massive, heavy bedded, crystalline, buff or light brown on fresh fracture, weathers deep brown, few fossils	2.0
Bluff Creek shale:	
Shale, yellow, sandy, containing lenses of sandstone, small iron concretions sometimes present, small lime concretions present, few fossils	34.5
Home Creek limestone	
	66.5

Section of lower Graham formation on northeast side of bluff on south bank of Colorado River, 0.75 mile southeast of Military Crossing, McCulloch County.

	Thickness *Feet*
Bluff Creek shale:	
Clay, yellowish gray, covered by brownish limestone slump	10.75
Limestone, grayish, weathers to grayish white with brownish and yellowish spots, rather hard	2.00
Clay, yellowish gray	7.00
Limestone, grayish, weathers to grayish brown or yellowish-brown, contains occasional echinoid spines and crinoid stems	1.00
Clay, grayish yellow with some shale partings, contains a brownish-gray, impure limestone 6 inches thick at base	14.00
Sandstone, hard, fine, reddish to yellowish gray, cross-bedded and contains excellent wave ripples; scattered clay ironstone concretions occur in it	2.25
Clay, yellowish to grayish, contains numerous reddish clay ironstone concretions	21.50
Ferruginous sandstone, weathers reddish to grayish, yellowish brown on fresh fracture, mottled reddish brown	1.75
Clay, sandy, reddish	1.50
Total thickness	61.75

The Bunger limestone was described by Plummer and Moore[16] as a lentil in the shales of the lower Graham formation in the Brazos River valley area. The limestone designated by the writers as Bunger in the Colorado River valley area occupies the same stratigraphic position as the limestone described as Bunger in the Brazos River valley area and also agrees in lithologic character and fossil content. However, the fact that it is a lentil in the northern area would make it rather unlikely that the Bunger of the Colorado River area is continuous with the Bunger of the Brazos River area. It seems less confusing, however, to use the same name for these beds which occupy approximately the same stratigraphic position. The Bunger varies somewhat in thickness but insofar as the immediate area is concerned there is no evidence to justify calling the Bunger a lentil. It is well developed in the area immediately adjacent to Colorado River. It is made up of two rather distinct beds separated by a shale parting. The upper part is thinly bedded and irregularly stratified while the lower part is massively bedded.

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[16] Plummer, F. B., and Moore, R. C., *op. cit.*, p. 129.

The upper bed weathers to a reddish color with an irregular surface while the lower layer is gray and weathers to smooth slabs with a definite bluish tinge. The Bunger is rather fossiliferous, the middle and upper portions especially so, containing an abundance of corals, such as *Syringopora, Michelinia,* and *Chaetetes,* echinoid spines, and other fossils. The chain corals seem to be quite characteristic as they have not been observed in abundance in other formations in the area. The Bunger has a thickness of approximately 20 to 25 feet. It is well exposed in the bed of the river just below Mitchell Crossing, where the Bunger dips rather steeply into the river. At this exposure a thickness of 27 feet was measured. From Mitchell Crossing it extends southward along Cow Creek, past Cow Creek Tabernacle, and continues southward. It occurs as outliers capping many of the hills between Bluff Creek and Cedar Creek.

Section of Bunger limestone, 1 mile downstream from mouth of Bluff Creek, on north bank of Colorado River, McCulloch County.

	Thickness *Feet*
Bunger limestone:	
Limestone, massive, thick bedded, crystalline, brownish gray, containing *Spirifer cameratus* Morton, crinoid stems, *Composita subtilita* (Hall), and echinoid spines	15.50
Shale, yellowish, contains *Lophophyllum profundum* Milne-Edwards and Haime	.75
Limestone, massive, thick bedded, crystalline, brownish gray, contains echinoid spines and *Campophyllum torquium* (Owen)	6.50
	22.75

The upper Bluff Creek shale, varying from 50 to 70 feet in thickness, separates the Bunger from the overlying Gunsight limestone. This interval, consisting of yellowish-brown shales and sandstones, is quite similar to the lower Bluff Creek shale. Good exposures of this section are rather rare. A rather poor section may be seen just to the west of Mitchell Crossing, up a small ravine on the south bank of the river.

Section of upper Bluff Creek from bed of Colorado River on west side of Mitchell Crossing to top of bluff on south bank, McCulloch County.

	Thickness *Feet*
Gunsight limestone:	
Limestone, gunmetal to yellowish gray, crystalline, weathers to smooth slabs, fusulinids noted	5.5
Upper Bluff Creek shale:	
Sandstones and clays interbedded; sandstones in lenses, iron-stained; ripple marks present; clays buff-colored	11.5
Slope, covered with alluvium	62.5
Bunger limestone in bed of river	
	79.5

Gunsight limestone.—The Gunsight limestone, named[17] from a little town (consists now of only a post office) in Stephens County, lies directly above the Bluff Creek shale. The Gunsight limestone consists of two and in some cases three limestone beds separated by shale intervals. The upper and lower beds are most prominent while the middle bed is more or less local. The lower bed is massively bedded, about 3 feet in thickness, yellowish to bluish gray in color, densely crystalline, weathers to smooth slabs, and locally contains an abundance of *Campophyllum torquium* (Owen) corals. The upper bed is thin bedded, marly, gray, somewhat nodular, and contains an abundance of crinoid stems and *Triticites* forms. Separating the two limestones is a yellowish-gray, fossiliferous shale varying from about 10 to 30 feet in thickness. The third limestone, referred to above, occurs as a lens in this shale. At the base of the Gunsight, particularly 2 miles east of Whon, Coleman County, and north of Camp Creek, the cup coral *Campophyllum torquium* (Owen) occurs in marked abundance. This is the horizon Drake called the "*Campophyllum* bed." A noticeable feature in regard to this *Campophyllum* zone is that these corals seem to be more or less local in distribution; in some places they are practically absent while in others they occur in marked abundance.

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[17] Plummer. F. B., Preliminary paper on the stratigraphy of the Pennsylvanian formations of north-central Texas: Bull. Amer. Assoc. Petr. Geol., vol. 3, p. 144, 1919.

Section of part of Graham formation (Gunsight and Wayland) on west bank of Colorado River, 1.5 miles upstream from Mitchell Crossing, McCulloch County. Measured from water's edge on west bank to top of bluff.

	Thickness *Feet*
Top of bluff:	
River gravel, containing weathered fragments of limestone, chert pebbles, sharp sand, and clay	26.5
Wayland shale:	
Shale, yellow or buff-colored, lower 10 feet containing an abundance of fossils including *Worthenia tabulata, Lophophyllum profundum* Milne-Edwards and Haime, *Dentalium* sp., and crinoid stems	28.5
Red clay, contains fragments of wood, streaks of white clay, grades into the yellow clay above	11.8
Gunsight limestone:	
Limestone, gray, thin bedded; the lower portion contains some fusulinids; top contains fucoids; lower portion nodular	2.7
Slope, covered by slump; probably contains thin beds of limestone and shale	11.9
Limestone, gray, laminated, thin bedded; lower bed contains abundance of fusulinids, weathers nodular	3.7
Shale, blue-gray	.9
Limestone, massive, variable in color, being gunmetal to yellowish gray, crystalline, weathers to more or less smooth slabs; fusulinids noted in marked abundance in the lower portion of the massive slabs	2.5
Upper Bluff Creek shale:	
Slope covered by slump with few exposures of argillaceous sand, buff-colored; some iron stain noted; weathers into small blocks; 4 feet beneath limestone ripple marks noted in two beds of sandstone; rest of slope covered by alluvium	16.3
	104.8

Wayland shale.—The upper member of the Graham formation is the Wayland shale. This member is characterized by a very prolific fauna. By means of this characteristic fauna the Wayland horizon has been traced throughout the outcrop of the Pennsylvanian of central Texas. The sequence of beds is somewhat variable, but ordinarily the first 30 or 40 feet immediately above the Gunsight limestone is made up of sandy beds intermixed with red shale. This is followed by about 25 feet of yellowish-gray clay containing an abundance of fossils. Some of the more common forms are as follows: *Lophophyllum profundum* Milne-Edwards and Haime, *Conularia crustula* White, *Fistulipora carbonaria* Ulrich, *Pustula nebraskensis* (Owen), *Chonetes granulifer* Owen, *Composita subtilita* (Hall), *Marginifera lasallensis* Worthen, *Spirifer cameratus* Morton, *Deltopecten texanus* Girty, *Nuculopsis ventricosa* Hall, *Leda bellistriata* Stevens, *Yoldia glabra* Beede and Rogers, *Pinna peracuta* Shumard, *Astartella concentrica* Conrad, *Trepospira depressa* Cox, *Phanerotrema grayvillense* Norwood and Pratten, *Meekospira peracuta* var. *choctawensis* Girty, *Pharkidonotus percarinatus* Conrad, *Zygopleura rugosa* Meek and Worthen, *Euphemus carbonarius* Cox, *Bucanopsis meekiana* Swallow, *Schizodus alpinus* Hall, *Schizostoma catilloides* (Conrad), *Orthoceras tuba* Girty, *Coloceras liratum* Girty var. *obsoletum* Girty, *Gastrioceras hyattianum* Girty, *Gonioloboceras welleri* var. *gracile* Girty, and *Orthoceras* sp. No attempt is made to give a complete list. The fossiliferous zone is followed by 40 to 50 feet of gray sandy shale in which no fossils were observed. This is followed by a thin limestone, yellowish brown to buff, which weathers to a more or less nodular mass. This limestone at some localities consists of two or three thin layers. rarely more than 1 to 2 feet in thickness. Approximately from 40 to 45 feet above this limestone and separated from it by sandstones and variegated shales is another limestone much more prominent than the lower one. It is yellowish gray, locally marked by yellow-brown iron splotches, irregularly bedded in layers varying from 3 to 6 inches in thickness. It weathers to large blocks with an irregular nodular upper surface and breaks with a fairly smooth fracture giving a buff to brownish-gray appearance on the fresh surface. Locally calcite stringers and fusulinid forms of the type *Triticites ventricosa* (Meek) are quite abundant. Less frequently fragments of brachiopods and gastropods are found. Its thickness is approximately 4 feet. Drake's[18] name, Speck Mountain limestone, is here revived for this bed. The Speck Mountain limestone is directly beneath the massive Parks Mountain conglomerate (Avis) although in some instances a few feet of sandy shale may separate the two beds.

In the original mapping of this area by the writers, the first massive sandstone above the fossiliferous portion of the Wayland

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[18] Drake, N. F., *op. cit.*, p. 408.

shale was mapped as the Avis sandstone. This sandstone, which appears in the section measured on Parks Mountain just above the first limestone in the Wayland, is decidedly lenticular and is not present at all places. If this sandstone be considered Avis, then the Speck Mountain limestone might well be correlated with the Ivan or Blach Ranch limestone of the Brazos River valley area. However, for reasons which will be set forth later, the massive conglomerate on Parks Mountain is mapped as Avis and all the strata between this conglomerate and the Gunsight limestone are considered as being Wayland. This gives a thickness of about 125 to 150 feet for the Wayland shale.

Good exposures of the fossiliferous zone of the Wayland may be found on a small knoll about 0.5 mile southeast of Parks Mountain, Coleman County; on the south side of Colorado River, about 1.5 miles southwest of Parks Mountain, McCulloch County; and along the highway 1½ miles east of Fife, McCulloch County. Good exposures of the upper portion of the Wayland, including the Speck Mountain limestone, may be seen on Parks Mountain, Coleman County. The Speck Mountain limestone is well developed also along the east side of the new Brady-Santa Anna highway about 0.5 mile south of the Colorado River bridge, McCulloch County.

Section of upper Graham formation at cemetery, about 1 mile northeast of Fife, McCulloch County.

	Thickness *Feet*
Speck Mountain limestone:	
Limestone, hard, crystalline, upper layer and basal 3-inch layer blue but weathers to brown; beds increase in thickness to 2 feet at the top; basal layer very fossiliferous, containing many specimens of fusulinids	10.5
Shale, variegated red, grading to yellow	10.8
Sandstone, gray, indurated, weathers to red	.8
Sandstone, soft, white	.5
Shale, red and buff, with gray streaks	10.7
Shale, covered with slumped beds	3.0
Sandstone, maroon, weathering to brown	12.6
	48.9

Section of upper Graham formation on south bank of Colorado River, 1.5 miles southwest of Parks Mountain, McCulloch County.

	Thickness *Feet*
Speck Mountain limestone:	
Limestone, bluish gray, weathers smooth, containing fusulinids; surface marked by "trail-like" markings	3.2
Wayland shale:	
Shale, yellow, nonfossiliferous, upper portion covered with slumped limestone fragments; thin veins of ferruginous material near the top	20.5
Sandstone, yellow to gray, soft, thinly bedded	4.0
Shale, covered slope	4.0
Sandstone, variegated, lower bed yellow to buff; upper bed grayish with yellow stains, lower part thinly bedded with shale partings	7.7
Clay, yellow, partially covered with slumped sandstone	9.5
Limestone, light bluish gray, hard, massive, surface rough, weathering to a darker gray	5.0
	53.9

Section of upper Graham and lower Thrifty formations on Parks Mountain, Coleman County.

	Thickness *Feet*
Avis (Parks Mountain conglomerate):	
Conglomerate, consisting of subangular to rounded chert pebbles ranging in size from one-fourth to 1½ inches in diameter; contains much sand, ferruginous, massive, weathers red; plant stems present as impressions	23.0
Covered, probably shale	5.0
Sandstone, white, fine grained, laminated	2.0
Speck Mountain limestone:	
Limestone, massive, gray, nodular, weathers gray, crystalline	3.0
Wayland shale:	
Shale, red, yellow, and gray variegated, nonfossiliferous, contains iron concretions	17.0
Sandstone, fine grained, laminated, gray to reddish, nonfossiliferous	12.0
Shale, weathers yellow, probably blue gray, nonfossiliferous	15.0
Sandstone, white to pinkish, weathers brown, cross-bedded, fine grained, nonfossiliferous	5.0
Top of upper limestone in Wayland shale is base of section	
	82.0

Section of part of Graham formation in bluff on Colorado River, 1.25 miles southwest of Parks Mountain, Coleman County. Measured from water's edge on south bank to top of bluff.

	Thickness *Feet*
Wayland shale:	
Shale, yellow, fossiliferous, contains *Worthenia tabulata* Conrad, *Lophophyllum profundum* Milne-Edwards and Haime, *Dentalium* sp., crinoid stems, etc., upper portion and top of hill covered by chert gravel and fragments of limestone	22.4
Sandstone, massive, fine grained, friable, white to pinkish, finely laminated toward top, lower heavy beds cross-bedded, weathers brown; no fossils observed	19.2
Covered slope, probably reddish shale	11.0
Sandstone, laminated, containing much calcareous cement	1.0
Gunsight limestone:	
Limestone, gray, crystalline, lower portion nodular, upper part contains *Spirifer cameratus* Morton, *Composita subtilita* (Hall); sandy toward top	2.0
Shale, yellow, mostly covered	6.5
Limestone, gray, crystalline, massive, heavily bedded, weathers a dark gray, upper surface nodular, contains fusulinids and crinoid stems	5.0
Alluvium, reddish-brown sandy silt	28.0
	95.1

Section of upper Graham formation on south bank of creek, 0.6 mile southeast of new bridge on Brady-Rockwood highway, McCulloch County.

	Thickness *Feet*
Speck Mountain limestone:	
Limestone, dark gray, irregularly bedded, nodular, weathered irregularly, with fusulinids abundant in the lower portion of the bed	3.0
Wayland shale:	
Shale, red grading into gray and yellow within 3 feet of the top	30.0
Sandstone, laminated, cross-bedded, buff, weathers dark brown, iron-stained spots	8.0
Clay, maroon-colored, grading into yellow within 2 feet of the top	8.5
Limestone, gray, nodular	0.5
Clay slope, fragmental (material on surface)	7.5
Limestone, gray, nodular, thin bedded	0.5
Clay slope, fragmental (material on surface)	2.5

	Thickness *Feet*
Limestone, gray, nodular, four beds ranging from 4 to 10 inches in thickness	3.7
Clay, weathers gray	0.5
Sandstone, buff, weathers to dark gray, laminated	1.0
	65.7

Section of upper Graham formation in Colorado River valley, southeast end of Parks Mountain, Coleman County.

	Thickness *Feet*
Wayland shale:	
Limestone, blue-gray, upper 3 feet massive, hard, weathers to nodular shape on surface; lower 2½ feet soft and laminated	5.50
Sandstone, massive, buff-colored, weathers to a dark gray	12.25
Shale, gray, somewhat sandy; no fossils observed	45.70
Shale. top of fossil zone, yellow; fossils noted were *Trepospira depressa* Cox, *Worthenia tabulata* Conrad, *Nuculopsis ventricosa* Hall, and *Yoldia glabra* Beede and Rogers	22.30
Alluvium, covers slope, red, probably conceals limestone beneath	36.00
	121.75

THRIFTY FORMATION

The Thrifty formation was named[19] for the town of Thrifty, Brown County, and was defined to include all strata from the base of the Avis sandstone to the top of the Breckenridge limestone.

In the area described in this paper, only two members are recognized in the Thrifty formation. They are the Avis sandstone and conglomerate and the Breckenridge limestone. The base of the Thrifty formation marks one of the most prominent breaks in the sedimentary record of the entire Pennsylvanian. The prominent conglomerate, the Avis, indicates that extensive erosion occurred between the deposition of the Graham and the overlying Thrifty sediments. In some places in the northern extent of the Pennsylvanian outcrop, all of the Wayland is missing and the Avis rests directly on the Gunsight limestone. In the Colorado River area the Wayland is always present, but its thickness is quite variable and much of this variation is due to erosion before the deposition

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[19] Plummer, F. B., and Moore, R. C., *op. cit.*, p. 152.

of the Avis. The writers have been somewhat at a loss to know just where to draw the Graham-Thrifty contact. As stated previously the first sandstone above the fossiliferous clays of the Wayland was at one time thought to be the Avis equivalent. The prominent Parks Mountain conglomerate, to be described below, was then considered to represent a Pennsylvanian stream channel deposit. The present conclusion based entirely on stratigraphic studies is regarded as only tentative and may be changed by subsequent investigations. Especially a study of the paleontology of the associated beds might lead to different conclusions.

Avis sandstone.—The Avis member, described by Drake[20] as the Parks Mountain conglomerate, is a sandstone conglomerate bed varying in thickness from 20 to nearly 50 feet. Where the conglomerate is firmly cemented, it holds up a prominent escarpment with massive blocks of conglomerate 15 to 20 feet in thickness forming the cap. The exposures of the conglomerate on Parks Mountain and the hill just to the north are of this type. In other places the hard conglomerate grades abruptly into a massive sandstone which is indurated in certain localities and loosely cemented in others. Along the south bank of Colorado River just west of the new bridge on the Rockwood-Brady highway, on the north bank of Colorado River opposite the mouth of Live Oak Creek, on the east bank of the river just above Chaffin Crossing, and up the unnamed creek which empties into the river opposite the mouth of Live Oak Creek, the Avis is exposed as a massive, reddish-brown, cross-bedded, ripple-marked, medium to coarse-grained, firmly cemented sandstone. South of Colorado River, as far as mapped, the Avis is a reddish-brown, soft, loosely cemented sandstone 20 to 35 feet in thickness. The conglomeratic phase was noted capping a hill approximately 3 miles S. 25° E. of Fife and on a second hill which is 1 mile directly west of Lohn.

The conglomeratic phase of the Avis consists dominantly of gray, white, pink, green, yellowish brown, and occasional black chert and flint pebbles, varying from one-fourth to 2 inches in diameter. These granules and pebbles are held firmly together by a rust-colored, iron-stained, siliceous sand cement. The extensive

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[20] Drake, N. F., *op. cit.*, p. 410.

outcrop of this sandstone-conglomerate bed and its definite stratigraphic position directly above the Speck Mountain limestone lead the writers to place this bed as a sheet deposit rather than a channel deposit. It has been observed to bevel some of the underlying beds, as at the east end of Parks Mountain, but nowhere has it been observed to cut through any of the underlying strata.

Breckenridge limestone.—Overlying the Avis member is the Breckenridge limestone member of the Thrifty formation. This bed was described by Drake[21] as the Chaffin bed and was correlated with the Breckenridge limestone of the Brazos River area by Plummer and Moore.[22] The Breckenridge limestone is a prominent, gray, finely crystalline limestone. It is steel-gray to buff in color on fresh fracture and weathers either to a honeycombed surface, smooth slabs, or more commonly to thin, irregular layers giving the massive bed the appearance of an old stone fence. It varies in thickness from 4 feet up to nearly 20 feet. Calcite veinlets are common; *Triticites ventricosa* (Meek) is locally abundant with other forms rather uncommon.

The Breckenridge limestone forms a prominent escarpment directly west of the new Brady-Rockwood highway beginning about 1 mile south of the new bridge on Colorado River. From this point it can easily be traced north and west paralleling the river for about 2.5 miles. A short distance to the west of the old Chaffin coal mine on Little Elm Creek, about one-half mile downstream from Chaffin Crossing, the Breckenridge comes to an abrupt end and is apparently replaced by a massive, reddish-brown, cross-bedded, and ripple-marked sandstone. Drake first noted this fact. The writers, on no evidence other than the abrupt contact, believe this to represent the side of a Pennsylvanian stream channel. Subsequent study, however, may provide another explanation. The hypothetical former position of the Breckenridge is dotted on the map (Pl. IV) from this point to the river. It has been determined by assuming that the overlying Waldrip beds maintain the same interval above the Breckenridge from the vicinity of Waldrip northward to the river. This may or may not be true as the dip of the strata here is locally to the south as indicated by observations on the Speck Mountain limestone. South of Chaffin Crossing the limestone occurs in the

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[21] Drake, N. F., *op. cit.*, p. 410.

[22] Plummer, F. B., and Moore, R. C., *op. cit.*, p. 155.

bed of the river while about one-half mile to the north it is at least 15 feet above the river. These two isolated patches of the Speck Mountain limestone cannot be connected because of the cover of river sand which has filled in subsequent to the erosion by the river.

Southward from Colorado River the Breckenridge forms a prominent horizon to a point about 1½ miles south of the new Brady-Rockwood bridge. From this point southward the extensive cultivation of land has largely obliterated the outcrop of the Breckenridge and its position can only be approximated. In a water well 0.6 mile N. 55° W. of Fife, the coal bed, which normally directly underlies the limestone, was encountered at 68 feet. More definite control was obtained by assuming that the thickness of the Thrifty is constant and using the Speck Mountain bed, the outcrop of which is well exposed, to determine the approximate position of the Breckenridge. Near the south edge of the area shown on the accompanying map (Pl. IV) the Breckenridge outcrops and is traceable to the south.

The Chaffin coal seam directly underlies the Breckenridge limestone at the old coal mine near the mouth of Little Elm Creek. This coal formerly outcropped in the bed of the creek but has since been removed by mining. There are now several old shafts in this area, but no coal has been taken out since 1921. The seam is reported to be 20 inches thick. This coal bed is not known to outcrop at any place, except at the old Chaffin mine, although the horizon is well exposed at many places throughout the area. The coal zone is marked by red ferruginous clays with abundant plant remains.

Section of Thrifty formation on hillside, 0.5 mile S. 25° W. of the Colorado River bridge, Rockwood-Brady highway. Measured from the top of the Speck Mountain limestone.

	Thickness *Feet*
Breckenridge member:	
Limestone, gray, yellow and brown splotched, finely crystalline, steel-gray to buff on fresh fracture; weathers to honeycomb surface, smooth slabs or thin irregular plates, giving a stone fence appearance; contains an abundance of calcite veinlets; *Triticites ventricosa* (Meek) fairly prominent, other fossils not common	4.0

	Thickness *Feet*
Avis member:	
Sandstone, yellowish to brownish, thin bedded, cross-bedded; covered here in part by slump but exposed along the river in massive blocks; medium to coarse grained; apparently with a thin shale bed toward the top	36.5
	40.5

HARPERSVILLE FORMATION

This formation derived its name from the town of Harpersville, located about 10 miles south of Breckenridge, Stephens County, Texas. It includes all strata from the top of the Breckenridge limestone to the top of the Saddle Creek limestone. Along the south side of Colorado River, the Harpersville has a total thickness of approximately 210 feet. The outcrop of the formation is from 3 to 5 miles wide. South of the river, the eastern edge of the outcrop extends east from Chaffin Crossing and follows the river to a point north of Fife, where it turns and passes just west of the town and thence southward to the western part of Cow Gap. The western edge follows the scarp on the west side of the valley of Saddle Creek and thence southward near Lohn to the Brady Mountains. This formation displays the characteristic Pennsylvanian alternation of limestones and shales with some sandstones. The lower part of the Harpersville contains at least two lignitic beds in addition to carbonaceous marine shales. The middle part of the formation consists of buff to yellowish-brown limestones, separated by calcareous sandstones, and bituminous and ferruginous shales. The formation is capped by a thin limestone known as the Saddle Creek. Following are the members of the Harpersville:

Saddle Creek limestone
Waldrip beds
Lower Harpersville

Lower Harpersville beds.—The lower portion of the Harpersville is made up of a series of reddish to yellowish clay beds separated by relatively thin red to brown sandstones. The total thickness of this series, up to the base of the limestone bed designated as Waldrip No. 1, is about 90 feet. At the top of this interval of shales and sandstones and about 2 or 3 feet below the lowest

Waldrip limestone is a thin impure coal bed. An outcrop of this coal may be seen on Colorado River three-quarters of a mile northwest of the town of Waldrip, McCulloch County. There are several other beds in this zone ranging from 4 to 30 inches in thickness consisting of a poor grade of coal to highly bituminous shales. At no place in the area studied could a continuous section of the lower Harpersville from the top of the Breckenridge limestone to the base of Waldrip No. 1 be obtained. Therefore, it was necessary to measure intervals between the prominent sandstone horizons and to map these for short distances in order to determine the thickness of this interval from detailed sections at the outcrop. The section, which is given below, is such a composite section measured westwards from a point near the mouth of Little Elm Creek, east of Waldrip. The section was measured in three parts, and the dividing line between each part is indicated by a broken line.

Composite section of lower Harpersville formation from top of the Breckenridge limestone 0.75 mile S. 58° W. of Chaffin Crossing, Colorado River, to Waldrip No. 1 on hillside 0.25 mile N. 36° E. of Waldrip, McCulloch County.

	Thickness *Feet*
Waldrip member:	
Limestone (Waldrip No. 1), gray, yellow-brown, splotched, dull greenish brown on fresh fracture, weathers to an irregular surface; fossiliferous, containing an abundance of *Triticites ventricosa* (Meek), *T. obesus* (Beede), numerous *Chonetes* sp., and *Productus* sp.	1.5
Clay, yellowish gray to reddish, containing thin, green, impure, lenticular, calcareous sandstone layers	21.0
— — — — — — — — — — — — — — — — —	
Sandstone, yellowish brown, calcareous, gray on fresh fracture	2.5
Shale, yellowish to red, arenaceous	11.0
— — — — — — — — — — — — — — — — —	
Sandstone, deep red to brown, calcareous, medium grained	4.5
Shale, yellowish to red, arenaceous, largely covered by slump at this point	17.0
Limestone, very arenaceous, grading into calcareous sandstone	0.2
Shale, reddish to yellowish gray, arenaceous	5.0
Sandstone, brown, lenticular, ripple marked, calcareous, grading in places into an arenaceous limestone	2.5
Clay, yellow to gray, apparently nonfossiliferous	20.0
	85.2

As a check on the thickness of the above section, several logs of wells in the vicinity of Waldrip were examined. Only one was of any value. On the C. S. Randals place, 0.6 mile south of Waldrip, the coal seam just below the Breckenridge was encountered at a depth of 105 feet. Since the Waldrip No. 1 horizon is approximately at the surface at the location of the well and if a thickness of 10 feet is assumed for the Breckenridge here, the total thickness for this interval would be 95 feet instead of the 85 feet given in the measured section; however, with the presence of lenticular sandstones, a variation of a few feet is not to be unexpected. Sections of lower Harpersville with a total thickness of 104 feet were measured on the north side of Colorado River northwest of Chaffin Crossing. The detailed sections are given below.

Section of lower Harpersville on Little Bull Creek 2.5 miles southwest of Rockwood, Coleman County.

	Thickness *Feet*
Limestone (Waldrip No. 1), yellow, soft, nodular	0.5
Clay	9.1
Sandstone, yellow, soft	0.5
Clay, yellow	3.5
Clay, ferruginous	0.3
Clay, variegated red and yellow	5.6
Coal, shaly, soft, bituminous	2.0
	21.5

Composite section of lower Harpersville, the lower 59 feet measured on east bluff of Colorado River, 0.5 mile above Chaffin Crossing, the remaining thickness on north side of draw about 0.5 mile northeast of first bluff, Coleman County.

	Thickness *Feet*
Shale, carbonaceous, woody, laminated, ferruginous, impure, yellowish brown; correlated with coal seam on Little Bull Creek 2.5 miles S.W. of Rockwood (see section above)	3.0
Clay	20.0
Clay (to top of the ferruginous clay), yellow, marly, grading into maroon, in upper part color is variegated; ferruginous with numerous iron concretions	17.1
Coal, soft, very poor grade, light-colored with very abundant plant remains	0.3

	Thickness *Feet*
Sandstone, light gray, weathering to buff, light yellow and dark gray, massive, with irregular wavy bedding	6.3
Shale, olive-green, weathering lighter	25.5
Sandstone, light green, thin bedded	1.5
Shale, green	7.7
Sandstone, light green, resembling limestone	1.3
	82.7
Total thickness of lower Harpersville	104.2

Waldrip beds.—This name was applied by Drake[23] to all the strata between the top of the Breckenridge limestone (Chaffin bed) and the base of the Saddle Creek limestone, the top member of the Harpersville. In this section there are three thin limestones which are the only breaks in an otherwise thick shale, sandstone, and coal succession. These three limestones, the lowest of which is near the middle of the Harpersville, Drake designated by number, as Waldrip No. 1, No. 2, and No. 3. Drake's usage of the term Waldrip beds is nearly synonymous with the Harpersville since it includes all the strata in the Harpersville formation except the Saddle Creek limestone. In this paper the Waldrip beds are restricted to the strata from the base of the first limestone, Waldrip No. 1, to the base of the Saddle Creek limestone, a thickness of about 115 feet.

Waldrip bed No. 1.—The lowest Waldrip bed is an arenaceous greenish-gray to buff limestone when weathered, slightly lighter greenish gray upon fresh fracture. When weathered, it is rather soft and has the appearance of being thinly bedded. Like most of the hard limestones in the area, it is fairly well jointed. Its weathered surface is very uneven. It contains many fusulinids, crinoid stems, and some brachiopods. This bed is well exposed on the east bluff of Colorado River four-tenths of a mile northwest of the old townsite of Waldrip. It may be seen again in Public Hollow, in the creek bed, about 1 mile south of the river. This lowermost Waldrip bed has a thickness of 6 to 12 inches.

Between Waldrip No. 1 and Waldrip No. 2 limestones are found a shaly clay, a sandstone, and another clay. The lower clay is

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[23] Drake, N. F., *op. cit.*, p. 412.

gray to maroon in color and nonfossiliferous. The sandstone is yellow to white in color and well indurated. Shale partings are present. The upper clay is markedly red in color and is nonfossiliferous. The thickness of the interval between Waldrip No. 1 and Waldrip No. 2 is approximately 50 feet, although less in some places. On the east bluff of Public Hollow, 1 mile south of Colorado River, the thickness of this interval is 51 feet.

Waldrip bed No. 2.—Waldrip bed No. 2 is usually about 1 foot in thickness. The lower 6 inches of this limestone is usually hard, dark gray, weathering yellow and somewhat nodular, and containing fusulinids, crinoid stems, bryozoans, brachiopods, and a few pelecypods. The upper part is hard, somewhat lighter gray, semicrystalline, massive, and weathers to a dark gray. Waldrip No. 2 sometimes contains calcite veins in abundance. Iron stains are often present on the exposed surfaces. Fresh fractures show a gray to bluish color. This bed is well exposed at the following localities: on the east bluff of Colorado River, four-tenths of a mile northwest of the old townsite of Waldrip; and also below the road crossing 1 mile north and 1 mile west of Marion School.

Waldrip No. 2 is separated from Waldrip No. 3 by arenaceous shales and clays which vary in thickness from 15 to 30 feet. These sediments are characterized by an unusually high ferruginous content.

Waldrip bed No. 3.—This bed is likewise very thin, usually having a thickness of about 1 foot. The bed is characterized by being dark blue to gray in color, hard, and crystalline. Block jointing occurs at almost every exposure of the bed. Crinoid stems are, at some points, very abundant and at other points are almost entirely lacking; fusulinids also occur irregularly. The weathering is smooth. Where considerable water has flowed over the bed it assumes a marked blue color. Waldrip No. 3 is undoubtedly the most easily recognized bed in this area. Because of its regular thickness and its even jointing, it is called "flat rock" in the vicinity of Waldrip. It is known also as "clink stone" locally because of the characteristic ring it has when struck a sharp blow with a hammer. Good exposures of Waldrip No. 3 occur along the east bank of Saddle Creek where it forms a distinct bench along the side of the creek for a distance of a mile or more south from the river.

Section of part of Harpersville formation on east bank of Colorado River at east bend of river 1 mile northwest of Waldrip, McCulloch County.

	Thickness *Feet*
Limestone (Waldrip No. 2), massive, hard, gray to buff	1.3
Shale, light buff to maroon	16.7
Sandstone, shale lenses, buff to gray	7.5
Shale, buff to reddish at bottom	16.0
Limestone (Waldrip No. 1), hard, massive, bluish gray, weathers gray to green	1.7
Shale, grayish brown to buff	3.2
Shale, soft, blue, very carbonaceous	0.5
	46.9

Section of part of Harpersville formation on Colorado River at sharp bend to west, 1 mile northwest of Waldrip, McCulloch County.

	Thickness *Feet*
Waldrip beds:	
Limestone (Waldrip No. 2), weathering to a light gray, weathered surface presenting a brecciated appearance; iron stains; few fossils; semi-crystalline	1.0
Clay, red to maroon; coloration very marked	16.9
Sandstone, white, alternating beds with thin shale partings, well indurated; well preserved ripple marks	4.5
Shale, gray to buff, nonfossiliferous	21.0
Limestone (Waldrip No. 1), blue-gray crystalline limestone, weathering irregularly; crinoid stems and fusulinids in abundance; questionably in situ at this point	1.0
Shale, gray to buff	4.5
Clay, black, highly carbonaceous; equivalent of coal bed	2.5
	51.4

Section of Harpersville formation on south bluff of east bend of Colorado River, 0.6 mile northwest of Waldrip, McCulloch County.

	Thickness *Feet*
Limestone (Waldrip No. 2), light to dark gray or brownish, finely crystalline, dense; weathers to dirty brown; contains stringers of brown calcite	6.7
Shale, lavender to maroon, poorly bedded, friable, thinly laminated	15.9

	Thickness *Feet*
Sandstone, fine grained, greenish, containing some hematite which gives a pink weathered surface, finely laminated, large ripple marks	4.6
Shale, orange-tan to pink, friable, mottled with red	2.2
Sandstone, fine grained, brownish to yellow and gray, mottled, laminated	0.3
Shale, interbedded maroon and light gray, friable, poorly bedded, argillaceous and micaceous	15.8
Limestone (Waldrip No. 1), arenaceous, crystalline, medium gray, contains calcite, finely textured; weathers to greenish brown; *Triticites* abundant	0.8
Shale, light gray, friable, irregularly bedded	3.3
Coal, lignite, interbedded with blue-gray carbonaceous shale	0.3
	49.9

Section of Harpersville formation on east bluff of Public Hollow, 1 mile south of Colorado River and due west of Kennedy House, McCulloch County.

	Thickness *Feet*
Waldrip beds:	
Limestone (Waldrip No. 3), brown to gray in color, well jointed into massive polygonal blocks, hard and crystalline; weathers smooth; fresh fracture dark blue to dark gray; occasional iron stains; abundance of crinoid stems and fusulinids; forms rather persistent scarp; questionably in place at this point	1.0
Clay, buff colored; shaly; covered with chert nodules	14.7
Limestone (Waldrip No. 2), weathers to light gray and weathered surface presents brecciated appearance; hard, semi-crystalline, iron stains; rather impure, few fossils	1.0
Clay, maroon to red; coloration due to presence of iron; nonfossiliferous; scarp slope covered with chert nodules	20.8
Sandstone, white to yellow; well indurated; forms a prominent scarp; contains well-preserved ripple marks	1.2
Clay, shaly; purplish maroon to gray, maroon predominating; nonfossiliferous	21.3
Limestone (Waldrip No. 1), gray, crystalline; weathers irregularly; marked block jointing; crinoid stems and fusulinids in abundance	1.0
Clay, yellow to gray or buff; nonfossiliferous	1.5
Shale, black to gray; carbonaceous	1.2
Coal bed, very poor grade lignitic coal; many wood fragments; some horizons show very black carbonaceous shale	0.9
	64.6

Section of upper Harpersville formation on east bank of Saddle Creek, 0.5 mile south of mouth, McCulloch County.

	Thickness *Feet*
Limestone (Saddle Creek), dark grayish blue, medium fine grained; contains small calcite crystals; sparingly fossiliferous, thick bedded, forms prominent scarp; weathers to slabs and blocks with rough surfaces	0.9
Clay, yellowish, covered with slump from Saddle Creek limestone	3.6
Sandstone, brownish gray, very impure, and nonresistant	9.9
Clay, yellowish buff	15.5
Clay, yellowish gray containing ferruginous concretions and segregations in uppermost portion; ferruginous bed quite fossiliferous at this point	18.7
Bed covered	5.2
Limestone (Waldrip No. 3), blue, very hard, weathers to a rusty brown, fossiliferous, containing many crinoid stems	1.2
Shale, bluish red, easily weathered, covered with slump from Waldrip No. 3 limestone	13.0
Covered with slump from Waldrip No. 3	10.3
Limestone (Waldrip No. 3), greenish gray, hard cryptocrystalline, nonfossiliferous	1.0
	79.3

Section of Harpersville formation on east bank of Saddle Creek, 1 mile south of Colorado River, McCulloch County.

	Thickness *Feet*
Limestone (Saddle Creek), hard, crystalline, light gray, containing calcite veins, fossiliferous; caps hill; all but base eroded away	3.0
Shale, arenaceous, yellowish, few fossils	6.5
Sandstone, yellowish, fine grained, laminated, thinly bedded, contains no fossils, limonite present	2.0
Shale, brown to yellow, contains limonite and lime nodules; fossiliferous, containing *Productus semireticulatus* Martin, *Spirifer cameratus* Morton, *Rhombopora lepidodendroidea* Meek?, crinoid stems in profusion, *Chonetes granulifer* Owen. At 10 feet above the bed below (Waldrip No. 3), there is a characteristic layer about 10 inches thick of highly ferruginous and fossiliferous material	33.5
Limestone (Waldrip No. 3), color a distinctive dark blue, hard, massive, crystalline, well jointed, fossiliferous, including	

	Thickness *Feet*
Spirifer cameratus Morton, *Chonetes granulifer* Owen, *Marginifera splendens* Norwood and Pratten. At the top of the bed is a sandy layer that contains many *Marginifera splendens* Norwood and Pratten; weathers to a brownish gray	0.9
Shale, laminated, very fine grained, yellowish; very fossiliferous containing a profusion of crinoid stems, *Spirifer cameratus* Morton, *Productus* sp., *Chonetes granulifer* Owen	3.3
Sandstone, argillaceous and calcareous, laminated, contains iron stains and streaks; nonfossiliferous; weathers light yellow to grayish	1.2
Shale and clay, variegated red to gray, reddish layer about 15 feet above bed below (Waldrip No. 2), lower part covered by fill but probably the same as the upper part; fossiliferous, containing *Spirifer cameratus* Morton, crinoid stems	25.0
Limestone (Waldrip No. 2), light gray, hard, massive, crystalline, containing calcite veins, weathers gray, iron stains, fossiliferous, containing crinoid stems, *Spirifer cameratus* Morton, *Marginifera* sp.	0.9
	76.3

Saddle Creek.—The uppermost member of the Harpersville is the Saddle Creek limestone. Its thickness ranges from 3 to 6 feet, averaging about 4 feet. It is light brownish gray, crystalline, moderately hard, and noticeably flaggy. On the light-colored surface, there are many irregular, elongate streaks of crystalline calcite and irregular veins of white amorphous calcite which is similar to the mass proper but which is different in color. Crinoid stems, specimens of *Campophyllum torquium* Owen, and fusulinids are found at some localities. One of the best exposures of this member is on Saddle Creek, the type locality for the member. The Saddle Creek limestone forms the cap of many of the erosional remnants in the valley of Saddle Creek and caps the west-facing escarpment on the east side of Saddle Creek. It forms the first bench, about 25 feet above the bed of Saddle Creek, and is continuous for some distance on the west bank of Saddle Creek beginning about 1 mile south of Colorado River. This limestone is one of the most easily recognized beds in the area. Its characteristic calcite veins, its jointing which results in rather well-shaped blocks, the irregular bedding planes, and its position directly above the highly ferruginous Waldrip beds all serve to identify this member.

Section from top of Waldrip No. 3 to top of Harpersville formation on south side of outlier 1.1 miles north of new Walker ranch house, approximately 1 mile west of Marion School, northwestern McCulloch County.

	Thickness *Feet*
Saddle Creek limestone:	
Limestone, light brown to gray, finely crystalline, thinly bedded, flaggy, containing *Campophyllum torquium* Owen; weathers light gray	4.7
Waldrip beds:	
Sandstone, red, fine grained, massive	1.8
Sandstone, light buff, highly quartzose, mottled with limonite stains; massive	1.8
Sandstone and shale, soft, buff, fine grained, highly quartzose, grading upward into a soft, buff, arenaceous shale	7.8
Shale, red or reddish brown, fairly soft	12.1
Sandstone, highly calcareous, fossiliferous, argillaceous, fine grained, yellowish brown; contains many *Spirifer cameratus* Morton, *Spiriferina kentuckiensis* Shumard, *Hustedia mormoni* Marcou, *Pustula* sp.	1.0
Shale, tan, thinly bedded, friable, with fossiliferous layers; contains large crinoid stems, *Spiriferina kentuckiensis* Shumard, *Hustedia mormoni* Marcou, *Marginifera lasallensis* Worthen?, *Phillipsia* sp.	10.2
Limestone (Waldrip No. 3), dark blue-gray, crystalline, weathering to drab-brown or to metal blue-gray in stream bottoms; exhibits block-jointing; contains abundant crinoid stems	
	39.4

PUEBLO FORMATION

The Pueblo formation was named[24] for the town of Pueblo in northeastern Callahan County, Texas. It includes all the strata from the Saddle Creek limestone to the top of the Camp Colorado limestone, having a total thickness of approximately 200 feet in northwestern McCulloch County. Bounded by two persistent, hard, and characteristic limestones, it is one of the easiest formations in the entire section to map. The Pueblo outcrops in a belt from 1 to 2 miles in width with Saddle Creek forming its eastern boundary. From Saddle Creek the formation extends southward, the Camp Colorado limestone, top member of the Pueblo, outcropping 1.75

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[24] Plummer, F. B., and Moore, R. C., *op. cit.*, p. 168.

miles west of Pear Valley and thence to the Brady Mountains. The Pueblo includes the following members:

Camp Colorado limestone
Salt Creek Bend shale
Stockwether limestone
Camp Creek shale

Camp Creek shale.—The Camp Creek shale consists of from 50 to 90 feet of alternating beds of shale, sandstone, and thin limestones. The color of the shales varies from yellowish to red to blue-gray. This member contains an abundance of rather pure hematite nodules. The Camp Creek is well exposed on the east side of the escarpment west of Saddle Creek and northwest of the new Walker ranch house. There are at least three thin limestones which are more or less persistent. The lowest one can be traced over the entire Saddle Creek area; it is a purplish, mottled, impure limestone which is prolific in fossils. In the Camp Creek, the fusulinid genus *Pseudofusulina* makes its first appearance. This genus is considered as characteristic of the uppermost Upper Pennsylvanian and Lower Permian. Good collections of fossils can be made from the Camp Creek shale on the west side of Saddle Creek. About 25 feet above the base of the Camp Creek shale is a thin flaggy limestone that is quite distinct because of the abundance of fossils that it contains. This bed usually holds up a small terrace, the first above the more prominent Saddle Creek limestone bench. It is a relatively soft, gray, argillaceous, nodular, fossiliferous limestone rarely exceeding 6 inches to 1 foot in thickness. The genus *Bellerophon* is especially common in this zone although other fossils including the following forms are also common: *Campophyllum torquium* Owen, crinoid stems, *Composita subtilita* (Hall), *Chonetes* sp., *Hustedia mormoni* Marcou, *Squamularia perplexa* McChesney, *Derbya crassa* Meek and Hayden, *Pustula nebraskensis* (Owen), *Productus semireticulatus* Martin, *Pugnax osagensis* Swallow, *Spirifer cameratus* Morton, *Marginifera splendens* Norwood and Pratten, *Pinna peracuta* Shumard, *Allorisma subcuneatum* Meek and Hayden, *Myalina kansasensis* Shumard, *Bellerophon crassus* Meek and Worthen, *Euomphalus* sp., and *Griffithides scitulus* Meek and Worthen. Probably the most profuse horizon of fusulinids in the whole Pennsylvanian section occurs at the top of this bed. Ant mounds are frequently made up almost entirely of fusulinids and in such cases they can be scooped up in large quantities. Additional details concerning the Camp Creek shale are given in the following sections:

Section of the upper Harpersville and lower Pueblo formations on south bluff of tributary on west side of Saddle Creek, 0.75 mile south of Colorado River, McCulloch County.

	Thickness *Feet*
Stockwether limestone:	
Limestone, light gray to tan, granular, weathers smooth	8.7
Clay slope covered with slump material	9.7
Limestone, hard, compact, semi-crystalline, gray, weathers to dark gray, contains many unrecognizable shell fragments	3.0
Camp Creek shale:	
Fossiliferous clay, slope covered with slumped blocks of limestone	9.7
Shale, red and yellow, very fossiliferous, *Myalina subquadrata* Shumard abundant	12.2
Sandstone, white to gray, nonresistant, thin bedded	0.7
Shale, ferruginous, variegated red to yellow, containing iron concretions	34.1
Limestone, soft, buff to gray, weathers into nodular masses, very fossiliferous, fusulinids very abundant	0.5
Shale, yellowish to gray	0.7
Limestone, purplish gray, thin bedded	0.5
Shale, variegated red and yellow	26.2
Saddle Creek limestone:	
Limestone, light gray, moderately hard, thin bedded, made up of wavy beds about 4 inches thick, weathers uneven into nodular masses, characterized by its "rock fence" appearance; contains grains of amorphous calcium carbonate	3.7
Waldrip beds:	
Marl, greenish to brown	1.3
Sandstone, gray, massive, indurated, weathers to blackish gray and tinged with yellow stains, made up of a series of layers each 6 to 8 inches in thickness, except the lowest bed which is about 1 foot thick	2.5
Shale, reddish brown, ferruginous, fossiliferous, grades to a yellowish clay in the upper 13 feet	25.0
Flat covered by alluvium.	
	138.5

Section of lower Pueblo, on escarpment on west side of Saddle Creek, 2 miles south of Colorado River, McCulloch County.

	Thickness *Feet*
Stockwether limestone:	
Limestone, same as below	9.5
Shale; light-colored, calcareous, non-ferruginous; with limestone nodules	2.5
Limestone, grading from light blue, very crystalline to yellowish brown and less crystalline; hard and massive; somewhat ferruginous	3.0
Camp Creek shale:	
Shale. brown, ferruginous	4.0
Limestone, gray, massive, fine grained, sandy	1.7
Shale, brown, ferruginous	10.0
Sandstone, light gray, semi-hard, calcareous	0.7
Shale, light to dark brown, friable, filled with iron segregations, masses of hematite; covered by slump limestone from above	36.7
Limestone; gray, nodular, weathers to dirty gray; fossiliferous, fusulinids abundant	0.5
Shale, yellow, calcareous	1.0
Limestone, gray, massive, medium hard, crystalline, few fossils	0.5
Shale, brown grading to yellow towards the top, contains hematite, fossiliferous	23.4
Saddle Creek limestone:	
Limestone, gray to brown, fine grained, crystalline; characterized by abundance of calcite veins; fossiliferous	3.0
	96.5

Section of upper Harpersville and lower Pueblo formations on Saddle Creek 2 miles south of Colorado River, McCulloch County.

	Thickness *Feet*
Stockwether limestone:	
Limestone, similar to that below	10.0
Shale, similar to that below	2.5
Limestone, hard, gray, massive, crystalline; bedded in 3-inch layers; contains veins of calcite which are in some cases replaced by iron; fossiliferous; contains *Marginifera lasallensis* Worthen?, *Composita subtilita* (Hall), *Spirifer cameratus* Morton	3.0
Camp Creek shale:	
Shale, yellow; similar to that below except that it has more limestone particles; weathers to a blackish soil; fossiliferous,	

	Thickness *Feet*
contains *Chonetes verneuilianus* Norwood and Pratten, *Productus semireticulatus* Martin, crinoid stems	2.2
Limestone, hard, massive, gray, crystalline with a reddish tint; fossiliferous, contains *Composita subtilita* (Hall), *Productus semireticulatus* Martin, and crinoid stems and plates	1.7
Shale, similar to that below except there are fewer iron particles; red color present	10.6
Sandstone, dark yellow; weathers black; contains streaks of iron oxide; no fossils; 2-inch layer of limonite under sandstone	7.2
Shale, in lower portion yellow with particles which oxidize to hematite; maroon in upper part; fossiliferous, contains *Pustula nebraskensis* (Owen), *Marginifera lasallensis* Worthen?, and *Composita subtilita* (Hall)	28.5
Limestone, nodular, dark yellow, weathers to a dark brown to black; soft, porous, weathers into nodules about 6 inches in diameter, contains many fossils including *Spirifer cameratus* Morton, *Dielasma bovidens* Morton, *Chonetes* sp., and crinoid stems	0.5
Shale, similar to that below	1.0
Limestone, gray, hard, crystalline; fossiliferous, containing *Composita subtilita* (Hall), *Marginifera lasallensis* Worthen?, *Productus semireticulatus* Martin	0.5
Shale, red, contains particles of hematite, yellowish towards top	24.0
Saddle Creek limestone:	
Limestone, distinct buff-gray; hard, crystalline, massive, calcite veins present; fossiliferous, contains *Composita subtilita* (Hall), *Marginifera lasallensis* Worthen?, *Productus semireticulatus* Martin, *Marginifera splendens* Norwood and Pratten	2.9
	94.6

Stockwether limestone.—The Stockwether is a hard, brownish-gray, compact, massive, crystalline, fossiliferous limestone containing an abundance of light-colored chert and a considerable amount of ferruginous material. The limestone varies in thickness from 5 to 20 feet. In many localities the Stockwether is divided into two layers, a lower and an upper, separated by a shale interval of variable thickness. In the section measured on the escarpment on the west side of Saddle Creek, for example, the lower limestone has a thickness of 3 feet and the top one a thickness of 9.5 feet, the two being separated by about 2.5 feet of shale. It is not certain whether all the Stockwether is present at this point. The Stockwether forms a prominent escarpment in parts of the Saddle Creek area. The chert of the Stockwether is much lighter in color than that found in the Camp Colorado limestone at the top of the Pueblo. The Stockwether contains many fusulinids in addition to a varied assortment of other fossils.

Salt Creek Bend shale.—The name Salt Creek Bend is here proposed for the strata between the Stockwether limestone and the Camp Colorado limestone. Drake referred to this interval as "Bed No. 13." At the type locality of this member, a sharp bend on Colorado River 0.1 mile east of the mouth of Salt Creek, it has a thickness of 128 feet. It consists predominantly of maroon-colored shales with two thin limestones near the middle of the member. The lower limestone is 2 feet thick, nodular, arenaceous, gray on fresh exposure and greenish on weathered surface. The upper limestone is about 6 inches in thickness, yellow in color, massive, and breaks into large rectangular slabs. Additional details regarding the Salt Creek Bend shale member are given in the accompanying section.

Section of upper Pueblo formation from bed of Colorado River up east face of bluff, 0.25 mile downstream from mouth of Salt Creek, McCulloch County.

	Thickness *Feet*
Watts Creek shale:	
Limestone, very similar to Camp Colorado but has slightly darker color, caps hill above river	
Shale, covered slope	6.2
Camp Colorado limestone:	
Limestone, cream to very light brownish gray, dense, very compact with conchoidal fracture, weathered surface usually smooth drab-gray; abundance of dark gray to brown to black chert	5.2
Salt Creek Bend shale:	
Shale, covered by slump	22.0
Limestone, hard, yellowish brown, fossiliferous, containing an abundance of *Allorisma* sp.	1.0
Shale, covered slope	17.3
Limestone, greenish gray, coarse grained, crystalline; almost a fossil breccia, surface rough due to ridges formed by fucoids	0.5
Shale, dark red, hematitic, friable, covered with slump from above	24.6
Sandstone, lower part massive, buff, clean and soft, grading upward into laminated cross-bedded hematitic layers	4.9
Shale, red, ferruginous, covered with slump from above	25.2
Limestone, light gray to greenish yellow, bedded, moderately hard with layers of arenaceous limestone; weathers to nodular, light	

	Thickness *Feet*
greenish brown; highly fossiliferous, including *Composita subtilita* (Hall), *Yoldia* sp.	3.2
Shale, with thin sandstone layers; ferruginous, partly covered with river alluvium	11.8
Sandstone, greenish yellow-gray, fine grained, soft, thinly bedded, no distinct division at top	3.3
River alluvium, probably shale beneath	17.5
Stockwether limestone:	
Limestone, light gray, massive, containing large calcite crystals, weathers to gray; slightly fossiliferous; *Composita subtilita* (Hall) present; top only exposed in bed of river	
	142.7

Camp Colorado limestone.—The Camp Colorado limestone is a hard, gray to brown, crystalline limestone containing much dark-colored chert, especially in the lower part. At some places the limestone gives way entirely to beds of chert which occur in layers from 6 inches to 1 foot in thickness. The limestone varies from 3 to 10 feet in thickness, averaging about 5 feet, and weathers in a rough, dark bluish to buff surface. This bed contains sandy phases near the top. It usually caps an escarpment about 60 feet in height, the slopes of which are covered by fragments of black chert from the weathering of the limestone above.

At some places the Camp Colorado consists of two limestones separated by a thin shale parting. The lower bed is cream-colored, dense, and has a conchoidal fracture. The weathered surface is generally smooth. The upper limestone is similar to the lower but has a darker gray color. Both limestones contain a large amount of chert which is distinguishable from the chert in the other limestones by its dark brown to black color. The abundance of dark-colored chert makes the Camp Colorado one of the most easily recognized beds in the entire section. The chert also makes the bed quite resistant to erosion and it usually caps a prominent escarpment. Good exposures occur on the bluff along the south side of Salt Creek near the point where it empties into Colorado River, northwestern McCulloch County. The Camp Colorado with its abundant black chert is well exposed also in the bed of Colorado River at the point where the bed crosses the river as shown on the geologic map (Pl. IV). In University of Texas Bulletin 3232, issued in 1933, the Camp Colorado limestone is regarded as the topmost member of the Pennsylvanian, the overlying Moran and Putnam formations being placed as Permian.

PERMIAN

WICHITA GROUP

The Wichita group is the lowest division of the Permian. As defined by Sellards, this group includes the following formations: Moran, Putnam, Admiral, Belle Plains, Clyde, and Leuders. Only the formations which outcrop in the area under consideration are described in this paper.

MORAN FORMATION

The Moran formation was named for the town of Moran in Shackelford County, where it is exposed typically on the hillside west of town and forms the escarpment around the Moran oil field. It was defined to include all the strata from the top of the Camp Colorado limestone to the top of the Sedwick limestone. The formation is predominantly shale with relatively thin limestones which do not form prominent escarpments. For this reason good exposures are rather uncommon and the usual occurrence is on gently sloping hills. The total thickness of the Moran formation, according to measured sections, is about 95 feet. The following beds, named and described by Drake,[25] are included in the Moran formation:

Sedwick limestone
Santa Anna shale
Horse Creek limestone
Watts Creek shale

Watts Creek shale.—This shale interval which separates the Camp Colorado limestone and the Horse Creek limestone consists of about 50 feet of reddish to purple shale with two thin, impure limestones in the lower part.

Horse Creek limestone.—This bed is rather poorly developed in the area immediately adjacent to Colorado River. It consists of a basal limestone consisting of two beds, each of which is about 18 inches in thickness, separated by a thin shale parting. A shale

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[25] Drake, N. F., *op. cit.*, pp. 419–420.

interval of approximately 3 feet separates this basal limestone from a thin, gray to purplish, nodular limestone containing some chert. This upper limestone is the top of the Horse Creek member. The entire thickness of the Horse Creek limestone is from 7 to 8 feet. The basal limestone is massive, gray, weathers with a smooth surface, and breaks into well-defined blocks. It contains an abundance of fusulinids. The upper bed of the basal limestone is quite similar to the lower except that the surface is covered with irregular patches of a rusty brown chert.

Santa Anna shale.—This name was applied by Drake to the shale separating the Horse Creek limestone and the Sedwick limestone. In the area discussed in this report the Santa Anna shale consists of about 22 feet of yellow to brown shale which on weathering has a decided reddish cast. A thin impure limestone about 6 inches in thickness occurs near the middle of the Santa Anna shale.

Sedwick limestone.—This member includes a series of thin yellow limestones with interbedded shales which form the top of the Moran formation. In the area immediately south of Colorado River, in northwestern McCulloch County, the Sedwick contains three relatively thin limestones which weather to a bright yellow color or in some instances are covered by bright yellow spots. The lowest limestone, about 2 feet in thickness, is arenaceous, ferruginous, and contains large specimens of *Pinna peracuta* Shumard. The second limestone is separated from the first by about 2 feet of gray marl. An outstanding characteristic of this limestone is the abundance of silicified gastropods and brachiopods. These silicified shells, being harder than the remainder of the rock, stand out in relief and on almost any weathered surface a number of these shells may be seen. Two of the most common forms are *Spiriferina kentuckiensis* Shumard and *Composita subtilita* (Hall). The top bed of the Sedwick is separated from the middle or upper layer of the lower bed by 10 to 12 feet of light yellow to brown shale. The upper limestone is dark gray, hard, crystalline, and has a thickness of about 1 foot.

The Sedwick limestone does not hold up a prominent escarpment, but in many places a low but distinct series of terraces is formed by the three limestones and the intervening shale beds. Good exposures of the Moran formation occur in the bluffs on the south side of Salt Creek in northwestern McCulloch County. The Sedwick limestone forms the top of the divide just south of Salt Creek. The outcrop of the Sedwick limestone extends in general northward parallel to Colorado River, crossing the river between Panther and Mercer creeks, Coleman County.

Section of Moran formation, 1.25 miles east of the mouth of Salt Creek, McCulloch County.

	Thickness *Feet*
Sedwick limestone:	
Limestone, dark gray, crystalline, hard, compact, weathers into rectangular blocks	0.7
Shale, chocolate-brown	2.3
Limestone, nodular, brownish gray, moderately hard	0.7
Shale, light yellowish brown	10.5
Limestone, light gray, thinly bedded, surface covered with silicified shells, hard, compact, crystalline; fossiliferous, containing brachiopods, corals, and crinoid stems	1.25
Shale, covered by slump	2.25
Limestone, dark gray, thinly bedded, hard, compact, crystalline, silicified shells on surface	1.7
Santa Anna shale:	
Shale, chocolate-brown	9.3
Limestone, dark yellowish brown streaked with calcite, thinly bedded, moderately soft	0.5
Shale, chocolate-brown to yellowish brown	11.75
Limestone, nodular, light gray to purplish gray, surface streaked with sheets of chert	0.5
Shale, covered by slump	2.5
Horse Creek limestone:	
Limestone, gray, crystalline, compact, surface covered by irregular masses of rusty brown chert	1.0
Shale, covered by slump	1.0
Limestone, light gray, calcitic, hard, compact, coarsely crystalline, weathers to dark gray color, fusulinids present	1.5
Watts Creek shale:	
Shale, chocolate-brown at top and bottom, with light brown in middle	27.7
Limestone, yellowish brown mottled with dark yellowish streaks and white calcite streaks, weathers to dirty gray, moderately hard, massive, fossiliferous	1.75
Shale, chocolate-brown	8.7
Limestone, hard, compact, dense, thinly bedded, weathers to yellowish gray, fresh fracture darker gray than limestone below	1.75
Shale, covered by slump	2.5

	Thickness *Feet*
Camp Colorado limestone:	
Limestone, hard, compact, crystalline, well jointed, thinly bedded, weathers to yellowish gray, fresh fracture steel-gray in color	3.3
	93.15

PUTNAM FORMATION

The Putnam formation is named for the town of Putnam in Callahan County, where the formation is exposed on the hillside west of the town. The formation includes all the strata from the top of the Sedwick limestone to the top of the Coleman Junction limestone. The Putnam formation has a total thickness of about 180 feet in northwestern McCulloch County. It consists of thick shales, a few fine-grained to conglomeratic sandstones, and a few thin, impure limestones. Two of Drake's divisions of the Cisco are grouped as members of the Putnam formation. They are:

Coleman Junction limestone
Santa Anna Branch shale

Santa Anna Branch shale.—This member includes all the strata from the top of the Sedwick to the base of the Coleman Junction limestone. Its thickness is about 175 feet in the area discussed in this paper, and it consists mainly of shales with some lenticular sandstones and a few thin limestones. About 50 feet above the base of the Santa Anna Branch shale is a dense, hard, cream-colored limestone about 14 inches in thickness. On weathering, this bed becomes somewhat nodular and breaks with a distinct conchoidal fracture. It is a good marker for both geologic and structural mapping and was quite useful in connecting separate sections of the Santa Anna Branch shale. Because of the good exposures of this bed on the hills just to the north and west of the Hardin School house in southwestern Coleman County the name Hardin School limestone is proposed for this bed. About 9 feet below the Hardin School bed and separated from it by yellow to gray clay is a rather prominent limestone about 18 inches in thickness. This lower limestone varies from dirty gray to yellow, is massive, and on weathering breaks into large rectangular blocks which frequently cover the slope below its outcrop. This lower bed is more prominent than the upper bed, Hardin School limestone, but for stratigraphic work the upper bed is more useful since it is the highest limestone in the thick Santa Anna Branch shale. In some places a thinly bedded, hard, gray limestone 1 to 2 feet in thickness occurs about 5 feet above the Hardin School bed, but this bed is apparently not persistent as it does not appear in all sections. The Hardin School limestone is followed by approximately 125 feet of predominantly buff-colored shale with a few relatively thin sandstones.

Coleman Junction limestone.—This limestone is one of the most prominent beds in the entire section. The base of the Coleman Junction was selected by Drake[26] as the Permian-Pennsylvanian contact. Plummer and Moore[27] shifted the contact to the top of the Coleman Junction, and since that time it has been moved to various positions lower in the section. Sellards[28] reviewed the problem in 1932 and concluded that the Permian-Pennsylvanian contact should be placed at the base of the Moran formation or at the top of the Camp Colorado limestone. It is not the purpose of this paper to consider this problem and it will not be discussed further. In the area considered in this report the Coleman Junction limestone consists of two beds separated by about 5 feet of shale. The total thickness assigned to the Coleman Junction, including the shale parting, is not more than 10 feet. The lower bed of the Coleman Junction is a hard, dark gray to brown, massive limestone spotted with yellowish to brown iron stains. Upon weathering it breaks into large rectangular blocks. Its thickness rarely exceeds 2 feet. The upper bed is not quite as massive as the lower bed, is grayish in color with numerous yellow stains, and on weathering becomes distinctly nodular. These two limestones cap one of the most prominent escarpments in the entire area, which can be readily traced for many miles.

The Coleman Junction limestone caps the prominent hill directly east of Mercer Creek and about 0.5 mile north of Colorado River, Coleman County. From this point the Coleman Junction can be traced westward, gradually getting lower and lower until it passes into the bed of Colorado River at Crane Crossing at the northwestern corner of McCulloch County. The Coleman Junction is

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[26] Drake N F., *op cit*, p. 421

[27] Plummer, F. B. and Moore. R C., *op. cit.*, p. 190.

[28] Sellards, E H., and others, The Geology of Texas, Vol. I, Stratigraphy, pt. I, The pre-Paleozoic and Paleozoic systems in Texas: Univ. Texas Bull. 3232, p. 140, 1932.

well exposed also on the south side of Bois d'Arc Creek about 2 miles southeast of Stacy, McCulloch County.

Section of Putnam formation, 0.5 mile north of mouth of Mercer Creek, Coleman County.

	Thickness *Feet*
Coleman Junction limestone:	
Limestone, hard, compact, grayish, with numerous yellow splotches; weathers into nodular lumps	1.20
Covered shale interval	4.25
Limestone hard, dull gray, massive, has chert and iron stains, weathers almost black, breaks into large rectangular blocks	2.00
Santa Anna Branch shale:	
Shale, dull buff in color	26.25
Shale, green, fine grained, finely laminated, edges become red upon exposure	.20
Material covered with slump	2.90
Sandstone, buff, fine grained, massive	1.50
Covered material	6.50
Sandstone, hard, compact, massive, fine grained, weathering irregularly from buff to brownish-black; two layers of sandstone separated by a finer grained, more thinly bedded sandstone followed by an arenaceous conglomerate	5.20
Shale, dull gray at bottom grading to buff near the top; partially covered with nodular, rectangular blocks of gray and yellow limestone	80.30
	130.30

Section of the upper Moran and lower Putnam formations on south side of hill 100 yards north of road 1.5 miles west of Hardin School on east side of Panther Creek, Coleman County.

	Thickness *Feet*
Santa Anna Branch shale:	
Hardin School limestone, yellow-red; forms top of hill, nodular weathering	1.2
Clay, yellowish to gray	8.9
Limestone, thick, massive, fossiliferous, dirty gray and yellow in places, one color grading into the other; weathers into large rectangular blocks, entire hillside covered by slump of these large blocks 18 inches thick and many feet square	1.5
Clay bed, alternates with a blue, purple, and red coloring, most part is dirty yellow; the whole outcrop of clay gives the hill a yellow aspect	30.7

	Thickness *Feet*
Limestone, nodular, extremely brecciated when weathered, also has a black discoloration when weathered; very hard and reddish gray upon fresh exposure	0.5
Clay, yellow	6.3
Sedwick limestone:	
Limestone, nodular, yellowish when weathered, full of crinoid stems and fossils, dense, crystalline, steel-gray on fresh exposure	0.3
Clay bed, yellowish to gray in color	11.3
Limestone, top of lower Sedwick	
	60.7

ADMIRAL FORMATION

The Admiral formation overlies with apparent conformity the Coleman Junction limestone of the Putnam formation. Only the lower part of the formation is exposed in the area covered by this paper, and for that reason no attempt is made to give a complete description. The Admiral formation is exposed in the extreme northwestern corner of McCulloch County, in the vicinity of Stacy. The formation, as exposed here, consists of thin, gray to brownish, nodular limestones with interbedded bluish-gray carbonaceous shales. The limestones rarely exceed 2 feet in thickness and the shale intervals range from a few inches to more than 8 feet. The lower part of the Admiral formation is exposed in the prominent bluff on the east bank of Colorado River, about 1 mile west of Stacy. At this place the Coleman Junction limestone forms the bed of the river. Although the bluff is some 80 feet or more in height, only a little over 36 feet of the Admiral is exposed, inasmuch as the upper part of the bluff is made of terrace gravels. A section of the lower Admiral formation west of Stacy is given below.

Section of lower part of Admiral formation on bluff of Colorado River, 0.5 mile west of Stacy, near Concho-McCulloch County line.

	Thickness *Feet*
Admiral formation:	
Conglomerate and river gravel forming top of bluff	
Limestone, dense, light brown weathering to dark gray, contains fossils	3.90
Shale, bluish gray, stained yellow in places	8.00
Limestone, nodular, hard, grayish brown, crystalline, shale partings	1.70
Limestone, dark gray, carbonaceous, some fossils	1.00
Shale, fissile, carbonaceous	0.70
Limestone, dark gray, carbonaceous	0.90
Shale and limestone, thicker beds of shale alternating with thin limestone beds averaging about 3 inches; shale, finely laminated and highly carbonaceous; limestone, fossiliferous and containing carbonaceous particles resembling charcoal	8.10
Shale, light gray, stained bright yellow and brown in places, fairly compact	2.30
Limestone, thin bedded, nodular, gray, grading into shaly layers at top	1.30
Shale, dark gray, laminated, carbonaceous	.75
Limestone, hard, dark gray, breaks into rectangular blocks	.70
Shale, carbonaceous, laminated	.90
Limestone, massive, only one bed, dark gray, jointed, fractures into large blocks, weathers yellow	2.90
Shale, greenish gray where exposed	3.50
Putnam formation:	
Limestone, top of Coleman Junction in river bed	
	36.65

THE TEXAS-OKLAHOMA EARTHQUAKE OF APRIL 11, 1934

E. H. SELLARDS

A small earthquake occurred in northeastern Texas and southeastern Oklahoma on April 11, 1934. In the region of maximum intensity the tremor was sufficient to be very generally felt. A few persons left their houses following the shock and others were more or less frightened or disturbed. Two shocks were recognized by many observers. No damage was done to buildings and no surface disturbance has been found. Over a small area the earthquake probably attained intensity V of the Rossi-Forel scale.

The following account of this earthquake is based on observations made on May 6 to 9, supplemented by news items which appeared in the press, and information gathered by circulars by the Bureau of Economic Geology of The University of Texas and by the United States Coast and Geodetic Survey. In addition seismograph records of the earthquake were obtained at The University of Texas, where a seismograph is maintained by the Department of Physics, and through the kindness of Rev. James B. Macelwane at other stations as follows: Little Rock, Arkansas, St. Louis and Florissant, Missouri. With regard to the seismograph records Father Macelwane writes as follows (letter of May 25, 1934): "The first movement was recorded at Florissant at 7h41m46s P. M. What is probably the transverse phase is clearly defined and arrived at 7h42m57s. The group that probably introduces the surface waves arrived at 7h43m29s. At Saint Louis with precisely similar short-period Wood-Anderson seismographs but located on limestone instead of on shale, there is no observable movement before 7h42m8s, whereas there should have been practically no difference between the arrival times at Saint Louis and Florissant since Florissant is seventeen miles northwest of Saint Louis and the same distance from the epicenter. At Little Rock the first observable movement which is exceedingly small arrived at 7h40m54s. What is possibly the transverse phase arrived at 7h41m29s and is sharply defined as at Florissant and Saint Louis . . . I would conclude from our records that the time of occurrence at the focus would be in the neighborhood of 7h40m6s P. M. (Central Standard time)." Subsequently (June 11, 1934) Father Macelwane wrote as follows: "At Cincinnati nothing was recorded even on the very sensitive seismographs. At Denver not enough was recorded to make it possible to use the records. On further study I doubt even that the record at Florissant includes the very beginning so that it will not be possible to determine the exact position of the focus of the earthquake from the seismograph records, Little Rock being the only station that surely recorded all the phases. The distance from Little Rock is quite consistent with the area within which you found that the earthquake was felt. The arrival time of the shear waves on the Florissant and Saint Louis records is also consistent with that area. But as I said, a precise determination of the epicenter could scarcely be made." The information thus supplied from seismograph records and that supplied by the United States Coast and Geodetic Survey, by the press, and by many individuals is greatly appreciated.

The tremor was perhaps most distinctly felt at Powderly, Arthur City, Trout Switch, Caviness, and Chicota in the northern part of Lamar County, Texas (area marked by V in fig. 33). Probably 90 per cent of the people of these five communities felt the tremor and many report having heard a noise. In north Powderly, preceding the shock, a noise was heard described as "like rumbling thunder a long way off." At this place the earth jarred and quivered and dishes rattled in the houses. At Trout Switch, a few miles north of Powderly, a "roaring" was heard, followed by two tremors. Some persons were frightened and the disturbance was recognized as an earthquake. At Arthur City a "rumbling" was heard by many. At Chicota, a few miles west of Arthur City, the shock is described as having caused some persons to go out of their houses. At Caviness the tremor apparently was sufficient to disturb slightly the foundation of a frame house. At Hugo, Oklahoma, two shocks were generally felt. It is estimated that 50 per cent or more of the people at Hugo felt the shock. At Paris, likewise, one-half or more of the people felt the tremor. On the sixth and seventh floors of the Gibraltar Hotel in Paris lights swayed and the guests were alarmed.

In the following table are given localities in Texas and Oklahoma where the earthquake is reported to have been felt. Localities from which negative records were obtained are not listed. However, many such localities are indicated on the map (fig. 33).

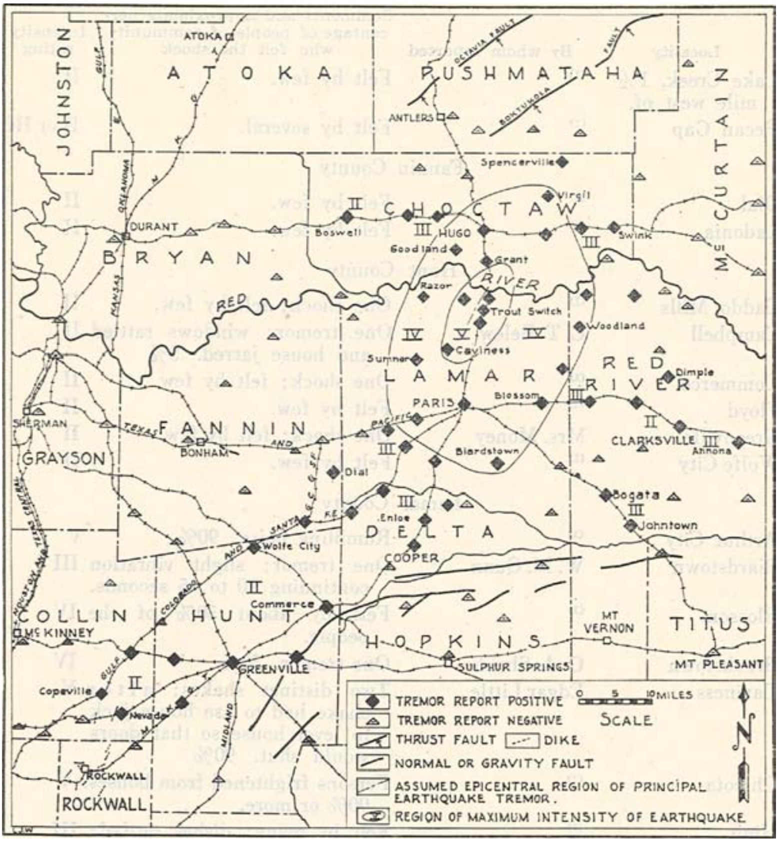

Fig. 33. Map showing the area in Texas and Oklahoma sensibly affected by the earthquake of April 11, 1934.

TEXAS

Locality	By whom reported	Comments and approximate percentage of people of community who felt the shock	Intensity rating
		Collin County	
Copeville	(1)	Slight shock. Felt by few.	II
Farmersville	(1)	Felt by few.	II
Nevada	E. J. Mayo	Mild tremor. 2%	II
		Delta County	
Ben Franklin	(1)	Slight shock; felt by several.	III
Cooper	R. H. Foster	One tremor. 10%	II
Enloe	A. W. Enloe	Vibration similar to heavy train passing. 25%	III

Locality	By whom reported	Comments and approximate percentage of people of community who felt the shock	Intensity rating
Lake Creek, 1½ mile west of,	(1)	Felt by few.	II
Pecan Gap	(1)	Felt by several.	II or III
Fannin County			
Dial	(1)	Felt by few.	II
Ladonia	(1)	Felt by few.	II
Hunt County			
Caddo Mills	(1)	One shock; felt by few.	II
Campbell	C. T. Belew	One tremor; windows rattled and house jarred. 5%	II
Commerce	(1)	One shock; felt by few.	II
Floyd	(1)	Felt by few.	II
Greenville	Mrs. Money	One shock; felt by few.	II
Wolfe City	(1)	Felt by few.	II
Lamar County			
Arthur City	(1)	Rumbling noise. 90%	V
Biardstown	W. M. Gunn	One tremor; slight vibration continuing 10 to 15 seconds.	III
Blossom	(1)	Felt by about 50% of the people.	IV
Brookstown	O. A. Sheide	One tremor. 50%	IV
Caviness	Edgar Little	Two distinct shakes; after shake had to use house jack to level house so that doors would shut. 90%	V
Chicota	(1)	Persons frightened from houses. 90% or more.	V
High	(1)	Felt by many; dishes rattled; water in pan moved.	III
Howland	(1)	Felt by few.	II or III
Paris	Joe Daniels	Two shocks followed by telephone calls to newspapers; hotel guests disturbed. 50% more or less.	IV
Post Oak	(1)	One shock.	IV
Powderly	(1)	Noise like rumbling thunder long way off; dishes rattled; earth jarred and quivered. 90%	V
Razor	A. K. Haynes	One tremor. 50%	IV
Roxton	(1)	Felt by few.	II or III
Sumner	J. S. Moody	Like a hard dash of wind; everything shook.	IV
Trout Switch	(1)	Two shocks; shook windows; persons frightened. 90% or more.	V

Locality	By whom reported	Comments and approximate percentage of people of community who felt the shock	Intensity rating
		Red River County	
Annona	M. M. Pittman	One tremor. 25%	III
Bagwell	(1)	Feeble shock. Less than 1%	II
Bogota	J. K. Ford	Sudden cracking of house followed by similar sound about 30 seconds later.	III
Clarksville	(1)	Mild. Less than 1%.	II
Detroit	(1)	Felt by several; dishes rattled.	III
Dimple	(1)	Felt by few.	II
Johntown	Mrs. Wilson	One tremor. 20%	III
Kanawha	J. M. Robinson	One tremor. 75%	IV
Manchester	(1)	Felt by several.	II or III
Woodland	Maggie V. Phillips	Sound like blasting. 50%	IV
		OKLAHOMA	
		Choctaw County	
Boswell	Hugh Hale	Mild. Less than 1%	II
Forney	U.S. Coast & Geodetic Survey	Rocking motion; felt by several.	III
Fort Towson	(1)	Mild.	II or III
Goodland	U.S. Coast & Geodetic Survey	Gradual swaying motion; trees and buildings swayed; felt by and alarmed a great many.	IV
Grant	U.S. Coast & Geodetic Survey	Two tremors; rapid swaying motion; trees and buildings swayed slightly; dishes moved on table; felt by nearly everyone; few alarmed.	IV
Hugo	U.S. Coast & Geodetic Survey	Two shocks; some people left the house.	IV
Sawyer	U.S. Coast & Geodetic Survey	General shake for about 10 seconds accompanied by light roaring sounds; felt by several.	IV
Soper	U.S. Coast & Geodetic Survey	Two shocks lasting 5 and 3 seconds respectively; abrupt rocking motion; hanging objects swung; felt by several; none alarmed.	II or III
Swink	L. H. Chesshic	One tremor; rocking to and fro. 5%	II
Virgil	Earl Potts	Two tremors; house shook. 50%	IV

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[1] Obtained by the writer by interviews with one or more persons of the community.

Careful inquiry indicates that the tremor was felt over an area which is greatly elongated in a northeast-southwest direction and is much more limited in the opposite direction, northwest-southeast. Thus over a narrow belt the tremor was perceptible from Nevada in southeastern Hunt County, Texas, to Spencerville in Choctaw County, Oklahoma, a distance in a northeast-southwest direction of about 100 miles. The width of the belt in a northwest-southeast direction, on the other hand, at no place exceeded 50 miles. The maximum width of the belt was attained in Oklahoma and as far south as Paris, Texas. South of Paris the belt across which the jar was perceptible to persons was no more than about 20 miles wide in northwest-southeast direction.

The rating of intensity V of the Rossi-Forel scale for the small area adjacent to Red River (fig. 33) is based upon the writer's inquiries at three localities on the railroad—Powderly, Trout Switch, and Arthur City—and at Chicota, and on the report made of the tremor at Caviness by Mr. Edgar Little. The rating of intensity IV in Oklahoma and Texas is based on personal inquiries, data obtained by the United States Coast and Geodetic Survey, and upon reports by circulars chiefly from postmasters. Localities having intensity rating III and II are very irregularly distributed. Thus Bogata and Johntown with intensity rating III are entirely surrounded by localities affording only negative reports. Annona, likewise, appears to have received a stronger shock than did some localities west of it and hence nearer the assumed epicenter of the earthquake.

It is well known that buildings standing on alluvial or otherwise incoherent material are more distinctly jarred by an earthquake tremor than are those built on solid rock. The alluvial valley of Red River may, therefore, in part at least, account for the widening of the belt in that region. It is true also that the surface formations in this region north of Paris, other than the river alluvium, contain more sand and less solid material than do the formations south of Paris. These conditions, however, are not sufficient to account for the extreme elongation northeast-southwest of the area in which the earthquake was felt by persons. On the contrary, it is believed that the elongation of the area in which the tremor was perceptible indicates that the earthquake did not have a single focal point but that there was slippage along a northeast-southwest trending fault.

It seems probable that the slippage was more pronounced near Red River, as shown by the stronger shock in that region. In locating an assumed faulting along which slippage occurred, it becomes necessary to postulate either two or more faults, and hence two or more earthquake centers, or one very long curved fault. Under the hypothesis of two or more faults, one fault may be assumed to have occurred near Arthur City on Red River and a much longer fault with small displacement extending from near Paris to beyond Greenville. One might even postulate accompanying minor "jars" or slips or slight movement of fault block near Johntown and near Annona. The tremor was felt in a belt approximately 20 miles in width for about 65 miles southwest from Paris. This elongation of the area southwestward seemingly can be explained only by assuming a very slight movement on a northeast-southwest trending fault line through this area. The assumption of two or more faults in some respects is simpler than to assume one very long curved line of faulting particularly as the Balcones zone contains many *en échelon* faults. The fact that two shocks were felt, the first being stronger, lends itself to this interpretation. The two shocks, however, do not require such interpretation and may be otherwise accounted for.

The Texas-Oklahoma region in which this earthquake was felt is one in which extensive faulting has occurred throughout geologic time. On the sketch map, Figure 33, some of the known faults of the region are indicated. Of these faults, two in Oklahoma, the Octavia and Buktukola fault lines, both of the Ouachita system of faults, are known to be of ancient origin, faulting along these lines having taken place in late Paleozoic time. Similar faulting is believed to have extended southwestward into Texas but is there covered and concealed by later deposits. The faults seen in Texas in this area, represented on the map, are of much later date. They are mostly of the Balcones and Mexia fault systems which are Cenozoic in age, some part of the faulting being possibly within Recent time.[2]

The faulting which must be postulated to account for the earthquake of April 11 does not coincide in all respects with either the Ouachita or Mexia fault zones. It does, however, lie almost if not exactly in the trend of the Balcones zone of faulting which is well

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[2] For description of a slight earthquake which occurred at Mexia in this zone on April 9, 1932, see Univ. Texas Bull. 3201, pp 105-112, 1932.

developed in central Texas. Many years ago R. T. Hill[3] postulated the extension of the Balcones zone to cross Red River at Arthurs Bluff near the railroad crossing north of Paris where small faulting was observed by him and where this earthquake was the most severe. The earthquake of April 11, 1934, may have been due to slight revival of faulting along the fault line observed by Hill at Arthurs Bluff.

In addition to the faults shown on this map there are numerous sandstone dikes, some of which in Collin and Rockwall counties are indicated on the map. These dikes are believed to represent fissures caused probably by earthquakes, such fissures having later been filled with sand.[4] These dikes probably lie in the Mt. Calm subzone of the Balcones system, and the line of slippage of this earthquake represents possibly an extension of this sub-zone.

The occurrence of this small earthquake serves as a reminder that reasonable care should be used both as to foundation and construction of buildings in Texas. The Balcones zone of faulting, in which this earthquake occurred, extends through Texas for about 500 miles and within this zone are built some of the large cities of the State including Dallas, Austin, San Antonio, Waco, and many smaller towns. The principal lesson to be learned from this earthquake is that this zone is not entirely quiescent and that other earthquakes may occur subsequently in this region.

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[3] Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Surv., 21st Ann. Rept., pt. 7, p. 383, 1901.

[4] Stephenson, L. W., On the origin of the "rock wall" at Rockwall, Texas: Jour. Wash. Acad. Sci., vol. 17, no. 1, pp. 1–5, 1927.

Patton, L. T., The sandstone dikes around Rockwall, Texas: Holland's Magazine, Dallas, Texas, vol. 44, no. 6, p. 5 plus, 1925.

Paige, Sidney, The "rock wall" of Rockwall, Texas: Science, new ser., vol. 30, pp. 690–691, 1909.

Kelsey, Martin, and Denton, Harold, Sandstone dikes near Rockwall. Texas: Univ. Texas Bull. 3201, pp. 139–148, 1932.

A NEW FORMATION IN THE CLAIBORNE GROUP

H. B. STENZEL

The stratigraphic sequence of the formations in the Claiborne group in east Texas has been well established in recent years and published by Renick, Ellisor, Wendlandt and Knebel, and Plummer.[1] The formations defined by these authors are:

Yegua (≧ Cockfield)
Crockett (= Lufkin Renick 1928)
Sparta (= Nacogdoches Renick 1928)
Weches (= San Augustine Renick 1928)
Queen City
Reklaw (= Cane River Renick 1928)
Carrizo

These formations have generally been accepted and their outcrops have been mapped over large areas.

Although there is general agreement as to the nature of the formations, there is as yet very little agreement as to the exact location of the boundaries between some of the formations. A well known example of the disagreement is the boundary between the Crockett and the overlying Yegua. That boundary has been placed at different levels and, in consequence, the discrepancies of mapping the two formations amount to as much as 5 miles in places. No doubt there exists an urgent need of revision of questionable formation boundaries. It is the purpose of this paper to elucidate the conditions at the Sparta-Crockett boundary in a very small area.

The problem of the boundary can be settled best by investigating the beds in detail at good exposures. Good exposures of the Sparta-Crockett contact are found in Burleson County at the classical

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[1] Renick, B. C., Recently discovered salt domes in east Texas: Bull. Amer. Assoc. Petr. Geol., vol. 12, pp. 527–547, 1928.

Ellisor, Alva Christine, Correlation of the Claiborne of east Texas with the Claiborne of Louisiana: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 1335–1346, 1929.

Wendlandt, E. A., and Knebel, G. M., Lower Claiborne of east Texas, with special reference to Mount Sylvan dome and salt movements: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 1347–1375, 1929.

Renick, B. C., and Stenzel, H. B., The stratigraphy and paleontology of the lower Claiborne along the Brazos River. Texas: Univ. Texas Bull. 3101, pp. 73–108, 1931.

Plummer, F. B., Cenozoic systems in Texas, *in* The Geology of Texas, Vol. I, Stratigraphy: Univ. Texas Bull. 3232, pp. 519–818, 1932 [1933].

locality of Stone City[2] (also known in the older literature as Moseley's Ferry or San Antonio Ferry) on the right bank of Brazos River. This locality was first visited by Ferdinand Roemer in 1847.[3] Penrose, William Kennedy, G. D. Harris, A. Deussen,[4] and others have collected fossils there and given descriptions of the outcrop. At low stages of the river it is possible to study more than 80 feet of beds in a continuous section exposed along extensive bluffs fringing the river in an east-west direction. Due to the dip of the strata, which is here rather large for the Coastal Plain country, the oldest beds outcrop at the west end of the exposure above the two bridges. The combined section of the bluffs is:[5]

	Thickness *Feet*
(ae) Shale; dove-gray when fresh, light yellow when weathered, laminated, calcareous, with few fossils	15.8
(ad) Glauconite; green. commonly red-brown and weathered, massive, marly, fossiliferous, with occasional limonite concretions	4.2
(ac) Limestone; red-brown, massive, nodular, more or less continuous, limonitic, impure, hard, forming a projecting bench	0.3

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[2] Description of the location: On right or south bank of Brazos River, at the bridges of State Highway 21 (Caldwell-Bryan road) and Houston & Texas Central (Southern Pacific) Railroad, 11.3 miles west of Bryan, Brazos County. as measured by speedometer along Highway 21; in east corner of B. A Porter Survey, Burleson County. Best available topographic map: Brazos River (Sheet 1), State Reclamation Department, advance sheet.

Good exposures are also found along Rocky Branch (or Dead Creek) about one-half mile west

[3] Roemer, Ferdinand, A sketch of the geology of Texas: Amer. Jour. Sci., ser. 2, vol. 2 p. 358, 1846

———, ———, Contributions to the geology of Texas: Amer Jour Sci., ser. 2, vol. 6 p. 21, 1848

——— ———, Texas . . . xiv, 464 pp., map, Bonn, Adolph Marcus, 1849.

[4] Penrose, R. A. F, Jr, A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Surv., 1st Ann. Rept., p 27, 1890.

Kennedy, William, Report on Grimes Brazos, and Robertson counties. Texas Geol Surv., 4th Ann. Rept., p 52 1893.

———, ———, The Eocene Tertiary of Texas east of the Brazos River: Acad. Nat. Sci. Philadelphia. Proc. 1895. pp. 89–160. 1896.

Harris, G D., New and otherwise interesting Tertiary Mollusca from Texas: Acad. Nat. Sci. Philadelphia. Proc. 1895, pp. 45–88, 1896.

Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Surv., Water-Supply Paper 335, pp. 58–59, Pl. IV, 1914.

Harris, G. D., Pelecypoda of the St. Maurice and Claiborne stages: Bull. Amer. Pal., no. 31 (vol. 6, pp. 1–268), 1919.

Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Surv., Prof. Paper 126, pp. 69–70, 1924.

[5] Lines between beds in the section indicate sharp boundaries without transition.

		Thickness *Feet*
(ab)	Glauconite; green, commonly red-brown and weathered, massive, marly, fossiliferous, weathering into concentric limonite concretions at the top; oyster bed at the base	3.7
(aa)	Conglomerate, composed chiefly of glauconitic limestone pebbles	0.2
	disconformity	
(x)	Moseley limestone; red-brown, thick bedded, glauconitic and limonitic, fossiliferous, impure, hard, forming the most prominent bench of the cliff	2.0
(w)	Glauconite; green or red-brown, weathered, massive, marly, fossiliferous, soft, forming a recess beneath the limestone	1.2
(v)	Shale with silt; chocolate-brown, laminated, lignitic, nonfossiliferous, with some lentils of finely bedded silt about 4 inches thick; there are also some fine-grained marcasite concretions and a 1-inch seam of crowded fossils	4.0
(u)	Glauconite; dark green, massive, marly, fossiliferous, resistant, forming a slight bench in the slope	1.6
(t)	Shale; greenish-brown, laminated, nonfossiliferous, soft	1.8
(s)	Main glauconite; green, massive to poorly bedded, marly, fossiliferous, resistant, forming a vertical face in the bluff, contains layers of rolled fossils, especially at the top. Large, hard, red-brown, irregular, ferruginous, calcareous concretions are found loosely spaced in the middle and crowded near the top, forming a continuous layer. In the basal part there are many slabs of the underlying shale or a 9-inch lentil of yellow, cross-bedded, fine sand	5.1
(r)	Shale; chocolate-brown to greenish-black, laminated, unctuous, with occasional fossiliferous layers	4.6
(q)	Silt; yellow to gray, somewhat glauconitic, lenticular-bedded	0.4
(p)	Glauconite; coarse grained, crowded with fossils, contains a few pebbles of dense, argillaceous, fossiliferous limestone	0.3
(o)	Shale and silt; same as top of (m)	0.8
(n)	Row of concretions; brown, flat, silty, calcareous, up to 9 by 2 inches in size, and silt lentils with silty, fine-grained marcasite concretions	- - -
(m)	Shale with silt; dark brown to black when wet, light purplish-brown when dry, laminated, lignitic, with light coffee-brown, thin (up to 2 inches), lignitic, shaly silt layers	10.0

		Thickness *Feet*
(l)	Interbedded silt and shale; silt is sulphurous yellow on weathered surface, light coffee-brown to light gray on fresh break, finely bedded, cross-bedded to lenticular-bedded, soft, marcasitic; some layers are up to 1 foot thick, average is 4 inches; shale is dark grayish-brown on weathered surface, dark chocolate-brown to black on fresh breaks, laminated, nonfossiliferous	6.2
(k)	Seam of friable fossils	0.1
(j)	Shale; same as (h)	0.8
(i)	Row of cannon ball concretions; light yellowish gray on surface, light greenish gray on fresh breaks, dense, sandy, calcareous, large (up to 2 by 1 feet), round, with fossils and many shrinkage cracks in the interior; the outside has fine, closely spaced joints of N.32° E. strike; where the concretions reach the bed of the river they are more nearly coalescing	-----
(h)	Shale; dark greenish gray to dark grayish brown, fine-bedded to laminated, lignitic, with gray, irregular, very thin partings; contains thin-shelled fossils in gray, round, small (1 to 2-inch diameter), calcareous concretions and two seams of fossils at about 4.3 feet from the top; at 3.8 feet from the top a 4-inch thick, light gray, finely bedded silt bed with marcasite concretions	8.7
(g)	Row of concretions; green, large (up to 1 by 0.8 feet), calcareous, fossiliferous, widely separated	-----
(f)	Shale; dark brownish green, laminated, containing some fossil layers, grading into bed (h)	5.4
(e)	Flat concretions; light gray-brown, nodular to pancake-like, extensive, often coalescing, dense, calcareous, sparsely glauconitic, fossiliferous, hard, forming a small bench	0.3
(d)	Glauconite; dark greenish black when fresh, yellowish brown in weathered places, poorly bedded, marly, richly fossiliferous, indurated, forming small bench	0.3
(c)	Glauconitic clay; dark greenish black to brown, massive to poorly bedded, richly fossiliferous, in places marly and light greenish gray when fresh, light brownish gray when weathered	1.5
(b)	Concretions; gray on outside, on fresh break light gray, rounded, often coalescing, dense, slightly clayey, nonfossiliferous, large, hard, forming a nearly continuous bench	0.5
(a)	Sand; dark gray-green when wet, dark gray when dry, loose, massive, coarse, nonfossiliferous, with glauconitic (?)	

	Thickness *Feet*
grains, contains greenish-brown when wet, gray-brown when dry, wavy, lignitic shale partings of one-eighth to one-fourth inch thickness; bottom not exposed	2.0

To understand the significance of this section it is advisable to compare it with a typical section of the Crockett formation such as is exposed nearby on the banks of Little Brazos River[6] in Brazos County. The combined section along Little Brazos River is:

		Thickness *Feet*
(o)	Shale; dove-gray, laminated, calcareous, poor in fossils, soft; total thickness unknown, covered by alluvium	5.4
(n)	Shale; brownish and limonite-stained, thin-bedded, limonitic, indurated	0.4
(m)	Shale; dark gray, laminated, calcareous, poor in fossils, soft	4.0
(l)	Shale; grayish brown, thin-bedded, calcareous, indurated, forming a slight bench	0.4
(k)	Shale; greenish gray, laminated, glauconitic, calcareous, fossiliferous, soft	2.4
(j)	Shale; gray to brown, medium- to thin-bedded, limonitic, calcareous, poor in fossils, indurated	0.8
(i)	Shale; dove-gray, laminated, calcareous, glauconitic, soft, containing many fossils in occasional thin layers; containing black, spherical concretions with numerous cracks in their centers. Some concretions contain fossil crabs	4.8
(h)	Row of concretions; reddish brown on outside, bluish on fresh break, ellipsoidal, dense, glauconitic, calcareous, fossiliferous, hard	----
(g)	Shale; brown, laminated, nonfossiliferous	1.3
(f)	Glauconite; intensely green, sugar-grained, calcareous, friable; in places this bed is hard, cemented by lime, and cut by numerous calcite veins	1.0
(e)	Marl and shale; dark brown to green, finely bedded; glauconitic, fossiliferous marl grading upward into dark brown, laminated, sparsely fossiliferous shale	3.3

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[6] Description of the location: On banks and in bed of Little Brazos River, from bridge of State Highway 21 upstream for about 0.3 mile, 9.43 miles west of courthouse in Bryan as measured by speedometer, in eastern part of W. Mathis Survey, Brazos County. Best available topographic map: Brazos River (Sheet 1), State Reclamation Department, advance sheet.

Compare also Kennedy, William, Report on Grimes, Brazos, and Robertson counties: Texas Geol. Surv., 4th Ann Rept., p 52, 1893; and The Eocene Tertiary of Texas east of the Brazos River: Acad. Nat Sci Philadelphia, Proc. 1895, pp. 89–160, 1896.

	Thickness *Feet*
(d) Limestone; discontinuous, irregularly bedded, greenish gray, concretionary, hard; with cone-in-cone structures at the bottom	1.2
(c) Marl; greenish gray, glauconitic, fossiliferous, soft	2.0
(b) Little Brazos limestone; red to brown, nodular, limonitic, glauconitic, hard; in places it lenses out and appears at a slightly different level; thickness is irregular	0.6
(a) Glauconite; greenish black, poorly bedded, marly, fossiliferous; total thickness not exposed	2.0

The Little Brazos section is entirely marine and predominantly shaly to marly. The beds contain much lime and glauconite but no lignitic matter except possibly bed (e) and there are many gradual transitions from one bed to the next one. On the other hand, the Stone City section is predominantly nonmarine and shaly to sandy. The majority of the beds contain much lignitic matter and there are many abrupt changes from one bed to the other. The difference in the character of the two sections is the more striking as the two sections are stratigraphically almost continuous, that is, the Little Brazos section starts only about 5 to 10 feet stratigraphically above where the Stone City section leaves off, as has been determined on upland outcrops, that contain the Moseley and Little Brazos limestones.

In the Stone City section geologists have recognized the Crockett formation in the upper, marine, glauconitic, marly, fossiliferous beds and the Sparta formation in the lower, nonmarine, lignitic, sandy to shaly, nonfossiliferous beds. Bed (1), for instance, has quite typical Sparta lithology. The two facies, namely the marine and the nonmarine, alternate or interfinger with varying thickness. If one descends in the section the interfingering marine beds become rarer and also thinner, and the nonmarine beds become more common and thicker and change from shale to sand.

The Sparta-Crockett boundary may be drawn at any one of the three possible places in this section of interfingering beds, as follows:

(1) Sparta-Crockett boundary at the base of the lowest marine bed. This has the advantage of placing all fossiliferous, marine beds in the Crockett but the disadvantage of placing a very much larger amount of beds with Sparta lithology in the Crockett. This boundary is also not very reliable in mapping because horizontally

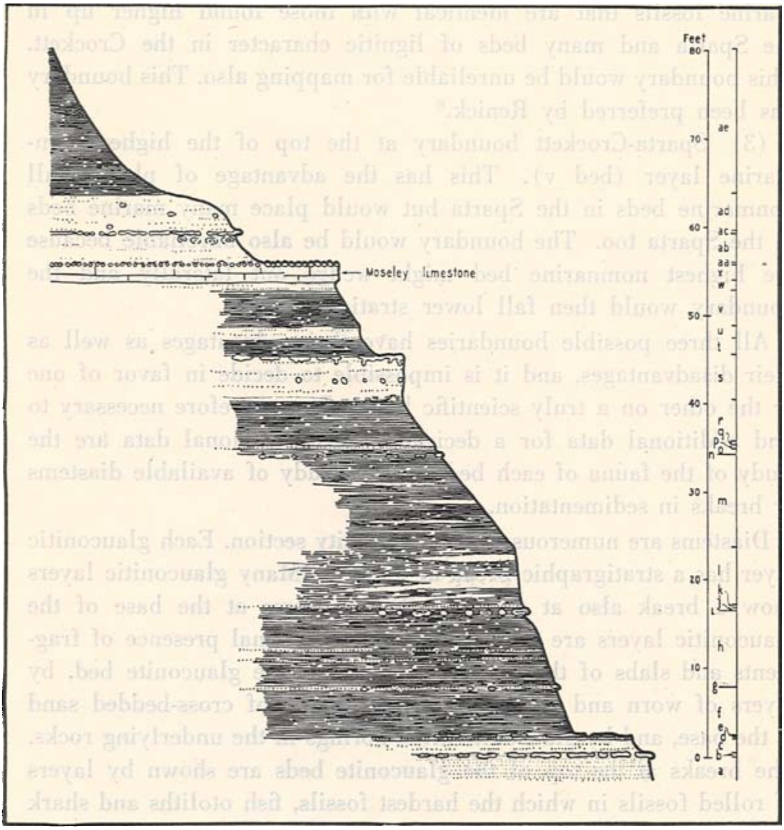

Fig. 34. Section of Stone City and Crockett formations on Brazos River at Stone City, Burleson County, Texas. Sand is represented by very fine dots, glauconite by heavy dots.

the lowest bed will lens out and be replaced by other lenses at higher or lower levels. These lower marine beds are well known for their lenticular character. This boundary has been preferred by F. B. Plummer.[7]

(2) Sparta-Crockett boundary in the middle of the sequence, perhaps at the top of bed (l). This has the advantage of placing the more sandy beds in the Sparta and the more shaly beds in the Crockett. But it has the disadvantages of placing many beds with

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[7] Plummer, F. B., Cenozoic systems in Texas, *in* The Geology of Texas, Vol. I, Stratigraphy: Univ. Texas Bull. 3232, p. 653, and footnote, p. 658, 1932 [1933].

marine fossils that are identical with those found higher up in the Sparta and many beds of lignitic character in the Crockett. This boundary would be unreliable for mapping also. This boundary has been preferred by Renick.[8]

(3) Sparta-Crockett boundary at the top of the highest nonmarine layer (bed v). This has the advantage of placing all nonmarine beds in the Sparta but would place many marine beds in the Sparta too. The boundary would be also unreliable because the highest nonmarine bed might wedge out laterally and the boundary would then fall lower stratigraphically.

All three possible boundaries have their advantages as well as their disadvantages, and it is impossible to decide in favor of one or the other on a truly scientific basis. It is therefore necessary to find additional data for a decision. Such additional data are the study of the fauna of each bed and the study of available diastems or breaks in sedimentation.

Diastems are numerous in the Stone City section. Each glauconitic layer has a stratigraphic break at its base. Many glauconitic layers show a break also at the top. The diastems at the base of the glauconitic layers are indicated by the occasional presence of fragments and slabs of the underlying shale in the glauconite bed, by layers of worn and rolled fossils, by lentils of cross-bedded sand at the base, and by glauconite-filled borings in the underlying rocks. The breaks at the top of the glauconite beds are shown by layers of rolled fossils in which the hardest fossils, fish otoliths and shark teeth, are more abundant. Naturally, the thickest glauconite bed (bed s) shows these features more plainly and the diastems at its base and top are probably of a little greater size than those of the other beds. This bed has an almost continuous shale-slab conglomerate at its base. However, it would be impossible to favor any one of these breaks as the Sparta-Crockett contact. These diastems are merely the signs of the oscillating seashore of that time. Each marine layer represents a transgression and regression of the sea. The waters in which the glauconitic layers were deposited were normal marine waters as is attested by the presence of corals and the absence or extreme rarity of typical brackish water forms. However, all the diastems are outclassed in importance by a recently

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[8] Renick, B. C., and Stenzel, H. B., The stratigraphy and paleontology of the lower Claiborne along the Brazos River, Texas: Univ. Texas Bull. 3101. p. 88, fig. 11, 1931.

discovered conglomerate. This conglomerate (bed aa) lies on top of the Moseley limestone (bed x). Its position alone is unusual for it lies not between a marine and a nonmarine bed but between two different marine beds. The pebbles of the conglomerate are well rounded; many of them are spherical. Their diameter is about 5 cm. on the average. Most of them consist of a hard, glauconitic, richly fossiliferous limestone that weathers dark brown to black at the outside. This limestone is very similar to, although not identical with, the underlying Moseley limestone. Much rarer are pebbles of a bluish-gray to green, dense limestone. This latter limestone is not present in the immediate underlying section and must be derived either from a layer unknown to the writer, from a layer that was removed through the making of the conglomerate, or from a layer outcropping much farther inland. Pebbles of this limestone show holes made by boring mollusks. The pebbles of the conglomerate are in places overgrown by corals or bryozoa. The

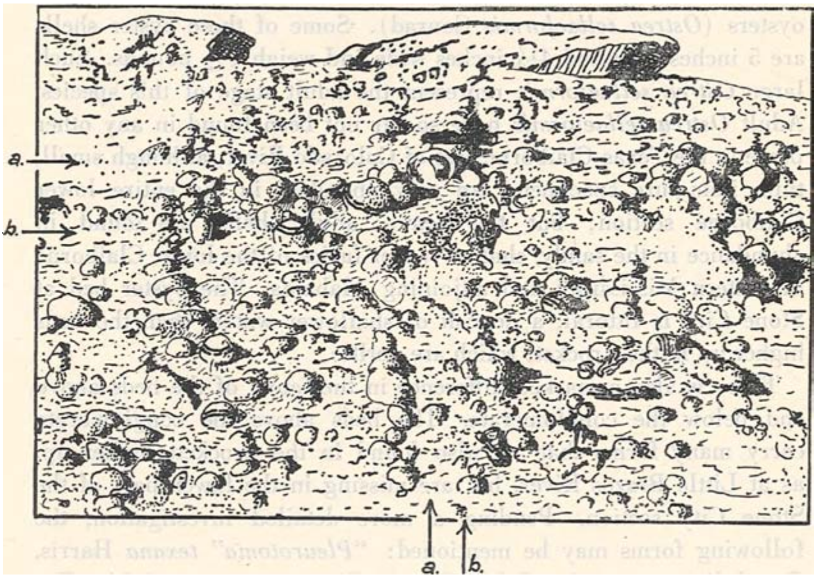

Fig. 35. The basal conglomerate of the Crockett marl at Stone City (bed aa of section) resting on the Moseley limestone ledge; seen obliquely from above and drawn from a photograph. At intersection of arrows (a) a pebble of the dense, bluish-gray limestone; at intersection of arrows (b) a large compound coral. Heavy black line above intersection of arrows (a) is 5 inches long.

bedding within the more common type of limestone pebbles is very distinct, stops at the surface of each pebble, and stands at any angle to the whole bed as should be the case in a conglomerate. These facts preclude an explanation of the pebbles as concretionary structures. The conglomerate is marine and transgressional.

Conglomerates are exceedingly rare in the entire Eocene section of the Coastal Plain. Another notable example is the conglomerate at the base of the Jackson group at Montgomery, Grant Parish, Louisiana. The conglomerate at Montgomery marks the unconformity between the underlying Yegua (or Cockfield) and the overlying Jackson. Such conglomerates must represent either important stratigraphic breaks or effects of local uplifts. There are no signs of an uplift of pre-Crockett age in the Brazos region. The conglomerate at Stone City represents, therefore, a major boundary, the base of the Crockett formation.

This conclusion is substantiated by the evidence of the fossils. Immediately above the conglomerate there are many large heavy oysters (*Ostrea sellaeformis* Conrad). Some of these oyster shells are 5 inches long and 4¼ inches wide and weigh 1½ pounds. Such large *Ostrea sellaeformis* represent the adult stage of this species. Adult *Ostrea sellaeformis* have so far not been found in any other place in the Texas Claiborne east of Colorado River, although small, thin, immature specimens are very abundant in the entire lower Claiborne section; but the heavy, adult shells are found in abundance in the sandy, shallow water facies of the lower Claiborne in eastern Mississippi and adjoining Alabama. The oyster bed at Stone City is littoral, a deposit of shallower waters than the beds higher up in the Crockett which are neritic.

There is also a marked difference in the fauna of the beds above and below the conglomerate. The beds above the conglomerate carry many forms that are also found in the Crockett higher up, as at Little Brazos River, but are missing in the lower part of the Stone City section. Pending a more detailed investigation, the following forms may be mentioned: *"Pleurotoma" texana* Harris, *Pseudoliva perspectiva* Gabb, *Crassatellites antestriatus* Gabb. The beds below the conglomerate have also their characteristic species: *Aturia (Brazaturia) brazoensis* Stenzel, *Pseudoliva carinata* Gabb, *Pseudoliva clausa* Harris MS., *Buccitriton texanum* Gabb form 1, *Anomia ephippoides* Gabb, *Corbula texana* Gabb, and abundant

Conus sauridens Conrad. The whole faunal assemblage in the two series is, of course, very similar as many species continue throughout the entire section. But the differences are marked so that it is easy to distinguish the two faunas. Both faunas are now under investigation.

The problem of the position of the lower partly marine beds of the Stone City section arises if the Crockett formation is restricted to the beds above the Moseley limestone. The break represented by the conglomerate and the fauna of the beds sets them off from the restricted Crockett, and it is necessary either to place them in the Sparta formation or to elevate them to formational rank. It would cause much confusion to include these beds in the Sparta because the Sparta is well established as a sandy, lignitic, nonmarine formation. Therefore, the writer proposes formally the name "Stone City beds" for the beds of the Stone City section that lie below the conglomerate to include the lowest glauconitic, fossiliferous bed, be the latter exposed at that place or even lower in the section. The stratigraphic section in the Brazos Valley would therefore be:

	Thickness *Feet*
Crockett marls	100
——disconformity——	
Stone City beds	85±
——transition by interfingering——	
Sparta sand	300–350

The Eaton lentil of Renick[9] falls in the Stone City beds and is only one of the many lentils of marine strata in the Stone City beds but a very prominent and well defined one.

This investigation was restricted so far merely to the two excellent outcrops in the Brazos Valley. Is it possible to distinguish these features on the uplands outside of good outcrops? State Highway 6 (Bryan-Hearne road) traverses the upland across the strike of the lower Claiborne beds. Along this highway the characteristics of the weathered formations may be studied conveniently. The following is a road log along this highway going northward:

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[9] Renick, B. C., and Stenzel, H. B., *op. cit.*, p. 78, fig. 10, pp. 90–91.

	Miles
Top of scarp of lower Yegua, outcrop in road cut, oak woods of Yegua belt disappear, mesquites of Crockett belt appear	0.0
Side road at bottom of scarp	0.33
Red-brown soil of upper Crockett	0.33–0.42
Black waxy soil and greenish subsoil of typical Crockett begins, extends to 2.07	0.42
Elm Creek bridge; dip slope of lower Crockett begins here	0.67
Brazos-Robertson county line, end of concrete pavement	0.92
Benchley filling station; prairie and fields	1.17
Top of scarp of basal Crockett beds; end of black waxy soil of prairies; end of dip slope of lower Crockett	2.07
Yellow limestone in road cut, probably Moseley limestone; Stone City beds start here. Soil and subsoil colors change gradually from yellow to orange and red. oak woods predominate, steep descent	2.14
Yellow sandstone ledges with ripple marks in road cut	2.20
Orange-red soil colors fade gradually	2.52
Road cut in Sparta sand	2.60–2.67
Underpass of H. & T. C. Railroad	2.70

The Crockett as now restricted is covered by chiefly black, waxy soils and greenish-brown subsoil forming large prairies that are under intensive cultivation; mesquite is characteristic in places. Much of this black land lies on the dip slope of the cuesta that is supported by the Moseley and Little Brazos limestones. At the front slope of this cuesta is the outcrop of the Stone City beds covered with yellow and red-orange subsoils and usually covered with dense woods; northward it grades into the rolling sand hill region of the Sparta, that has less dense woods and some fields under cultivation.

This short examination of the upland region is sufficient to show that the Stone City beds can be mapped as a separate unit because of characteristic topography, soils, and vegetation. How far the Stone City beds can be traced laterally only detailed mapping can show. At present these beds have been traced eastward through Burleson, Brazos, and Leon counties to Trinity River. In addition some well known fossil localities carry the typical Stone City fauna as, for instance, the bluff on the Texas side of Sabine River, 2 miles by river above Columbus in Sabine County (locality 23 of A. C. Veatch;[10] collected by C. L. Baker, Rio Bravo Collection No. 310), and the locality 0.4 mile south of Pleasanton courthouse, on the road to Christine, Atascosa County. It is possible that the separation of the Stone City beds from the Crockett beds will necessitate considerable revision of mapped boundaries in the southwestern Coastal Plain of Texas.

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[10] Veatch, A. C., The geography and geology of the Sabine River: Louisiana State Experiment Station, Geology and Agriculture of Louisiana, pt. 6, pp. 101-148, maps, 1902.

Dumble, E. T., The geology of east Texas: Univ. Texas Bull. 1869, pp. 71-72, 1918.

MICROSCOPICAL EVIDENCE OF THE NAVARRO-TAYLOR CONTACT IN SUBSURFACE SECTIONS IN CENTRAL TEXAS

HELEN JEANNE PLUMMER*

The outcrops of lower Navarro and upper Taylor in central Texas offer excellent opportunity to study their rich faunal assemblages. Many Upper Cretaceous species are common to both formations, but numerous species in each fauna are restricted, and some are sufficiently common and widespread to be of value as formational markers in mapping the contact of these formations on the surface. Since subsurface formational contacts must be harmonious with accepted surface contacts, the study of this problem began with a careful examination of as much outcrop material as could be found. Unfortunately no single outcrop has offered the actual contact of the Navarro and Taylor formations. The numerous exposures in the vicinity of Kimbro, eastern Travis County, present perhaps the best opportunity to observe the faunal distinctions between uppermost Taylor and lowermost Navarro. The high banks along Cottonwood Creek just west of the town of Kimbro and the area to the northwest carry the distinctive Taylor microfauna. A steep gully crossing the Kimbro-Austin highway 0.2 of a mile south of Kimbro school exposes typical Navarro clays, and along the strike of the formational contact basal Navarro is exposed one and one-half miles southwest of Kimbro in a shallow road ditch about 0.2 of a mile west of Cottonwood Creek on the Kimbro-Austin highway. The faunal differences that have proved reliable in differentiating the two formations on the surface have been carefully compared with the faunal changes in subsurface sections in Lee, Caldwell, and Bastrop counties,[1] and several sets of well samples from other parts of the state have also been available. All the subsurface sections critically examined have encountered these formations at moderate depths, and it is therefore possible that the criteria recognized as salient in designating the contact at

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[1] The author is indebted to Mr. Kenneth Blackmar of McNeill Petroleum Company for permission to publish the graphic sections of their wells.

no great distance from the outcrop must be somewhat modified where this horizon lies much deeper.

In lists of Navarro and Taylor Forminifera published[2] recently, asterisks designate several species as diagnostic. These lists were compiled from considerable outcrop material from all parts of the state, and since the study of the Navarro-Taylor contact was at that time under way and ranges of many species were in doubt, asterisks were rather conservatively employed. Ranges of the rarer species are still questionable, but more complete lists of the common restricted species have now been compiled.

Diagnostic Navarro Foraminifera in outcrops

Gaudryina navarroana Cushman
Gaudryinella pseudoserrata Cushman
Clavulina insignis Plummer
Dorothia bulletta (Carsey)
Trochammina gyroides Cushman and Waters
Astacolus dissonus Plummer
Vaginulina simondsi Carsey
Vaginulina webbervillensis Carsey
Flabellina reticulata Reuss
Frondicularia clarki Bagg
Pseudopolymorphina cuyleri Plummer
Guembelitria cretacea Cushman
Loxostomum plaitum (Carsey)
Bulimina obtusa d'Orbigny
Siphogenerinoides plummeri (Cushman)
Pulvinulinella ripleyensis Sandidge
Discorbis correctus Carsey
Anomalina pseudopapilosa Carsey

Diagnostic Taylor Foraminifera[3] not present in overlying formations

Lituola taylorensis Cushman and Waters
Flabellammina compressa (Beissel)
Frankeina taylorensis Cushman and Waters
Textularia ripleyensis W. Berry
Gaudryina carinata Franke
Gaudryina chapmani Franke
Gaudryina filiformis Berthelin
Marssonella oxycona (Reuss)
Clavulina amorpha Cushman
Clavulina trilatera Cushman
Heterostomella foveolata (Marsson)
Eggerella trochoides (Reuss)
Dorothia bulletta Carsey. var.
Robulus pondi Cushman
Astacolus taylorensis Plummer
Vaginulina regina Plummer
Vaginulina strigillata (Reuss)
Dentalina alternata (Jones)
Flabellina projecta (Carsey)
Kyphopyxa christneri (Carsey)
Frondicularia microdiscus Reuss
Eouvigerina americana Cushman
Eouvigerina gracilis Cushman
Pseudouvigerina plummerae Cushman
Buliminella carseyae Plummer
Bolivina clavata Cushman
Bolivina gemma Cushman
Bolivina incrassata Reuss
Bolivinoides decorata (Jones)
Gyroidina micheliniana (d'Orbigny)
Cibicides excolata (Cushman)
Cibicides nelsoni (W. Berry)
Anomalina henbesti Plummer, sp. nov.
Anomalina taylorensis Carsey

After penetrating the Midway group of strata (Wills Point and Kincaid formations) and an uppermost Navarro zone characterized mainly by *Robulus navarroensis* (Plummer), *Anomalina*

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[2] Adkins. W S., The Mesozoic systems in Texas: Univ. Texas Bull. 3232, pp. 477–478. 510–511. 1933

[3] Some of these species are present in underlying formations. but they are useful in establishing the Navarro-Taylor contact in well sections

pseudopapillosa Carsey, and *Haplophragmoides excavata* Cushman and Waters, any of the long-range Upper Cretaceous species are likely to occur in increasing abundance downward. Outstanding are the several species of *Gümbelinae* and *Globotruncanae*, which may be observed in the topmost Navarro. Any of the Navarro species in the list formerly published[4] may be observed anywhere in the entire section of the subsurface Navarro.

In outcropping lower Navarro strata the small pelecypod, *Crenella serica* Conrad, is frequent,[5] and in a few well sections studied fragments of this shell have been found in abundance. Since this species occurs within the lower hundred feet of the Navarro, when encountered in drilling it serves to indicate close proximity to the Navarro-Taylor contact. Its delicate reticulate surface, its strongly incurved beak, and the fragility of the shell makes the species easy to identify even from small fragments. The zone carrying *Crenella serica* is especially rich in Navarro Foraminifera, and it is frequently called the "*Bulimina* zone."

The lists above indicate that at the end of Taylor times a large number of species of foraminifera became extinct. In the rich outcropping clays and marls of both Taylor and Navarro formations a sufficient number of these species is always present to make formational identification easy. In the examination of well cuttings contaminated by overlying formations, especially by the loosely consolidated Kincaid sandy and glauconitic beds, the main problem has been to ascertain which diagnostic Taylor forms are sufficiently common, persistent, and widespread immediately below the base of the Navarro to permit consistent recognition of the true contact. Many of the species recognized as diagnostic of the Taylor are rarely observed in well cuttings, either because these species do not occur far downdip from the outcrop or because they may occur so rarely in the strata represented by the cuttings, that the handful of contaminated material washed for study may contain too little material from the depth represented to yield specimens of such tests. Further, laboratory technique[6] has by experience proved to

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[4] Adkins, W. S., The Mesozoic systems in Texas: Univ. Texas Bull. 3232, pp. 510–511, 1933.

[5] *Crenella serica* Conrad is abundant in the lower part of the exposure at Jones Crossing on Onion Creek southeast of Austin on the Austin-Bastrop highway, Travis County. It occurs commonly also in the marl in the clay pit southwest of Corsicana, Navarro County.

[6] A comparison of methods has been made for such a series of highly contaminated well samples as those from the Beatty No. 2, in which the loose Littig glauconite at the base of the

be an important factor, for hard rubbing of a sample during the cleaning process can easily destroy the few diagnostic tests that are more likely to be present in the dried concentrate from a sample that has been subjected to less heroic treatment.

In the study of well material the dominant faunal changes in sets of continuous cuttings taken through the Wilcox, Midway, Navarro, and Taylor formations have been carefully recorded in order to ascertain which diagnostic surface criteria employed for the differentiation of formations harmonize with changes that can be observed downdip in well sections. In surface outcrops *Inoceramus* prisms have been found in no strata later than those of Taylor age, and in most samples taken from Taylor outcrops the prisms are so abundant that they are conspicuous in the concentrates. That a large and dominant group of pelecypods became suddenly extinct at the end of Taylor times is significant of a major change. Since their shells have left throughout Taylor sediments abundant and readily observable evidence in samples prepared for microscopic study, this noteworthy faunal break demands close comparison with accompanying changes in the microfaunas. In the careful examination of all sets of well samples from the base of the Midway to the chalks in the base of the Taylor, *Inoceramus* prisms have been observed only after several hundred feet of well-recognized Navarro strata have been penetrated, the thickness of the Navarro varying

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Kincaid formation so dominated all samples well down into the Taylor formation, that only the greatest care in washing and the closest scrutiny of concentrates revealed the true Kincaid-Navarro and the Navarro-Taylor contacts. For best results, samples received from a well are first thoroughly dried. The dry samples then break up almost completely in cold water within a few minutes The disintegrated mud is then brought to the boiling point, when a tablespoon of sal soda is added. The mixture is allowed to boil for three or four minutes. Decantation with plenty of water in deep pans floats off most of the argillaceous matter, but usually some tough clay remains in small chunks, which can often be broken down gradually by whirling of this mud in the pan between each addition of water in the decantation process. Usually such a sample is returned to the heat (either to an oven or to the broad cooking gas flame turned as low as possible) and dried slowly. Cold water poured on to the very warm dry clay disintegrates it completely, as a general rule, and further decantation cleans the residue with the least possible abrasive action.

Examination of the dry concentrate is very greatly facilitated by the use of two cloth screens, one of a very fine organdie (about 80 threads to the inch) and another of organdie voile (an imported material with about 55 threads to the inch). Unhemmed squares of these materials can be mounted in embroidery frames for use, or they can be used without any special frame support. If the frame is used, it should always be removed for thorough cleaning of the cloth after screening each sample. The most useful diagnostic forms occur mainly in the coarsest and medium grades of concentrate, and they are most likely to be found in the medium. More than half the concentrate can by screening be eliminated from the process of critical examination, much time can be saved, and greater precision attained.

considerably. In cuttings that are not badly contaminated, the prisms usually appear in considerable numbers or even in abundance in the first sample taken below the horizon that marks the uppermost occurrence of these forms. Wells that penetrate loose strata higher in the section offer samples so badly contaminated, that examination must often be made with utmost care to find the uppermost occurrence of *Inoceramus* prisms.

The only diagnostic Taylor foraminifer that has been found to occur consistently with the first *Inoceramus* prisms in the downward sequence of cuttings from central Texas wells is *Anomalina henbesti* Plummer, sp. nov. So far this association has never failed, and so far the most persistent search for this species has not revealed its occurrence above the zone of prisms. Very commonly associated with the first prisms encountered in the downward succession of well samples is *Cibicides nelsoni* (W. Berry), and where it can not be found at the top of this zone, it most generally occurs within 10 to 20 feet of the top. Both these Foraminifera were evidently so abundant up to the close of Taylor deposition, that even high contamination in cuttings does not totally obscure their presence in concentrates of carefully washed samples of moderate size. Since this association of criteria is so consistent, it must be significant, and since these same criteria mark the uppermost Taylor in outcrop, their highest occurrence is here accepted as reliable subsurface evidence of uppermost Taylor strata in well sections. Other foraminiferal species that are frequent in subsurface sections at or near the contact (as defined by the upper limits of prisms, *Anomalina henbesti*, and *Cibicides nelsoni*) are *Textularia ripleyensis* W. Berry, *A. taylorensis* Carsey, and *Buliminella carseyae* Plummer. Less frequently *Nodosaria alternata* (Jones), *Bolivina incrassata* Reuss, and *B. gemma* Cushman are found very high in the Taylor section. The plotted well sections (figs. 36 and 37) offer some indication of the highest occurrence of diagnostic Taylor species. All are reliable Taylor markers when found, but most species are not dependable as contact markers.

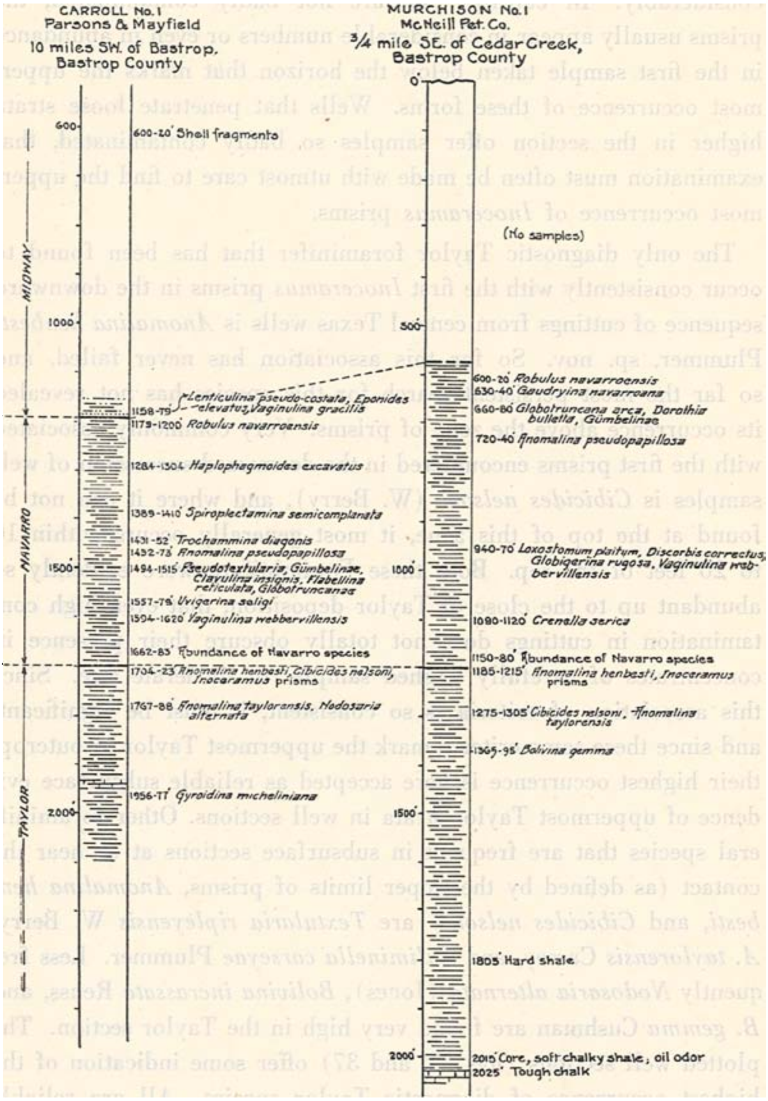

Fig. 36. Columnar sections of the Carroll No. 1 and the Murchison No. 1 in Bastrop County, Texas. Cuttings were received from both these wells. The continuous series of samples from the Carroll No. 1 began at the base of the Kincaid formation of the Midway group. The samples from the Murchison No. 1 began at the depth of 600 feet and were taken every 22 feet into the top of the chalk. The names of the Foraminifera have been placed at their uppermost limit as represented in the cuttings.

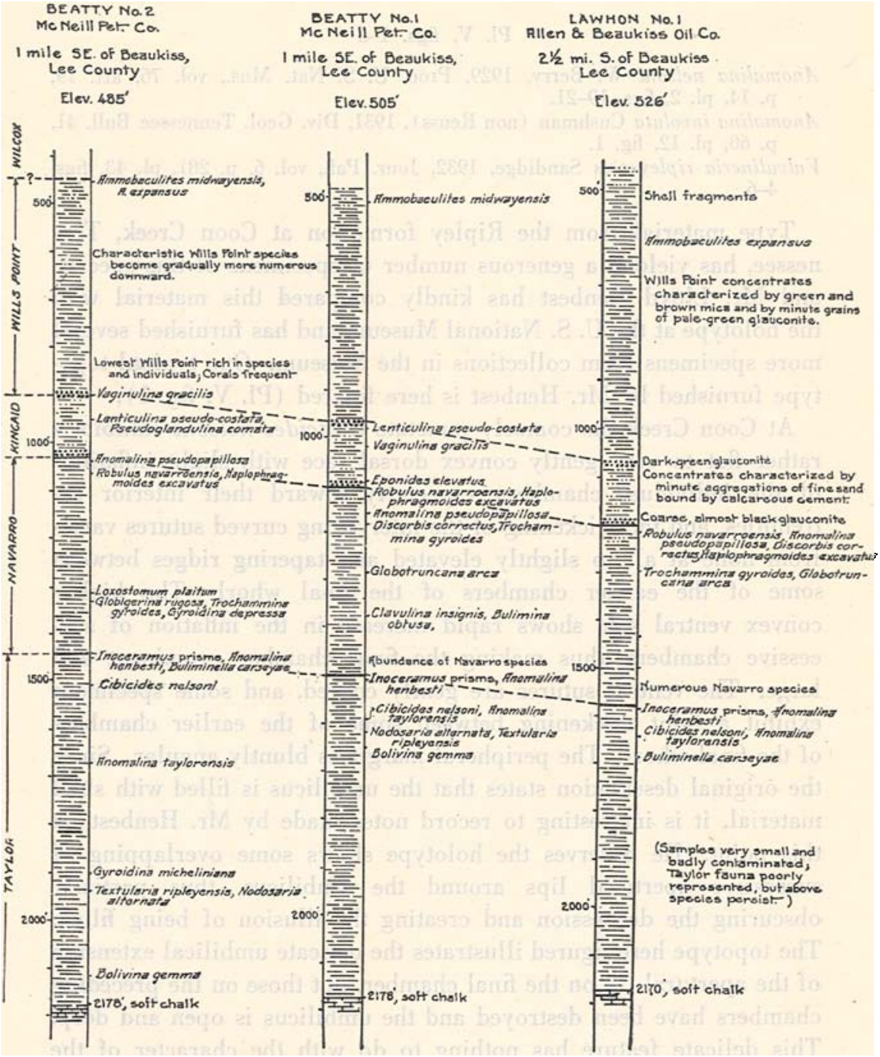

Fig. 37. Columnar section of the Beatty No. 1, Beatty No. 2, and Lawhon No. 1, in the extreme western point of Lee County, Texas. Cuttings were collected every 22 feet throughout the depths of these wells, and the names of the significant Foraminifera represent their uppermost occurrence in the sections.

CIBICIDES NELSONI (W. Berry)

Pl. V, figs. 1-6

Anomalina nelsoni W. Berry, 1929, Proc. U. S. Nat. Mus., vol. 76, art. 19, p. 14, pl. 2, figs. 19–21.

Anomalina involuta Cushman (non Reuss), 1931, Div. Geol. Tennessee Bull. 41. p. 60, pl. 12, fig. 1.

Valvulineria ripleyensis Sandidge, 1932, Jour. Pal., vol. 6, p. 281, pl. 43, figs. 4–6.

Type material from the Ripley formation at Coon Creek, Tennessee, has yielded a generous number of specimens of this species, and Mr. Lloyd Henbest has kindly compared this material with the holotype at the U. S. National Museum and has furnished several more specimens from collections in the Museum. One typical topotype furnished by Mr. Henbest is here figured (Pl. V, fig. 1).

At Coon Creek the coarsely punctate *Cibicides nelsoni* exhibits a rather flat to very gently convex dorsal face with slight inflations of the individual chambers, especially toward their interior extremities, and the thickening of the intervening curved sutures varies from none at all to slightly elevated and tapering ridges between some of the earlier chambers of the final whorl. The highly convex ventral side shows rapid increase in the inflation of successive chambers, thus making the final chamber prominent and large. The ventral sutures are gently curved, and some specimens exhibit a faint thickening between some of the earlier chambers of the final whorl. The peripheral margin is bluntly angular. Since the original description states that the umbilicus is filled with shell material, it is interesting to record notes made by Mr. Henbest on this point. He observes the holotype shows some overlapping of successive apertural lips around the umbilicus, thus partially obscuring the depression and creating the illusion of being filled. The topotype here figured illustrates the delicate umbilical extension of the apertural lip on the final chamber, but those on the preceding chambers have been destroyed and the umbilicus is open and deep. This delicate feature has nothing to do with the character of the umbilicus itself, which is typically small and deep. Few specimens retain the several successive apertural lips, and the development of this umbilical extension of the apertural feature is highly variable. Even on the few perfectly preserved specimens found the umbilical points at the ends of the successive apertural lips hug the depression so closely as to obscure comparatively little of its depth. The average size of mature specimens is about 0.3 mm. The holotype is 0.49 mm. in longest diameter and is larger than any specimen found either by the author or by Mr. Henbest, but the salient characteristics of the species are well illustrated by the specimen chosen by Dr. Berry.

The Texas specimens of *Cibicides nelsoni* average larger (about 0.4 mm.) than those at Coon Creek, but all the significant structural characteristics of the species persist. The greater abundance of tests in the Taylor calcareous clays allows opportunity to observe its variations in development of its minor features. The dorsal and ventral curvatures of the seven to eight chambers per whorl are essentially the same as those at Coon Creek, and even amongst typical tests from the type locality some slight variation in the degree of curvature of dorsal sutures exists. The bluntly angular peripheral angle of the Coon Creek tests persists in Texas specimens. The most noteworthy difference lies perhaps in the somewhat greater dorsal inflation of the last few chambers of many Texas tests of the species, but such inflation generally affects such tests as are distinctly larger than the largest Coon Creek tests found in type material available. Most Texas specimens that are about the size of the average Coon Creek test do not exhibit marked tumidity. Ventrally the Texas form of *C. nelsoni* carries the same strikingly rapid increase in inflation of the successive chambers, and the final chamber thus becomes very prominent. Probably because the environment in Texas Taylor seas was more calcareous than in those of Tennessee, sutural thickening on the Texas specimens is more general. The aperture is typically a low arch over the peripheral angle extending ventrally as a slit to the umbilicus, and well-preserved tests show a distinct rim or lip along the base of the final chamber over the apertural opening. The umbilical extension of the septal face into a point is not so prominent a feature on Texas Taylor specimens as on those at Coon Creek, but it is commonly present.

From all other rotalid coils in the Taylor fauna *Cibicides nelsoni* is readily distinguishable by the rapidly increasing inflation of the chambers on the dorsal side.

In the Texas stratigraphic section *Cibicides nelsoni*, with *Anomalina henbesti*, sp. nov., is abundant in the upper Taylor strata and is highly valuable as a Navarro-Taylor contact marker both in outcrop and in well sections. It persists in this same zone northeast across Texas, Arkansas, Tennessee, and southeastward into Alabama. In the southeastern states it occurs in the lower Ripley formation, which is correlative with the Texas upper Taylor deposits.

ANOMALINA HENBESTI, sp. nov.

Pl. V, figs. 7–10

Anomalina involuta Cushman (non Reuss), 1931, Div. Geol. Tennessee Bull. 41, p. 60, pl. 12, figs. 2, 3.
Anomalina complanata Sandidge (non Reuss), 1932, Amer. Midland Nat., vol. 13, p. 368, pl. 31, figs. 30, 31.

The almost equally biconvex and nearly nautiloid coil of 10 to 12 chambers is rather coarsely punctate with puncta closely spaced. The gently curved chambers are slightly inflated on both sides of the late chambers and the very bluntly angular to narrowly rounded periphery is faintly lobate. The earliest whorls are covered on the dorsal side by a smooth and slightly convex boss that is surrounded by a very shallow depression, and only the last four or five chambers of the penultimate whorl are visible on the dorsal face. On the ventral side the umbilicus is occupied by a conspicuous and uneven boss that is surrounded by a narrow and rather deep depression, especially along the inner margin of the last six to eight chambers. The development of the umbilical boss varies greatly, but it is consistently large and not perfectly smooth, as is the central boss on the dorsal face. Sutural thickening is more general on the ventral side of Texas tests, but it is rarely a prominent feature of the relief of either face. The aperture is a distinct arch over the peripheral angle, and this arch merges ventrally into a very narrow slit at the base of the septal face and extends into the umbilicus. Just above the elongate opening is an extremely narrow and delicate lip, which on very many specimens ends umbilically in a prominent point. Many ventral views show the succession of pointed extremities of the last eight or nine chambers standing in relief around the deep and narrow depression surrounding the umbilical boss (Pl. V, fig. 10).

An average diameter of this species in central Texas is about 0.6 mm., and a maximum is about 0.9 mm.

The nearest ally in the Texas Taylor fauna is *Anomalina taylorensis* Carsey, which has a very much sharper peripheral angle, is more compressed, exhibits more chambers of the penultimate whorl on the dorsal side, and is more finely punctate.

Anomalina henbesti is widespread in Taylor equivalent strata of the Gulf Coast. It persists in the upper Taylor across Texas, northeastward into Arkansas and Tennessee, and southeastward into Alabama. The lower portion of the Ripley formation of the southeastern states carries the typical Taylor fauna and is undoubtedly of the same age. The Ripley formation as mapped is a distinctive lithologic unit, but faunally it should probably be subdivided into two units to fit the formational divisions west of the Mississippi.

Cotypes are from a small creek bank about 0.1 of a mile south of the bridge over Onion Creek at Moore's Crossing, Travis County, Texas (see Univ. Texas Bull. 3101, pp. 120, 121, fig. 12, Sta. 226–T–8). Paratype from Murchison No. 1, McNeill Pet. Co., near Cedar Creek, Bastrop County, Texas; cuttings from topmost Taylor strata, 1185–1215 feet.

Dr. J. A. Cushman has very generously supplied a topotype of *Anomalina involuta* Reuss from the Mukronaten-Kreide of Lemberg. This test shows a flat dorsal face and an evenly rounded and faintly conical ventral face with a smooth umbilical filling, the convexity of which merges into the general convexity of the face. None of the chambers show the slightest inflation, nor does the peripheral outline exhibit any lobation. This Reuss species is somewhat similar to a rather rare form in the Taylor and is probably a *Cibicides*. Dr. John Sandidge kindly made identifications of the Ripley species that correspond to the two species here described.

PLATE V

Figures—

1. *Cibicides nelsoni* (W. Berry). Views of a topotype from Coon Creek, Tennessee. *a,* Dorsal view; *b,* peripheral view; *c,* ventral view.

2–6. *Cibicides nelsoni* (W. Berry). All specimens from Taylor formation exposed in a small gully near the south end of the bridge over Onion Creek at Moore's Crossing, Travis County, Texas.

   2. Dorsal view of a test showing unusually straight sutures.
   3. Dorsal view of a test that is approximately the size of the average Coon Creek tests of the species. At this stage the Texas form of the species commonly shows the relatively flat face with little inflation of the chambers.
   4. Peripheral view of a young specimen showing at this stage the rather flat face of the typical test of the species.
   5. Dorsal view of a test that closely approximates the size of the average Coon Creek test, showing strong inflation of the last two chambers, a development that is not general in Texas tests at this stage.
   6. Views of a Taylor specimen of average size, which is larger than the average Coon Creek test. The last few chambers are typically rather strongly inflated on the dorsal side, and yet the dorsal face as a unit is not nearly so strongly convex as is the ventral side. *a,* Dorsal view; *b,* peripheral view showing the strong inflation of the final chamber; *c,* ventral view showing the small but distinct umbilicus and prominent final chamber.

7–9. *Anomalina henbesti,* sp. nov. Three cotypes from near the top of the Taylor formation exposed in a small gully near the south end of the bridge over Onion Creek at Moore's Crossing, Travis County, Texas.

   7. Dorsal view of a typical test showing the very smooth and gently convex central boss.
   8. Peripheral view showing arched aperture which merges ventrally (to the left) into a very narrow slit at the base of the septal face.
   9. Ventral view showing the apertural lip. On this specimen the pointed umbilical extensions of the lip were not well developed until the last three chambers were formed. The umbilical boss is typically uneven.

10. *Anomalina henbesti,* sp. nov. Paratype from Murchison No. 1, cuttings from 1185–1215 feet, the topmost Taylor sample. This specimen shows the well-developed pointed extremities of the successive apertural lips around the irregularly developed umbilical boss, which merges into sutural thickenings between chambers in the early part of the final whorl.

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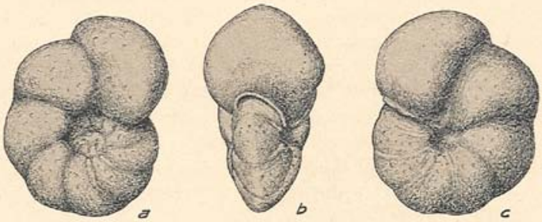

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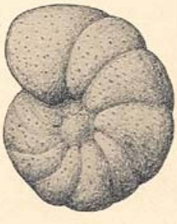

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INDEX

LEGEND

PERMIAN

WICHITA GROUP

ADMIRAL FORMATION	PUTNAM FORMATION	MORAN FORMATION
Cad	Cpt	Cmo
	COLEMAN JUNCTION LIMESTONE-Cjc, AT TOP.	SEDWICK LIMESTONE-Cse, AT TOP.

PENNSYLVANIAN

CISCO GROUP

PUEBLO FORMATION	HARPERSVILLE FORMATION	THRIFTY FORMATION	GRAHAM FORMATION
Cpu	Cha	Cth	Cgh
CAMP COLORADO LIMESTONE-Ccc, AT TOP. STOCKWETHER LIMESTONE-Csw.	SADDLE CREEK LIMESTONE-Csc, AT TOP. WALDRIP BEDS LIMESTONE-Cwa_3-Cwa_2-Cwa_1.	BRECKENRIDGE LIMESTONE-Cb, AT TOP.	SPECK MOUNTAIN LIMESTONE-Csp, AT TOP. LOWER GUNSIGHT LIMESTONE-Clg. BUNGER LIMESTONE-Cbu.

CANYON GROUP

CADDO CREEK FORMATION	BRAD FORMATION	GRAFORD FORMATION
Ccd	Cbr	Cgf
HOME CREEK LIMESTONE-Chc, AT TOP.	RANGER LIMESTONE-Cra, AT TOP. UPPER CLEAR CREEK LIMESTONE-Cuc. LOWER CLEAR CREEK LIMESTONE-Clc.	ADAMS BRANCH LIMESTONE-Cab, AT TOP.

GEOLOGIC MAP OF
NORTHERN MC CULLOCH COUNTY, TEXAS

BY FRED M. BULLARD AND ROBERT H. CUYLER

SCALE

0 1 2 3 4 MILES

A. HOEN & CO., LITH.