THE UNIVERSITY OF TEXAS BULLETIN

No. 3201: January 1, 1932

CONTRIBUTIONS TO GEOLOGY, 1932

Bureau of Economic Geology
E. H. Sellards, Director

PUBLISHED BY
THE UNIVERSITY OF TEXAS
AUSTIN

Publications of the University of Texas

The University publishes bulletins four times a month, so numbered that the first two digits of the number show the year of issue and the last two the position in the yearly series. (For example, No. 3201 is the first bulletin of the year 1932.) These bulletins comprise the official publications of the University, publications on humanistic and scientific subjects, and bulletins issued from time to time by various divisions of the University. The following bureaus and divisions distribute bulletins issued by them; communications concerning bulletins in these fields should be addressed to The University of Texas, Austin, Texas, care of the bureau or division issuing the bulletin: Bureau of Business Research, Bureau of Economic Geology, Bureau of Engineering Research, Interscholastic League Bureau, and Division of Extension. Communications concerning all other publications of the University should be addressed to University Publications, The University of Texas, Austin.

Additional copies of this publication may be procured from the Bureau of Economic Geology, The University of Texas, Austin, Texas.

THE UNIVERSITY OF TEXAS PRESS

THE UNIVERSITY OF TEXAS BULLETIN

No. 3201: January 1, 1932

CONTRIBUTIONS TO GEOLOGY, 1932

Bureau of Economic Geology
E. H. Sellards, Director

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

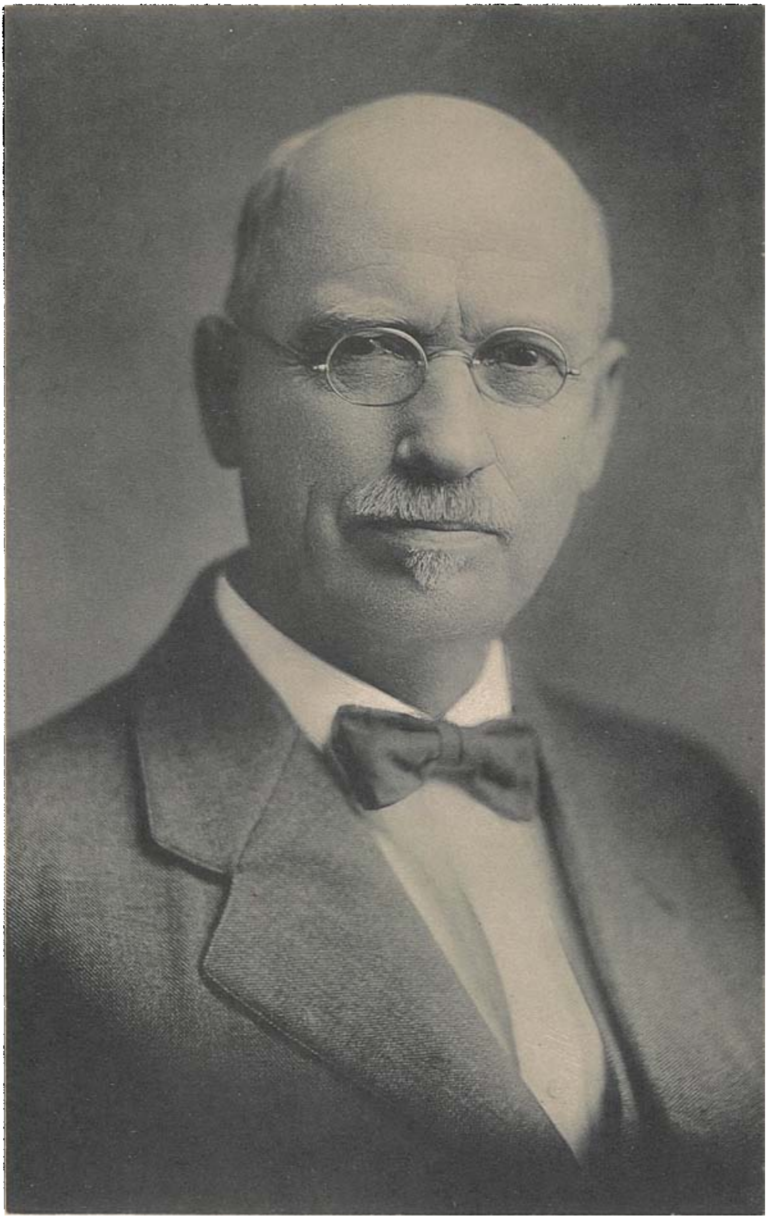
CONTENTS

ILLUSTRATIONS

Figures

Plates

Following page 188



JOHAN AUGUST UDDEN
1859—1932

FOREWORD

The "Contributions to Geology," issued by the Bureau of Economic Geology of The University of Texas, include shorter papers of which in addition to other Bureau publications, usually, one volume per year is published, the present volume being the fifth of the series. Each volume of the "Contributions" bears a bulletin number and is thus a part of the series of The University of Texas bulletins issued from the Bureau of Economic Geology.

The 1932 volume of "Contributions" has been issued as a memorial to Dr. Johan August Udden and is published from funds generously contributed by his many friends to the Johan August Udden Publication and Research Fund. The great service to the geologic sciences rendered by Dr. Udden makes this volume a most fitting memorial to his life and work.

The cost of field work necessary to complete the paper on Pennsylvanian conglomerates of north-central Texas included in this volume has been met in part by contributions made by the Fort Worth and North Texas Geological Societies. These contributions are greatly appreciated.

E. H. SELLARDS.

MEMORIAL TO DR. JOHAN AUGUST UDDEN

Dr. Johan August Udden was born at Lekasa, Sweden, March 19, 1859. Two years later he came to America with his parents, Andrew Larsen and Inga Lena (Andersdotter) Udden. His early youth was spent in Minnesota, where his parents had settled. He was graduated with a bachelor's degree from Augustana College, Rock Island, Illinois, in 1881, and was married to Johanna Kristina Davis in 1882. He was a student at the University of Minnesota in 1886 and received the degree of Master of Arts from Augustana College in 1889. From 1881 to 1888 he taught natural science and civics at Bethany College, Lindsborg, Kansas, and from 1888 to 1911 was professor of natural history and geology at Augustana College. He received honorary degrees as follows: Doctor of Philosophy, Augustana College, 1900; Doctor of Science, Bethany College, 1921, and Texas Christian University, 1923; and Doctor of Laws, Augustana College, 1929. He held membership in several scientific societies, including the American Association for the Advancement of Science (Fellow, 1906), Geological Society of America, Society of Mining and Metallurgical Engineers, American Association of Petroleum Geologists, Sigma Xi, and the Illinois, Iowa, Oklahoma, and Texas (Fellow) Academies of Science. In 1929 he was elected honorary member of the Society of Economic Paleontologists and Mineralogists, and in 1927 honorary member of the American Association of Petroleum Geologists. His fields of investigation included stratigraphic and areal geology, work of the atmosphere, till in the upper Mississippi Valley, clastic sediments, and related subjects. His published papers on these subjects number about 100 titles.[1] In recognition of his distinguished service in science, he was decorated by the King of Sweden in 1911 with the Swedish Order of the North Star.

The geological investigations carried on by Dr. Udden were original to an unusual degree. The training of his student days afforded no opportunity for specialization. For this reason he early came to the conclusion, as he remarked on one occasion, that his best contribution to geology would come through close observations in limited and, in the main, neglected fields of geology. In this connection, Bain, under whom he served on the Illinois Geological Survey, says: "He was not only a man of high character and fine personality, but had a singular ingenuity in finding methods of attack on a problem. I have often thought that was one compensation for his having had largely to train himself. If he had gone through the mill of scholastic training, who knows but his insight might have been blunted." This deliberate selection of unusual problems may be illustrated by citation of some of the titles of his papers. Thus almost the first of his papers, published in 1893, was one on the formation of pellets. In 1894 came the first of his papers on sedimentary processes of the atmosphere, a line of investigation carried through several years culminating in his important publication on the mechanical

[1]A list of Dr. Udden's papers will be given in connection with a memorial to be published in the Bulletin of the Geological Society of America. Those of his papers relating to Texas are listed in the bibliography of Texas geology included in University of Texas Bulletin 3232.

composition of wind deposits. In 1895 he published on fossil frost impressions and again in 1918 on fossil ice crystals. In 1897 appeared the first of his papers on loess deposits. While many of his papers are records of observations, theoretical deductions are not wanting. Thus in advance of actual knowledge he reasoned that potash should be found in the Texas Permian basin. It was on theoretical grounds likewise that he advised the Regents of the University in 1916 of the probable occurrence of oil and gas in the University lands of west Texas.

With regard to his services at Bethany College, his first appointment following graduation, Dr. Ernest F. Philblad said in a recent letter: "He was the first teacher of our institution, which was organized as an academy, and remained in this service until 1888. During the last years of his service his teaching was confined to Biological Science and Geology. Dr. Udden during these pioneer years made a most valuable contribution to the cultural life of the Swedish emigrant in Kansas, which Bethany College was endeavoring to serve. The writer enjoyed the privilege of being a member of his classes. I recall him as a great teacher and warm-hearted friend." In his earlier years at Bethany College, it may be added, he not only taught many subjects but in addition edited the local paper, the "Posten."

From Bethany College he was called to his Alma Mater, Augustana College. With regard to his service at Augustana College, Professor F. M. Fryxell, who is now his successor in that college, writes: "Dr. Udden was a member of the faculty here from 1888 to 1911, and, in my opinion, made some of his most valuable scientific contributions—at least in the field of pure science—during this period. That he was able to accomplish so much in the way of research is all the more remarkable in view of the fact that he had an extremely heavy and varied teaching schedule, one which nowadays would be considered intolerable. He taught the various courses in Botany, Zoology, Physiology, Meteorology, and Geology during all these years, and at times he helped out in remote fields, History for example. It is interesting to know that he even took his turn at conducting chapel exercises. The Science Club became a live organization under his leadership. One of the finest contributions which Dr. Udden made in behalf of Augustana was the founding of a series of monographs published under auspices of the college, 'Augustana Library Publications.' Fourteen volumes of this series have been published to date, five being contributed by Dr. Udden during the years he was on our staff."

It would seem that with a teaching load at Augustana College, described by his successor as intolerable according to present standards, conditions would be unfavorable for research, yet during these years originated some of his most valuable contributions to pure science.

Although he had given temporary service in 1903–1904, his permanent connection with The University of Texas did not begin until 1911. This connection continued until his death, January 5, 1932. He was made a member of the graduate faculty of the University in 1929. His companion and helper in this long life of active work, Johanna Kristina Davis Udden, survived him only five months, having died June 5, 1932.

Dr. Udden was connected with several geological survey organizations. He was special assistant to the Iowa Geological Survey, working chiefly during the summer months, in the years 1897 to 1903; geologist of The University of Texas Mineral Survey, 1903–1904; geologist of the Illinois Geological Survey, 1906–1911; special agent of the United States Geological Survey, 1908–1914. He became geologist in the Bureau of Economic Geology and Technology of The University of Texas in 1911 and director in 1915.

Of his long and diverse services on these surveys only a limited account can be given here. Dean G. F. Kay, State Geologist of Iowa, says of him: "The work which he did while connected with the Iowa Geological Survey during the summers of 1897 to 1903 reveals clearly his fine observational powers, his keen analytical mind, and his devotion to the solution of baffling problems."

Of his work for the Geological Survey of Illinois, Professor F. W. DeWolf writes as follows: "Dr. Udden was a teacher of science at Augustana College, Rock Island, when the Survey was established in 1905 under the direction of Dr. H. Foster Bain. The two men had been previously associated on the Iowa Geological Survey, and Bain promptly engaged Udden to undertake work in Illinois during the summer months, and to give as much additional time as could be spared from college duties. Even after Bain's resignation in 1909, Udden continued this work until his own removal to Texas in 1911. During this six years of service in Illinois, Dr. Udden engaged in four principal investigations, of which the results were issued in state or federal publications. Three of these were of routine character, being geological surveys of quadrangle areas, but the thoroughness with which the work was done, in response to Dr. Udden's native curiosity and minute care, which amounted to genius, raised these reports to an unusually high level as to quality.

"Most notable of these reports is that covering the Peoria quadrangle, published in complete form as Bulletin 506 of the U. S. Geological Survey, in coöperation with the State. Besides mapping and describing the various formations of ordinary character, Dr. Udden recognized an exposure of old (Pre-Illinois) glacial drift, from its resemblance to materials seen previously in Iowa, and contributed an important chapter on artesian water resources. The outstanding feature of scientific character, however, was the division of the Pennsylvanian formations into four rhythmical cycles, each characterized by the same sequence of sediments, which were, in ascending order, coal, shale, limestone, sandstone, and clay. The amount of coal or any other bed was variable in the several cycles, but the sequence was the same, and was interpreted as marking natural sequence of conditions of sedimentation in a great basin affected by intermittent subsidence. The time scale and the ratio of time needed for each kind of sediment were computed in a very suggestive way. Only in the past few years has the significance of this work been appreciated, in connection with new studies of cyclic deposition and correlation throughout the Illinois coal basin.

"Another bold but sound contribution in the Peoria coal studies cleared up the problem of certain 'faults' and other irregularities which had puzzled mining men. These 'faults' were confined to outcrop areas of the coal where surface valleys exist, and were found by Udden to be due to the tremendous power of glacial ice which invaded pre-existing valleys and up-rooted and moved great blocks of strata in which coal beds were contained. Some blocks had been turned upside down, and in certain large areas a double thickness of coal was due to one coal-bearing block being imposed on top of another.

"One other illustration of Dr. Udden's work should be mentioned because its later development in Texas became of great commercial importance to the oil companies. During his service in Illinois he studied innumerable samples of cuttings from drilled wells, and developed methods and technique well in advance of the current practice. Some of his results relating to thirty-five sets of samples from the Illinois oil fields were published as Bulletin 24 of the State Survey. This included introductory chapters outlining his detailed methods for the study of all such samples as to physical and chemical character and fossil content. Just such methods were introduced later by Dr. Udden in the laboratory of the Texas Bureau, and still later, in modified form, they were adopted by oil company geologists as a basis for identification and correlation of key horizons in the oil-field formations. If Dr. Udden's own work was not directly responsible for this commercial development it was at least pioneering work of sound character directly in line with the later development, and marking him, as always, as a prophet of geological accomplishments."

The geologic activities of Dr. Johan August Udden have left far-reaching effects in myriad directions upon the development of both theoretical and economic geology in Texas. The qualities of his mind and the circumstances of his early scientific training combined to give him those preeminent characteristics as a research geologist which were later to prove so valuable to the science of geology and to the State of Texas. Because of the slight development of specialized geological training in his early school days, he received relatively little professional schooling in the subject. It is an outstanding merit of his work that he early determined to rely upon his own powers of observation and reasoning, and to get at the features of his geological problems at first hand. The richness and originality of his work and the independence of his geological thought are attested by all his principal papers on Texas geology. In Texas he worked on a virgin field with an observant, open, and critical mind, and his labors found their rich reward in far-reaching additions to both the science of geology and the economic development of the State.

His paper on the mechanical composition of clastic sediments embodied the work of years on a field in which he made pioneer observations, established an adequate quantitative method of treating the material, and outlined the major features of this early branch of sedimentology.

Some of his earliest work in Texas was on dominantly Cretaceous areas, where he left the permanent impress of his accurate and logical mind. His works on the Eagle Pass and the Chisos districts are marked by their originality of conception, judicious weighing of the evidence relating to various novel or little-treated stratigraphic and physiographic features, and complete objectiveness in getting the facts. Similar pioneer work is displayed in his papers on the Marathon Paleozoic section.

His active mind was ever alert for the development of new geological methods. He was one of the first in America to point out and stress the value of seismograph observations for locating geologic structure. His work on the technique of examining subsurface material, now universally followed, was purely pioneer research, and it is to the credit of The University of Texas that these methods were largely developed in the laboratories of its Bureau of Economic Geology.

His greatest work of economic importance for the State of Texas concerned three of its most valuable mineral resources, quicksilver, oil, and potash. Dr. Udden first called attention to the influence of geological structure in the accumulation of quicksilver, a fertile idea which has been tested and proved in many of the great quicksilver fields of the world. A report of his made to the Regents of the University concerning the oil resources of University lands in west Texas was directly responsible for the opening of the Big Lake pool and. following it, the other major oil fields in west Texas. His early and very important paper on potash in the Texas Permian, a direct outgrowth of his laboratory work on subsurface samples, laid down the main fundamentals for the conditions of occurrence of potash and established the probability of the occurrence of vast deposits of that natural resource in west Texas and eastern New Mexico.

From these activities alone it can be said that no other geologist has contributed more to making possible the utilization of the wealth, partly realized but mostly still unexploited, of Texas than has Dr. Udden.

The following extract is from a resolution prepared by a committee of the general faculty of The University of Texas and adopted by the faculty on February 9, 1932:

"Great indeed were his accomplishments as a scientist, but greater still were his outstanding characteristics as a man and a friend. His sturdy individuality and independence of thought were accompanied by a profound respect for the opinion of others. He was helpful to the fullest extent to his associates and patient in listening to and understanding the problems of those who came to him for help. During his long term of service no one who applied to him was denied his most careful consideration and the benefit of a matured opinion freely given.

"Twenty-one years of his life were given in the service of the State of Texas. During this time he initiated important new methods of investigation, recorded new observations valuable to many industries, promoted the development of resources of great value to the State, and gave advice to thousands who consulted him. His high-mindedness, his cordiality, his gentle manner, his loyalty to principles and to his friends endeared him to all who intimately knew him and marked him as one of God's real noblemen. The world has been enriched materially, intellectually, and spiritually by his life."

In grateful recognition of services which he gave. Dr. Udden's many friends have joined in establishing in his honor the Johan August Udden Publication and Research Fund of The University of Texas, from which this volume is published. It is felt that in no way can his memory be more fittingly perpetuated than in fostering research and publication in the science to which he so largely contributed.

TEXAS PENNSYLVANIAN CONODONTS AND THEIR STRATIGRAPHIC RELATIONS

By

Clinton R. Stauffer and Helen Jeanne Plummer

INTRODUCTION

Conodonts are known to occur sparingly in the Pennsylvanian strata in Texas. Out of a large number of outcrop samples collected across the geologic section, only the five recorded in this paper have yielded these forms in sufficient numbers to be worthy of consideration. Though it is very probable that they will be found at many other stratigraphic positions in the Carboniferous section in this state, the search must be persistent and patient. Two of the outcrops that have contributed material for this paper are especially noteworthy. One lies in the East Mountain shale member of the Minerals Wells formation (upper Strawn) in the steep south slope of East Mountain in Minerals Wells; the other lies in the Brownwood shale member of the Graford formation (lower Canyon) in the north edge of Bridgeport. Both shales carry frequent specimens of this interesting group of remains, but the East Mountain locality is outstanding for its variety of forms.

Grateful acknowledgment is made to the Research Department of the University of Minnesota for assistance in the preparation of the plates and manuscript for this paper. Though most of the material studied has been collected by F. B. Plummer and the junior author, two very interesting samples carrying conodonts were contributed by C. L. Thompson, while he was engaged in detailed mapping in north-central Texas.

The figured specimens of all forms described in this paper have been deposited in the museum of the Bureau of Economic Geology in Austin, Texas.

HISTORICAL RÉSUMÉ

Conodonts appear to be restricted to the Paleozoic and are found throughout that era. At some stratigraphic positions, especially in the Devonian, they occur in great numbers. Their small size and inconspicuous occurrence in many formations has often caused

Issued November 3, 1932.

them to be overlooked. They have been found in all kinds of sediments but more abundantly in the shales, especially the black shales.

Conodonts were discovered, named, and described by Dr. C. H. Pander[1] who found them in the Ordovician greensands associated with the soft bluish or greenish shale cropping out along the River Neva at Petrograd and westward along the Gulf of Finland to the cliffs near Narva. He regarded them as the teeth of primitive fishes of near kinship to the Selachians or sharks.

Dr. J. Harley, however, found them in the Ludlow bone-bed associated with the crustacean remains and concluded that conodonts are merely spines similar to those attached to the margins of the carapace of *Limulus* and the caudal segment of *Squilla.*[2] Although most of Dr. Harley's forms are probably not conodonts, he was apparently one of the first to disagree with Dr. Pander's disposal of these minute fossils and thus opened a controversy that continued more than half a century.

In his Textbook of Paleontology, Richard Owen of the British Museum reviewed the evidence on which conodonts had been referred to the fishes and concluded that "they have most analogy with the spines, or hooklets, or denticles of naked mollusks or annelides. The formal publication of these minute ambiguous bodies of the oldest fossiliferous rocks, as proved evidences of fishes, is much to be deprecated."[3]

In 1873 Dr. J. S. Newberry said that "the conodonts obtained by Pander from the Lower Silurian rocks of Russia, were described by him as the teeth of Elasmobranchs, and as affording evidence of the existence of sharks and rays at a much earlier period in the world's history than had been before suspected. Since the character of these organisms is still under discussion, they cannot be accepted as conclusive evidence of the truth of Prof. Pander's generalization."[4] Dr. Newberry collected great numbers of conodonts from the Cleveland shale along Tinkers Creek at Bedford,

---

[1]Pander, C. H., Monographie der fossilen Fische des silurischen Systems der russich-baltischen Gouvernements, St. Petersburg, 91 pp., 9 pls., 1856.

[2]Harley, J., The Ludlow bone-bed and its crustacean remains: Quart. Jour. Geol. Soc. London, vol. 17, pp. 547–549, 1861.

[3]Owen, Richard, Textbook of Paleontology, 2nd Edition, Edinburgh, p. 118, 1861.

[4]Newberry, J. S., Descriptions of fossil fishes: Paleontology. Geol. Survey Ohio, vol. 1, pt. 2 p. 254, 1873.

Ohio, and apparently submitted them to various of his scientific friends. Professor Louis Agassiz "pronounced them the teeth of Selachians." Professor E. S. Morse said "that they bore a strong resemblance to the teeth of Mollusks." Professor William Simpson "gave the opinion that they might very well be the lingual teeth of Mollusks, but they could not have formed the dentition or spinous armament of any Crustacean." Others apparently suggested that "these singular bodies are the teeth of Cyclostomous fishes" and still others suggested that "they are dermal ossicles." Amid this confusion of opinion, even among the best authorities of his day, Dr. Newberry finally chose to follow the group that related them more closely to the fishes and announced that "waiting further evidence of the nature of these organisms, I take the liberty of offering, as a possible and plausible explanation of the enigma, the theory that they are the teeth of Cyclostomous fishes."[5]

Dr. E. O. Ulrich compared the conodonts of the Cincinnati region with the chitinous jaws of several species of living annelids and observed a "striking resemblance" between them. Although it is evident that he was not satisfied with the relationship, he finally concluded to accept temporarily the theory "which seems to afford the most probable explanation and assume that the conodonts * * * are the hooklets of a species of annelid."[6]

Dr. George J. Hinde made extensive collections of conodonts in Ontario and adjacent parts of the United States. During the course of their study these were submitted to Professor Huxley "who expressed the opinion that some of them so closely resemble the teeth of the Hag-fish (Myxine) that it would be difficult to prove that they did not belong to fishes of this order."[7] Although it is evident that he favored relating the conodonts to the fishes, Dr. Hinde appears to have preferred not to commit himself too definitely on their classification. He says that "whilst conodont teeth do not correspond in minute structure with, and are far more varied in form than, the teeth of any known fish, they yet approach closest to those of the Myxinoids. As it is not at all

[5]Newberry, J. S., Paleontology of Ohio, vol. 2, pp. 42–43, 1875.

[6]Ulrich, E. O., Observations on fossil annelids, and descriptions of new forms: Jour. Cincinnati Soc. Nat. Hist., vol. 1, p. 88, 1878.

[7]Hinde, G. J., On conodonts from the Chazy and Cincinnati groups of the Cambro-Silurian and the Hamilton and Genesee shale divisions of the Devonian in Canada and the United States: Quart. Jour. Geol. Soc London, vol. 35, p. 355, 1879.

improbable that there was in Paleozoic times as great a development of the Cyclostome Fishes as of the Ganoids and Elasmobranchs, with a consequent great amount of variation in their structural development, we could hardly judge, from their pauperized descendants of the present day, how far this variation may have extended in former times. We should not, therefore, on account of the imperfect analogy of the conodonts with the teeth of the existing Myxinoids, reject altogether the probability that they may have belonged to similar low type of fishes. At present, however, the facts at hand appear insufficient to decide the question."[8]

Mr. U. P. James seems to have regarded the conodonts as "the jaws and lingual teeth of Mollusks."[9] Dr. J. V. Rohon and Dr. Karl von Zittel made a microscopic study of the structure of conodont teeth and concluded that they are wholly unlike the teeth of any of the fishes, Mollusca or Crustacea but that they resemble very closely such structures in the annelids and Gephyrea.[10] This conclusion, although perhaps favoring the minority, was rather generally accepted by workers throughout America, and conodonts were classified with the Vermes. Even Dr. Newberry began to waver in his opinion as to their classification, for in his monograph on fossil fishes, while discussing the abundant conodonts of the shales at Bedford, Ohio, he remarks that "whether they are the teeth of Cyclostomous fishes, shell-less Mollusks or Annelids remains undecided."[11] Dr. Zittel appears not to have been so certain that the conodonts are worm teeth for in his Handbook of Paleontology he treated them as a footnote under the Cyclostomi, although he stated that their structure is identical with that of the annelid jaw.[12] In the first edition of Eastman's English translation of Zittel's Handbook, Dr. Hinde said that "Zittel and Rohon . . . consider that they (conodonts) are annelid teeth but their true position cannot be said to be satisfactorily determined."[13]

---

[8]*Idem*, p. 356.

[9]James, U. P., On conodonts and fossil annelid jaws: Jour. Cincinnati Soc. Nat. Hist., vol. 7, p. 146, 1884.

[10]Rohon, J. V., and Zittel, Karl von, Uber Conodonten: Sitz. k. Akad. Wiss Munchen, Math.-Phys. Klasse, vol. 16, pp. 108–136, pls. 1, 2, 1886.

[11]U. S. Geol. Survey Monograph XVI, p. 123, 1889.

[12]Handbuch der Paleeontologie, Bd. 3, p. 58, 1890.

[13]Zittel, Karl von, Text-book of Paleontology, Eastman's Translation, vol. 1, p. 255, 1900.

Dr. A. S. Woodward remarked, with regard to conodonts, that "their histological structure is so different from that of any teeth known that their affinities are quite undeterminable."[14]

Dr. A. W. Grabau and Dr. H. W. Shimer said that conodonts "were at first considered to be fish teeth and have been regarded as pertaining to the lingual ribbon of molluscs, or to crustacea", . . . but "the jaws and toothed plates have the characters of the jaws of modern annelids,"[15] and hence they listed them with the Annelida.

Many of the subsequent writers on conodonts avoid a discussion of the classification of these admittedly difficult forms. Dr. R. S. Bassler, however, listed the conodonts with the fishes.[16] The question mark which he placed after the word "teeth" leads one to suspect that he doubted whether they are real teeth rather than that he meant to raise a doubt as to the classification.

Dr. W. A. Parks restudied some of the Ordovician annelid teeth and the conodonts occurring in the vicinity of Toronto. With regard to the latter, he said, "They are frequently referred to as the teeth of Cyclostomes, but their affinities are quite uncertain."[17]

In connection with an extensive study of the Genesee conodonts, Mr. W. L. Bryant reviewed the literature, especially that pertaining to relationships of these interesting forms. The first statement of the article is that "Conodonts are the teeth of some unknown family of animals,"[18] thus expressing doubt as to the validity of the classification ordinarily used. Associated with the conodonts Mr. Bryant found "certain fragmentary ornamental plates which may have formed the defensive covering of these mysterious animals. The plates are always broken, rarely exhibiting a natural contour. They, like the conodonts, are composed of structureless carbonate and phosphate of lime and have the same fine, polished submetallic or resinous lustre."[19] Plates almost identical with those figured by Mr. Bryant occur abundantly in association with the Ordovician conodonts in Minnesota, thus increasing the possibility that they may have constituted part of the armour of some conodonts. Mr.

---

[14]Vertebrate Paleontology, p. 1, 1898.

[15]North American Index Fossils, vol. 2, p. 240, 1910.

[16]Bassler, R. S., Bibliographic index of American Ordovician and Silurian fossils: U. S. Nat. Mus. Bull. 92, p. 1426, 1915.

[17]Parks, W. A., The stratigraphy and paleontology of Toronto: Ontario Dept. Mines, vol. 31, pt. 9, p. 35, 1922.

[18]Bryant, W. L., The Genesee conodonts: Bull. Buffalo Soc. Nat. Hist., vol. 13, p. 3, 1921.

[19]*Idem*, p. 11.

Bryant, however, found a still more suggestive specimen in the *Polygnathus rotundilobus* Bryant cemented "to a fragmentary plate of an undescribed fish, perhaps an Arthrodire."[20] This relationship may have been accidental as suggested by its position on the bony plate, but that it is a natural association is rendered more probable since the similar finds of Professor Kirk, as discussed later. Through extended studies of the conodonts Mr. Bryant had "become convinced that the true conodonts have hardly anything really diagnostic in common with Annelid jaws. If . . . certain of the leaf-like forms are of the nature of pavement teeth, then the conclusion seems almost unavoidable that the conodonts must be considered as the dentition of some primitive type of fish."[21] That this was not the universal opinion of science is evident from the statement by Dr. A. W. Grabau that the conodonts "are believed to be the oesophogeal teeth of annelids."[22]

In commenting on the conodonts Dr. Bashford Dean said that they are "microscopic fossil teeth of an unknown family of animals ranging from the Silurian to the Lower Carboniferous. By Newberry and others these are thought to be the teeth of extinct Cyclostomous fishes; in general they are held to belong to the Annelids."[23]

Dr. J. M. Macfarlane suggested that perhaps conodonts represent complex derivatives from the Metanemertini which, "by progressive change may have given rise to Cyclostomes, some of which retained horny teeth as in existing types, while others may have advanced to a more complex calcareous type."[24] He also gives a set of illustrations to show the close resemblance between the teeth of conodonts and those of existing Cyclostome fishes.[25] In Dr. Macfarlane's later book, "Conodontes" is given as the first order under the Malacodermata, a subclass which includes the most primitive living and fossil fishes.[26] He also stated that he "would wholly accept the conclusions of the two last-named authors (Newberry and Hinde) in viewing them (the conodonts) as the circumoral teeth

---

[20]*Idem*, p. 27.
[21]*Idem*, p. 12.
[22]Grabau, A. W., Textbook of Geology, pt 2, p. 584. 1921.
[23]Dean, Bashford, Bibliography of fishes: Am. Mus. Nat. Hist., vol. 3, p. 665, 1923.
[24]MacFarlane, J. M., Evolution and Distribution of Fishes, p. 107, 1923.
[25]*Idem*, p. 108.
[26]MacFarlane, J. M., Fishes, the Source of Petroleum. p. 33, 1923.

of primitive members of that more primitive group of fishes, the Cyclostomata."[27]

Mr. P. V. Roundy stated that "the zoologic relationship of conodonts has been a subject of much controversy, and they have been regarded by various authors as parts of gastropods, fishes, annelid worms, and crustaceans. Until more is known about these organisms their zoologic position must remain unproved."[28]

During the same year, however, Dr. E. O. Ulrich and Dr. R. S. Bassler published their classification of conodonts with descriptions of American Devonian and Mississippian species,[29] in which it is definitely stated that they "believe the conodonts to be the teeth of primitive fishes and not necessarily all of the same group." Some "seem to be related to the Myxines while the more complicated Prioniodidae and Prioniodinidae show resemblance to the Salachians. . . . However as no true conodonts are known in Post-Paleozoic strata it is possible they belong to an extinct group of fishes."[30]

Grace B. Holmes reviewed briefly the history of classification of conodonts and used Ulrich and Bassler's classification in her bibliography and treatment of some early Mississippian species.[31]

S. R. Kirk found a fair abundance of conodonts associated with the famous fish remains in the Harding sandstone in the vicinity of Cañon City, Colorado. "The particular interest of these bodies is in the fact that they show basal attachment to fragments of plates which are so abundantly scattered through the various beds of the Harding. As is well known, these plates have generally been referred to the Ostracodermi."[32]

Similar attachment of conodonts to fragments of plates has been observed in Middle Ordovician specimens from Kansas,[33] but the

---

[27]*Idem*, p. 36

[28]Roundy, P. V., The microfauna in Mississippian formations of San Saba County, Texas: U. S. Survey Prof. Paper 146, p. 9, 1926.

[29]Ulrich. E. O., and Bassler, R. S., A classification of the tooth-like fossils, conodonts, with descriptions of American Devonian and Mississippian species: Proc. U. S. Nat. Mus., vol. 68, art. 12, pp. 1–63, pl. 1–11, 1926.

[30]*Idem.*, p. 2.

[31]Holmes, Grace B., A bibliography of the conodonts with descriptions of early Mississippian species: Proc. U. S. Nat. Mus., vol. 72, art. 5, pp. 1–38, pls. 1–11, 1928.

[32]Kirk, Stuart Raeburn, Conodonts associated with the Ordovician fauna of Colorado: Am. Jour. Sci., ser. 5, vol. 18, p. 493, 1929.

[33]Stauffer, C. R., Decorah shale conodonts from Kansas: Jour. Pal., vol. 6, pp. 257–264, pl. 40, 1932.

material composing the plates cannot be recognized as bone, much less as the plates of Ostracodermi. Such finds as those at Cañon City quite naturally lead to the suggestion that conodonts are the teeth or spines of the primitive fishlike denizens of the Paleozoic seas. However both Ostracodermi and the Arthrodira are believed to have been limited to the late lower and middle Paleozoic, whereas the conodonts ranged throughout the era. This latter is made certain by the work of Mr. F. H. Gunnell who has found them "in the Permian of Kansas."[34]

PROBABLE TAXONOMIC POSITION OF CONODONTS

Ever since the publication of the classification by Dr. Ulrich and Dr. Bassler, the conodonts have been receiving more attention from those interested in microscopic faunas, and these investigators are calling them the teeth of primitive fishes. Whether the question of classification can ever be settled is not yet beyond doubt, but it is evident that the solution of the problem lies near the fishes. It appears that the whole group of fishlike animals, called conodonts and now represented by teeth, spines and plates, became extinct in Permian time. The Cyclostomata and the more primitive Elasmobranchii, such as the selachians, are probably their nearest living relatives.

One of the strong arguments in favor of including the conodonts with the fishes is their chemical composition. Just what percentage of the original tooth material may be present in the fossil is a question rather difficult to determine. It is true that whether the conodonts came from the Ordovician, the Devonian, or the Pennsylvanian they have essentially the same physical characters even to color, but little is known about the possible variation in composition with increasing age. They are very small and often too scarce to obtain in sufficient quantity for complete chemical analysis. Dr. Pander, however, did make chemical analyses of the conodonts he collected and reported them to be composed chiefly of calcium carbonate, but British chemists later found in them a trace of phosphorus. Dr. Harley says that "they are composed of phosphate and carbonate of lime, the former, contrary to my expectations, the more abundant constituent. The colour is due to sesquioxide

[34]Gunnell, Frank H., Conodonts from the Fort Scott limestone of Missouri: Jour. Pal., vol. 5, p. 244, 1931.

of iron."[35] Mr. Roundy says that "chemically they appear to be a phosphatic carbonate of lime,"[36] and that is the usual statement made by subsequent workers, although there is no indication that additional chemical analyses have been made.

Recently Dr. Ellestad of the Rock Laboratory, University of Minnesota, made a preliminary analysis of conodont teeth from the East Mountain shales at Minerals Wells, Texas, and he reports calcium phosphate ranging from 30 to 50 per cent with probably no organic matter. If this be an indication of the original composition of the teeth, one is forced to the conclusion that they are far removed from the chitinous or horny teeth of the Arthopoda, the Chaetopoda, or the Mollusca. The following table shows the composition of chitin and various forms of horn.

TABLE 1.—*Comparison of chemical analyses of chitin and various forms of horn.*

	Chitin[a] (crab shells)	Horn[b]	Horse hoof[b]	Whale bone[b]
Carbon	46.40	50.86	51.10	51.86
Hydrogen	6.44	6.94	6.77	6.87
Nitrogen	6.66	17.30	17.28	15.71
Oxygen	40.50	4.80?	4.60	3.60
Sulphur	0.00	20.00?	20.15	21.17
	100.00	100.00	99.90	99.21

[a]Brach, Hugo, and Fuerth, Otto V., Biochem. Zeit., vol. 38, pp. 468–491, or Chem. Abstr., vol. 6, pt. 1, p. 1433, 1912.
[b]Given by R. A. Gortner, University of Minnesota.

Conodont teeth are probably chiefly calcium phosphate. Chitin is referred to as a polymerized monoacetylglucosoamine, and horn scleroprotein. Although chitin shows some relationship to horn it is more nearly related to cellulose, $(C_6H_{10}O_5)X$, than to the bone or ivory structures common among vertebrates.

Conodonts are small and delicate crests of highly polished teeth, which are usually brown or amber colored but may be white or even transparent and colorless. Commonly they consist of a bar or base from which one or more cusps arise and these are often followed by a series of denticles in comblike fashion; others are thick

[35]Harley, J., The Ludlow bone-bed and its crustacean remains: Quart. Jour. Geol. Soc., vol. 17, p. 547, 1861.
[36]Roundy, P. V., The microfauna in Mississippian formations of San Saba County, Texas: U. S. Geol. Survey Prof. Paper 146, p. 9, 1926.

and massive with ridged surfaces or tuberculated plates; still others are simple and spinelike. There are, in fact, a great variety of forms, and the number known increases greatly with continued study and search for these minute bodies.

In many specimens the under side of the base is hollowed out and may have a distinct cavity, which in some specimens may be observed to send extensions into the cusps. The whole crest may show shaping into rights and lefts undoubtedly conforming to opposite sides of the same or similar individuals. Occasionally the teeth are found attached to tissue, which was probably either cartilaginous or similar in composition to the teeth themselves. In a few conodont-bearing beds occur fragmentary plates of unknown affiliation, which may belong to the same animal bearing the teeth.

Some conodonts show that the bar or base is composed of two elongate pieces and that the denticles are imbedded in, or set in, the groove formed where these two elements of the bar are cemented together along their sides. When a specimen is treated with hydrochloric acid, it is not uncommon for the denticles to fall out indicating very definitely that the denticles are set in, and are not a part of, the bar. Usually the denticles are so buttressed or reinforced about the base, and by the same material as that composing the bar, that they appear to be more a part of the bar than is really true. Conodont teeth resemble ivory in their microscopic structure and seem to resemble the teeth of vertebrates in their chemical composiion. Their form is not unlike that of teeth possessed by certain of the most primitive living cyclostomous fishes. It would seem, therefore, that their place in the classification is with the most primitive fishes.

DESCRIPTIONS OF COLLECTING LOCALITIES

PALO PINTO COUNTY

Sta. 181–T–9. Steep exposure of 113 feet of East Mountain shale, Mineral Wells formation, in east edge of Mineral Wells and just north of the main road east from this city. This outcrop is the old site of the brick plant that is now located just east of this cliff and on the east side of the outlier capped by the Lake Pinto sandstone member. Two samples that have yielded numerous conodonts have been collected from this exposure, as follows:

B. Very dark, carbonaceous, brittle shales carrying small Pectens, just above a brown calcareous shale layer and about ten feet below the Lake Pinto sandstone. This tough shale washes with difficulty after prolonged boiling in a strong solution of sodium carbonate to a small concentrate that yields frequent conodonts, several species of ostracods, and the foraminifera *Thurammina texana* Cushman and Waters, *Reophax* sp., and *Ammodiscus incertus* (d'Orbigny).

The table of distribution of conodont species shows 43 forms present in this zone; of these 25 are new species.

A. Highly fossiliferous, soft, gray shale in the low banks on the west side of the steep exposure and about ten feet above the base. This material washes readily to a moderate-sized concentrate rich in shell fragments, spines, ostracods, and the foraminifera *Hemigordius calcareous* Cushman and Waters, *Ammodiscus incertus* (d'Orbigny), *Orthovertella protea* Cushman and Waters, and *O. sellardsi* Plummer.

This stratigraphic section has been measured by Plummer and Moore,[37] and numerous fossils collected from these shales have been listed and figured. From a sample collected from the lower fossiliferous shales of this outcrop *Lituotuba centrifuga* (H. B. Brady) has been reported.[38] From a sample collected from near the top of the excavation of the present brick yard and above the calcareous layer *Hemigordius liratus* Cushman and Waters has been described.[39] Coryell and Sample[39a] have used this slope as the type locality for numerous new species of ostracods.

Sta. 181–T–80. About six miles northwest of Mineral Wells and about one-half mile southwest of Pat Gallagher's stone house in a southeastward-facing escarpment and about a hundred yards north of the wagon road. The sample was collected by C. L. Thompson about 15 feet below the base of the Palo Pinto limestone and in the upper part of the Keechi Creek shale of the Mineral Wells formation. This very compact gray shale breaks with conchoidal fracture and washes readily to a small concentrate. Several bryozoan fragments, thirteen species of foraminifera, a few ostracods, and one species of conodont, *Idiognathus delicatus* Gunnell, have been observed in this material. This has become[40] the type locality for the two holothruians *Paleochiridota radiata* Croneis and *P. terquemi* Croneis, and with these occurs also *Protocaudina kansasensis* (Hanna).

SAN SABA COUNTY

Sta. 205–T–29. Steep banks on both sides of San Saba-Lampasas highway 7.5 miles by road east of the courthouse in San Saba. A ten-foot section of typical reddish-brown Strawn sandstones and intervening heavy, unctuous, gray

---

[37]Plummer, F. B., and Moore, R. C., Stratigraphy of the Pennsylvanian formations of north-central Texas: Univ. Texas Bull. 2132, pp. 77, 82, 83, pls. 13, 14, fig. 9, 1921. (Locality 68.1, p. 224.)

[38]Harlton, Bruce H., Some Pennsylvanian foraminifera of the Glenn formation of southern Oklahoma: Jour. Pal., vol. 1, p. 17, 1927.

[39]Cushman, J. A., and Waters, J. A., Some foraminifera from the Pennsylvanian and Permian of Texas: Contrib. Cushman Lab. Foram. Res., vol. 4, p. 44, pl. 5, figs. 11, 12, 1928.

[39a]Coryell, H. N., and Sample, C. H., Pennsylvanian ostracods. A study of the ostracod fauna of the East Mountain shale, Mineral Wells formation: Amer. Midland Naturalist, vol. 13, No. 5, pp. 245–281, pls. 24–26, Sept., 1932.

[40]Croneis, Carey, and McCormack, John, Fossil holothuroidea: Jour. Pal., vol. 6, pp. 111–148, 1932.

clays are well exposed. Conodonts are rare in these clay beds and consist of only *Idiognathus delicatus* Gunnell.

In this exposure *Mooreinella biserialis* Cushman and Waters is very common, and it is probable that this is the type locality for this genotype.[41] Other species described from this same place and found in abundance with a few more foraminiferal species are *Thuramminia texana* Cushman and Waters, *Proteonina cervicifera* Cushman and Waters, and *Hyperamminoides protea* (Cushman and Waters). No large fossils have been found in these strata.

STEPHENS COUNTY

Sta. 214–T–25. Southward-facing slope on the north side of Palo Pinto Creek, 1.4 miles in direct line due east of Wiles and about 0.2 of a mile east of the highway to Strawn, in the east half of the B. B. B. & C. RR. Survey, in the southeast corner of Stephens County. In this slope the Wiles limestone lentil, Graford formation, is the uppermost limestone in the section exposed. This ledge and two thinner limestones below are separated by two 25-foot shale beds. The sample containing conodonts in abundance was collected by C. L. Thompson from the shale immediately above the second limestone layer below the Wiles lentil and about 45 feet below the base of that bed.[42] This very compact, buff, unctuous clay washes to a small concentrate composed almost wholly of fragments of large fossils, in which brachiopod spines, bryozoa, ostracods, and foraminifera of three species are present. Of the 16 forms of conodonts recognized, 11 are new. The holothurian, *Protocaudina kansasensis* (Hanna), has been recorded from this same shale bed.

WISE COUNTY

Sta. 248–T–6. Clay pit at brick plant of Bridgeport Brick Company in the north edge of Bridgeport. These beds lie in the Brownwood shale member of the Graford formation above the Willow Point limestone. Numerous samples of the very compact, tough, fossiliferous gray clay in the lower ten feet of the exposure around the abandoned pit were studied, and two or three proved exceptionally rich in conodonts.

The calcareous foraminifera occurring in these strata have been described and figured,[43] and a list of all the species found shows a rich and varied fauna. Ostracods are abundant and large fossils of many kinds occur in large numbers throughout the series of strata. Recently this has become the type locality for two species of holothurians, *Ancistrum brownwoodensis* Croneis, and *A. ludwigi* Croneis.

---

[41]Cushman, J. A., and Waters, J. A., *op. cit.*, pp. 33, 37, 50, pls. 4, 6.

[42]The graphic geologic section on the Stephens County geologic map, Coöperative Mapping Committee, Bureau of Economic Geology, shows the succession of these strata. The Wiles lentil and the two underlying limestone beds are indicated as Yk_2, Yk_3, and Yk_4, respectively. The sample of clay yielding conodonts was collected immediately above limestone Yk_4.

[43]Plummer, Helen Jeanne, Calcareous foraminifera in the Brownwood shale, near Bridgeport, Texas: Univ. Texas Bull. 3019, pp. 1–21, pl. 1, 1930.

FORAMINIFERAL EVIDENCE OF THE MIDWAY-WILCOX CONTACT IN TEXAS

By

Helen Jeanne Plummer

INTRODUCTION

The problem of establishing the contact of the wholly marine Midway formation and the partially marine lower Wilcox formation in Texas confronts both the field geologist and the laboratory worker. No one criterion in itself can be regarded as sufficient basis for a satisfactory solution wherever the question must be considered. The broad generalizations here presented must be regarded mainly as a possible basis for better standardization in establishing the conformable contact of the Midway and Wilcox formations, for the problem presents itself in so many aspects, that no brief discussion can deal adequately with each of its variable factors. The present study has been the outgrowth of close observations of indisputable and well-exposed contacts of these two formations, thus eliminating at first some of the unknowns with which the geologist must deal in so many areas. Application of the broad lithologic and faunal characters of each of the two formations as seen in well-exposed contacts to areas where the actual contact is more obscure has led to very satisfactory results. In the solution of this problem the foraminiferal evidence has proved to be one of the most reliable guides.

In surface mapping the problem of establishing the Midway-Wilcox contact is solved with less difficulty than in subsurface work. In the field the marked differences in the character of sedimentation of the two formations are intensified by weathering agencies, and the change from the homogeneous Midway to the heterogeneous Wilcox is in most places abrupt and readily observed in the lithology alone. Since, however, the lithologic characteristics of the two formations in the zone of their contact have been insufficiently well established to obviate confusion, as shown by a few published records, the question has here been carefully considered both lithologically and faunally.

Issued February, 1933.

In the study of well samples the Midway-Wilcox contact is likely to be less definitely defined by lithology, as many of the large features visible in outcrop are missed altogether in well sections or seen in samples so small, that interpretation is less precise. Numerous samples carefully taken at close intervals may present sufficient evidence lithologically and faunally to make the conclusions very definite. Core samples taken through this zone constitute a highly satisfactory basis for identifying the two formations. Cuttings complicate the problem so greatly that the contact is very likely to be placed lower than it really lies. Interpretation of much of the subsurface data must necessarily be less precise than that of outcropping strata, for the change from one formation to the other is in general much less abrupt down dip than along the outcropping section nearer the old coast lines.

OUTCROPPING GEOLOGIC SECTION

UPPERMOST MIDWAY STRATA

In outcrop the uppermost Midway section across central and northeast Texas consists largely of dark, compact, gray to bluish-gray and greenish-gray silts, silty clays, clayey silts, and some pure clays, in most of which mica and very fine-grained glauconite occur as evenly distributed constituents. Under the hammer fresh material in which the clay content is sufficient to act as a firm binder breaks out from these strata in heavy, irregular chunks, which commonly exhibit subconchoidal fracture. More silty layers are likely to be looser and somewhat more friable, but coarse sandy layers are very rare. Bedding planes in the compact strata are obvious, but not conspicuous, in the pieces broken from the exposure by force; fragments that weather away from the outcropping face exhibit more strongly these natural planes of weakness. The well-assorted and evenly distributed mineral constituents of the uppermost Midway beds and the lithologic homogeneity throughout the upper part of the formation indicate stable conditions of deposition in moderately deep water and far enough from the coast to show no influences of seasonal changes, storms, and slight fluctuations in elevation.

In extensive outcrops of uppermost Midway strata, as at the abandoned Humble Pumping Station on the west bank of Trinity

River east-northeast of Kerens,[1] the monotony of the dominant, dark, compact, silty clays may be broken by a few somewhat limonitic clayey beds and by hard, calcareous, nodular concretionary ledges from a few inches to a foot or more in thickness. Some isolated boulderlike concretions seemingly unassociated with any definite and continuous hard ledge may project here and there from the dark clays. The concretions associated with uppermost Midway outcrops along stream channels or in the talus at the base of a steep exposure are likely to average somewhat smaller, be somewhat more spherical, and to be finer grained than those so common in the overlying Wilcox beds. Many show very little granular texture, and none show cross-bedding. As these masses are variable in character in both formations, they alone can not be regarded as altogether reliable criteria in identifying the formation. The dominance of marine-deposited, dark, compact, clayey, and in most places fossiliferous beds is the most outstanding character of the formation as a whole up to the base of the Wilcox.

Most of the silty beds in the upper part of the Midway carry varying amounts of glauconite and mica, which locally are abundant. The glauconite is most commonly dull, earthy, pale yellowish green, and very fine grained, and is difficult to observe in most unwashed samples. The mica consists of a little muscovite, but by far the largest portion is altered biotite in coppery brown and vivid green flakes that have been distorted by pressure against fine silt particles. The flakes are so evenly distributed throughout the clays, that they do not contribute to ready fracture along bedding planes as they do in similar Wilcox beds. Irregular and conchoidal fracture alone has proved a very reliable guide to the Midway age of small outcrops of dark clays that can not be observed in relation to beds above and below.

Fossils are present in all uppermost Midway strata. In some outcrops typical Midway gastropods and pelecypods are frequent, and specimens of *Hercoglossa* have been found at a few places.

---

[1]Plummer, Helen Jeanne, The foraminifera of the Midway formation in Texas: Univ. Texas Bull. 2644, p. 49, fig. 9, 1927. The location of this 35-foot bluff extending for several hundred feet along the river is indicated on this sketch map. The actual contact with the Wilcox does not occur in this bluff, but typical Wilcox occurs down the river not far distant. The exposure of Midway strata near this old pumping plant is typical of this part of the section.

Perfect specimens of *Ringicula alabamensis* Aldrich are especially common in concentrates of washed samples. Almost any concentrate from about the uppermost fifty feet of the formation yields ostracods characteristic of the formation as a whole, a few otoliths, and the diagnostically uppermost Midway foraminifera, *Ammobaculites midwayensis* n. sp. and *A. expansus* n. sp. *Spiroplectammina rossae* n. sp. is less persistent in, but characteristic of, this zone. Accompanying these arenaceous species distinctive of these beds are in some places a few of the hyaline forms that belong to the upper Midway[2] faunal zone. Of these *Hemicristellaria longiforma* (Plummer) is the most frequent, and in places just below the Wilcox formation it is abundant. Other hyaline species that have been more rarely observed are *Lenticulina midwayensis* (Plummer), *Siphonina prima* Plummer, *Globigerina pseudo-bulloides* Plummer, *Ceratobulimina perplexa* (Plummer), *Anomalina welleri* (Plummer), *Bifarina eleganta* (Plummer), *Cibicides alleni* (Plummer), *Loxostoma applinae* (Plummer), and a few others.

LOWERMOST WILCOX STRATA

The outcropping Wilcox strata immediately overlying the Midway are marked by variety in the lithologic character, in the color, and in the degree of cementation of its component beds. Within comparatively few feet of vertical section it is possible to find four- to five-foot beds of very fine, almost loesslike silt that exhibits no stratification, cross-bedded coarser sands and clayey sands from a few inches to several feet thick, well-stratified to very finely laminated micaceous sands and silts, clayey sands and sandy clays, compact, lignitic clays with thin, black, carbonaceous partings, thin sulphurous layers, limonitic layers and laminae, and hard, heavy nodular concretionary, coarse sandstone lenses and layers. A particularly common type of bedding comprises as many as fifteen to twenty thin laminae of various kinds of unconsolidated sediments to the inch.

---

[2]The term "upper Midway" is used here in the same sense in which it was used by this author in Univ. Texas Bull. 2644, where it was applied to the sequence of beds lying above the Tehuacana limestone in the Mexia area and above the *Venericardia bulla* glauconitic bed in central Texas. In the forthcoming Univ. Texas Bull. 3232 on the geology of Texas, this upper Midway zone will be called the Wills Point formation of the Midway group. The "basal Midway" of Plummer will receive a new formational name.

Some of the beds are locally rather persistent, and others are lenticular and interfinger with one another through so short a range that a measured section showing details in sequence of strata in one place is likely to be merely a typical section of this part of the formation, which can not be duplicated in the same sequence of individual beds a few miles away. This diagnostic heterogeneity of small lithologic units and poor assortment of constituent minerals within most of the units indicate unstable conditions of deposition in very shallow water near shore, where seasonal climatic conditions on the adjacent land and probably slight fluctuations in elevation along the coast were registered by abrupt and rapid changes in the character of the successive sediments.

Although most of the material comprising these various kinds of beds is characteristically very friable, some dark, heavy, compact, micaceous clays from one to several feet thick occur locally and resemble the upper Midway strata. Such a bed outcrops along Moss Branch on Caldwell Ranch south of Colorado River near the west edge of Bastrop County, and another is exposed along Geronimo Creek two miles east of Seguin, Guadalupe County. In small exposures that do not show clearly the relationship of such a bed to the more typical Wilcox strata above and below, its identity may be questionable. Most dark, compact, silty, micaceous clays in the lowermost Wilcox formation break readily into more platy fragments and exhibits more distinct bedding planes than does similar Midway material. Mica flakes in abundance are oriented parallel to these planes, whereas in Midway clays this mineral is more evenly distributed through the clay and does not therefore influence cleaveage so markedly. Flakes of carbonized organic matter in Wilcox clays are likely to be so coarse and so abundant, that they can be readily seen along the bedding planes in the outcrop, whereas the very small amount of similar material present in some Midway clays can be observed only in the clean concentrates of washed samples. In washing Wilcox clays the argillaceous matter of the disintegrated sample is much more like a fine slime than that of Midway samples.

The lower part of the Wilcox formation is marked especially by its very hard, concretionary sandstone layers that weather out into large elongate and flattened and irregular boulders, which become a conspicuous feature in the landscape of an area underlain by these strata. Cross-bedding is common in the concretions, and this feature alone is sufficient to identify the beds of the Wilcox. Cementation of these resistant layers is variable, so that some boulders are smooth and hard as quartzite; others are softer and more irregular and emit a hollow sound when struck with the hammer. The harder layers commonly carry numerous pelecypods and gastropods, most of which are so well imbedded in the matrix, they are almost impossible to extract. Rare concretions show these shells in relief.

Colors of the strata vary from almost white through yellow to vivid brick red. Carbonaceous beds are black or very dark gray. Sulphurous laminae and lenses are common, and ferruginous layers and well-disseminated stains are especially characteristic of these outcropping lower Wilcox beds.

So far no microfossils have been found in any outcropping Wilcox strata. Since marine gastropods and pelecypods are frequent in the hard concretionary portions and very rare in fragmentary condition in less well-consolidated layers, the early Wilcox epoch must have been marked by frequent fluctuations in elevation of a relatively shallow sea bottom and consequent variety in the characters of its successive deposits. In so shallow and changeable a sea, the more open-water conditions with fresh currents and good circulation favorable for foraminiferal life must have been rare. That foraminifera were originally present and have been leached out of some marine outcropping strata by oxidizing agencies is possible, but since tests are rare in typical lower Wilcox material in subsurface sections farther from the weathering agencies, it seems reasonable to suppose that the coastal sediments of the outcrop must have supported even fewer such forms or none at all. The abundance of lignitic matter in concentrated beds and in flakes disseminated through the clays and silts is significant of highly unfavorable environmental conditions for foraminiferal life in the early Wilcox sea.

MIDWAY-WILCOX CONTACT IN OUTCROP

The contact of the relatively homogeneous, dark, compact, fossiliferous Midway clays or silty clays and the heterogeneous, dominantly reddish-brown, sandy, unconsolidated, finely laminated to heavily bedded, and almost nonfossiliferous Wilcox strata is sharp in most areas. The presence of large fossils in the concretions and rarely in the more unconsolidated strata of the lowermost Wilcox in some places has led to some confusion in differentiating the two formations. Since detailed, and as yet unpublished, studies of these fossils in the zone of contact show that the faunal break lies at the top of the compact, dark clays or silty clays, and since Midway foraminifera and ostracods persist to the top of these same compact beds and have not been found above in any of the layers of the overlying heterogeneous series of sediments, the formational boundaries are readily recognized both lithologically and faunally.

In field mapping lithology alone is in most places a sufficient guide to identification of the uppermost Midway and lowermost Wilcox. Where small exposures of dark clayey strata introduce any doubt, laboratory examination of samples from such beds is very helpful. The presence of *Ammobaculites midwayensis* n. sp., *A. expansus* n. sp., and a few other typical upper Midway species indicates uppermost Midway age within a zone from 50 to 75 feet at the top of the formation. Similar Wilcox clays are devoid of fossil remains and carry commonly conspicuous quantities of carbonaceous matter.

SUBSURFACE GEOLOGIC SECTION

Numerous core sections in central Texas, a few series of cuttings from north Texas, and two core sections in Arkansas have shown that the Midway-Wilcox contact is less sharply defined lithologically down dip than it is in outcrop. The subsurface sediments of both formations represent probably somewhat deeper-water facies, and features such as cross-bedding and fine lamination readily seen in outcrop are more obscure in small core samples and are practically lost in cuttings. Weathering agencies that accentuate marked differences in mineralogic content of strata in outcrop do not constitute a factor in subsurface studies. In general the lower Wilcox formation in well sections is likely to be much more silty, more micaceous, and distinctly more carbonaceous than underlying Midway strata. Commonly samples of Wilcox silty clays carry soluble organic matter that is released by sal soda to make a dark, chocolate-brown liquid during disintegration of the material prior to decantation.

Rarely Midway samples show this same character and only those very close to the contact.

The two formations in well sections are most readily differentiated by foraminifera. In some well sections thin streaks of slightly fossiliferous clay carrying Midway foraminifera are interbedded with typical Wilcox strata before the persistently fossiliferous succession of Midway beds is encountered. It is to be expected that two formations conformable along the outcrop will change from one into the other through a more gradual transition down dip from the outcrop. In such a succession it perhaps becomes a question whether the top of the Midway shall be placed where the first Midway species is encountered in the downward succession of beds or where the beds become persistently fossiliferous downward. Since in outcrop the Midway strata are foraminiferal up to the contact with the Wilcox strata, and since the lower part of the Wilcox is in part marine, as evidenced by much of its bedding and by its larger fossils, it seems reasonable to expect that within a few miles down dip the lowermost marine Wilcox will carry a few beds or lenses bearing foraminifera that are identical with, or closely related to, those in the true Midway strata.

The top of the Midway formation is therefore placed at the top of the series of persistently fossiliferous strata bearing typical Midway species, and of these species *Ammobaculites midwayensis* n. p. is the most characteristic of the uppermost beds and is likely to be the only species present in the upper 20 to 25 feet and may be frequent with other Midway forms as far as 200 feet below the top of the formation. It is accompanied in some places in the topmost strata by *A. expansus* n. sp., *Spiroplectammina rossae* n. sp., and other species diagnostic of the upper Midway zone. The rare foraminiferal lenses above the contact and in the lowermost Wilcox formation yield the same forms present in the uppermost true Midway. In order to establish satisfactorily the Midway-Wilcox contact in well sections, it therefore becomes necessary to study samples collected at close intervals. Cuttings obscure the problem, since contamination of uppermost Midway material by nonfossiliferous Wilcox that has fallen from above makes the few Midway tests difficult to detect, until from 25 to 35 feet of the formation has been penetrated, where tests are usually frequent enough to make identification of the strata definite.

Excellent sets of cores from the Youngblood No. 1 and the Long-Bell No. 1, Shaffer Oil and Refining Co., Grant County, Arkansas, reveal very sharp contacts at the respective depths of 1660 feet and 2160 feet, with no trace of foraminifera above these depths but continuous foraminiferal strata below. Numerous shallow core tests in Bastrop and Caldwell counties, Texas, show the change from nonfossiliferous to persistently fossiliferous strata to be abrupt. Cores from the core test No. 2, Red Bank Oil Co., west-northwest of Fort Sullivan, Milam County, show a thin bed carrying a trace of *Ammobaculites midwayensis* n. sp. a few feet above the contact and separated from it by coarse brown sands and slightly carbonaceous, silty, and micaceous clay typical of the Wilcox. Core samples taken every five feet from the continuous core of the Wise No. 1, Reiter and Foster, near Cameron, show an abrupt change at 300 feet from very silty and highly micaceous, nonfossiliferous Wilcox to more clayey and persistently fossiliferous strata typical of the Midway.

Many miles south or southeast of the outcrop of the zone of contact, the lower Wilcox in some places carries foraminifera in sufficient abundance to obscure greatly the horizon of contact that is recognized near the outcrop. Except at such considerable depths, the top of the continuously foraminiferal strata bearing Midway species has proved very practicable and correlates well with the contact of the two formations in outcrop.

DESCRIPTIONS OF OUTCROPS AND SAMPLES

In collecting samples from strata in the zone of the uppermost Midway and lowermost Wilcox special care should be taken to procure the least silty or sandy material available and to avoid, where possible, the more limonitic layers in an outcrop. The sulphuric acid arising from the alteration of pyrite to limonite is likely to penetrate the mass of the clay and to dissolve some or all the calcareous fossils sought as criteria in determining the stratigraphic position of the outcrop in question. A series of samples from several parts of any outcrops is always desirable, in order to exhaust the possibilities of the fossil content.

After the fresh, tough, hard chunks of material have been thoroughly dried, they disintegrate rapidly in water, and boiling with sal soda yields a fine mud that can be reduced readily to a clean concentrate. Most concentrates from this zone in question are composed largely of very fine quartz silt, more or less glauconite, and some mica. The comparatively few foraminifera present in such a sample can be concentrated quickly and safely by screening the whole concentrate through two or three grades of organdie cloth, which is wirey and easily found in various grades of mesh and can be cleaned and used with more safety than the copper screens commonly used in laboratory work. Pieces about one foot square can be held on opposite sides and convenient portions of the concentrate shaken on it. The author uses most commonly one coarse-mesh cloth with about 55 threads to the inch and another considerably finer with 80 threads to the inch, two screens that separate material into three convenient grades. Grading of almost any concentrate facilitates rapid and thorough examination, and any convenient arbitrary grades are just as suitable as standard grades.

The most reliable and persistent uppermost Midway species, *Ammobaculites midwayensis* n. sp. and *A. expansus* n. sp., are very likely to be found in the coarsest or medium grade of screened concentrate, and since these portions are likely to be small, the tests present in the sample can be rather quickly found. If these species are present as under-developed tests in a sample, they may occur only in the finest concentrate, but this is rare. *Spiroplectammina rossae* n. sp. is normally very small and is most likely to be present only in the finest concentrate, which may carry other minute tests of Midway species.

Bastrop County

Sta. 11–T–3. Midway-Wilcox contact in right bank of Solomon's Creek about one-quarter of a mile east of its junction with Wilbarger Creek[3] and about 1 mile west-southwest of Lawrence Solomon's house, which lies on the west side of the Elgin-Utley road, 5.8 miles by road south-southwest of the railroad crossing south of Elgin. Just back of the house the creek valley exposes typical Wilcox strata[4] carrying fossiliferous concretions. By walking down

[3]On the Bastrop quadrangle the outcrop lies on the small unnamed creek (generally known as Solomon's Creek) between the *r* and the *g* of the name "Wilbarger" about 4¼ miles north of Rogers Park. The old wagon road is shown crossing the creek just a little northeast of here.

[4]Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 43, 1924. The fossiliferous beds along the creek west of Solomon's

the channel southwestward an excellent section can be followed and measured bed by bed. About .4 of a mile walking distance along the meandering creek bed and abandoned wagon bridge in dilapidated condition spans the narrow gorge, and about 800 feet farther down the creek from the old bridge the loose, thin-bedded to thick-bedded variable strata of the Wilcox formation lie conformably on well-exposed, dark, hard, compact, heavily bedded and homogeneous fossiliferous clay. A large *Dentalium* is common in these layers, and a perfect shell of *Natica reversa* Whitfield was found. The washed concentrate carries the very small gastropod *Ringicula alabamensis* Aldrich, fragments of *Strepsidura heilprini* Aldrich, and a species of *Turbonilla,* that is common in upper Midway strata. Of the microfossils, ostracods are common, shark teeth rare, otoliths frequent, and well-developed tests of *Ammobaculites midwayensis* n. sp. and *A. expansus* n. sp., for both of which this outcrop is the type locality, are common.

Freestone County

Sta. 81–T–2. Midway-Wilcox contact on both sides of bridge over Willow Creek about one-quarter of a mile west of the small settlement of New Hope, which is about 4 miles east-northeast of Mexia.[5] The sharp contact of the underlying dark, compact, very tough, and somewhat fossiliferous clays of the uppermost Midway formation with the overlying Wilcox is exposed close to the base of the creek bank and can best be seen about 200 feet south of the bridge. The Wilcox strata are typically finely laminated, micaceous, sandy silts, and limonitic partings, and loose cross-bedded sand so typical of the formation, and these can be observed rather extensively in the numerous steep gullies tributary to this main creek channel in the area south of the bridge. North of the bridge in Midway clay a specimen of *Hercoglossa* has been found, and several gastropods, amongst which *Ringicula alabamensis* Aldrich is common, have been collected. Washed concentrates of these dark uppermost Midway clays yield large numbers of nacreous fragments. Ostracods are rather common in the material. *Ammobaculites midwayensis* n. sp. is frequent and well developed; *A. expansus* n. sp. is rare. Other foraminifera are *Hemicristellaria longiforma* (Plummer), for which this is the type locality, *Lenticulina midwayensis* (Plummer), *Cibicides alleni* (Plummer), *Gyroidina aequilateralis* (Plummer), and traces of a few others.

Guadalupe County

Sta. 94–T–5. Midway-Wilcox contact under new bridge over Guadalupe River about 3 miles southwest of Seguin on the new Seguin-San Antonio highway now under construction. The site of the new bridge was visited just after the lowermost concrete shafts had been set in place on the north side of the river, and around these shafts large quantities of very silty, greenish,

---

house have been included in the Midway formation by this author. The species of gastropods and pelecypods occurring in this section have since been found to be typically Wilcox.

[5]Plummer, Helen Jeanne, Foraminifera of the Midway formation in Texas: Univ. Texas Bull. 2644, pp. 53, 54. fig. 10. Sta. 37, 1927.

compact, fresh clay taken from the excavations lay in large piles. According to information from workmen, the material outcrops about at the level of the river, but along the undisturbed river bank, it is covered by alluvium and talus. The excavations high on the bank exposed typical Wilcox strata and fossiliferous concretions. It is clear that the bridge marks the Midway-Wilcox contact on Guadalupe River.

The concentrate of a washed sample of the compact greenish clay at the base of the slope yields numerous typical Midway gastropods and a few immature pelecypods. *Ringicula alabamensis* Aldrich is common; one specimen of *Natica reversa* Whitfield was found; several youthful shells of *Strepsidura heilprini* Aldrich, *Cylichna emoryi* Gardner n. sp. (Ms.), *Tienostoma eoa* Gardner n. sp. (Ms.), and other shells too youthful for identification. Ostracods and holothurian fragments are very frequent, sponge spicules are rare, and foraminifera of the species *Ammobaculites midwayensis* n. sp., *A. expansus* n. sp., *Hemicristellaria longiforma* (Plummer), and *Siphonina prima* Plummer are frequent.

Navarro County

Sta. 174–T–6. Uppermost Midway clay on south side of Foggyhead Creek in Smith's pasture and about .15 of a mile west of the bridge on the Kerens-Round Prairie road 3.8 miles by road south-southeast of the railroad station in Kerens. Along the upgrade south of the bridge on the Kerens-Round Prairie road the Wilcox strata are well exposed. Although the actual Midway-Wilcox contact can not be seen anywhere in this vicinity, relationships prove that the Midway strata exposed on Foggyhead Creek are only a few feet below the contact.

The Midway strata exposed here have been measured and described by Miss Gene Ross, who reported the outcrop to the Bureau of Economic Geology in 1931. The lower 3 feet of the bank comprise dark, compact, very slightly silty clay that breaks with conchoidal fracture and yields the largest number of fossils. Overlying these dark, heavy clays are about 8 feet of somewhat yellowish compact clays stained by streaks of limonite and yielding only a trace of fossils. This limonitic clay grades upward to soil at the top of the bank.

Several gastropods and a few pelecypods occur in these beds, and a very fine specimen of *Hercoglossa ulrichi* (White) has been collected here by Miss Ross. The concentrate from a washed sample of the lower dark clays is composed of very little silt, an abundance of echinoid spines and plates, few holothurian fragments, several otoliths, few crab shells, numerous typical ostracods, and foraminifera. Many well-developed tests of *Ammobaculites midwayensis* n. sp. and *A. expansus* n. sp. are accompanied by an unusual number of hyaline upper Midway forms: *Ceratobulimina perplexa* (Plummer), *Bifarina eleganta* (Plummer). *Lenticulina midwayensis* (Plummer), *Siphonina prima* Plummer, *Anomalina welleri* (Plummer), and *Globigerina pseudobulloides* Plummer. A very small arenaceous species, *Spiroplectammina rossae* n. sp., which is more common in well samples, is common in these outcropping strata, and this is therefore chosen as the type locality for the species.

DESCRIPTIONS OF SPECIES

AMMOBACULITES MIDWAYENSIS n. sp.

Pl. 5, figs. 7–11

Test elongate, slender, very coarsely arenaceous and roughly finished, composed of angular quartz grains bound by a reddish insoluble cement up to the last chamber which is conspicuously whiter than the rest of the test; early 5 to 7 chambers arranged in a tight, compressed coil of a little more than one convolution and with rounded periphery; succeeding chambers rectilinear, about as high as broad, and varying from uncompressed to considerably compressed; sutures visible and very slightly depressed on some tests, but in general obscure or even hidden by the texture of the wall; aperture terminal and round or somewhat elongate, depending on the degree of compression due to forces of fossilization of a somewhat plastic original test.

Length of holotype .65 mm.; diameter of coil .20 mm.; width of rectilinear chambers .18 mm. In samples carrying well-developed tests of this species a length of 1 mm. is not uncommon. Where conditions have been less favorable for their growth, the average test present may be much smaller than the holotype, which is representative of the species at its type locality.

Like many of the more primitive and coarsely arenaceous forms, *Ammobaculites midwayensis* n. sp. is highly variable in shape and proportions, and its acquaintance should be made from a generous number of specimens. The figures present some of these variations, which in part are no doubt due to deformation. The compression of the rectilinear portion of many tests must be the result of mechanical forces operative in the sediments after the death of the protoplasm. Some tests are almost uncompressed; others, especially the smaller and more fragile tests developed under somewhat unfavorable conditions, are strongly compressed.

The reddish metallic color of any typical test of *A. midwayensis* n. sp. up to the last chamber is not due to the pyritic or limonitic fillings commonly present in the chamber cavities. In the numerous tests examined by transmitted light these fillings were found in all chambers to the aperture, yet these same viewed in reflected light show white, or nearly white, final chambers. Regardless of the age of the test, the final chamber is white, indicating that each penultimate chamber in succession was stained during the construction, or after the completion, of the final chamber. In only two samples under observation are tests of this species devoid of all color, and since they are underdeveloped it can be assumed that environmental conditions were unfavorable for typical growth. In the other numerous outcrops and well samples carrying this form, the characteristic reddish-brown tone is a persistent feature.

Most tests show the somewhat flattened initial coil very clearly in the somewhat unsymmetrical and broadly rounded outline of this part of the test and in a faint umbilical depression. At a few localities the peripheral outline of the test is more nearly like a somewhat flattened cylindrical form. Close observation of such tests with transmitted light is likely to show the arrangement of the early chambers, if they are filled with a dense mineral.

In general aspect *A. midwayensis* n. sp. resembles somewhat some Pennsylvanian species in Texas, but it is much larger and much more coarsely arenaceous than any of the older forms of superficially similar structure and proportions.

A. midwayensis n. sp. is the most persistent uppermost Midway foraminifer both in outcrops and in well sections near the outcrop. The author has had no opportunity to examine subsurface samples in the zone of the Midway-Wilcox contact at considerable depths. Just below the Wilcox the species most commonly occurs alone in the Midway beds, though it is commonly accompanied by *A. expansus* n. sp. Almost any of the typical upper Midway forms characteristic of about the upper 300 feet of the formation may be present in the topmost strata of the formation with these two species of *Ammobaculites*, but they are likely to be rare or poorly developed. *Hemicristellaria longiforma* (Plummer) and *Lenticulina midwayensis* (Plummer) are the most frequent hyaline species in these uppermost strata. *Ammobaculites midwayensis* occurs in the outcropping section almost wholly in the upper 50 to 75 feet of the formation, and because of its peristence in this zone across Texas, it is one of the valuable markers. In well sections it is found commonly throughout the upper 200 feet of the formation, but as depth increases the common hyaline Midway species become more and more numerous in individuals and in species, and these forms of *Ammobaculites* disappear.

Holotype and paratypes, Plummer Collection (S–868), from north bank of Solomon's Creek near its junction with Wilbarger Creek, 6½ miles south-southwest of Elgin, Bastrop County (11–T–3). Metatypes in museum of Bureau of Economic Geology.

AMMOBACULITES EXPANSUS n. sp.

Pl. 5, figs. 4–6

Test broadly elongate, very coarsely arenaceous and roughly finished, composed of angular quartz grains bound by a reddish and insoluble cement up to the apertural rim, which on many specimens is white; about the first 12 chambers arranged in a tight and very strongly compressed and slightly umbilicate coil of two convolutions; final two or three chambers arranged in rectilinear succession and also strongly compressed; sutures very obscure except between last two or three chambers of a fully mature test where they are somewhat depressed; aperture a narrow elongate opening at the end of the final chamber.

Length of holotype .58 mm.; breadth .40 mm.; thickness of final chamber .06 mm. Lengths up to 1 mm. have been observed, but the holotype is representative of the size of this species.

Ammobaculites expansus n. sp. varies somewhat in peripheral outline. The degree of compression is so slightly variable, that probably its fossilized state represents its original form, unless the shell was so very plastic that all tests collapsed completely and therefore equally after death of the protoplasm. The rectilinear chambers are so fragile that most tests found in a washed sample show fracture tangent to, or close to, the coil. In very tough clays that are difficult to concentrate, it is almost impossible to find complete specimens.

The dark, metallic, and somewhat reddish cement in the shell wall extends up to the rim of the aperture. This character is not so persistent a character of this species of *Ammobaculites* as it is of *A. midwayensis* n. sp. The color of this broad flat form is commonly almost black due to the pyrite filling, and tests bearing the reddish tone are not necessarily the rule.

A. expansus n. sp. is readily distinguished from its congeners in the Texas section by its large coil of many chambers, its short broad outline, and its strong compression.

In outcrops and in well sections this species occurs with *A. midwayensis* n. sp. in the upper part of the upper Midway zone. It is not so persistent a species in these beds, and is therefore not so valuable as a marker. In outcrops it has been found restricted to about the uppermost 50 feet of the formation; in well sections it persists downward into the Midway farther than *A. midwayensis* and becomes more and more rare with depth. These two species are the most reliable markers of uppermost upper Midway and in most of the strata in this zone they are about the only foraminifera present.

Holotype and paratype, Plummer Collection (S–869), from north bank of Solomon's Creek 6½ miles south-southwest of Elgin, Bastrop County (11–T–3). Metatypes in museum of Bureau of Economic Geology.

SPIROPLECTAMMINA ROSSAE n. sp.

Pl. 5, figs. 1–3

Test very small, elongate, expanding gradually from the somewhat bluntly pointed initial extremity, strongly compressed, thickest along the axis, white, composed of very fine siliceous particles bound by an insoluble cement, thin shelled; early four or five chambers arranged in so minute a coil that the average peripheral outline hardly suggests this structure; later chambers typically biserial, narrow, slowly lengthening through early maturity and still more slowly through late maturity, sloping from the axis on each side at an angle of about 45 degrees and gently curved downward along the outer edge; sutural limbations strongly elevated on each side of the center but not merged, and tapering rapidly toward the peripheral margin, which is very narrowly rounded and unflanged; aperture a rather high arch at the base of the septal face.

Length of holotype, .32 mm.; width .19 mm.; thickness .09 mm. The average test is somewhat less than twice as long as broad, but unusually long ones may be more than twice as long as broad, since in late maturity the breadth increases little, if at all. The largest specimen measured was .40 mm. long and .18 mm. wide.

Some tests show deformation and various degrees of lateral compression due to a slight collapse of the chamber walls; consequently the ratio of thickness to width and the resultant cross-section varies from about .45 to .65. This ratio in most of the numerous tests measured is about .5. Several full-bodied tests that are obviously fossilized in their original proportions show a ratio of thickness to width equal to .55. The marked sutural elevation is an original character and is not due to collapse of the intervening chamber walls, though this feature may be somewhat emphasized by collapse.

The outline of a very few tests is spatulate, but by far the larger number are composed of chambers that lengthen throughout growth, and their outlines are typically somewhat flaring.

The early coil is a very obscure structure in most tests. Fortunately the thin shell wall, the lateral compression, and the frequent pyrite filling of the chamber cavities permits easy observation by transmitted light.[6]

The initial extremity of *Spiroplectammina rossae* n. sp. is so fragile. that many specimens are likely to be devoid of this early structure, and since the loss of this portion is not always readily detectible, hasty observations of a few specimens may reveal only the biserial structure. The close study of a large number of pyrite-filled tests by transmitted light shows that the early coil of 4 or 5 chambers varies considerably in size, and therefore the peripheral outline of the initial end varies from almost a point in rare tests to a rather broad curve. This variation is probably in part a factor of the dimorphism or trimorphism in the species.

S. rossae n. sp. is very distinct from *S. expansa* (Plummer) in the same formation in its less V-shaped outline, its blunter periphery with flange, shape of chambers, angle between direction of chambers and the axis, and character of sutural elevation.

---

[6]Since transmitted light from a mirror below the stage is difficult to soften sufficiently to obviate a glare. a convenient method for studying the structures of pyrite- or limonite-filled thin tests is to mount specimens in a drop of water on a thick glass slide backed by very white paper and direct the light from the lamp toward the specimens at a rather low angle from above the stage of the binocular. The reflection from the white paper upward through the dampened specimens is sufficient to give beautiful silhouette views of the chamber fillings. Calcareous agglutinate tests of greater size and stoutness than this species can be successfully decalcified, in order to reveal the arrangement of the mineral fillings of the chambers, but this technique is unsatisfactory in studying very delicate tests.

In well sections this species is very frequent in the uppermost Midway strata, and it is a helpful guide in establishing the Midway-Wilcox contact. In outcrop the form is too rare to be of much assistance in mapping, but at its type locality it is abundant.

This form has been named for Miss Gene Ross, who collected the sample during summer field work in 1932.

Holotype and paratype, from bank on Foggyhead Creek 3.8 miles by road southeast of Kerens railroad station, and a few feet below the overlying Wilcox strata, Navarro County (Sta. 174–T–6); Plummer collection S–870. Metatypes in museum of Bureau of Economic Geology.

FUSULINIDS OF THE BIG LAKE OIL FIELD, REAGAN COUNTY, TEXAS

By

C. O. Dunbar[1]

The age of the Carboniferous beds in the Big Lake oil field, Reagan County, Texas, is still a matter of controversy. A few specimens of fusulinids occurring at depths between 7600 and 8336 feet led me to assign the beds at those depths to the base of the Permian. While some of the micropaleontologists in the field have supported this correlation, others, working upon other data, have concluded that the beds are of middle Pennsylvanian (Strawn) age.* Publication of the information underlying these conflicting opinions should help us to evaluate the evidence. It is the purpose of this note, therefore, to set forth the facts which have led me to believe that the fusulinids are of early Permian instead of middle Pennsylvanian age.

Sellards and Patton[2] in 1926 gave an account of the discovery and early developments in the field. At that time the deepest well had reached about 6000 feet. It was recognized that the wells started in the Comanche limestones and passed downward through basal sands of the Lower Cretaceous into red beds which include much salt and anhydrite, then into dolomite, and finally into dark sands and shales and black shale. At that time Sellards and Patton recognized 300–600 feet of Comanche, 100–500 feet of Triassic, and below this, Permian. In the absence of any fossils from the lower part of the section, they concluded that "the deepest well drilled in the field, approximating 6000 feet, has not afforded evidence of having passed the base of the Permian."

By the end of 1928 wells had penetrated below 8000 feet and in April, 1930, a core from Big Lake Oil Company No. 1-C well at a depth of about 8450 feet revealed Ordovician rock. By this time a few fossils had been secured from the dark sediments below

---

[1]Yale University, New Haven, Conn.

*Letter from Bruce Harlton, July 12, 1932.

[2]Sellards, E. H , and Patton, Leroy T., The subsurface geology of the Big Lake oil field: Bull. Am. Assoc. Petr. Geol., vol. 10, pp. 365–381, 1926.

Issued February, 1933.

7600 feet. One of the first of these was a fusulinid, embedded in a small chip of limestone from Big Lake Oil Company No. 3-C well. In February, 1930, E. H. Sellards transmitted this specimen to me with the following memorandum:

> Mr. Grant, who sends this fossil, says that at the time the piece of rock came out of the well the casing in the well was set at 7806 feet. The fossil is necessarily from below that depth, and he believes that the rock came from between 8280 and 8301 feet as the hole was caving from that depth. If this fossil can be sufficiently determined to show that part of the Pennsylvanian is present between 7806 and 8300 feet, it will be a very important advance in our knowledge for that locality.

Preliminary exploration with needles under a binocular indicated the orientation of the broken specimen in the rock and permitted me to grind one side away to a well oriented axial section showing the proloculum. The buried end of the specimen was found to be slightly broken but the early volutions were intact and the preservation good.

The specimen proved to be an elongate, subcylindrical shell with a diameter of 3.3 mm. and a length (restored by extrapolating the ratio of increase of the inner volutions) of between 12 mm. and 14 mm. It possesses 6 volutions, a rather large proloculum, measuring about 230 microns in diameter, and septa that are rather deeply and regularly fluted so that the longitudinal chambers (as seen in tangential slices) are well divided basally into chamberlets. Chomata are almost completely lacking. The wall increases gradually in thickness from about 60 microns in the third volution to 150 in the fifth and shows a well developed keriotheca. The tunnel is wide, spreading from 55° in the third and fourth volutions to about 90° in the fifth.

The character of the septal fluting, the obsolescence of chomata and the large size and subcylindrical form of the shell suggested a comparison only with early Permian species of the group now known as *Pseudofusulina*. I therefore wrote Dr. Sellards as follows:

> The fusulinid turns out to be a rather early form of the *Fusulina elongata* stock, and represents a variety which occurs in the Wolfcamp formation of the Glass Mountains section. It is not a Pennsylvanian form—at least nothing like it is present in our collections from the Gaptank formation, nor have I seen anything like it from the Cisco

of central Texas. It is rather more advanced than *Fusulina longissimoidea* of the higher Wabaunsee division of the Kansas-Nebraska Pennsylvanian, and I feel quite confident that it is too highly specialized to occur anywhere in our Pennsylvanian. It is almost surely a Wolfcamp fossil.

It must now be added that since the above was written Roth[3] discovered a fusulinid fauna under the Saddle Creek limestone in the upper Cisco, which contains two species of *Pseudofusulina*, *P. longissimoidea* and *P. forakerensis*. This is a fauna which in Oklahoma and Kansas includes *Schwagerina* and is found in the Foraker-Neva horizon. Its discovery does not alter the import of my original correlation.

The macrofossils occurring in these wells at horizons below 8000 feet and above the Ordovician have kindly been made available to me by Dr. Sellards. Among these fossils I recognize the following found in cores from well No. 2-B at the depths indicated:

Orbiculoidea sp. cf. *O. missouriensis* (all juvenile); at depths 8060, 8140, 8141, 8144, and 8145 feet.
Lingula sp. cf. *L. carbonaria* (all juvenile); at depths 8215 and 8223 feet.
Dictyoclostus sp.; at depths 8217 and 8221 feet.
Chonetina sp.; at depth 8217 feet.
Monilopora sp.; at depth 8219 feet.
A low spired, smooth gastropod; at depths 8144 and 8145 feet.
Ganoid fish scales; at depth 8147 feet.
A large distinctive ostracod with a very wide, radially striated frill and with two transverse nodes; at depths 8140, 8144, 8145, 8146, and 8215 feet.

Of these fossils, some are of doubtful relationship by reason of being juvenile, and others are too fragmentary to be identified. The ostracod is apparently new. These fossils are indeterminate as to Pennsylvanian or Permian age. Well No. 3-C, from which the fusulinid was obtained at a depth below 7806 feet and probably from between 8280 and 8301 feet, entered the Ordovician at 8470 feet, and well No. 2-B, from which the macrofossils were obtained between depths 8060 and 8223 feet, entered the Ordovician at 8225 feet.

---

[3]Roth, Robert, New information on the base of the Permian in north-central Texas: Jour. Paleont., vol. 5, p. 295, 1931. The fusulinids were referred by Roth to the Waldrip or Crystal Falls limestone, but according to Sellards (letter of December 5, 1932), the horizon as located by Roth in his published paper lies about 20 feet below the Saddle Creek limestone.

Early in 1930 fusulinids were secured by H. A. Hemphill from well cuttings at four horizons in the Big Lake Oil Company, University Well No. 1-C. These may be designated Lots 1 to 4 as follows:

Lot 1—depth 7670–7689
Lot 2—depth 7689–7701
Lot 3—depth 8320–8330
Lot 4—depth 8330–8336

The specimens were few, mostly small and immature, and nearly all somewhat broken. Nevertheless, Mr. Hemphill made splendid use of his material and succeeded in getting a few well oriented sections showing the proloculi. This material, sent to me in May, seemed to confirm the previous identification of early Permian age. My comments, along with many other data on the field, were published by Sellards, Bybee, and Hemphill in 1931.[4] None of the specimens has heretofore been illustrated, however. Since the material is so meager, it seems unsafe to make specific identifications and, therefore, unwise to write formal descriptions of the several specimens. I wish, however, to present the evidence which leads me to identify two of the specimens of lot 2 (depth 7689–7701 ft.) as juvenile specimens of a *Schwagerina* near *S. fusulinoides*.

The specimens of lot 2 prepared by Mr. Hemphill include an axial and a sagittal section of the *Schwagerina* in question (Pl. VI, fig. 2, a, b, c). These are shown here for comparison, between similarly oriented sections of young specimens of *Schwagerina* cf. *fusulinoides* (Pl. VI, fig. 1, a, b, c.) from the Wolfcamp formation near Wolfcamp, and of the similarly shaped and widely distributed *Triticites ventricosus* (Pl. VI, fig. 3, a, b, c.) from the Upper Pennsylvanian. All six specimens are shown at the same magnification and the photographs have not been retouched or in any way altered.

Both specimens from the deep well have suffered some in preservation. The outer volution in each is partly filled with dark sediment and the walls throughout have been silicified so that the primary wall structure is to a large extent obscured and the septa

[4]Sellards, E. H., Bybee, H. P., and Hemphill, H. A., Producing horizons in the Big Lake oil field, Reagan County, Texas: Univ. Texas Bull. 3001, pp 149–203, 1930.

thickened. Nevertheless, clear evidence of a well developed alveolar texture can still be seen in places in both sections. Four features of these shells deserve emphasis: (1) the walls are rather thick and have an alveolar texture; (2) the early volutions are tightly coiled to form a well defined nucleoconch, whereas the outer volutions expand much more rapidly and appear very deep in the sections; (3) there is little evidence of chomata; and (4) the septa, though widely spaced, are rather strongly fluted, even in the equatorial zone.

In all these features the agreement of the specimens in question with similarly oriented sections of *Schwagerina* appears evident. In the last three characters, the disagreement with a typical Pennsylvanian *Triticites* appears equally marked. The sagittal section of the deep well specimen shows a well defined nucleoconch of about 3¼ volutions, following which there is a very decided inflation so that the fourth volution attains a height equal to three volutions of the *Triticites* of equal diameter. The axial section likewise shows a nucleoconch, but the number of its volutions is of course less clearly shown. In the latter section the practical absence of chomata forms a marked contrast with the *Triticites* in which these structures appear as heavy deposits on each side of the tunnel. All the other fusulinid genera save *Schwagerina* expand gradually, as does *Triticites,* and as a result have no distinct nucleoconch.

I see no escape, therefore, from the conclusion that two of the fusulinids in question represent a species of *Schwagerina* of the tribe of *S. fusulinoides,* though, unfortunately, neither one is probably over half grown. If the identification is correct, it is out of the question to consider the beds at this depth as of Strawn age.

The other specimens studied are less diagnostic. Probably all are juvenile individuals and most of them are broken. It may be emphasized, however, that every one of them shows the thick wall and alveolar texture of the Schwagerininae[5] and not the type of wall seen in the lower Pennsylvanian forms such as *Fusulina* (s.s.), *Fusulinella* and *Wedekindia.* From the zone of 7670–7689 there are two axial sections representing, apparently, juvenile shells of a *Pseudofusulina.* One of these has a phenomenally large proloculum,

---

[5]Dunbar, C. O., and Henbest, L. G., The fusulinid genera *Fusulina, Fusulinella* and *Wedekindia:* Am. Jour. Sci., 4 ser., vol. 20, pp. 357–364, 1930.

measuring 550 microns in diameter. While this is hardly proof of Permian age, it is strongly suggestive thereof since much smaller proloculi are the rule in the Pennsylvanian fusulinids.

It is evident that if the beds in the Big Lake oil field are Permian to a depth of 7700 or even 8300 feet, the Pennsylvanian is largely lacking. In this case we may expect that the field lies upon a pre-Permian structural feature.

A PENNSYLVANIAN SPONGE FAUNA FROM WISE COUNTY, TEXAS

By

Ralph H. King

INTRODUCTION

The object of this paper is to draw attention to a little-known group of sponges that is apparently restricted in its vertical range, and may therefore be of some assistance in correlating strata in areas where representatives of this group are found. Unfortunately, up to date only eleven localities in three widely separated areas have yielded material for study, and the range of the fauna has not been definitely determined.

In 1908, Girty[1] described a group of sponges from the top of the Allen limestone (now called Plattsburg) in a "cut on the Santa Fe Railroad, 6 miles southwest of Chanute, Kansas." One of the species described, *Heterocoelia beedei* Girty, had been figured previously under another name by Beede,[2] who had collected his specimens at Thayer in the same county and probably from about the same stratigraphic position. In October of 1932 the writer's father collected and made available for study material from the type locality of Girty's species and from other nearby localities.

In the Glass Mountains of west Texas, Beede and others have collected from the Gaptank formation representatives of this same fauna. These specimens are at present in the collection of the Bureau of Economic Geology at Austin.

At a locality on the banks of McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas, the writer has collected material that represents a very extensive development of about the same fauna found in Kansas and the Glass Mountains. It is here proposed to establish one new genus and four new species based on this material. The strata from which this fauna has been obtained include a yellow sandy limestone approximately 1 foot thick

[1]Girty, Geo. H., On some new and old species of Carboniferous fossils: U. S. Nat. Mus., Proc. vol. 34, pp. 281–303, pls. 14–21, 1908.

[2]Beede, J. W., Carboniferous invertebrates: Univ. Geol. Survey Kansas, vol. 6, p. 15, pl. 1, fig. 2f, 1900.

Issued February, 1933.

between beds of yellow clays, the entire section being about 20 feet in thickness. This exposure lies in the Brownwood shale from about 35 to 55 feet below the Rock Hill limestone of the Graford formation of the Canyon group of north-central Texas.[3] Other material from nearby localities is in the collections of the Bureau of Economic Geology and of Texas Christian University.

The localities are here numbered for convenience and described as follows:

1. Midway of slope on left bank of west fork of McCoy's Creek about one-half mile above junction of forks, and about 4 miles northwest of Bridgeport, Wise County, Texas (Bureau Econ. Geol. Sta. 248–T–24). Graford formation. Collectors, Ralph H. King, Roy H. King. This is the type locality for *Heterocoelia sphaerica* n. sp., *Girtycoelia typica* n. sp. (genotype), *Maeandrostia toıtacloaca* n. sp., and *Heliospongia excavata* n. sp.

2. Böse's locality on the west side of Martin's Lake, a mile south of Bridgeport and just south of bend in road where road turns south after running east, Wise County, Texas (Bureau Econ. Geol. Sta. 248–T–4). Palo Pinto formation. Collector, Emil Böse.

3. "Parr Ranch, south of Chico," Wise County, Texas (Bureau Econ. Geol. Sta. 248–T–5). "Graford" formation. Collector, Emil Böse.

4. "Near Martin's Ranch," Wise County, Texas (Bureau Econ. Geol. Sta. 248–T–7). "Graford" foımation. Collector, Emil Böse.

5. At Gap Tank in Glass Mountains, Pecos County, Texas (Bureau Econ. Geol. Sta. 185–T–3). Gaptank formation. Collector, J. W. Beede.

6. "Below Wouldridge Tank, Hueco Mountains," Hudspeth County, Texas (Bureau Econ. Geol. Sta. 114–T–7). Collector, J. W. Beede.

7. About 2 miles southeast of Gap Tank, Pecos County, Texas (Bureau Econ. Geol. Sta. 185–T–1). Collector, J. W. Beede.

8. Near milepost 132, on Santa Fe Railroad, 6 miles southwest of Chanute, Kansas. Cut in Plattsburg limestone. Collector, Roy H. King. This is the type locality for *Heterocoelia beedei* Girty, *Girtycoelia benjamini* (Girty), *Maeandrostia kansasensis* Girty, *Coelocladia spinosa* Girty, *Heliospongia ramosa* Girty, and *Heliospongia parallela* Girty.

9. Small knoll, .5 of a mile south and .9 of a mile west of the west end of Main Street, Chanute, Kansas. Collector, Roy H. King.

10. High on bank on west side of road 3.2 miles north of Altoona station, Kansas. Lane shale just below Plattsburg limestone. Collector, Roy H. King.

11. One-half mile north of road in escarpment one-half mile west of Joplin, Jack County, Texas, at point where Devils Den limestone pinches out. Graford formation. Collector, Gayle Scott.

———

[3]Scott, Gayle, and Armstrong, J. M., The geology of Wise County, Texas: Univ. Texas Bull. 3224, pp. 29–31, 1932.

The following table shows the distribution of sponge species in these eleven localities:

	Locality										
	1	2	3	4	5	6	7	8	9	10	11
Heterocoelia beedei Girty	K				B			G, K	K	K	S
Heterocoelia sphaerica n. sp.	K										
Girtycoelia benjamini (Girty)								G	K	K	
Girtycoelia typica n. sp.	K										S
Maeandrostia kansasensis Girty	K				B	B	B	G, K	K	K	S
Maeandrostia tortacloaca n. sp.	K		B	B	B						
Coelocladia spinosa Girty	K	B	B					G, K			
Heliospongia ramosa Girty	K				B		B	G, K		K	
Heliospongia parallela Girty								G, K			
Heliospongia excavata n. sp.	K										

K indicates material in the collections made by the writer and his father, Roy H. King.

G indicates material collected by Girty.

B indicates material in the collection of the Bureau of Economic Geology collected by Beede, Böse, and others.

S indicates material in the collection of Texas Christian University collected by Scott.

In addition to the material listed, Beede[4] reports a *Coelocladia* sp. from the Gaptank "about 3 miles south of Gap Tank."

The fauna from the McCoy's Creek locality, exclusive of sponges, is as follows:

Lophophyllum profundum (Milne-Edwards and Haime)
Spirifer fragments
Productid fragments
Astartella varica McChesney
Astartella concentrica (Conrad)
Patellostium montfortianum (Norwood and Pratten)
Euphemus carbonarius (Cox) (abundant)
Meekospira peracuta? (Meek and Worthen)
Orestes brazoensis (Shumard)
Phanerotrema grayvillensis (Norwood and Pratten)
Pharkidonotus tricarinatus (Shumard)
Sphaerodoma primigenia? (Conrad)
Trepospira illinoisensis (Worthen)
Worthenia tabulata (Conrad)
Zygopleura rugosa? (Meek and Worthen)
Echinoid spines and plates
Crinoid stems, spines, and plates
Bryozoa spp.
Delocrinus sp.

[4]Udden, J. A., Notes on the geology of the Glass Mountains: Univ. Texas Bull. 1753, p. 38, 1917.

DESCRIPTIONS OF GENERA AND SPECIES

Genus HETEROCOELIA Girty

Heterocoelia Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, p. 283.

Forms belonging to this genus are stemlike in shape. Each stem, consisting of a row of small spherical cells, may be straight, curved, or branching. Through each stem runs a central cloaca, which is continuous from cell to cell, and the constituent spheres communicate with this cloaca through pores. The chambers may be just in contact, overlapping, or separated by an interval bridged by the cloaca. In all specimens the walls of the separate cells are distinct and do not merge with the walls of the adjacent cells. Each sphere is perforated by several large ostia, which serve as a means of communication between the sphere and the exterior.

Genotype, *Heterocoelia beedei* Girty.

HETEROCOELIA BEEDEI Girty

Pl. 7, figs. 5–6

Amblysiphonella prosseri Beede (part), 1900, Univ. Geol. Survey Kansas, vol. 6, p. 15, pl. 1, fig. 2f.

Heterocoelia beedei Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, p. 284, pl. 14, figs. 1–8.

Specimens of this species are straight, bent, or branching stems, composed of small spheres about 10 mm. in diameter, laid end to end and connected by means of a central cloaca. The individual spheres communicate with the exterior through six to eight large, spoutlike ostia, and with the cloaca through small pores. The wall structure is somewhat laminated and imperforate except for the apertures mentioned.

In the material from McCoy's Creek, most of the stems have been broken up into single spheres, the nature of which is such as to indicate that in that area the constituent spheres of most of the specimens did not overlap but were separated rather widely.

Beede's collection from Gap Tank in the Glass Mountains contains etched specimens of indeterminate species, but P. B. King[5] reports *Heterocoelia beedei* Girty from the same locality.

Plesiotypes, Bureau of Economic Geology, Coll. No. 11728, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

[5]King, P. B., Geology of the Glass Mountains: Univ. Texas Bull 3038, p. 47, 1930.

HETEROCOELIA SPHAERICA n. sp.

Pl. 7, figs. 7–8

The external appearance of this species is similar to that of *H. beedei* Girty, except that the ostial margins are barely elevated instead of spoutlike, and the shape of the individual segments is nearly spherical rather than slightly elongate, as are most undistorted specimens of *H. beedei* Girty. The individual segments are slightly larger than those of *H. beedei* Girty, and the amount of overlap is much more uniform. In no specimen so far examined have the segments failed to be in contact. The diagnostic difference between the two species, however, is the size of the cloacal pores. In the generic description the inference is that the cloacal pores are small, or at least smaller than the ostia, as is illustrated by the genotype. In this species, however, the cloacal pores and the ostia are almost exactly the same size. The cloaca itself is also larger than in *H. beedei* Girty.

Cotypes, Bureau of Economic Geology, Coll. Nos. 11726 and 11727, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

Genus GIRTYCOELIA n. gen.

In describing *Steinmannia benjamini*, Girty[6] pointed out several possible differences between the specimen he was describing and the genus to which he was assigning it, but the poor state of preservation of his specimen made its determination difficult. The central osculum appeared to be absent, internal vesicles were not so prominent as in typical species of the genus *Steinmannia*, the perforations appeared to be all of one size, and there was a thin, imperforate outer wall, separated from the perforate inner wall by a narrow space filled with matrix. Under the circumstances, he did not regard it as advisable to establish a new genus, but some of the specimens found by the writer on McCoy's Creek show the details of structure quite clearly. Hence, the genus is established on this new material and named for Dr. Girty in recognition of his observations of most of the generic characteristics even in his poor specimen.

---

[6]Girty, Geo. H., On some new and old species of Carboniferous fossils: U. S. Nat. Mus., Proc. vol. 34, pp. 286–7, 1908.

The genus *Girtycoelia* is represented by two species, *G. benjamini* (Girty) and *G. typica* n. sp. The specimens of this genus consist of spheres overlapping and arranged to form more or less contorted, occasionally branching stems. Some of the spheres are flattened in a direction parallel to the axis of the stem, but most are elongate. The party wall is single, and the outside of one sphere forms the floor of the next chamber. There are numerous small pores in each segment, and a few large ostia in most segments. The chambers contain some vesicular material and connect by means of the pores. Some specimens retain traces of the thin, imperforate outer wall, which is so molded to the thick inner wall as not to obliterate completely the pores and ostia but to veil them sufficiently to make them indistinct, yet leave their position still apparent. A single specimen of *G. typica* n. sp. from McCoy's Creek and one collected by Scott retain the terminal chamber, and these specimens have not the central osculum of *Steinmannia*, but communicate with the exterior through the pores and ostia instead. The absence of the osculum, the rarity of internal vesicles, the presence of pores of only one size, and the presence of the outer wall distinguish this genus from *Steinmannia*.

Genotype, *Girtycoelia typica*, n. sp.

GIRTYCOELIA TYPICA, n. sp.

Pl. 8, figs. 3–5

Most of the characteristics of this species have been included in the generic description, but some of the characters may be specific. In the type material of this species most of the segments contain one to three ostia, most of which are at the junction of the segments. The spheres contain but little vesicular material, but more than those of *G. benjamini* (Girty). The largest specimen, broken at both ends, is 35 mm. in length and about 10 mm. in diameter, but most of the specimens are less than 8 mm. in diameter, and many are less than 5 mm. The pores are extremely irregular in arrangement and variable in size, so that the statement that the pores are of only one size might be debatable.

Cotypes, Bureau of Economic Geology, Coll. Nos. 11723 and 11724, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

GIRTYCOELIA BENJAMINI (Girty)

Pl. 8, figs. 1–2

Steinmannia benjamini Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, pp. 286–7, pl. 15, fig. 8.

This species was established on a single specimen embedded in matrix so that none of the external characteristics were discernable. In the writer's collection well-preserved specimens of this species from the localities 1 mile southwest of Chanute and from 3.2 miles north of Altoona show clearly the surface characteristics and the external appearance of the species. The individuals are 10 mm. or more in diameter and are quite straight but short, the longest being about 13 mm. in length. The segments are nearly spherical and contain very little vesicular material. Each segment is perforated by a number of pores of rather uniform size and arrangement, and some segments show as many as three ostia, though the usual number is two, and many segments have only one or none at all. This species is larger than *G. typica* n. sp., and its pores are much more uniform in size and arrangement. The chambers contain less vesicular material than those of *G. typica* n. sp., and the constrictions between chambers are deep and subangular rather than broadly rounded to indistinct.

Plesiotypes, Bureau of Economic Geology, Coll. No. 11733, from knoll 1 mile southwest of Chanute, Kansas, Coll. No. 11734, from 3.2 miles north of Altoona, Kansas.

Genus MAEANDROSTIA Girty

Maeandrostia Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, p. 285.

Specimens of this genus are stemlike in form, more or less contorted and branching. Through the center is a large, continuous cloaca. The thick walls are structureless and imperforate, except for vermiform chambers which open to the exterior through scattered circular ostia and which communicate with each other and the cloaca by means of irregular apertures. The surface is comparatively smooth, though roughened by the irregular growth of the individual and by the ostia, but in specimens from which the outer wall has been removed by erosion, the irregular vermiform chambers are exposed on the surface and give a minutely pitted appearance.

Genotype, *Maeandrostia kansasensis* Girty.

MAEANDROSTIA KANSASENSIS Girty

Pl. 7, figs. 9–10

Maeandrostia kansasensis Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, p. 285, pl. 15, figs. 1–7.

Most specimens of this species are less than 13 mm. in diameter and are of variable length, as both ends of every specimen are broken. Ostia are numerous, and when the outer wall is removed by erosion the vermiform chambers are readily apparent to the unaided eye. The ostia and the chambers are somewhat less than a millimeter in diameter. The relative amount of pore space and matter in the space between the cloaca and the outer wall is highly variable, as is the relative diameter of the cloaca, which is in most specimens at least one-third that of the entire body.

Plesiotypes, Bureau of Economic Geology, Coll. No. 11729, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

MAEANDROSTIA TORTACLOACA n. sp.

Pl. 7, figs. 1–4

Specimens of this species are thin; the maximum diameter observed is about 6 mm. The surface is smooth when uneroded, but under a lens the worn surface shows minute pits. Ostia are small and very sparse, but on some specimens a few may be detected. They are visible without the aid of a lens. Some specimens have the appearance of being wrapped in a loose covering which hangs in baggy folds.

Transverse sections of some specimens exhibit a peculiar "double-barreled" appearance, due to the eccentric position of the cloaca. The outer portion of the individual is made up of a larger percentage of matter and a smaller percentage of pore space than the inner portion, which has a radius about half that of the entire specimen. The cloaca lies within the inner portion of the specimen but in some parts of some specimens it is tangent to the outer portion rather than concentric with the rest of the body. Where the cloaca is not central, the scarcity of matter in the central portion gives that portion the appearance of a crescentic pseudo-cloaca partially surrounding the true cloaca. On the weathered ends of such specimens the "double-barreled" effect is more pronounced, as the tips of the crescent do not weather as rapidly as the cloaca and the center of the crescent of the pseudo-cloaca, so that there are two roughly circular cavities developed side by side.

In internal structure this species is undoubtedly closely allied to *Maeandrostia*, but the almost complete absence of ostia and the consequently smooth surface may cause some doubt as to its generic identity. Since the classification of fossil sponges at present includes nearly as many genera as species, the writer believes that new genera should not be established on such fine distinctions. Hence this form has been given only specific rank.

Cotypes, Bureau of Economic Geology, Coll. No. 11732, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

Genus COELOCLADIA Girty

Coelocladia Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, p. 287.

Specimens of this genus are straight or branching stems with a large uninterrupted central cloaca. The thick walls are composed of consolidated spicules and are pierced by numerous ostia. The ostia ramify in approaching the exterior surface. The spicular element is probably a tetract.

Genotype, *Coelocladia spinosa* Girty.

COELOCLADIA SPINOSA Girty

Pl. 8, fig. 7

Coelocladia spinosa Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, p. 288, pl. 16, figs. 1–7.

In the original description this species was said to consist of "rather straight cylindrical fragments, which rarely exceed 10 mm. in diameter." Most of the specimens from McCoy's Creek are less than 6 mm. in diameter, but they are referred to this species, as size is the only apparent difference between the types and the specimens collected along McCoy's Creek, in which material the internal structure is too poorly preserved to show details. The specimens from Martin's Lake, Wise County, agree closely with the types, and are apparently conspecific with those from McCoy's Creek. The ostia are extended outward as spiniform processes, and the cloaca is large and communicates with the exterior by means of the ostia. No large fragments were found, but some individuals were branching and all were nearly straight.

Plesiotype, Bureau of Economic Geology, Coll. No. 11725, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

Genus HELIOSPONGIA Girty

Heliospongia Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, p. 289.

Specimens of this genus are large and dendritic with round branches, which tend to coalesce on coming in contact with one another. The cloaca is comparatively small, and continuous. The spicular element is a hexact, so oriented that the arms of the spicules form continuous lines. One set of these rays radiates from the cloaca downward and outward to the exterior. One set forms concentric rings apparent in transverse cross sections. The third set extends longitudinally, bending outward from the cloaca to the exterior. Ostia are absent, but between the arms of the spicules are freely connecting radial canals, which open upon the surface in small pores.

Genotype, *Heliospongia ramosa* Girty.

HELIOSPONGIA RAMOSA Girty

Pl. 8, fig. 6

Heliospongia ramosa Girty, 1908, U. S. Nat. Mus., Proc. vol. 34, pp. 289–90, pl. 16, figs. 8, 9; pl. 17.

These large branching sponges were originally described as reaching a diameter of 23 mm. Many of the specimens from McCoy's Creek are as large as 45 mm. in diameter, but they are so broken that they do not indicate clearly the mode of growth. It is therefore possible that *H. parallela* Girty is also represented here. The generic description given above presents all the characteristics of this rather simple form, except the size, which is variable with the stage of growth.

Plesiotype, Bureau of Economic Geology, Coll. No. 11731, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

HELIOSPONGIA EXCAVATA n. sp.

Pl. 8, fig. 8

This form may possibly be regarded by some as merely a variety of *H. ramosa* Girty, since it differs in only one surface feature, but this difference is so marked and distinct that it seems to the writer to be of specific value. Though the surface of *H. ramosa* Girty is rough, due to the small pores that give it a uniform stippled appearance, the exterior of *H. excavata* n. sp. is not only rough but marked by large pits that on some specimens are arranged roughly in rows. A section through one of these pits shows it to be a surface feature only, with no connection through to the cloaca. The pits average about 3 mm. in diameter and are about the same in depth.

Holotype, Bureau of Economic Geology, Coll. No. 11730, from McCoy's Creek, 4 miles northwest of Bridgeport, Wise County, Texas.

XIPHACTINUS AUDAX, A FISH FROM THE CRETACEOUS OF TEXAS

By

J. Willis Stovall[1]

INTRODUCTION

The University of Oklahoma has recently acquired an excellent specimen of the great teleost or bony fish, *Xiphactinus audax* Leidy, which measures, as restored, 12 feet and 2 inches from the front of the skull to the fork of the tail. The fossil is not a particularly large one for some of the giants of this genus were 20 feet in length and were certainly the largest bony fish that ever lived. They were limited to the Cretaceous. They inhabited the open seas and were doubtless able competitors of the large predacious marine reptiles of the time. *Xiphactinus audax* Leidy belongs to the family Ichthyodectidae and is closely related to the family Chirocentridae, members of which now live in the Indian Ocean.

The following notes are based on three specimens of *Xiphactinus audax* Leidy from the Austin formation 40 miles north of Dallas, Texas. The specimen with which this paper is largely concerned came from the farm of Roy Williams, 4 miles northeast of Celina, Collin County, Texas. Another specimen, a caudal fin, was discovered about 1 mile north of the location given above. The third specimen, still largely in the matrix, came from a creek bank 3 miles due east of Celina. In this connection the writer wishes to thank Homer Merritt, Celina, Texas, for the aid he rendered in securing these specimens, and Professor R. W. Harris for identification of the associated invertebrate fossils. The Austin formation is correlated with the Niobrara formation of Colorado and Kansas.

The rocks in which this fossil was imbedded are composed of numerous small lenses of dark, highly argillaceous limestone. In fact, some of the small lenses are more argillaceous than calcareous. Other layers are lighter in color, and in general less shaly. Scattered through the mass are many small pelecypods, *Inoceramus labiatus* Schlotheim, filled with chert. This condition existed particularly

[1]Assistant Professor of Geology, University of Oklahoma, Norman, Oklahoma.
Issued February, 1933.

in the region of the head, the orbit having been filled with numerous fossils, all of which were filled with, and cemented together by chert.

DESCRIPTION OF SPECIES

XIPHACTINUS AUDAX Leidy

Pl. IX

Xiphactinus audax Leidy 1870, Acad. Nat. Sci. Phila. Proc., p. 12; U.S. Geol. and Geog. Survey Terr. (Hayden), p. 290, pl. 17, 1873.
Saurocephalus audax Cope 1870, Amer. Phil. Soc. Proc., p. 533.
Saurocephalus thaumas Cope 1870, Amer. Phil. Soc. Proc., p. 533.
Portheus molossus Cope 1871, Amer. Phil. Soc. Proc., p. 174; U.S. Geol. and Geog. Survey Terr. (Hayden), pp. 194–196, 1875.
Portheus thaumas Cope 1875, U.S. Geol. and Geog. Survey Terr. (Hayden), pp. 196–201.
Xiphactinus audax Stewart 1900, Kansas Univ. Geol. Survey, vol. 6, p. 267.

Since the species has been described under various names,[2] it seems advisable to give a detailed description of this specimen with a hope that assistance may thus be given in clarifying the status of the species.

Head.—The height of the skull of this individual from the supraoccipital crest to the ventral edge of the dentary is 539 mm. Its length is 480 mm. from the anterior border of the mandible to the condyle. The teeth range in size from 15 mm. to 56 mm. in length, the largest and strongest being in the premaxillary. The following table illustrates the variation in size of the teeth in both the upper and lower jaws, a feature to be expected in view of the fact that the teeth are replacable, as may be seen from the presence of new teeth in some of the alveoli.

Tooth No.	Premaxilla *mm.*	Maxilla *mm.*	Dentary *mm.*
1	56	17	36
2		9	40
3		42	7
4		Broken off	30
5		42	40
6		20	27
7		15	20

Cope[3] emphasizes the size and arrangement of the teeth in his species *Xiphactinus molossus* and *Xiphactinus thaumas*. A glance

[2]Stewart, Alban, Cretaceous fishes, teleosts: Kansas Univ. Geol. Survey, vol. 6, p. 269, 1900.
[3]Cope, E. D., On the families of fishes of the Cretaceous formation of Kansas: Amer. Phil. Soc. Proc., vol. 12, p. 334, 1872.

at the above table will show the lack of uniformity in size and arrangement of the teeth in *X. audax.* Hence the teeth can not be used as criteria in specific determination, except in a negative way.

The premaxilla is large and strong, convex upward, and ankylosed to the maxilla. It contains two teeth, one of which is very large, pointed, non-striated, and projecting forward. The second tooth is wanting, but judging by the alveoli is much the smaller of the two. The premaxilla was joined to its fellow by ligaments.

The maxilla is roughly spatulate in shape, thinning greatly posteriorly. The posterior half of the bone is wanting in the right jaw, but present in the left. The teeth are all small.

The dentary is a strong, somewhat rectangular-shaped bone. The alveolar border is slightly concave, bearing numerous conical teeth, the two most anterior ones being large and similar to those in the premaxilla. The articular is present only in the left mandible, where it is short and heavy, and extends outward into a coronoid process. Hay[4] has described two bones in this element, the derm and the antarticular, but I am unable to find more than one suture, the one which separates the articular from the dentary. Hence it seems to me that the distal element of the lower jaw is the articular.

The quadrate is incomplete, only about two inches of the lower end being present. The condyle, which articulates with the articular of the mandible, is concave. The lower end is heavy due to two prominent tubercules, one of which probably served to give attachment for the nasal. The palatine is represented by a small fragment which overlaps the restored end of the quadrate.

The ethmoid is narrow anteriorly but vertically is very thick. In the process of preservation it was not separated from the premaxilla. The frontals are large, and with the prefrontals form the superior rim of the orbit. Posteriorly, the frontals unite with the supraoccipital, which is a very large triangular bone, expanded at the base, and thin along the upper and posterior margins. These bones form a prominent crest which extends sharply backward.

The basioccipital is strong and concave backward, where it articulates with the first vertebra.

The branchial rays are long, and about the shape and size of a dorsal rib of a horse. The gill rakers were doubtless cartilaginous,

[4]Hay, O. P., Observations on the genus of fossil fishes called by Prof. Cope *Portheus,* by Dr. Leidy *Xiphactinus:* Zool. Bull., vol. 2, p. 39, 1898.

but their imprints have been well preserved. They may easily be seen below and behind the orbit.

The orbital ring is made up of heavy bones, bounded above by the frontal and prefrontal, and below by the suborbitals. The sclerotic ring is complete, and composed of two bones, the outer borders of which are thick.

There are other bones below the orbit, but they are too indistinct to be described in this paper.

Pectoral Girdle.—The pectoral girdle is fairly complete. The group forming this unit was rather badly disarranged; nevertheless most of the cleithrum is present. It is a large and thin bone, thickened toward the anterior margin, and thinning toward the posterior margin. The lower and anterior part of this bone has been restored from drawings of Sternberg's specimen at Hays, Kansas. The large upper preserved portion is covered with pronounced striae, which radiate upward and backward from its lower margin.

The scapula is a small but heavy bone, which articulates above with the cleithrum and below with the basiosts of the pectoral fin. The coracoid, which normally should cover the cleithrum, is not preserved in this specimen.

The pectoral fin spines were in good condition and were in place when the fossil was found, but due to accident in handling they were so badly damaged that only parts of them could be used in restoration. These spines are rather massive, and slightly suggestive of mammalian ribs. All were close together, evidently so in nature. The first is broad and relatively thin, and the remainder become gradually thinner. The second is thicker than the first. All are slightly bent backward somewhat suggestive of a saber, hence the generic name *Xiphactinus,* which means saber-rod, as applied by Leidy.[5] I do not hold that these fins were used as weapons of offense and defense as implied by Leidy, and stated by Stewart.[6] A fish the size of *Xiphactinus audax* would certainly require rather heavy balancing organs, the normal function of the pectoral fins.

Pelvic Girdle.—The pelvic elements were not preserved in the matrix. The restoration is based upon the Sternberg specimen referred to above.

[5]Leidy, Joseph, Remarks on ichthyodorulites from Kansas and Tennessee and on mammalian remains from Illinois: Acad Nat. Sci. Phila. Proc., p. 12, 1870

[6]*Op. cit.*, p. 284.

Fins.—The anal fin is represented by fragments of bone and by a complete set of imprints which show the shape, general structure, and relationship of the elements of that fin. There were seven fin rays. The first and second are small, and the third is the largest. The proximal ends of all are expanded into knobs, as are the distal ends of the basiosts. The most anterior basiost is 17½ inches long, terminating near the vertebra. This bone shows a groove down the outside from one extremity to the other.

Ribs.—The ribs terminate just in front of the anal fin. In this specimen nearly all of the ribs are completely or partially preserved. Like the anterior basiost of the anal fin, they show a groove down one side. From this fact I infer that the ribs and certain basiosts were hollow, probably serving a hydrostatic as well as skeletal function. The proximal end of the ribs articulate with the centra through the intervention of a saddle-like structure, which in turn appears to articulate with two elongate slots in the vertebrae. The vertebrae are in excellent condition and only slightly flattened. Seventy-three were preserved in this specimen, the posterior series being destroyed by a charge of dynamite set off for the purpose of digging a water hole. The vertebrae do not vary materially in size. Well up in the caudal region three longitudinal slots evenly spaced on the exposed surface of the vertebrae may be seen. In this region, however, these slots are narrow and not well developed. Just anterior to the pelvic fins the vertebrae again show the three longitudinal grooves. The function of the most dorsal of these grooves is problematical, but it may be that the base of the neural arch used it in the same way that the ribs use the lower two. The neural spines are independent of the neural arches, articulating with the centra by means of the saddle-like neural arch referred to above. The haemapophyses also articulate with the centra by a saddle-like structure, but it is impossible to tell if the spines are separate from this device.

The caudal fin in the accompanying restoration (Pl. VII, Fig. 2) is that of another specimen found 4 miles distant from the one described above. It is well preserved and virtually complete. A second specimen shows that there were six vertebrae in the caudal series. The rays of this fin are complete in the upper lobe, and nearly so in the lower, only the very end being absent. The ninth ray is much the longest of the group. There are nine in the series anterior to this long spine. They gradually become longer from front to back. The series posterior to the long spine referred to above also decrease in length. The proximal ends of these rays are expanded into strong heads which are concave on the articulating surface. All of these rays have pronounced transverse ridges and many small striae. The ridges mark segments which separate rather easily into small discs, hence each ray has the appearance of being made up of many small elliptical discs.

Beginning in the region of the first vertebrae, and terminating at about the twentieth vertebrae, there are several small bones, from 8 to 10 inches long, which lie close to the vertebrae on either side of the neural spines. They closely resemble the neural spines with the exception that they are much smaller. The function of these bones is not evident, although they may be ossified tendons which served to further strengthen the region just back of the skull.

The description as given above agrees with the description by Leidy,[7] Cope,[8] and Stewart,[9] in so far as the latter is applicable. Leidy named the genus from a pectoral spine described in a short contribution to the Philadelphia Academy of Natural Science in 1870.[10] A more nearly complete specimen was described the following year by Cope,[11] and the name *Saurocephalus* was assigned to it; but as Stewart[12] has pointed out in his paper on Cretaceous fishes, the two spines are identical. The writer has made a careful study of the subject. Mr. L. I. Price compared this specimen with similar species at the University of Kansas and at Hays, Kansas, where Sternberg's excellent specimen is located. He found the specimen at Oklahoma University to be identical with those at Hays and Lawrence. It seems evident that Mr. Stewart's findings are further confirmed in the specimens here described.

---

[7]*Op. cit.*, p. 12.

[8]Cope, E. D., Brief account of an expedition in the valley of the Smoky Hill River in Kansas: Amer. Phil. Soc. Proc., vol. 12, p. 174, 1871.

[9]*Op. cit.*, p. 267.

[10]*Op. cit.*, p. 12.

[11]Cope, E. D., On the fossil reptiles and fishes of the Cretaceous rocks of Kansas: U. S. Geol. and Geog. Survey Terr. (Hayden), p. 418, 1871.

[12]*Op. cit.*, p. 282.

GEOLOGIC NOTES ON THE LOWER CRETACEOUS OF EAGLE MOUNTAIN AND VICINITY, TARRANT COUNTY, TEXAS

By

John B. Hawley[1] and John Peter Smith[1]

INTRODUCTION

The area treated in this study lies in northwestern Tarrant County around the margin of Lake Worth and in the Eagle Mountain Lake basin, as shown on the accompanying map. The most intensive work was done on the Walnut formation between the Dido Bridge and the Ten Mile Bridge along the high escarpment capped by the Walnut shell agglomerate which flanks the West Fork of the Trinity River to the east. Most of the data used for this area were gathered, originally, to interpret the attitude of Walnut and older sediments around the site of the Eagle Mountain Dam. The more extensive area was studied to get a more comprehensive knowledge of the local attitude of the Walnut, and of the relation existing between the Fredericksburg group, of which the Walnut is the oldest member, and the Paluxy sand, the youngest formation of the Trinity group as developed in North Texas.

PHYSIOGRAPHY

In northwest Tarrant County the West Fork of the Trinity River is in a mature stage with a low gradient, elaborate meanderings, a well developed natural levee, and a maze of sloughs on either side which in time of flood carry a considerable amount of water. Its valley averages over a mile in width and more where it is joined by sizable tributaries, and the channel swings from one side to the other.

In recent times there has been much deposition of material by the river, as shown especially well by construction data of the Eagle Mountain Dam. Thus, steel sheet piling driven for a center line cut-off along the entire length of the main dam, near the present

[1]Consulting Engineers, Fort Worth, Texas.

Issued February, 1933.

river channel passes through seventy to eighty feet of material below the flow line of the stream, which is back filled.

The two and a half million cubic yards of sand and clay placed in the embankment are taken from river deposited beds which are remarkable for the variation of materials both laterally and vertically. Soils are for the most part sandy, red, green, or yellow in color and overlie bedded deposits of fine white sand with pockets of coarse sand and gravel. These highly colored sandy clays are peculiar in their composition, containing a large percentage of extremely fine material, a considerable amount of coarse sand, but very little material of intermediate gradation. More recently deposited clays are black, gray, or rarely green in color, contain very little sand, and are probably derived from the soil mantle on nearby limestone hills. The only coarse particles in these silty clays are reworked shells of *Gryphaea marcoui* Hill and Vaughan, shells of the river clam *Anodonta implicata* Say, and peculiarly irregular lime concretions formed by several thin plates of calcite intersecting at random angles.

Hills to the east of the river valley are capped by Lower Cretaceous limestones which develop a distinct cuesta topography. They are covered by a thin mantle of black loamy soil formed by the disintegration of limestones and marls.

To the west of the river the Walnut shell rock occurs in the form of a few conspicuous outliers and an escarpment following the south side of the Ash Creek valley into Parker County. The sands below the Walnut support a hummocky topography mantled by a sandy residual soil and covered with a thick growth of post oak and blackjack.

STRATIGRAPHY

SEDIMENTS OLDER THAN WALNUT FORMATION

The oldest rocks studied outcrop in the basin of Walnut Creek, 2 to 2½ miles north of the town of Azle. These are sands and sandy clays of doubtful age which lie below the highest member of the Glen Rose limestone, shown by Gayle Scott on his map of Parker County as Glen Rose (MS). This bed is shown in the Parker County report to be a lens of Glen Rose, interfingering to the north and west with inversely lensing members of the Paluxy, and for this reason Scott has designated underlying sands and clays as Paluxy.

The most significant local feature of this lens of Glen Rose is a reef-like coquina facies about nine feet thick and less than 2000 feet wide which strikes about N. 64° E, through the bridge over Walnut Creek on the Azle-Boyd road. Below this coquina bed is a ten foot section of alternating lime flags and clay, the topmost, and thickest flag being rich in the fossil species *Exogyra weatherfordensis* Cragin, *Trigonia stolleyi* Hill and other clams. (See section 3, fig. 1.) Both northwest and southeast of this reef-like facies and to a slight extent along its strike to the northeast, the limestone thins out, lensing into the Paluxy sand to the northwest just east of Reno in Parker County.

At the most southeasterly point where the Glen Rose outcrops along the south side of Walnut Creek, the 649.0 foot contour, margin of Eagle Mountain Lake, leaves the basin of the West Fork and swings up Walnut Creek valley. Here the Glen Rose is exposed as a thin series of thin limestone flags and laminated clays poorly exposed on account of gravel overwash. South and east of this point all headlands extending into the Eagle Mountain Lake basin are covered by a thick mantle of gravel and other river drift, all Cretaceous deposits having been cut out and back filled by the meanderings and migrations of the West Fork.

At a point in the bed of Ash Creek 4000 feet southeast of Azle the greatly thinned Glen Rose dips under the bed of Ash Creek and is lost in the embed. At this point not over eight inches is exposed, but possibly another foot or foot and a half lies under the bed of the creek. Here the Glen Rose is overlain by a thin seam of lignite, four feet of black laminated shale, fifteen feet of sand and sandstone; (this locality is 2200 feet S. 21° E. of the locality where section 1, fig. 1 was measured).

On the Fort Worth-Jacksboro highway under the bridge over Ash Creek just southeast of the Azle townsite the Glen Rose, though thin and non-typical, is well exposed, lying one to three feet above the channel of the creek. The total thickness of sandy limestone and limestone is not over three feet, consisting of a bottom ledge of cross-bedded sandy limestone with few fossils, capped by an inch or two of limestone rich in *Glauconia branneri* Hill, about a foot of shale, and a rotten limestone about a foot thick, rich in *Exogyra weatherfordensis* Cragin, *Trigonia stolleyi* Hill, *Isocardia* sp., other clams, and *Glauconia branneri* Hill. A seam of clay in this upper limestone has yielded a few microfossils; an ostracod and foraminifer with hyaline tests. (Section 2, fig. 1.)

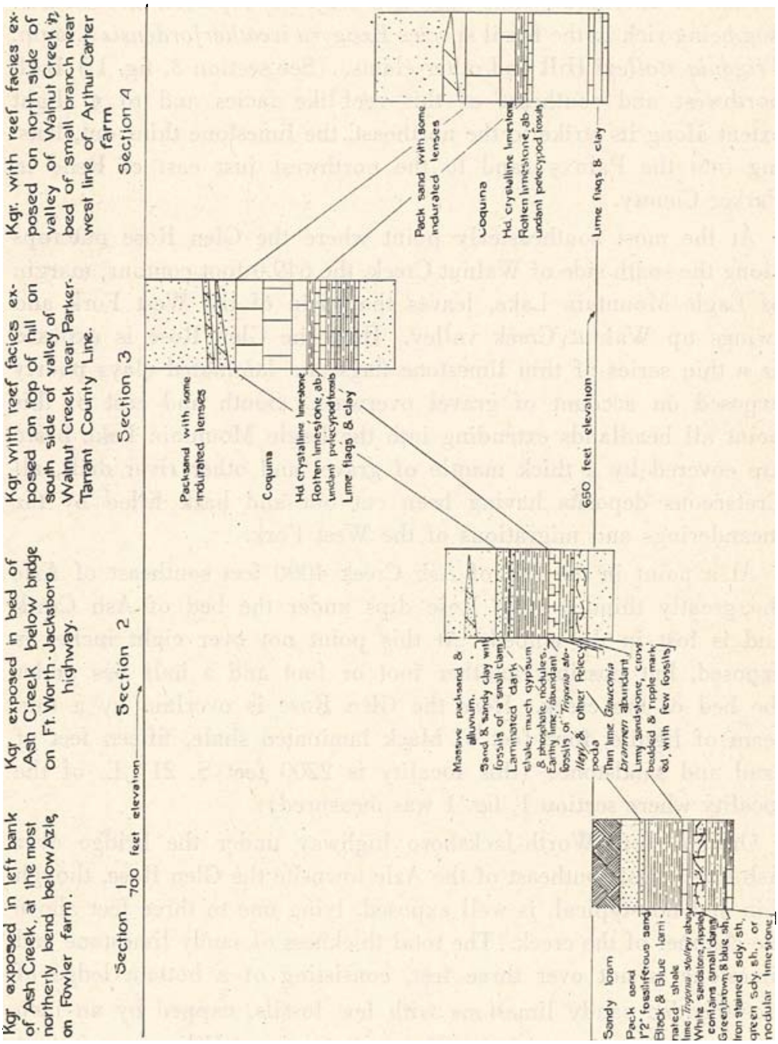


Fig. 1. Sections of the Glen Rose formation (Kgr) near Eagle Mountain, Tarrant County.

Above this limestone are four feet of finely laminated dark shale, samples of which were washed and examined for microfossils. Fish teeth and bones poorly preserved in phosphate were seen; there were numerous nodules and concretions of phosphate and frequent phosphate casts of *Glauconia* sp. aff. *branneri* Hill. Large quantities of secondary gypsum were noted. Above the shale are thin beds totaling one to three inches of sandy clay and soft sandrock bearing fossils of a minute clam and above this, massive white packsand with a few indurated lenses, about fifteen feet thick. (Section 2, fig. 1.)

At the point where the Glen Rose is last seen dipping under Ash Creek it has an elevation of approximately 640 feet, the interval between it and the base of the Walnut formation being about 140 feet. At spillway of the Eagle Mountain Dam 12,000 feet farther southeast (16,000 feet S. 45° E. of the Azle townsite) the stilling pool excavation below the spillway has an elevation, at the bottom of the apron cut-off wall of 546.0 feet, exposing a section, 80 feet thick (from 104 feet to 184 feet below the base of the Walnut). This section is chiefly sand and sandy clay (fig. 2-B) with a thin nodular limestone six inches to eighteen inches thick from elevation 624.5 to 626.0 feet (104 feet below the base of the Walnut). No fossils have been found in this limestone and its interval below the Walnut does not check with that of the Glen Rose, so it is interpreted on a lithological basis as another calcareous lens exactly comparable with Glen Rose of Gayle Scott, related in lithology and depositional history to other members of the Glen Rose facies.[2] In central Parker County a comparable, possibly identical ledge, is exposed four-tenths of a mile east of the Prairie Pipeline booster station about five miles east of Weatherford where it lies about twenty feet above the Glen Rose. From this point it can be traced to the southeast about 3 miles along the north side of the Willow Creek valley. On account of its thinness, limited extent, and lack of fossils characteristic of the Glen Rose, Scott has not differentiated this member from the Paluxy on the map or the sections accompanying his report on the geology of Parker County.

The Glen Rose formation is exposed at elevation of 660.0 feet in ditches on either side of the road leading west across Dido Bridge

---

[2]This is the interpretation given by Dr. Scott when he first saw this material in the field.

at a point ½ mile west of the bridge. This point is about 1 mile northwest of the strike of the reef-like facies which strikes down the valley of Walnut Creek, and two miles N. 45° E. of the greatest development of the coquina bed as seen near the Parker-Tarrant County line. At this locality west of the Dido Bridge Glen Rose is exposed as a hard siliceous limestone flag about sixteen inches thick, with abundant *Glauconia branneri* Hill.

At other points along the valley of the West Fork no Glen Rose of this age is exposed. As noted above, this is possibly the result of the erosive action of the river, at least between Dido Bridge and the mouth of Walnut Creek, but farther downstream, at the site of the hydraulic fill of the Eagle Mountain Dam, excavations from the base of the Walnut (elev. 668.0) to the bed of the river (elev. 588.0) and pile driving operations (to elevation 508.0) failed to reveal anything similar to the Glen Rose, which, if it persists this far should lie at about elevation 528. As it likewise seems to be absent at the site of the spillway of the dam, 2½ miles west, the member of the Glen Rose designated as Kgr may be regarded as lensed out in the vicinity of Eagle Mountain, 24,000 feet southeast of the strike of its reef-like phase in the valley of Walnut Creek. Since this area is on a structural "high" of the Walnut it is possible that it is an area of flexure which raised the sea bottom during the time when, or immediately after, Glen Rose was deposited, causing this local hiatus.

Above these calcareous beds which are assigned to the Glen Rose facies of the Trinity group on account of their calcareous composition and marine or brackish water origin, lies the Paluxy formation, topmost and shoreward facies of the Trinity group. It consists, for the most part, of cross-bedded packsands, with locally developed lenses of sandrock, frequently ripple-marked, sandy clays often bearing scraps of lignite, and lenses of sandy clay, dark gray, greenish gray or of a striking purple.

These "royal purple" clays deserve more than passing mention. Ordinary exposures are of an earthy texture, but extensive excavations show the unweathered clay to be massive, waxy, and with numerous glazed slickensided joints. The coloring matter, probably peculiarly hydrated oxides of iron with possibly a little manganese, is finely divided and invested in the argillaceous component of the material, as the washed residue consists of fine, well sorted, angular, white quartz grains, with a low percentage of larger, well rounded grains. These clays occur in thick interfingering lenses which occupy a broadly defined level about 40 to 50 feet below the base of the Walnut. Through eastern Parker and northwestern Tarrant counties these beds are a characteristic feature of the middle Paluxy, and are mentioned and discussed by Scott.[3]

These "red beds" of the Paluxy are sometimes underlaid, overlaid, or divided by greenish sandy clays of a waxy consistency, and the series is, in turn, overlaid by massive white packsands and sandstones to the top of the Paluxy formation. In general two broadly defined levels in the Paluxy may be recognized: the zone of "royal purple" clays near the middle of the formation, and a zone of conspicuous ironstained concretions occurring in a soft sandrock at about the bottom of the top quarter of the Paluxy.

WALNUT SHELL ROCK

In striking contrast with the varied lithology of lagoon, strand, and non-marine deposited members of the Trinity group of northwest Tarrant County are the constant thickness and lithologic features of the Walnut formation and of overlying beds. The Walnut shell rock lies upon the Paluxy in unconformity as is excellently demonstrated by the wavy contact seen in the "key trench" at the east end of the main fill of the Eagle Mountain Dam (fig. 2-A). The contact here has a relief of about two inches, the topmost member of the Paluxy being a packsand, the lowest member of the Walnut a brown sandy clay about eight inches thick. This basal Walnut clay bears well preserved specimens of *Gryphaea marcoui* Hill and Vaughan, *Exogyra texana* Roemer, *Pecten irregularis* (Böse), and other characteristic Walnut fossils, but when washed for microfossils the residue showed only fine, rounded sand, and silt, very similar to material from the underlying Paluxy, and probably reworked from that formation by the transgressing Fredericksburg sea. The almost total lack of siliceous sand in higher members of the Walnut indicates the rapidity with which this transgression took place, quickly covering up such nearby sources of sand as the sandy beaches of the old Trinity sea.

---

[3]Scott, Gayle, The stratigraphy of the Trinity division as exhibited in Parker County, Texas: Univ. Texas Bull. 3001, p. 47, 1930.

Above this clay lies a hard, finely crystalline limestone with an almost constant thickness of about a foot. This bed is remarkably persistent for one so thin; has very constant characters and a conspicuous and characteristic fauna marked by an abundance of *Protocardia texana* (Conrad) and comparatively few specimens of *Gryphaea marcoui* Hill and Vaughan, *Pecten irregularis* (Böse), *Trigonia sp.* and other clams. Not only is the lithology of this member, which will be further referred to as the zone of *Protocardia texana* (Conrad), strikingly similar to certain members of the overlying Goodland, but also the faunas are very closely related, and the occasional occurrence of species characteristic of this zone in higher levels of the Walnut suggests that they were crowded offshore by increasingly large numbers of *Gryphaea marcoui* Hill.

Above the zone of abundance of *Protocardia texana* (Conrad) there are 14 feet of shelly clays intercalated between lenses of shell rock with a calcareous clay matrix and lenses of impure limestone. This material is poorly bedded and true ledges are rare or absent. The dominant faunal elements are *Gryphaea marcoui* Hill and Vaughan and *Exogyra texana* Roemer, but other fossils often found are *Pecten irregularis* (Böse), *Holectypus planatus* Roemer, *Epiaster whitei* (Clark), *Heteraster texanus* (Roemer), *Engonoceras pierdenale* (von Buch), *Oxytropidoceras acutocarinatum* (Shumard) and unimportant gastropods. This is also the zone of the greatest variety of foraminiferal and ostracod tests.

The upper 9 feet of the Walnut comprise massive, imperfectly bedded ledges with a few lenses of shells in an unconsolidated clay matrix. In these upper ledges shells of *Gryphaea marcoui* Hill and Vaughan are firmly cemented by a calcareous cement probably leached by percolating waters from the shells themselves. On account of the unusual resistance which this upper member offers to erosion, by far the greater number of outcrops of the formation exhibit a section of almost constant thickness (24 feet) and a carefully measured section at any good exposure in northwestern Tarrant and northeastern Parker counties will not deviate far from this.

Key trench excavations at either end of the Eagle Mountain Dam site afforded, during construction, excellent exposures of the Walnut formation in contact with the Paluxy. This was especially true of the one at the east end of the embankment which gave a complete and quite typical section represented in the columnar section (fig. 2-A). Photographs of the excavations at the west and east ends of the dam are shown in Plate 10.

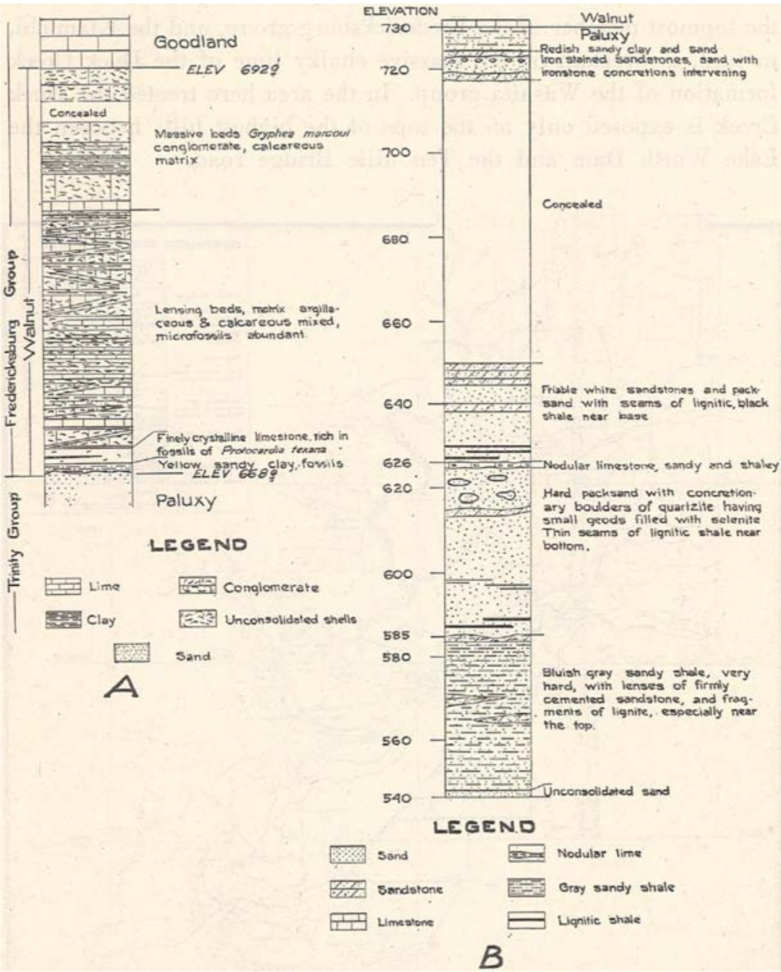


Fig. 2. A, section of the Walnut formation exposed in the key trench at the east end of Eagle Mountain Dam. B, columnar section at the excavation for stilling pool of spillway.

SEDIMENTS YOUNGER THAN WALNUT FORMATION

The Walnut is conformably overlain by the Goodland limestone. These formations are separated by a radical change in facies and a corresponding change in lithology, the faunas differing in comparatively few new elements developed in the Goodland and in relative abundance of forms common to both formations.

The Goodland is overlain by the Kiamichi clay (35 feet thick) the topmost member of the Fredericksburg group, and the Kiamichi, in turn, is overlain by the massive chalky lime of the Duck Creek formation of the Washita group. In the area here treated the Duck Creek is exposed only on the tops of the highest hills between the Lake Worth Dam and the Ten Mile Bridge road.

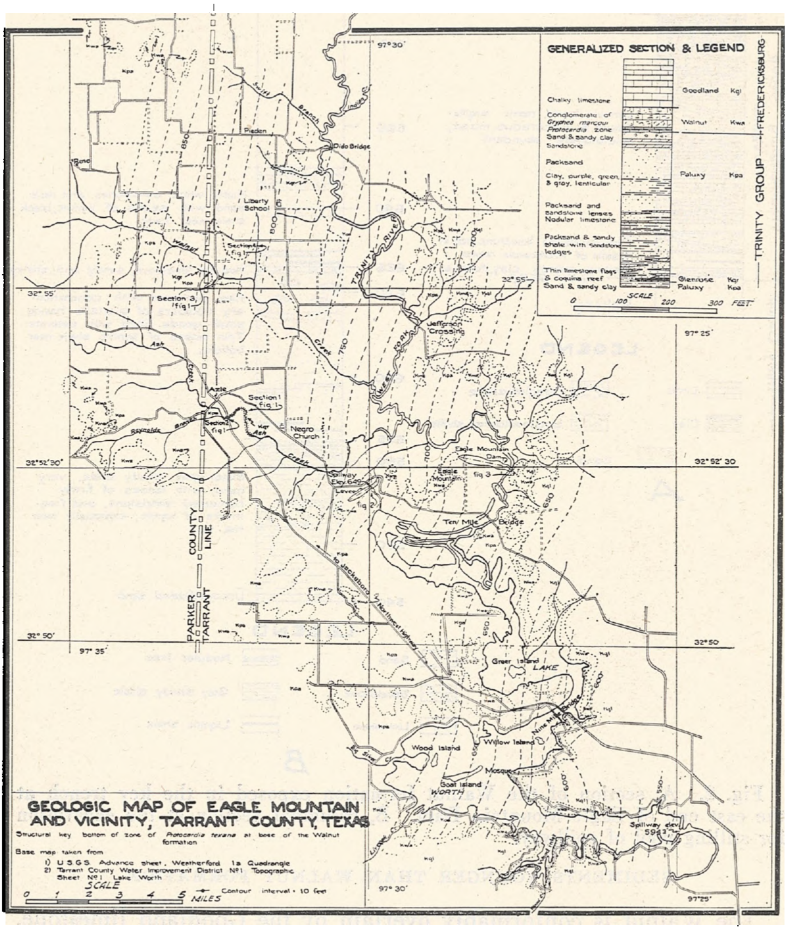


Fig. 3. Geologic map of Eagle Mountain and vicinity, Tarrant County, Texas.

ATTITUDE OF WALNUT FORMATION

The first thing that impelled us to work on the Walnut was the presence of anomalous structure in the immediate area of the Eagle Mountain Dam site as shown when an attempt was made to measure the dip and strike of beds across the valley of the West Fork of the Trinity River. After numerous controlling points were determined, structural contours were drawn as shown on the accompanying map. Flexures are gentle and of low relief, the sharpest one being the anticlinal nose at the east end of Eagle Mountain Dam. The construction road from the Ten Mile Bridge to the east end of the dam going around on top of the hill overlooking the river, passes over one of the upper ledges of the Walnut exposed in the bed of the first small "wet weather" creek encountered. Here the crossing is about 10 feet upstream from a 20-foot waterfall, and a sharp flexure is shown in the hard ledge which forms the bed of the creek. The possibility that this restricted area (at least) may have been the site of disturbance in late Glen Rose times has been suggested above, but structure in the Walnut itself was probably controlled by the movements which formed the larger Fort Worth syncline.

MICROFOSSILS OF WALNUT FORMATION

The microfossils of the Walnut are not very abundant but of surprising variety. As is true of the large fossils, most of which are to be found in the overlying Goodland limestone, the microfossils of the Walnut are closely related to or identical with those of the Goodland. The most conspicuous differences between the microfaunas of the two formations are the absence of certain Goodland forms and the marked scarcity of others in the Walnut.

The foraminifera show this relationship especially well, as the great majority of species recorded from the Walnut occur in younger rocks of the Comanche series.

The ostracods, moreover, bear this relationship out well. There are only five species which cannot be identified with Goodland species. Two of these belong to the genus *Cytherelloidea*, a comparatively new genus[4] which has not been exhaustively studied so

[4]Alexander, C. I., Ostracoda of the Cretaceous of north Texas: Univ. Texas Bull. 2907, p. 55, 1929.

the species we have from the Walnut might well occur in the Goodland. Another, of the genus *Cytheropteron*, marks a clear evolutionary step from a similar species abundant in the Glen Rose to *Cytheropteron howelli* Alexander, Goodland.

SUMMARY

From the foregoing data, which have been gathered in connection with field work preceding construction of the Eagle Mountain Dam and our own independent field work, we offer the following conclusions:

(1) That beds older than the Fredericksburg were deposited close inshore, are erratic and discontinuous in lithology, and are complicated by minor diastems. The submergence by the sea was oscillatory, as is further shown by the lenticular nature of calcareous beds assigned to the marine and semi-marine Glen Rose lithologic group. Moreover, these oscillations were part of a larger regressive cycle as beds become more definitely non-marine to the very top of the Paluxy, where they are overlain by the littoral but unmistakably marine Walnut.

(2) The transgression of the sea at the beginning of Walnut times was very rapid in this locality, as is shown by the presence of reworked material from the Paluxy only in the bottom 8 inches of the Walnut, the higher members being surprisingly free from transported sand.

(3) At some time after the deposition of the Walnut the bottom of the sea was gently deformed, producing local anomalies of low relief. Eagle Mountain is probably located near the northwest limit of movements which produced the Fort Worth syncline.

THE WORTHAM-MEXIA, TEXAS, EARTHQUAKE

By

E. H. Sellards

INTRODUCTION

A small earthquake which occurred in the early morning of April 9, 1932, centered near Wortham and Mexia, Texas. The exact time of the occurrence of the shock is imperfectly determined, but was near 4:17 A.M.[1] The following account is based on observations made on May 2 to 5. Acknowledgment is made to publications relating to structural conditions in this region; to Mr. R. A. Liddle of Fort Worth who has supplied observations on the severity of the shock at Mexia; and to Mr. W. A. Reiter of Mexia whose guidance at the locality was especially helpful. The location of faults shown on the map, Figure 4, has been supplied by Mr. Reiter.

LOCAL GEOLOGIC CONDITIONS

These towns, Wortham and Mexia, are located in the Mexia fault zone. This zone consists not of a single fault but includes a complicated series of faults varying in amount and direction of throw. The faults are interpreted by most of those who have studied them as normal or tension faults. The trend of the fault zone at Mexia is N. 25° or 30° E. While this is the prevailing trend, individual faults vary in a part or all of their course, becoming in some instances approximately cross faults. Many of the faults have *en échelon* arrangement. The upthrow of several of the large faults is on the southeast side. In some, however, the reverse is true, the upthrow being on the northwest side. The fault zone, therefore, contains grabens and horsts. The general plan of faulting in this area is indicated in Figure 4, which shows the major faults only. In detail the fault pattern is more complicated than can be expressed on a map of this scale. The formations at the surface are Lower Eocene and are underlain to a depth of 6000 or more feet by Cretaceous. No wells at this locality have passed below the Cretaceous, the maximum depth reached being 6060 feet. In the adjoining county to the west, the Cretaceous is underlain by somewhat

[1]This record as to the time is based on observations by Mr. L. E. Jones at the Majestic Hotel, Mexia. Mr. Jones was up at the time the shock occurred and took note of the time from an electrically controlled clock in the hotel.

Issued February, 1933.

altered and probably strongly folded Paleozoic formations, and it is probable that either these Paleozoics, or possibly pre-Paleozoics, immediately underlie the Cretaceous at this locality. The regional dip in the Cretaceous and Eocene formations is to the southeast. Accordingly, many of those faults having upthrow to the southeast bring about structural conditions favorable to the accumulation of oil, and the earthquake occurred in or very near the great Mexia and Wortham oil fields in which production is obtained in the basal Upper Cretaceous formation, the Woodbine sand, at a depth of from 2900 to 3200 feet.

The region most strongly affected includes Wortham and Mexia and the intervening area, the distance between the two towns being about 8 miles. These towns are near a line of faulting, Mexia being on the upthrown and Wortham on the downthrown side. The Mexia fault has a throw approximating 550 feet. This fault by *en échelon* arrangement passes into the Wortham fault[2] in which the throw is 600 or 650 feet. The dip of the fault plane varies: that of the Wortham fault is about 45°, and that of the Mexia possibly somewhat less.[3] This line of faulting continues northward forming by *en échelon* arrangement the Currie and Richland faults on which are located the Currie and Richland oil fields. The continuation of the fault line southward is seen also in the Groesbeck and Kosse faults (see map, fig. 4). A few miles west of the Mexia and Wortham faults is the Tehuacana fault zone. Several minor faults, not shown on the map, intervene between these major faults.

DETAILED OBSERVATIONS

No appreciable damage to buildings was caused by the earthquake. In Wortham where the shock was strongest, the effect was only to shake bricks from a few chimneys and to enlarge or develop cracks, possibly already present as incipient breaks, in one brick veneer building. The most pronounced of these cracks is at the northeast side of the house and runs in a zigzag course from the roof to a window and from the bottom of the window to the concrete base-board and through the base-board to the ground. The crack follows the mortar and does not pass through the brick.

[2]W. A. Reiter, personal statement.

[3]Lahee, F. H., Oil and gas fields of the Mexia and Tehuacana fault zones, Texas: Structure of Typical American Oil Fields, vol. 1, pp. 304–388, 1929.

Some cracks in this building had formed previous to the earthquake. At the residence of Mrs. Turner in the southwestern part of Wortham the four top layers of brick were loosened from the chimney. Twenty-four bricks fell to the ground, and the others of these four layers were more or less displaced. A few bricks fell from at least three other chimneys in the southern and southwestern parts of the town. The bricks in the chimneys affected were probably not firmly held by the mortar, as is indicated by the fact that the bricks separated in falling.

With regard to the effect on persons, almost everyone at Wortham was awakened and more or less alarmed. Many ran out of their houses or made examinations to determine the cause of the disturbance. For this immediate region, the earthquake would apparently be ranked as of moderate intensity, or about V of the Rossi-Forel scale.

At Mexia and in the region intervening between Wortham and Mexia, the effects were less perceptible. At Mexia only a few people were awakened. Many were more or less alarmed, but no damage of any kind resulted. At this place the intensity was not above IV of the same scale.

The following observations on the earthquake have been kindly supplied by R. A. Liddle who was in a room on the second story of a well built three-story frame house in Mexia. Mr. Liddle was awakened and felt two shocks which came with gradual onset, the first shock being accompanied by a southeast-northwest swaying of the building. No sound was heard other than the creaking of the building. He recognized the shock as an earthquake and made careful notes. Mr. Liddle says:

> To several people it was distinct that movement was from southeast to northwest. To those sleeping near the southeast corner of the houses the sound was as if dozens of large cats ran across the roof from the southeast corner of the house toward the northwest. To those in the northwest rooms, like the observer, the sound was as if the houses were coming apart at all joints; dishes and stoves rattled. The shock was fairly severe, for a telephone ringing (answered by a member of the household in which I was staying) less than five minutes before failed to waken me, but I woke immediately at the shock of the quake in plenty of time to feel the bed sway for a few seconds. Then I ran to my watch and read the time as 3:15. I have read where others gave the time as 4:15 but I don't think I read

> my watch wrong, even though I was a bit dazed from waking so suddenly.
>
> I think the quake was a slight movement along the faulting in the vicinity—probably the Wortham fault, for from what I can learn the movement was slightly more intense in Wortham than in Mexia. At Groesbeck, south of Mexia, I understand the shock was very slight. The second movement was several seconds after the first, and was barely noticeable.

In all directions from Mexia and Wortham the tremor died out very rapidly. At Richland, 10 miles northeast of Wortham, the earthquake was felt by only a few persons who were already awake. At Teague, 12 miles east, and at Groesbeck, 11 miles south of Mexia, a light shock was felt by only a few persons. To the west as far as Prairie Hill, 18 miles, the shock was felt by several persons some of whom were awakened. The maximum distances at which the shock was at all perceptible to persons awake are as follows: Corsicana, 21 miles north of Wortham; Thornton, 19 miles south of Mexia; and Watts, 23 miles west of Mexia. The shock apparently was not perceptible at Fairfield, 19 miles east of Mexia, and scarcely perceptible at Streetman, 10 miles northeast of Wortham. That the earthquake wave did not travel far is further supported by the fact that it failed to register on seismographs at Denton and at Austin, a distance of 110 and 120 miles from the origin.

No definite disturbance at the surface has been observed. A crack cutting diagonally across the concrete highway between Mexia and Wortham approximately at the crossing of the Wortham fault line may have formed as a result of the shock. This break was examined by W. A. Reiter on the day following the earthquake and appeared at that time to have been recently formed, the margins not being crumbled as they necessarily are as the result of travel. The trend of the break across the concrete is N. 67° E. while the trend of the fault at this place is probably near N. 31° E.[4] Numerous more or less similar breaks are found in the concrete road between Mexia and Wortham particularly where it rests on a clay foundation and has few expansion joints. Of many such breaks examined, all except the one referred to above cross the road nearly at right angles. The fact that this one break was freshly formed, is diagonal

---

[4]Lahee, F. H., *op. cit.*, p. 350 (map).

to the road, coincides with the position of a fault line, and approximates the fault trend, suggests that it may have been caused either by the force of the shock or as the result of a slight subsidence coincident with the shock.

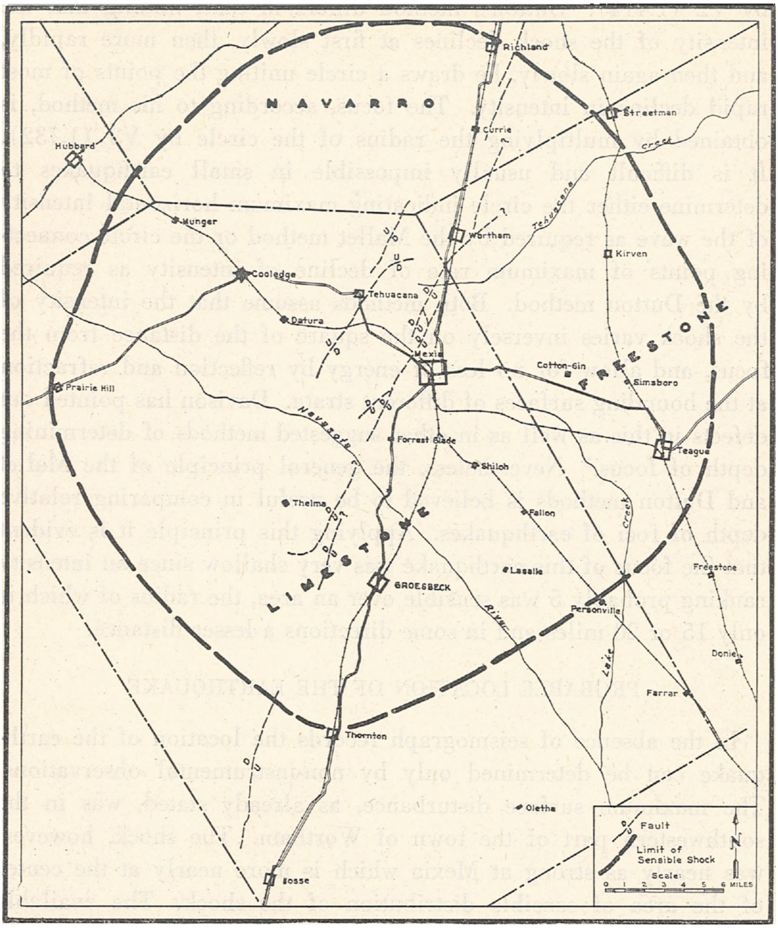


Fig. 4. Sketch map of the Mexia-Wortham region showing outer limits of sensible shock of earthquake of April 9, 1932.

PROBABLE DEPTH OF FOCUS

According to principles developed by Mallet and Dutton, the more rapidly the shock declines outward from the epicenter, the less is the depth of the focus. Mallet uses the horizontal component only which from zero at the epicenter increases rapidly in all directions to a maximum and then decreases gradually. A circle is drawn through the points of maximum intensity. The depth of the focus is then obtained by multiplying the radius of the circle by V2 (1.414). Dutton's method differs in that, finding that the intensity of the shock declines at first slowly, then more rapidly, and then again slowly, he draws a circle uniting the points of most rapid decline in intensity. The focus, according to his method, is obtained by multiplying the radius of the circle by V3 (1.732). It is difficult and usually impossible in small earthquakes to determine either the circle indicating maximum horizontal intensity of the wave as required by the Mallet method or the circle connecting points of maximum rate of decline of intensity as required by the Dutton method. Both methods assume that the intensity of the shock varies inversely on the square of the distance from the focus, and allow for no less of energy by reflection and refraction at the bounding surfaces of different strata. Davison has pointed out defects in this as well as in other suggested methods of determining depth of focus.[5] Nevertheless, the general principle of the Mallet and Dutton methods is believed to be useful in comparing relative depth of foci of earthquakes. Applying this principle it is evident that the focus of this earthquake was very shallow since an intensity ranking probably 5 was sensible over an area, the radius of which is only 15 or 20 miles and in some directions a lesser distance.

PROBABLE LOCATION OF THE EARTHQUAKE

In the absence of seismograph records the location of the earthquake can be determined only by non-instrumental observations. The maximum surface disturbance, as already stated, was in the southwestern part of the town of Wortham. The shock, however, was nearly as strong at Mexia which is more nearly at the center of the area of sensible distribution of the shock. The available evidence is most completely satisfied by assuming that the tremor was caused by a slight movement along a line near, but west of, Mexia and thence northward to Wortham. The occurrence is placed west of Mexia to satisfy conditions at Tehuacana, where the shock was fairly strong and also because the tremor was sensible for a

---

[5]Davison, Charles, A manual of seismology, Cambridge p. 131, 1921.

greater distance west than east of Mexia. The line as thus placed coincides essentially with the Mexia-Wortham faults and possibly more particularly with the Wortham fault. One inconsistency, however, remains. Wortham, where the shock was strongest, is not central with respect to the area in which the tremor was felt. If the focus at Wortham was nearer the surface than at Mexia the observed difference in the relation of the force of the tremor to its distribution would be explained. Such difference in depth of focus is possible but lacks proof.

PROBABLE CAUSE OF THE EARTHQUAKE

Faulting in this zone, in the opinion of most of those who have studied the area, has been progressive, the throw being greater in the Cretaceous than in the Eocene formations.[6] It may be, therefore, that this small earthquake was the result of a slight additional movement in this zone of faulting indicating that the fault zone is not yet quiescent. On the other hand, the fact that the tremor centered in a region of large oil production lends force to the idea that the tremor may have been caused by adjustment in the land surface incident to operations in the oil fields. That adjustments of level may occur under these conditions is known from the history of the Goose Creek oil field in Harris County, Texas, where subsidence of three or more feet has occurred.[7] The subsidence in the Goose Creek field was so gradual through several years as not to produce appreciable tremors. The geologic section in this field includes only relatively incoherent strata. Under conditions as at Mexia, where the section includes resistant strata, as the limestone of the Midway and Austin formations, subsidence, if such occurs, might result in a jar producing locally a tremor of considerable force. The amount of fluid, oil and water, removed from the Goose Creek oil field previous to the completion of subsidence has been estimated at possibly 100,000,000 barrels. The total production of oil, gas, and water from the Mexia oil field to the end of 1931 was as follows: oil, 90,436,791 barrels or 452,000,000 cubic feet; gas, 565,000,000 cubic feet; water, assuming 2½ barrels of water for

---

[6]Lahee, F. H. *op. cit.*, p. 337.

[7]Sellards, E. H., Subsidence in Gulf Coastal Plains salt domes: Univ. Texas Bull. 3001, p. 29, 1930.

each barrel of oil, 1,130,000,000 cubic feet; and from the Wortham field, oil, 22,243,499 barrels or 111,000,000 cubic feet; gas, 139,-000,000 cubic feet; and water, 277,500,000 cubic feet; total 2,674,-500,000 cubic feet.[8] The amount of water is necessarily an estimate. W. E. Pratt[9] is of the opinion that the flow of water is nearer 5 than 2½ barrels for each barrel of oil. If 5 barrels of water accompany each barrel of oil the total production from the two adjoining fields is then 4,082,000,000 cubic feet.[10]

It is true that as oil, gas, and water are removed, water under a slightly reduced pressure takes their place. Nevertheless as evidence that disturbance involving subsidence may take place accompanying the removal of fluids, it is necessary only to appeal again to the Goose Creek field where the amount of subsidence is definitely recorded. Whether this tremor therefore proves continued activity in the Mexia-Wortham line of faulting or records merely local subsidence in these oil fields incident to the removal of oil is at present undetermined.

---

[8]These data on production have been kindly supplied by the Humble Oil and Refining Company.

[9]Letter of June 6, 1932.

[10]The cubic feet of gas as measured at the surface is, of course, greater than the cubic feet of gas underground since the pressure at the surface is much less.

THE VALENTINE, TEXAS, EARTHQUAKE

By

E. H. Sellards

INTRODUCTION

In the early morning of August 16, 1931, an earthquake of some severity originating in Trans-Pecos Texas affected a region including northern Mexico, eastern New Mexico, and much of Texas. The strongest shock from this earthquake occurred at or near 5:40.20 A.M. central standard time. Lighter shocks were felt earlier and several successive light shocks occurred during the next two months. Immediately following the earthquake, an investigation was made which included a visit to the localities of appreciable damage. In addition, circulars were distributed to many persons in the region affected and press reports were assembled and checked for the entire area over which the earthquake was of sufficient strength to cause comment. The geologists of Texas very considerately supplied observations from all parts of the state.

The results of the investigation show that the maximum damage done was at Valentine, in the southern part of Jeff Davis County, and at Lobo, in Culberson County, and at intermediate points. Minor damage was done over a larger area, including Sierra Blanca to the west, Presidio to the southeast, Marathon and Alpine to the east, and Monahans to the north. Not all towns in this larger area were equally affected, although the seeming discrepancies may be due in some degree to lack of complete information.

Seismograph records on the earthquake have been kindly supplied by several stations. In this connection indebtedness is acknowledged to the United States Coast and Geodetic Survey, Loyola University, New Orleans, and particularly to Dr. Perry Byerly of the University of California, who is making an exhaustive study of the world record of the earthquake based on instrumental records.

The non-instrumental information available includes, in addition to personal observations, reports received by correspondence or otherwise from a large number of geologists in Texas, New Mexico, and Mexico, and reports from non-geologic observers in Texas and Mexico. To these has been added certain of the reports on critical

Issued February, 1933.

localities supplied by the United States Coast and Geodetic Survey obtained by that organization from circulars sent to postmasters. Special acknowledgment is due to the officials of several Mexican cities who responded fully to letters of inquiry in regard to the effects of the earthquake.

SCALE OF INTENSITY

The scale that has been most generally used in expressing earthquake intensity is that known as the Rossi-Forel scale. This scale may be summarized as follows:[1]

I. Microseismic shock.—Recorded by a single seismograph or by seismographs of the same dole, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. Extremely feeble shock.—Recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. Very feeble shock.—Felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. Feeble shock.—Felt by persons in motion; disturbance of movable objects, doors, windows; cracking of ceilings.

V. Shock of moderate intensity.—Felt generally by everyone; disturbance of furniture, beds, etc.: ringing of some bells.

VI. Fairly strong shock.—General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings.

VII. Strong shock.—Overthrow of movable objects; fall of plaster; ringing of church bells; general panic; without damage to buildings.

VIII. Very strong shock. Fall of chimneys: cracks in the walls of buildings.

IX. Extremely strong shock.—Partial or total destruction of some buildings.

X. Shock of extreme intensity.—Great disaster; ruins; disturbance of the strata, fissures in the ground; rock falls from mountains.

In the actual application of this scale some considerable difficulty is met with, particularly when, as in the present instance, the reports are from several sources. It is difficult, even when the observations have been made at many stations, to define the limits of the intensities, and the lines drawn must therefore be accepted as approximate. In some respects the scale itself is difficult to apply. Thus "rock falls from mountains" is placed in intensity X. As a matter of fact it is evident that a very mild shock would in some instances cause rocks to fall from mountains. However, by careful sifting of all available evidence an approximate interpretation of

[1] U. S. Coast and Geodetic Survey, Seismological report, Serial Number 503, p. 2. 1927.

intensity may be made, this being all that is claimed for the system. It is understood that a new scale of intensities has been proposed by Dr. H. O. Wood which, however, has not yet been published.

LOCAL GEOLOGIC CONDITIONS

The earthquake occurred in the mountainous region of Trans-Pecos Texas. The town of Valentine, where the maximum effect was felt, is located in an intermontane valley. This valley at this place is chiefly synclinal in nature, although it may be in part bounded by faulting. Northward the valley extends into New Mexico. In the Van Horn region, this northward continuation of the valley, there known as the Salt Flat, is a graben or rift valley set off from the bordering mountains by faults that in places have a throw of several thousand feet. Southward from Valentine the valley terminates near the Chisos Mountains. The valley as a whole is filled with debris from the bordering mountains and south and east of Valentine received extensive Tertiary lava flows. Towns east of Valentine, including Ryan and Marfa, are built upon the lavas. The structure lines in this part of Trans-Pecos Texas as indicated by this valley are prevailingly northwest-southeast.

Southwest of Valentine, forming the margin of the valley in that direction, are the Tierra Vieja Mountains. On the opposite side and forming the northeastern margin of the valley are spurs of the Jeff Davis Mountains, which are chiefly volcanics of Tertiary time. Some of the mountains west of Valentine are heavily faulted, the faults having in the main a northwest-southeast trend. At its west margin the Tierra Vieja Mountains terminate by a great fault forming the topographic feature known as the rim rock. Just how close to Valentine faulting occurs cannot be determined, owing to the valley fill. However, fault lines may and probably do exist in the valley underneath the fill.

The epicenter of the earthquake is located by the United States Coast and Geodetic Survey from instrumental records at 29°40′ N. and 104° W.[2] This location places the epicentrum some 70 miles south-southeast of Valentine and on or among the Tertiary volcanics. The nearest towns to the epicenter as thus located are Casa Piedra,

---

[2]Letter of October 10, 1931.

15 miles north; Shafter, 21 miles northwest; Presidio, 25 miles southwest; and Marfa, 25 miles north. No report has been received from Casa Piedra. However, at all of the other towns nearest to this instrumental location of the epicentrum the effects of the earthquake were slight as compared to those at Valentine. Professor Perry Byerly of the University of California, after making a study of all available instrumental records, locates the epicenter at 30°53′ N. and 104°11′ W.[3] This location places the epicenter in the Davis Mountains some 30 miles almost due northeast of Valentine. This latter location, which more nearly agrees with the observed surface disturbances, places the epicenter near a syncline of the igneous flows which constitute the Jeff Davis Mountains.

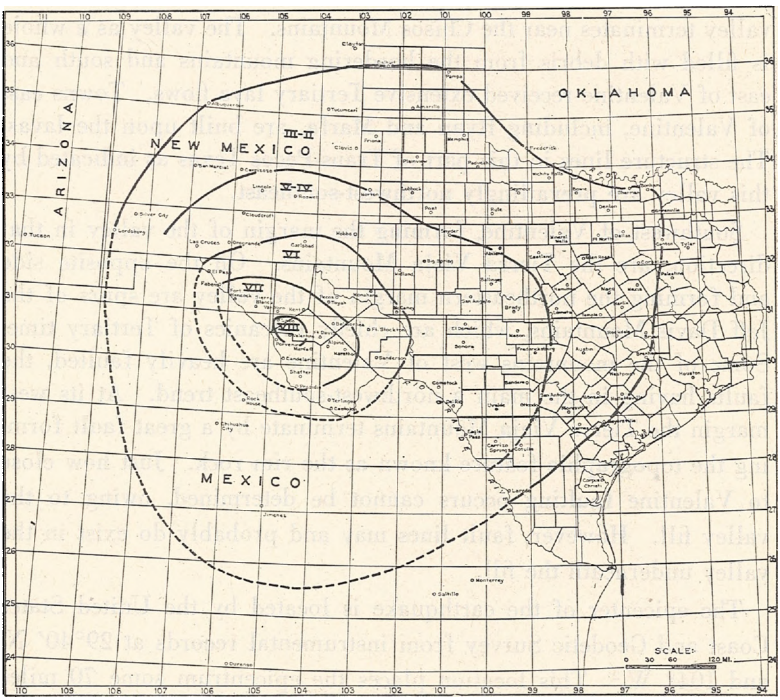


Fig. 5. Map of Texas and adjoining states to show extent of sensible shock of earthquake of August 16, 1931.

---

[3]Letter of February 29, 1932.

DETAILED OBSERVATIONS

Region of Maximum Damage

The earthquake of August 16, 1931, is regarded as of intensity VIII of the Rossi-Forel scale, this intensity having been observed at Valentine and Lobo and in the intermediate area.

VALENTINE

An inspection of conditions at Valentine was made on August 20, 21, and 22, 1931. The buildings at this place include reinforced concrete, hollow block tile, brick, frame, stucco, and adobe houses.[4] The effect on these several types of building and on monuments in the cemetery and on concrete tanks is given in the following notes.

Concrete buildings.—The one reinforced concrete structure at Valentine is a one-story building. This building was cracked at the union of walls and ceiling. There were also cracks entirely through the wall, particularly at the south side, where the wall was weakened by a door and a small window. The cracks developed in this side of the house are for the most part vertical. One extends from the top of the building to the door and again from the bottom of the door to the ground. Above the small window are at least three breaks, which extend from the top of the building to the window and thence diagonally downward. Some other minor breaks are seen in the building.

Concrete tanks.—The force of the earthquake wave at this place is further well shown in a concrete tank located about one and one-half miles west of Valentine. This tank is approximately 21 feet square, has walls about 8 inches thick, and is reinforced with steel rods. The tank was badly broken, the breaks being approximately horizontal. The west side of the tank was most badly damaged. The water of the tank broke out through this side, moving large blocks of the broken concrete with it.

About 10½ miles west of Valentine and south of the public road is a concrete tank about 15 feet square. The walls of this tank are 6 inches in thickness. This tank has longitudinal and vertical cracks on the east and south sides made by the earthquake and chiefly

---

[4]Adobe houses are constructed of bricks made from silt or clay with intermixture of straw, the whole being sun dried.

vertical cracks on the west side and a large horizontal crack on the north side. At the Vaughn ranch house, 13 miles west of Valentine and about ½ mile south of the road, the chimney of an adobe house was knocked down and the plaster of the house injured. The concrete tank at this place was uninjured by the earthquake.

Hollow block and brick.—The schoolhouse at Valentine consists of two parts, the front being hollow concrete block, and the rear, a later addition, being brick. It is a one-story building with cupola at the front. This building shows considerable damage in both the concrete tile and the bricks. For the most part the cracks do not pass through the blocks or the bricks, but follow the mortar. The southeast face of the cupola gave way in its central part, the blocks slipping, and the cupola almost caved by moving northwestward. All chimneys in the building were affected, being thrown down, entirely or in part. Both the concrete tile and the brick walls have cracks entirely through the wall. On one of the chimneys at the northeast side of the building a concrete block which formed the cap of the chimney was thrown approximately northward clear of the roof. The remainder of the chimney remained in place. Approximate measurements of the height of the chimney and the distance the cap was thrown are as follows: height of chimney from the ground, about 32 feet; from chimney to edge of roof, 3 feet, 9 inches; block thrown beyond the edge of roof, 5 feet; total horizontal throw, 8 feet, 9 inches. The cement cap apparently did not turn over in falling but hit the steps to the schoolhouse in the same position, or approximately so, as it rested on the chimney.

Frame houses.—The damage at Valentine to frame houses was chiefly the loss of chimneys, most of which were injured or entirely destroyed above the roof, and to the plaster. Plaster on frame buildings was somewhat but not badly broken. The chimney of a two story frame residence standing in the block next northeast of the schoolhouse was broken at the level of the roof and thrown clear of the roof. The chimney which is estimated to weigh 200 or 250 pounds remained intact until it hit the ground when it broke into two pieces. This chimney likewise remained approximately upright in its fall having hit the earth, as shown by the indentation, in a sloping position. This chimney which had a total height of 16 or 17 feet broke 12 or 14 feet from the ground. The direction of throw in this case is approximately due northeast, the horizontal throw being about 7½ feet. A small house resting on posts has been constructed at the west side of Valentine by the United States Department of Agriculture to serve as a quarantine station. An examination of the posts on which the house rests shows that the posts moved appreciably in a southwest-northeast direction. The greatest amount of movement is seen in the post at the northeast corner which enlarged the hole in which the post rests by as much as three-quarters of an inch at either side in this direction. These observations on the chimneys and on the posts of this house are believed to establish a north or northeast to south or southwest direction for the vibrations at this place. Several of the frame houses at Valentine rest on posts. In none of these posts, however, was the movement found to be so definite as at the small house of the quarantine station. The considerable movement of the posts at the quarantine station is possibly due to the fact that the ground was not well compacted, the house having been built in February, 1931.

Adobe houses.—The injury to adobe houses was much more severe. A few of these. especially the older ones, were partly down. Thus at one residence the three gables of an adobe house fell, all falling into the interior of the house. The ends fell out of several adobe houses. The walls of a large number of the adobe houses were badly cracked so that the houses can with difficulty, if at all, be repaired. The plaster likewise was very badly broken in houses of this type. Some repairs had been made before the writer reached the locality and it was not possible to make a very close estimate on the number of adobe houses injured. However, some residents of the city estimated not fewer than 100 badly injured adobe houses. A few of the newer and well constructed adobe houses suffered relatively little injury.

Monuments.—In the principal cemetery at Valentine it was found that seven of the tombstones had moved more or less without having been thrown down. The upper stone of two other tombstones had fallen to the ground. However, there is evidence that these tombstones were leaning and fell for that reason. Of the 7 stones that showed disturbance, 5 were found to be moved anti-clockwise, the twisting amounting to an eighth of a turn or less. The remaining

2 disturbed stones were moved clockwise, the twisting being approximately the same as for those that moved in the opposite direction. In each instance the uppermost stone or shaft was broken loose from the stones below and moved on those stones. This effect on the monuments of the cemetery is shown in Plate XII, Figures 1, 2, and 3. In Figure 2, two monuments of essentially the same size and same general character are shown to have moved in opposite directions. In another cemetery south of the road containing only a few monuments, the shafts of 2 monuments were found to have moved, one having been moved clockwise, the other anti-clockwise.

The safe of the Valentine Trading Company, said by the owner to weigh 470 pounds, mounted on a sill 6 inches square, was slightly twisted, the twisting being anti-clockwise.

REGION ADJACENT TO VALENTINE

The region adjacent to Valentine is thinly settled and there are but few ranch houses from which to determine the effect of the earthquake. An adobe house at a ranch 12 miles southwest of Valentine was somewhat cracked and the plaster on the house fell. On the other hand, an adobe house 8 miles south of Valentine was less severely affected, the chimney remaining standing. An adobe house 14 miles south of Valentine received no appreciable damage. Another adobe house 22 miles south of Valentine on the Sam Buston ranch had the plaster knocked down in part. In the Davis Mountains about 25 miles north of Valentine and 10 miles more or less south of Boracho station, the brick chimneys fell from an old adobe building. The chimneys on a stucco house with rock foundation on the Bright ranch 10 miles south of Valentine were injured and the plaster slightly cracked. An adobe house 15 miles east or southeast of Valentine had the chimney down and slight cracking of plaster. South of Valentine 25 or 30 miles under the "rim rock" Mr. R. R. Landrum sleeping on a cot in a tent felt two shocks. An old adobe house belonging to A. Nagle 9 miles farther southwest was damaged beyond repair, and springs were muddied.

LOBO

Lobo is a station on the Southern Pacific Railroad 28 miles west of Valentine. The settlement at this place consists of the depot, residence for the depot agent, and a residence for the signal light superintendent, a filling station, and a large two story brick hotel now being used as a ranch house. This hotel building which is a brick veneer over frame was seriously injured by the earthquake, the walls being cracked, particularly on the northwest and southeast ends. A considerable amount of brick fell eastward from the northeast side of the house. There is no cemetery with monuments at this place.

Between Valentine and Lobo on the Southern Pacific Railroad are station houses at Wendell and at Chispa. These are frame buildings on which the chimneys were knocked down or broken. Pronounced land slides occurred in the Van Horn Mountains southwest of Lobo.

Region of Slight or No Damage to Well Constructed Buildings

Localities suffering slight damage from the earthquake to well constructed buildings include Alpine, Fort Davis, Kent, Marfa, Marathon, Presidio, San Solomon Spring, Shafter, Sierra Blanca, and Van Horn. Within the large area indicated by these towns there are many buildings and some towns that escaped appreciable injury.

Alpine.—At Alpine only slight damage was done. Three chimneys on the residence of Judge Van Sickle were thrown to the ground. A few bricks fell also from some other chimneys in town and some bricks were knocked from the margin of the telephone building. In at least one adobe house the plaster fell in small amounts. One comparatively new hollow concrete block, steel reinforced, building showed some effects of the earthquake by the development or enlargement of small cracks and only slight breaking in the plaster where the beams of the building rest. In one building constructed of a 1:5 mixture of crushed rock, sand, and cement, covered with plaster a horizontal break occurred at approximately the roof level. This break which is seen on the west side of the building extends almost the entire length of the building but affects the plaster only and according to the owner does not show on the interior of the building. There was no disturbance to monuments in the churchyard.

Fort Davis.—It is reported by Weather Bureau Observer E. H. Carlton through the United States Coast and Geodetic Survey that at Fort Davis an elevated steel water tank split in one of the bottom seams allowing the water to escape and that some chimneys and plaster fell. A roaring sound like a mighty wind was heard.

Kent.—Slight damage to one building is reported at Kent.

Marfa.—At Marfa slight damage is reported to the courthouse and the postmaster reported to the United States Coast and Geodetic Survey as follows: "One very distinct shock, rapid onset and rocking E-W motion. Taller buildings swayed visibly. A few chimneys shaken down and small perpendicular cracks observed on well constructed adobe buildings. Objects fell E-W. Plaster shaken down in some cases. Several clocks stopped. Rumbling sound like approaching hail storm."

Marathon.—At Marathon the effect of the earthquake was somewhat less evident than at Alpine. The hotel building at this place built of brick in 1926 suffered very slight cracks in the plaster in one or more rooms. In the Albert Chambers house which is stucco over frame, numerous cracks developed on east, north, and west sides. The west side has small cracks extending almost the full length. These cracks appear to affect the stucco only, not the frame work of the house. Bricks fell from the chimney of the Gage ranch house 12 miles east of Marathon and south of the public road.

Presidio.—At Presidio relatively slight damage was done. The plaster fell from some of the adobe houses. However, no conspicuous cracking of the walls of adobe houses was reported. In only one instance was the chimney of an adobe house seen to be disturbed. In this case the upper part of the chimney which was brick was slightly off-set westward. A hollow brick concrete building occupied by the Ford Sales and Service Company showed some cracks at the west end which were said to have been enlarged by the earthquake. The Riggs Studio, a reinforced concrete building, developed numerous small cracks and enlarged others already existing. Slight cracks were developed in the cement floor also. The occupants of the house were not awakened. A reinforced hollow block tile building plastered over the tile showed, according to the occupant, cracking previous to the earthquake and was appreciably more cracked following the earthquake. Cracks enlarged very decidedly in a hollow block concrete building. At the cemetery in this place no disturbance of monuments was observed.

No appreciable damage is reported at Ojenaga in Mexico across the river from Presidio.

Rio Grande Valley.—That the damage on the Rio Grande south of Valentine, except that recorded for Presidio, was inappreciable is indicated by the following observations. The residence of Mr. Snider 6 miles west of Pilares was unaffected by the earthquake. An adobe chimney of the building remained intact and there was no cracking of the walls or plaster.

At Porvenir, 12 miles west of Pilares, there was no appreciable damage to adobe buildings although a few rocks shook from the wall of one building and a small amount of plaster fell. At Pilares while a strong shock was felt no appreciable damage was done to adobe buildings. At Candelaria, 28 miles down the river from Pilares, brick flues were not knocked down and the plaster was but little injured although a two story adobe house at this place had slight cracking of plaster. At Ruidosa, 12 miles down the stream from Candelaria, brick chimneys were not affected and no plaster fell.

Seventeen miles up the Rio Grande from Pilares the residence of Mr. Z. Monroe, a log house, suffered no damage, the chimney not having been destroyed. From the more precipitous mountain region considerable falling of rock was reported. This is true in particular of the "rim rock" country between Valentine and Pilares.

San Solomon Spring.—The San Solomon spring at Balmorhea became muddy following the earthquake and was still disturbed, according to observations made by Vaughn L. Maley, as late as August 19.

Shafter.—Relatively little damage occurred at Shafter. However, it was reported to the United States Coast and Geodetic Survey that there was general alarm, trees and buildings swung, and that, according to Mr. Speed, manager of the mining properties at this place, there was some damage to reinforced concrete and cement. The direction of motion was northwest-southeast. Nearly all persons here were awakened.

Sierra Blanca.—At Sierra Blanca the Red Ball Bus Station, a frame building with stucco and metal lath plaster, has very small cracks extending almost around the building. The cement floor also is slightly cracked. Small cracks also developed in the Ford garage building which is a metal lath and beaver board building. The printing office which is brick plastered on the inside developed small cracks. In the Broadway Cafe the part of the building built of rock pulled away somewhat from the other part of the building which is hollow tile. No chimneys were knocked down at Sierra Blanca and there was no disturbance to monuments in the church yard.

Sierra Blanca to Fabens.—Very slight damage was done in towns west of Sierra Blanca. At Fort Hancock plaster cracked off in one adobe house. At Tornillo some plaster fell in an adobe house. At Fabens very slight damage was done to the adobe walls, the older part of one building pulling away from the newer part.

Van Horn.—At Van Horn some bricks were moved from the chimney of a concrete block house and small cracks appeared in plaster of one building. The water pipe leading to the stand tower at this town leaked slightly following the earthquake due evidently to motion at the time of the earthquake. The direction of motion at this place is said to have been east-west. There was no disturbance to monuments in the church yard.

Region of Strong Shock With Slight Damage

At a distance of from 60 to 125 miles from the locus of the earthquake is a region of strong shock but in which in only a few instances is actual damage recorded. The principal towns of this region at which observations were made or from which reports were obtained are as follows: Carlsbad (New Mexico), El Paso, Fort Stockton, Juarez (Mexico), McCamey, ranch south of the Rio Grande (Mexico), Monahans, Pecos, Sanderson, Terlingua, Toyah.

The limited information obtained from Mexico indicates reduced force of the earthquake south of the Rio Grande. An observer about 75 miles southwest of Candelaria sleeping in a rock house was not awakened by the earthquake. His wife, however, felt the tremor. No damage was done at this place, which is about midway between Candelaria and Chihuahua.

Carlsbad, New Mexico.—From Carlsbad, New Mexico, about 125 miles north of Valentine, reports on the effect of the earthquake were kindly submitted by F. B. Coryn, Edgar Kraus, E. Obering, C. G. Staley, and R. J. G. Stewart. The shock at this place was of considerable intensity; almost all persons were awakened. Mr. Staley writes that the only damage done was bricks shaken from the chimneys of an old two story house. Mr. Kraus essentially confirms this report stating that "one brick chimney had about one-third of its bricks shaken down. The owner says the house and chimney were old having been up for many years. One other chimney was found to have lost but one brick . . . . Two metal ventilating pipes on gas water heaters were shaken down." Mr. Stewart reports a third chimney, said to be old, from which bricks were reported to have fallen. Mr. Coryn adds that there was a north-south rocking motion of buildings and that some small cracks formed in the walls of one of the hotels. Other reports show that animals were disturbed, telegraph poles swayed north-south, and water spilled over the sides of tanks. Through Mr. W. B. Lang notice is received that rock slides are reported to have occurred in McKittrick and Dog canyons in the Guadalupe Mountains.

El Paso.—At El Paso chairs moved, lights swayed, some persons left houses, and animals were disturbed. Guests in the upper stories of hotels were particularly disturbed by the swaying motion. No actual damage to buildings seems to have occurred although some minor damage to adobe houses is reported. President J. B. Barry reports clock out of plumb. Mr. M. B. Arick who was on the sixteenth floor of a hotel at El Paso writes as follows: "My wife and I were awakened by the tremor; the people in all the adjoining rooms were also awakened. The tremor was accompanied by a rumbling sound which we attributed to sash weights shaking. The hotel in the upper stories swayed over 2 feet from side to side, the direction of movement being apparently about northwest-southeast. The chandeliers in the center of the room swung from side to side. A mirror suspended on the south wall swung in an arc which could be measured by the scratches on the wall. This arc measured 6 feet. No objects in the hotel were damaged, and, except for a few dishes which were shaken from racks, no damage was reported in El Paso."

Juarez, Mexico.—The only damage reported at Juarez, Mexico, is minor injury to adobe buildings. Similar minor damage to adobe houses, probably more or less defective, is reported in this part of the Rio Grande Valley.

Fort Stockton.—Of the effects of the earthquake at Fort Stockton, Mr. Waldo Williams gave the following information: Two property owners claim injury by the earthquake. Of the two buildings concerned, one is of stone and brick and was badly built about twenty years ago. The cracks now in the building may have been caused by the earthquake or may have already been there. The other damaged building is an old adobe house in bad repair from which some plaster is said to have fallen. The water of Comanche Spring was slightly cloudy, not muddy, for several hours after the earthquake. Well constructed buildings such as the new and old schoolhouses were not injured.

McCamey.—From McCamey about 150 miles east-northeast of Valentine reports have been submitted by W. B. Collins, V. A. Brill, J. B. Carsey, and C. J. Taylor. No damage is reported at this place. However, the considerable force of the shock at that place is indicated by the fact that almost all were awakened and such small objects as pictures standing upright were overturned. Mr. Carsey writes: "The beds were given a persistent rhythmic motion on their springs and the metal handles on a chest of drawers swung sufficiently to be heard hitting the drawers to which they were attached."

Monahans.—At Monahans a two story brick building suffered slight breaks in the plaster in some of the rooms. A crack developed in the concrete floor. This crack extends east-west and can be followed for approximately 15 feet. The direction of motion reported here is approximately north-south. The intensity if judged by this building alone would seem to be above the average for this distance from the locus of the earthquake. However, no other damage was seen at Monahans and it seems probable that the damage to this building is to be attributed to the condition of the foundation.

Pecos.—No damage other than a slight cracking of plaster is reported at Pecos. However, the shock is described as severe. A stone building occupied by the Mint Cafe is said to have rocked approximately east-west, so much so that all persons left the building. At the Crockett Hotel chandeliers swung east-west and beds moved. W. A. Cannon at this place believes the direction of motion was more nearly north-south.

Sanderson.—No actual damage is reported at Sanderson, and the shock seems to have been only moderately strong. Approximately 50% of the people are reported to have been awakened.

Terlingua.—In the Big Bend region the earthquake was relatively slight. At Terlingua, according to observers, not all of the people were awakened. At Boquillas the shock caused rocks to fall in the Chisos Mountains and dishes to rattle in the houses, but did no damage to buildings or chimneys and no plaster fell.

Toyah.—At Toyah one flue is reported to have been shaken down. Bottles were shaken from shelves in a drug store. Mrs. B. Davis observed movement of the ground; a fence in front of her window apparently moved northward.

Region of No Damage to Buildings

The spread of the earthquake wave was attended by gradually reduced intensity until the shock became inappreciable except to the seismograph. Of towns in area of intensity V or less special mention will be made of only a few.

Big Spring, Midland, San Angelo.—An apparent intensity above that which would be expected reported in San Angelo, Midland, and Big Spring, is due probably to the fact that in these towns are found high office buildings and hotels, the tremors of the earthquake being more noticeable in high buildings than in low. At Big Spring much confusion is reported at the hotels, many of the guests in the upper stories having left their rooms. From Midland reports were made by F. F. Friend, W. W. Patrick, M. S. Ray, and Chas. D. Vertrees. Mr. F. F. Friend reports as follows: "Was on fourth floor Scarborough Hotel; head of bed to north; motion distinctly east-west; first impression that someone was shaking bed, next impression that of a high wind; lampshade over ceiling fan rattled and the window panes made considerable noise." Other reports show that not all were awakened, floors and walls creaked, and window weights rattled. Reports from San Angelo were submitted by W. B. Anderson, H. P. Bybee, Gordon Damon, Floyd Dodson, G. E. Green, Philip Maverick, Geo. D. Morgan, H. I. Morgan, Mrs. C. C. Pope, S. R. Self, and C. E. Walton. These reports show that not all were awakened and that beds and windows shook and buildings swayed. Mr. Gordon Damon, who was on the eleventh floor of a hotel, states that he distinctly observed an east-west swaying of the hotel building.

Mr. F. M. Getzendaner describes the effects of the earthquake at Uvalde approximately 300 miles east of Valentine as follows: "I felt the tremors very distinctly. They shook the building very perceptibly and rattled the head of my bed against the wall, making considerable noise. The second tremor felt by me was something like a minute after the first. It was not severe enough to make any noise although I felt the vibrations very clearly. Between the two tremors I looked at the clock and after getting up I set my watch with the clock and then went to the Western Union to check the time. It was 5:40 A.M. (C.S.T.) when I looked at the clock. This was right after the first tremor. No damage was done at Uvalde and not all were awakened."

Geologists who kindly reported observations on the earthquake at Austin are J. A. Udden, F. W. Simonds, F. B. Plummer, H. A. Hemphill, and R. H. Cuyler for Mrs. R. H. Cuyler, Sr. A report was received also from Mrs. A. A. Stiles. The shock here more than 350 miles from the locus was slight. No more than a small percentage of the people were awakened. However, buildings vibrated appreciably and beds and windows shook. Mrs. Cuyler reports that the doors at her house jammed and two breaks were made in the cement curb in front of her house, and that beds swayed from west to east in hammock motion.

Observations on the effects of the earthquake at Amarillo have been submitted by A. B. Kautz and L. R. Hagy. At this locality approximately 350 miles north of the center of disturbance the shock was mild and few were awakened. On the upper floors of hotels the tremor, according to Mr. Kautz, was quite appreciable. According to press reports, windows rattled and some clocks stopped.

Geologists who have kindly reported personal observations on the earthquake at San Antonio are as follows, H. H. Cooper, E. R. Eastin, C. O. Falk, M. A. Harrell, R. C. Haydon, H. H. Henderson, Dan Heninger, R. Imbt, W. W. Kelley, E. W. Owen, H. H. Roberts, R. H. Thompson, A. K. Tyson, A. W. Weeks, F. M. Van Keuren, and R. E. Vandruff. The earthquake shock at that place, about 350 miles from Valentine, was not strong, but was sufficient to shake houses and beds and to cause light fixtures to swing. Some were frightened. A roaring sound is reported by Mrs. C. E. L. Mermion and a sound as of rubber balls falling upon the roof by Mr. Heninger. An east-west direction of motion is recorded by some and a north-south motion by others. Mrs. I. T. Bradford observed a north-south swing of chandeliers in her house at 1009 Drexel Avenue. Miss Alta Fairrel states that the house swayed, bed rocked as on a raft floating on somewhat rough water, and window weights rattled. Mr. R. E. Vandruff writes as follows:

> I was awakened the morning of August 16 by an oscillation of sufficient magnitude to roll me back and forth in bed perhaps an inch or more, which I at once recognized as an earth tremor. The bed upon which I was lying seemed to move under me and my body tended to act like the "heavy mass" of a seismograph. I felt only one shock; if there was another following the one which woke me I was not in position to feel it, for I got up immediately after being conscious of its being an earth tremor to note the time. It was 5:40 A.M. I had no timepiece at hand that would give the time closer than one minute. No noises were noticed. The house in which I was sleeping is of frame construction and two stories in height. I was sleeping on the main floor. All of the occupants of the house (6 in number) were awakened. The frequency of the tremors was about 3 per second. The intensity was sufficient to cause the house to "creak," but was not strong enough to move any of the furniture or cause the bed to roll across the floor.

Geologists reporting from Fort Worth who did not feel the earthquake are L. E. Bredberg, E. B. Kimball, Alan Bruyere, P. C. Dean, and R. A. Liddle. However, Mrs. W. B. Anderson describes the shock as slight but sufficient to detect a north-south swaying of the house and bed. The tremor at this place is reported also by Ruby Mixson and Bessie Massey.

From Dallas observations on the earthquake were submitted by E. N. Daniels, Miss Knapp, E. J. Foscue, H. L. Millis, L. M. Mitchell, E. W. Shuler, L. C. Smoot, and L. W. Storm. This locality is about 450 miles east-northeast of Valentine and is within about 100 miles of the limits in that direction of the region in which the earthquake was perceptible. Nevertheless the shock was quite appreciable at Dallas. Mr. Storm reports that three shocks were felt by him. Miss Knapp reports that light fixtures swayed almost due north-south. Mr. Smoot reports that all or nearly all were awakened above the fifth floor in the hotels. Of the effects of the shock Mr. Mitchell says: "Motion north-south; awakened by trembling of the bed as if someone were shaking it; rocking chair moved back and forth; noticed that pictures on wall were slowly sliding back and forth with a displacement of about one inch; also the door in the hall was gently opening and closing as if someone on the outside were pulling it back after opening it just a trifle." Mr. Foscue states that so far as he can learn no one in University Park, Dallas, felt the earthquake (sub-stratum Austin limestone) and Dr. Shuler adds that most of those who felt the shock (except in tall buildings as hotels) were in houses on the Trinity River terraces. Mr. Daniels says that a friend in the Baker Hotel was awakened by the swaying of his bed and that his electric light moved four or five inches out of plumb. Another party in east Dallas was awakened by his bed vibrating against the wall.

From Roswell, New Mexico, reports have been received from W. B. Lang and Tom Petty and by the Southern Petroleum Exploration Company. Mr. Lang reports fresh slides in Rhodes Canyon, San Andreas Mountains. Mr. Petty writes: "The apparent duration of the above mentioned tremor, according to those who were awakened about the town of Roswell, was fifteen seconds . . . . A great many people were awakened by the first shock about 2 o'clock (some say 3 o'clock), and several felt two intervening shocks before the distinct one at 4:40. Several people have said that the tremors at 2 and 4:40 were preceded by a roaring sound similar to an approaching wind storm, or a large rain or hail storm. One man who thought a wind storm was approaching got out of bed to close the windows of his house and while in the action of doing this noted that no leaves or limbs on the trees were moving and that there was absolute stillness outside, then he felt the tremors. The best idea of the intensity in this area is obtained from witnesses, who state that houses creaked, swinging lights oscillated, and sash weights in the window casements swayed to and fro making a rocking sound against the casement walls, and some noted vibration of bed springs . . . An artesian well is reported to have flowed muddy water for about two hours following the last shock . . . People who were sleeping in upper stories in houses noted the swaying motion of the building . . . A few cracks in plastering and also a crack across one of the city paved streets have been reported. . . This crack crosses a street running north and south, and its report might not be authentic, as it may have been an old contraction crack that had not been noticed by the one reporting it previously. This also might be true of the plaster cracks."

From Sherman 500 miles or more east-northeast from the center of disturbance the shock was felt distinctly. Reports at this locality have been received from Dr. H. I. Stout, N. W. Brillhart, and Frank A. Forbes. Dr. Stout writes:

> I retired along about midnight August 15, and at five minutes of 6 the following morning I was awakened by the house trembling. My wife, sleeping in an adjoining bed, thought that the noise she first heard, which caused her to awaken at the same time that I awoke, was that the child had fallen out of bed. On turning on the lights, she saw the doors quivering. The articles, loose in the attic above us, were rolling around and the windows shaking. The first vibrations were felt at five minutes of 6 and lasted about two minutes. There was an interval of about three minutes and another series of vibrations was felt, which again shook the house, lasting about one-half minute. . . . I could not say that there was any particular direction of the swaying. The whole house, a two-story structure with attic, was vibrating. I would suggest that the vibrations were about 80 per minute, but with no particular direction.

Mr. Forbes, who was already awake and in the second story of a two-story house, writes:

> The whole house seemed to move or sway in a northerly direction up to a certain point and then come to a sudden stop or halt; this so-called tilting or falling caused a queer feeling in the pit of my stomach like unto a slight nausea some people have from a ride on boats (not hardly sea sickness, but uneasiness). Immediately following this impression there came several apparent vibrations which rattled glassware on the furniture, turning over one small-based, long-stemmed vase. At the beginning of the first sensation that the house was falling, I looked toward the wall just opposite me in the room and noticed a mirror, which was hung on the wall by picture cord, move probably an inch or more and then apparently settle. I feel positive this was no illusion.

At West Point, about 450 miles east of Valentine, G. A. Lanaux, who was sleeping on the ground floor, was awakened by the tremor, as were all others in the house. He states:

There seemed to be two shocks, with a lapse of a few seconds between; the tremor was accompanied by a noise similar to that of rumbling thunder; beds and other furniture were shaken, windows and chandeliers rattled, and the frame house creaked.

Notes on other localities will be found in the following tabulated data by towns in Mexico, New Mexico, Oklahoma, and Texas.

TABULATED DATA ON THE EARTHQUAKE OF AUGUST 16, 1931

The following table contains a summary of data obtained from all sources, including personal observations, reports from geologists, reports contributed by the United States Coast and Geodetic Survey, from officials in Mexico, from individuals, and from the press. A partial statement of seismograph records is included. The towns listed are arranged alphabetically for each state or country concerned. A few of the towns in which the earthquake is reported as not felt are listed since these help to define the outer limits of the region of perceptible shock. On the other hand, many towns from which limited data were obtained are omitted from the list. No record has been obtained of the shock being felt in Arizona and only one such record from Oklahoma.

MEXICO

Town	*Source of Information*	*Record*	*Intensity Assigned*
	STATE OF CHIHUAHUA		
Chihuahua	Press	Not strong; no damage.	
Jimenez	El Presidente Municipal	Mild: felt by few persons; no damage.	
Juarez	Press	Adobe buildings cracked.	
	STATE OF COAHUILA		
Piedras Negras	W. A. Baker	Felt.	
Saltillo	El Presidente Municipal	Not felt.	
	STATE OF DURANGO		
Durango	El Presidente Municipal	Not felt.	
	FEDERAL DISTRICT		
Mexico City	F. K. G. Mülleried	Recorded by seismograph. Beginning 5.43:20.	
	STATE OF NUEVO LEON		
Monterrey	El Presidente Municipal and others	Not felt.	

Town	*Source of Information*	*Record*	*Intensity Assigned*
		STATE OF OAXACA	
Oaxaca	El Presidente Municipal	Not felt.	
		STATE OF SAN LUIS POTOSI	
San Luis Potosi	El Presidente Municipal	Not felt.	
		STATE OF TAMAULIPAS	
Tampico	D. Trumpy	Not felt.	
		NEW MEXICO	
Alamogordo	Press	Dishes and windows rattled; some adobe walls cracked. E-W facing clocks reported stopped	5
Artesia	U.S.C.G.S.	Felt by many; clocks stopped; motion E-W; no appreciable damage.	
Carlsbad		See account on earlier pages	6
Carlsbad Cavern, 6 miles NE of	U.S.C.G.S.	Many awakened; no damage at Carlsbad Cavern.	
Carrizozo	Press	Distinct shock.	
Cloudcroft	F. H. Lahee	Beds shook; water tank swayed; not all awakened	5
Clovis	F. M. Van Keuren	Mild	2–3
Hagerman	Press	Felt.	
Hobbs	Press	Felt.	
Las Cruces	U.S.C.G.S.	Many awakened; dishes rattled; clocks stopped.	
Lincoln	U.S.C.G.S.	Many awakened.	
Lordsburg	Press	Felt.	
Mescalero	Press	Distinct shock.	
Orogande	U.S.C.G.S.	Most people awakened; animals disturbed.	
Picacho	U.S.C.G.S.	Felt by many; some plaster fell at schoolhouse.	
Portales	Press	A number of persons awakened; rumbling sound.	
Ranch 70 miles N of Pecos	Chas. Fitzgerald	Rumbling sound; house rocked E-W.	
Roswell	W. B. Lang	Not all awakened; beds rocked moderately	5
	Tom Petty	Motion apparently N-S; lights swung.	
San Marcial	U.S.C.G.S.	Felt by many; two shocks; motion E-W.	
Silver City	Press	Mild.	
Tucumcari	Press	Felt.	
Tularosa	U.S.C.G.S.	Felt by many; one shock.	
		OKLAHOMA	
Frederick	A. H. Holloman	Mild tremor	2

Town	*Source of Information*	*Record*	*Intensity Assigned*
		TEXAS	
Abilene	W. A. Riney	Not all persons awakened; no damage	4
	T. K. Knox	Motion apparently E-W.	
Allamooıe	Pıess	Some adobe houses injured	7
Alpine		See account on earlier page	8
Alvarado	Press	Several awakened; no damage	2–3
Amarillo		See account on earlier page	2
Austin		See account on earlier page	3–4
Ballinger	Press	Many awakened	4–5
Bartlett	Press	Few awakened; clock stopped	3
Beaumont	Several observers	Not felt.	
Big Spring		See account on earlier page	5
Bonham	Press	Few awakened; windows rattled; lights swayed; house swayed gently	2
Brady	Press	About one-half people awakened; a few frightened; windows, dishes, furniture rattled	4–5
	G. S. Langford	Rumbling sound.	
Brownwood	J. R. Mitcham	Windows rattled; no damage; houses creaked; many awakened	4
Cameron	Press	Windows and dishes rattled	3
Camp San Saba	I. T. Elder	Well water muddy following earthquake.	
Candelaria		See account on earlier page.	
Canton	A. A. Stiles	Mild	2
Carlsbad	State Sanitorium	Few awakened; no damage.	
Castolon	U.S.C.G.S.	General alarm; rocking and swaying E-W with up and down motion; several walls cracked in old adobe building	6
Christoval	Press	Beds and dishes rattled; pictures moved	5
Coleman	M. G. Cheney	Not all awakened; no damage	4
Colorado	Press	Tables and chairs swayed; beds shook; some frightened	4
Comstock		Not felt by all who were awake; dishes rattled.	
Corpus Christi	W. A. Price	Not felt.	
Corsicana	Press	Beds and windows rattled; lights swayed	2–3
Cuero	Press	Few awakened; windows rattled	2
Dallas		See account on earlier page	3
Del Rio		Not all awakened; rumbling sound at Pecos Crossing.	
Denton	Press	Mild	2
Dryden		Not all awakened; horseback rider 25 miles S did not feel shock.	

Town	*Source of Information*	*Record*	*Intensity Assigned*
Eagle Pass	U.S.C.G.S.	Felt by about 10 per cent; some awakened; surface sounds heard; crockery fell from sills; postmaster's clock stopped	4
Eastland	J .G. Blatt	Few awakened; no damage	3
El Paso		See account on earlier page	6
Ennis	Press	Windows and dishes rattled; lights swayed	2–3
Forney	Press	Clocks stopped; few awakened; no damage	2
Fort Davis		See account on earlier page	7
Fort Hancock		See account on earlier page.	
Fort Stockton		See account on earlier page	6
Fort Worth		See account on earlier page	2–3
Fredericksburg	M. E. Roberts	Few awakened; shook buildings; rattled dishes	3
Georgetown	Press	Windows and dishes rattled	3
Giddings	Press	Three shocks felt; chairs and lights swayed; motion SW-NE	3
Gonzales	Press	Windows rattled; beds shook; clocks stopped	3
Greenville	Press	Clocks stopped; lights swung	2
Hearne	Press	Some awakened; clocks stopped	2
Hondo		Two shocks felt; clock stopped.	
Hot Springs	U.S.C.G.S.	Three shocks; moderately loud roaring sound; no damage	6
Houston	Several observers	Not felt.	
Ingram	Mrs. E. W. Brucks	Beds shook; not all awakened; no damage	3
Kent		See account on earlier page.	
Kerrville	Press	Many awakened; windows and lights moved; sound heard; no damage	3
La Grange	Press	Clocks stopped	2–3
Lajitas	U.S.C.G.S.	Felt by several; population alarmed	5–6
Laredo	Press	Beds rocked	2
Lewisville	Press	Windows and beds rattled	2–3
Lobo		See account on earlier page.	
Lometa	Press	Some frightened	3
Longview	Several observers	Not felt.	
Lubbock	H. M. Roberts	Windows and beds rattled; house trembled; no damage	3
	L. T. Patton	Not all awakened.	
McCamey		See account on earlier page	5–6
Marathon		See account on earlier page	7
Marfa		See account on earlier page.	
Marlin	Press	Windows rattled gently; pendulum clocks stopped	3

Town	*Source of Information*	*Record*	*Intensity Assigned*
Melvin	Loften McDonald	Noise like distant thunder; house shook; walked with difficulty.	
Memphis	Press	Rattled doors and windows and shook house	2–3
Meyersville	C. A. Stewart	Not felt.	
Midland		See account on earlier page	5
Mineral Wells	Press	Some awakened; no damage	2–3
Monahans		See account on earlier page.	
Moulton	Press	Windows shook; some frightened	2–3
Odessa	M. E. Roberts	Not all awakened; no damage; south and west walls shaken most; motion E-W	5
Omaha	M. E. Irby	Not felt.	
Palestine	M. A. Davey	Not felt.	
Pampa	Press	Windows and beds shook	2
Pecos		See account on earlier page	6
Pilares		See account on earlier page	6
Porvenir		See account on earlier page	6
Presidio		See account on earlier page	6
Pyote	E. W. Fate	Building rocked SW-NE	5
	Frank Atkinson	Bed rocked N-S strongly.	
Quanah	Press	Few awakened	2
Rockdale	P. H. McCawley	Slight shock	2
	Press	Clocks stopped; windows rattled.	
Rogers	Press	Dishes shaken; some frightened	2
Royse City	Press	Windows rattled; beds shook	2–3
Ruidosa		See account on earlier page	6
San Angelo		See account on earlier page	5
San Antonio		See account on earlier page	3–4
Sanderson		See account on earlier page	6
San Solomon Spring		See account on earlier page	7
Seguin	N. H. Tuley	Appreciable tremor	2–3
Seymour	Mrs. O. S. Moilliet	Windows on north and south walls of second floor rattled; windows on first floor did not rattle; not all awakened	3
Shafter		See account on earlier page	7
Sherman		See account on earlier page	2–3
Sierra Blanca		See account on earlier page	7
Smithville	Press	Three shocks; windows and lights moved; clocks stopped	2–3
Somerville	Press	Clocks stopped	3
Stamford	Press	Three shocks felt	3–4
Sweetwater	Press	Many awakened; windows rattled; lights swayed	4
Taylor	Press	Clocks stopped	3

Town	*Source of Information*	*Record*	*Intensity Assigned*
Temple	Press	Many awakened; beds and lights shook; clocks stopped	3
Terlingua		See account on earlier page	6
Tesnus	U.S.C.G.S.	Sounds heard; all positive of ground movement; beds displaced; rocking N-S; roaring sound	6
Texon	M. J. Collins	Beds shook; no damage	5
	Mrs. E. J. Compton	Motion E-W; not all awakened.	
Thrall	Press	Windows rattled; lights swayed	3
Toyah		See account on earlier page	6
Tyler	Several observers	Not felt.	
Uvalde		See account on earlier page	5
Valentine		See account on earlier page	8
Van Horn		See account on earlier page	7
Waco	Frank Bryan	Window weights rattled; no damage	3
Westpoint	G. A. Lanaux	Rumbling sound; beds and furniture shaken; windows and chandeliers moved	2–3
Wichita Falls	S. V. White	Automobiles swayed N-S	2
Yoakum	Press	Three shocks felt; lights moved; clocks stopped	2

FORE AND AFTER SHOCKS

Preliminary shocks occurred, one of which was recorded by John W. Crain at Denton, Texas, at 5.16.55 A.M., and at St. Louis, Missouri, at 5.18.14 A.M., August 16.

A large number of after shocks are reported, all of which were of greatly reduced intensity as compared to the main shock, many of them being reported as having been felt at Valentine only. Among stronger after shocks felt in nearby towns are those of August 18 and 26 and October 2. The tremors occurring on August 18 are recorded in press reports as having been felt in Pecos, Alpine, Valentine, and Lobo. Those of August 26 are said to have been felt at Fort Davis, Marfa, Alpine, and Valentine. Those of October 2 are reported from El Paso.[5]

[5]Seismograph records on this earthquake have been assembled by the United States Coast and Geodetic Survey. The approximate travel time of the earthquake waves is indicated by the time required to reach the four following distant stations: Sitka, Alaska, primary wave, 6 min. 51 sec., secondary wave, 12 min. 23 sec.; Honolulu, H. I., primary wave, 8 min. 51 sec., secondary wave, 15 min. 50 sec.; Paris, France, primary wave, 12 min. 2 sec., secondary wave, 21 min. 50 sec., long or surface wave, 30 min. 50 sec.; Strasbourg, Germany, primary wave, 12 min. 11 sec., secondary wave, 22 min. 22 sec., long or surface wave, 35 min. 40 sec. (Letter of Nov. 20, 1931, from R. S. Patton, Director U. S. C. and G. Surv.).

SUMMARY

The observations on this earthquake indicate that the intensities were notably irregular in distribution, so much so that it is with difficulty that an intensity map with areas delimited by isoseismals can be constructed. For this reason in the map here presented no separation is attempted between isoseismals of intensities V and IV and III and II. The isoseismals of the immediate region of the earthquake form ellipses elongated northwest-southeast in accordance with the structural trend lines of that region. Displacement at the surface has not been detected, and with the possible exception of small breaks at the schoolhouse at Valentine no disturbance of the ground has been found. There is evidence of a north-south or northeast-southwest motion at Valentine including the dislocation of chimneys thrown to the north or northeast and northeast-southwest motion of supports to the inspection office of the United States Department of Agriculture. A rumbling sound was frequently reported accompanying the earthquake. This sound, indicating waves of such frequency as to be audible, is not confined to reports originating near the locus of the earthquake but is common to a large part of the area over which the earthquake was of sufficient intensity to be felt.

The earthquake, as shown by the accompanying map, Figure 5, was felt a greater distance to the northeast than in other directions. Thus in a northeasterly direction the shock was distinctly felt for a distance of 500 miles from the locus of the earthquake. To the north the shock was felt almost, although not quite, equally far. In other directions, notably to the northwest, the shock was felt a distance not in excess of 300 miles. This notable difference in transmission of shocks of perceptible intensity is based on very good records and is believed to be well authenticated and is possibly due to varying structural conditions in the superficial rocks of the earth crust. To the northeast from the locus of the earthquake the rock strata are prevailingly relatively level-lying, continuous and but little interrupted or broken by disturbances of any kind. To the northwest on the contrary, lies the highly folded, faulted, and broken formations of the Cordilleran mountains. Under these conditions it seems probable that the waves traversing surface or near-surface formations in this direction are damped in intensity as compared to those traversing the relatively unbroken level-lying formations to the northeast.

SANDSTONE DIKES NEAR ROCKWALL, TEXAS

By

MARTIN KELSEY* and HAROLD DENTON*

ABSTRACT

Sandstone dikes were discovered near Rockwall in 1851 and in 1897. The writers have located in Rockwall and Collin counties nine additional dikes, the general trend of which is parallel to the Balcones fault zone. Examination of heavy minerals in the dike sand supports the conclusion published by Stephenson, that the sand was derived from the Wolfe City member of the Taylor formation. The writers, however, differ from Stephenson regarding the mode of origin of the dikes: they consider that the sand was injected upwards into open fissures in the Pecan Gap marl from the underlying Wolfe City sand, not washed into the fissures from the surface of the ground.

INTRODUCTION

In 1851, ten years after the arrival of the first settlers in the area now known as Rockwall County, Texas, one of the group, T. U. Wade, while digging a well on the east side of the valley of the East Fork of Trinity River near the western edge of the present townsite of Rockwall, discovered a wall made of jointed sandstone blocks. Because of the strikingly artificial appearance of the wall, current opinion held that it was built by a prehistoric race. Both the town and county of Rockwall derived their names from this wall. During the dry season of 1897, Messrs. Deweese and Meredith found on their farm northwest of Rockwall another wall which was much larger than the first one discovered, being from 12 to 14 inches thick.

Richard Burleson (1) visited the dikes in 1874 and described them as igneous occurrences. In 1901, Dr. Robert T. Hill (11) published the first identification of the wall rocks as clastic dikes. In 1909 Sidney Paige (23) wrote an article, "The 'Rockwall' of Rockwall, Texas," in which he identified the walls as dikes. In 1925, as a result of the interest and support of Colonel Frank P. Holland, who secured the services of Professor James E. Pearce, archeologist, and Dr. L. T. Patton, geologist (24), the Rockwall area again became a center of interest. In February, 1925, the archeologist,

*Southern Methodist University, Dallas, Texas.

Issued February, 1933.

Count Byron Kuhn de Prorok, visited Dallas and the Rockwall area, and was quoted as believing the walls artificial (25). In March of the same year the late Dr. R. S. Hyer, former President and Professor of Physics at Southern Methodist University, visited the area and pronounced the walls of natural origin (12). In 1927 L. W. Stephenson (28) examined and described the dike first discovered by T. U. Wade. J. W. Fewkes (8), of the Smithsonian Institution, pronounced the structure a sand dike but left both the origin of the fissures and the source of the sand open to discussion.

DESCRIPTION OF THE DIKES

Field observations by the writers show that the dikes in both Rockwall and Collin counties are more widely distributed than was formerly supposed (fig. 6). Lithologically, the dikes are composed of a fine-grained, gray, angular to subangular quartz sand, cemented with calcium carbonate, and containing numerous clay inclusions. A thin section of the dike sand reveals predominantly a fine quartz sand cemented in a matrix of calcium carbonate, the individual quartz grains being separated from each other by the cementing material. On the average 35 per cent of the material by weight is soluble in hydrochloric acid. All of the dikes mapped cut through the Pecan Gap member of the Taylor marl, which in this area contains a higher percentage of argillaceous materials than in the type section. The marl contains an abundant foraminiferal fauna including the following forms: *Gümbelina, Nodosaria, Globotruncana, Robulus, Ammobaculites, Frondicularia, Globigerina, Anomalina taylorensis, Cibicides refulgens, Haplophragmoides,* and *Gaudryina.* Numerous *Inoceramus* prisms and shells are found in the marl.

For help in locating many of the dikes the writers are under obligations to Mr. J. S. Mason, county surveyor of Rockwall County. Notes on individual dikes follow. Numbers correspond to those on the map (fig. 6).

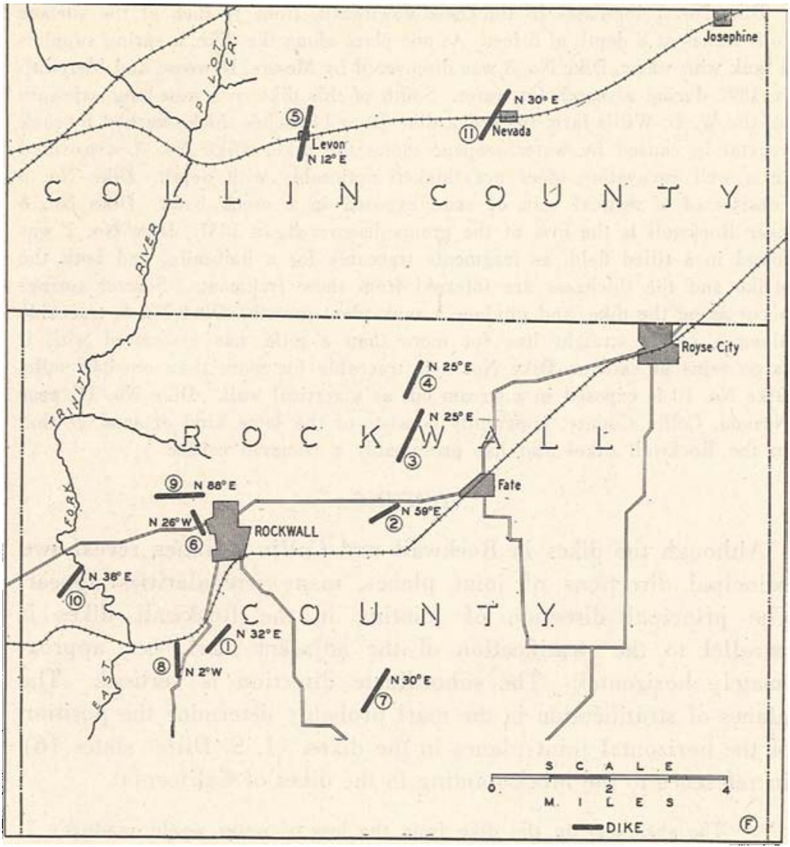


Fig. 6. Sandstone dikes in Rockwall and Collin counties, Texas:

Dike No.	Strike	Thickness, inches
1	N. 32° E.	½–5
2	N. 59° E.	6–7
3	N. 25° E.	12–14
4	N. 25° E.	7–8
5	N. 12° E.	3–4
6	N. 26° W.	3–4
7	N. 30° E.	2–3 (?)
8	N. 2° W.	2–3
9	N. 88° E.	2–3
10	N. 38° E.	5–6
11	N. 30° E.	----

Dike No. 1 increases in thickness downward. from ½ inch at the surface to 5 inches at a depth of 6 feet. At one place along the dike, a spring supplies a tank with water. Dike No. 3 was discovered by Messrs. Deweese and Meredith in 1897 during a search for water. South of this dike in a mile-long exposure on the W. D. Willis farm there is a dike 12 to 14 inches thick, marked by rank vegetation caused by water seepage along the dike. Dike No. 4, discovered in a well excavation, does not thicken noticeably with depth. Dike No. 5 consists of a vertical vein of sand exposed in a creek bank. Dike No. 6 near Rockwall is the first of the group discovered, in 1851. Dike No. 7 was found in a tilled field, as fragments traceable for a half-mile, and both the strike and the thickness are inferred from these fragments. Several springs occur along the dike, and produce a rank plant growth. Dike No. 8, traceable along a nearly straight line for more than a mile, has associated with it large veins of calcite. Dike No. 9 is traceable for more than one-half mile. Dike No. 10 is exposed in a stream cut as a vertical wall. Dike No. 11, near Nevada, Collin County, apparently consists of the same kind of sand as that in the Rockwall dikes and has presumably a common source.

JOINTING

Although the dikes in Rockwall and Collin counties reveal two principal directions of joint planes, many irregularities appear. The principal direction of jointing in the Rockwall dikes is parallel to the stratification of the adjacent marl, *i.e.*, approximately horizontal. The subordinate direction is vertical. The planes of stratification in the marl probably determine the position of the horizontal joint planes in the dikes. J. S. Diller states (6) in reference to the block-jointing in the dikes of California:

> The shrinkage in the dike from the loss of water would produce a strain at right angles to the stratification, and when the strain becomes greater than the cohesion of the dike it cracks transversely, parallel to the strata.

Most of the joint planes of a given direction are straight, but some are curved, and may even merge. Block-jointing is a common characteristic of sandstone dikes in California, Georgia, and South Dakota. In the dikes of these localities both horizontal and vertical joint planes occur.

Block-jointing, which is common in the competent sandstone dike material, is more noticeable because of contrast with the incompetent argillaceous marl. In some localities where the dikes have been exposed by excavation it can be seen that the marl adjacent to the dikes has crept into the joint fissures, and has been partially disintegrated as the result of alternate wetting and drying. On the west bank of the East Fork of Trinity River a dike recently excavated by the writers contains only a meager amount of marl between the joint planes.

In the Rockwall area some tensional forces must have existed to produce the fissures into which the dike material passed. Robert T. Hill (**11**), in tracing the Balcones zone through Rockwall County by means of these clastic dikes, says:

> Traces of the Balcones fault zone are also visible in Hill County between Aquilla and Whitney, and in Dallas County, but the displacements are unknown. At Arthurs Bluff on the Red River the strike of the zone of faulting is clearly indicated in the faults there seen in the Woodbine clay. This is also seen one-quarter of a mile south of Rockwall where there is a so-called dike. This dike is a vertical vein three inches thick composed of a siliceous glauconitic quartzite with clay inclusions.

The displacements southwest and northeast of Rockwall, and the fact that eight of the eleven dikes mapped have a strike of about N. 30° E., indicate that the same forces which produced the faulting may have developed a series of tension fissures. However, there is in the area no evidence of actual faulting, and slickensides on the walls of the dikes are absent. The three dikes which do not have the northeast-southwest trend may be explained by a combination of component stresses (**17**) (fig. 6).

SOURCE OF THE SAND

Obviously the sand forming the dikes came from either below or above the dikes. Stephenson (**28**) believed that the sand was washed in from above:

> Since the dikes are horizontally stratified the materials must have been washed in from above and were probably deposited in standing water in the fissures. The fissures must have remained open during the time they were being filled with sand.

In Rockwall and adjacent counties the following Upper Cretaceous formations exist:

Navarro clay including the Nacatoch sand
Taylor marl including
Pecan Gap chalk and marl and
Wolfe City sand
Austin chalk
Eagle Ford shale
Woodbine sand

The three possible sources of the sand forming the dikes are: (1) the Nacatoch, a subdivision of the Navarro, lying stratigraphically above the present dike exposures; (2) the Wolfe City sand, lying directly beneath the argillaceous equivalent of the Pecan Gap chalk (the formation in which the dikes occur); and (3) the Woodbine sand, approximately 1800 feet below the dikes.

It is the writers' conclusion, supported by the evidence listed below, that the Wolfe City sand is the source of the dike material.

The fact that the sand in the dikes appears free from argillaceous material, with the exception of angular shale inclusions which are themselves free of arenaceous matter, indicates a source below. The shale inclusions show a good Taylor microfauna, but no Navarro fossils, additional evidence that the dike material came from below. Other indications that the sand was injected from a lower stratum as a plastic mass are: (1) the dikes increase slightly in thickness with depth; and (2) it is improbable that the sand came from above to fill fissures several miles long, more than 150 feet deep, and of a thickness ranging from ¼ of an inch to 18 inches.

The Wolfe City sand, which lies immediately beneath the marly country rock, and the Woodbine sand found at a depth of 1800 feet in the water well in Rockwall, appear to be the only adequate sand sources below the dikes.

The heavy mineral content of the dike sand shows a definite relation to the heavy mineral residues of samples taken at the outcrop of the Wolfe City sand. On the other hand, the heavy mineral association of the dikes does not reveal any relation to the Woodbine sand. The Wolfe City sand is characterized by a comparatively large amount of zircon and a moderate amount of garnet. Titanite, rare in the Woodbine, is usually present in moderate amounts in the Wolfe City; staurolite and rutile are relatively unimportant in the Wolfe City heavy mineral residue.

Heavy mineral percentages of the dike sand are as follows:

	Per Cent
Zircon	55
Garnet	17
Tourmaline	13
Rutile	2
Staurolite	2
Titanite	10
Brookite	1

The above heavy mineral association is distinctly not characteristic of the typical Woodbine. The moderate amount of garnet in the dike sand, either absent or meager in the study of over two hundred heavy mineral samples of the Woodbine sand, indicates a source of dike material other than the Woodbine. Titanite, an easily weathered mineral which occurs in the heavy mineral content of the dike sand, although it is characteristic of the Wolfe City, is rare in the heavy mineral associations of the Woodbine.[1]

ORIGIN OF THE DIKES

It is the writers' conclusion that the dike material was injected upwards into the fissures from the underlying Wolfe City sand, not washed into the fissures from the surface of the ground.

Neither Paige (23) nor Patton (24) reached any definite conclusions as to the origin of the dikes, although Patton suggested that the fissures may have been caused either by earth movements or by drying and cracking of the marl, and that the material may have come from either above or below. L. W. Stephenson (28) does not believe that the drying of the marl would produce adequate cracks. He says:

> The fissures are too deep, I think, to have been formed by desiccation from the surface downward. Earth movements that produced and widened joints into fissures seem adequate to account for them.

Numerous clastic dikes have been described in the literature, and to explain their origin it has been conjectured that unconsolidated sand accompanied by water acted as a plastic mass, which in reaching a pressure equilibrium was forced up into the fissures of the overlying cracked stratum. As proof that such is possible Mallet (20), Crosby (3), Goodfellow (9), and Diller (6), each cites

[1]Moore, William, personal interview.

occurrences in which sand and water have been forced along fissures produced by earthquakes. Diller (6) describes the phenomenon as follows:

> During the great Calabrian earthquake of 1783 many fissures were formed in the ground, and from some of them great quantities of sand and water issued. After the flow ceased the openings were left full of sand. In our own country the fissures formed by the earthquake of New Madrid, Missouri, in 1811–1813. were still plainly visible in 1846 when Sir Charles Lyell visited the scene. He says that they were often parallel, and yet there was considerable diversity of direction, varying from N. 10° W. to N. 45° W. Many were yet traceable for half a mile and upwards. It is said that during the earthquake, powerful jets of water filled with sand and coaly matter issued from these fissures; and distinct traces of them could be seen after the lapse of thirty-four years. Similar phenomena accompanied the earthquake of 1819, at the mouth of the Indus.

OTHER SANDSTONE DIKES IN THE TEXAS COASTAL PLAIN

Other dikes have been observed in Bastrop,[2] Caldwell, Gonzales, and Wilson[3] counties. Without exception their strikes are parallel to the zone of faulting.

H. J. Weeks,[2] in an unpublished manuscript, mapped a sandstone dike in Bastrop County whose strike was approximately N. 35° E., which is parallel to the general trend of the faulting in that area.

Charles Row[3] says:

> In my observations of sandstone dikes through Caldwell, Gonzales, and Wilson counties I have found, without exception, that they strike parallel to the trend of the Balcones fault from around N. 30° E. in Caldwell County to about N. 65° E. in Wilson County. The dip varies from 35° toward the northwest to vertical. In many cases these dikes have formed in joints along which there has been little or no movement vertically. It seems that in the case of faults where much displacement is involved these dikes have not formed, probably because of the extreme amount of associated fracturing not permitting underground waters to bring sand to the present surface from its source.
>
> The sandstone dikes are best developed to the southwest of Ottine, northwestern Gonzales County, and in the Sutherland Springs-Alum

[2]Weeks, H. J., by permission of Dr. F. H. Lahee, Chief Geologist, Sun Oil Company, Dallas, Texas.

[3]Row, Charles H., by permission of Dr. F. H. Lahee, Chief Geologist, Sun Oil Company, Dallas, Texas.

> Creek area of northern Wilson County. In these localities there are dikes that can be followed for hundreds of yards without breaks, and associated with them are open cracks in the ground parallel to the dikes. Natives say that these open cracks have developed in the past couple of generations and that at the time of their formation there were local miniature earthquakes and rumbling sounds. I am inclined to believe these stories. It seems certain that these open cracks have been formed fairly recently else they would be filled with soil. Along some of them are active springs. Perhaps dikes are now in the stage of formation in some of these joints.

The above facts indicate that a series of weaknesses was produced parallel to the Balcones zone of faulting which formed fissures; these under favorable conditions were adequate for the introduction of sand.

The strikes of the sandstone dikes in Rockwall and Collin counties as described in this paper, as well as those in Bastrop, Caldwell, Gonzales, and Wilson counties, appear to have a direct relationship to the Balcones fault zone.

BIBLIOGRAPHY

1. Burleson, Richard, Report of Assistant State Geologist: Geol. Agric. Surv. Texas, 1st Ann. Rept., pp. 128–130, 1874.
2. Campbell, M. R., Conglomerate dikes in southern Arizona: Amer. Geol., vol. 33, pp. 135–138, 1904.
3. Crosby, W. O., Sandstone dikes accompanying the great fault of Ute Pass, Colorado: Essex Inst. Bull., vol. 27, pp. 113–147, 1897.
4. Cross, Whitman, Intrusive sandstone dikes in granite: Bull. Geol. Soc. Amer., vol. 5, pp. 225–230, 1894. Abstracts in Amer. Geol., 13: 215, 1894; Am. Jour. Sci., (3) 47: 142, 1894.
5. Darwin, Charles, Geological observations on coral reefs, volcanic islands, and on South America, pt. 3, p. 150. 1851.
6. Diller, J. S., Sandstone dikes: Bull. Geol. Soc. Amer., vol. 1, pp. 411–442 [p. 437], 1890.
7. Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Surv., 22d Ann. Rept., pt. 1, pp. 386–407, 1901.
8. Fewkes, J. W., Bureau Amer. Ethnology, 37th Ann. Rept.
9. Goodfellow, G. W., Irruption of the earthquake at Sonora, Mexico, May 3, 1887: Sci., vol. 10, p. 81, Aug. 12, 1887.
10. Hay, Robert, Sandstone dikes in northwest Nebraska: Bull. Geol. Soc. Amer., vol. 3, pp. 50–55, 1892.
11. Hill, Robert T., Geography and geology of the Black and Grand Prairies, Texas: U. S. Geol. Surv., 21st Ann. Rept., pt. 7, pp. 382–383, 1901.
12. Hyer, R. S., [Dallas] Daily Times Herald, March 29, 1925.

13. Irving, R. D., The copper-bearing rocks of Lake Superior: U. S. Geol. Surv., Mon. V, 1883.
14. Jenkins, Olaf P., Sandstone dikes as conduits for oil migration: Bull. Amer. Assoc. Petr. Geol., vol. 14, p. 411, 1930.
15. Jenkins, Olaf P., Clastic dikes of eastern Washington: Amer. Jour. Sci., (4) vol. 10, pp. 234–246, 1925.
16. Lahee, Frederic H., Field geology, 3rd edit., pp. 72, 74, 1931.
17. Link, Theodore A., *En échelon* tension fissures and faults: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 627–643, 1929.
18. McCallie, S. W., Sandstone dikes near Columbus, Georgia: Amer. Geol., vol. 32, pp. 199–202, 1903.
19. McMillan, J. M., Jr., Clastic dike in Fort Hays chalk, Kansas: Bull. Amer. Assoc. Petr. Geol., vol. 15, p. 842, 1931.
20. Mallet, Robert, Secondary effects of the earthquake of Jan. 10, 1869, in Cachar, India: Quart. Jour. Geol. Soc. (London), vol. 28, pp. 255, 270, 1872.
21. Meek, C. E., Genesis of a sandstone dike as indicated by heavy minerals: Bull. Amer. Assoc. Petr. Geol., vol. 12, pp. 271–277, 1928.
22. Newsom, J. F., Clastic dikes: Bull. Geol. Soc. Amer., vol. 14, pp. 227–268, 1903.
23. Paige, Sidney, The "rock wall" of Rockwall, Texas: Sci. (n.s.), vol. 30, pp. 690–691, 1909.
24. Patton, Leroy T., The sandstone dikes around Rockwall, Texas: Holland's Mag., vol. 44, pp. 5, 86, June, 1925.
25. Prorok, Count Byron de, Dallas News, Feb. 22, 1925.
26. Russell, W. L., Origin of the sandstone dikes of the Black Hills region: Amer. Jour. Sci., (5) vol. 14, pp. 402–408, 1927.
27. Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas, pt. 1, Stratigraphy: Univ. Texas Bull. 3232, 1932.
28. Stephenson, L. W., On the origin of the "rock wall" at Rockwall, Texas: Jour. Wash. Acad. Sci., vol. 17, pp. 1–5, 1927.

A STUDY OF CERTAIN PENNSYLVANIAN CONGLOMERATES OF TEXAS

By

HARRY X BAY

INTRODUCTION

There are two great Pennsylvanian areas in north-central Texas protruding through the Cretaceous and Permian strata. Cretaceous rocks border these areas on the east, while to the west and north the Pennsylvanian strata dip under the Permian. The northernmost, or Brazos River, area lies largely within the boundaries of the Brazos River watershed and includes part or all of the following counties: Montague, Clay, Jack, Wise, Young, Stephens, Erath, Shackelford, Palo Pinto, Parker, Comanche, Callahan, and Eastland. To the south, separated from the Brazos River inlier by a narrow belt of Cretaceous, lies the second great Pennsylvanian area, in the Colorado River basin. This Pennsylvanian outcrop is confined within the boundaries of the Colorado River watershed and is to be found in the greater part of Brown, the eastern half of Coleman, the northern part of San Saba, Mills, Lampasas, and the northeast part of McCulloch counties. At the south this Pennsylvanian area is bordered as shown in the sketch map, Figure 11, by earlier Paleozoic formations.

The beds dealt with in this paper are confined to these two great areas. The strata dip gently to the northeast, and the escarpments formed by the indurated ledges strike northeast-southwest.[1]

The purpose of the investigation was to ascertain, by means of field observation supplemented by laboratory study: the general lithology of the conglomerate beds; the source of materials contained in the conglomerate; the direction from which it came; the distance that it was transported; the mode and manner of transportation; and the environment of deposition.

The field work was carried out during the months of August and September, 1929, and July and August, 1930. The study in general has been of two principal types: a field study, the purpose of which

[1]For the succession of Pennsylvanian strata in these areas, the reader is referred to The University of Texas Bulletin 3232, The Geology of Texas, Vol. I, Stratigraphy.

Issued February, 1933.

was to determine the extent and thickness of the beds, their variation in color, texture, and mineralogy, the character of bedding, the fossil content, the relation of subjacent rocks, and the collection of samples for laboratory study; and a laboratory study to determine by means of various sedimentary analyses, the sizes, shapes, and mineral content of the included pebbles, the nature of the matrix and cementing materials, the fossil content of the pebbles, and to conduct certain experiments in the rounding of pebbles with attempts to formulate a ratio between abrasion and distance of transportation.

Although considerable work has been done in connection with the Pennsylvanian rocks of north-central Texas and several critical studies have been made of the outcropping formations, there has been little quantitative study relative to the conglomerates of this field. Only one other study similar in nature to this one, so far as the writer is aware, has been attempted. This was by John W. Clark (7), who made a detailed field study of the lithologic characteristics of the Avis conglomerate from which he derived certain conclusions regarding the manner of transportation of the sediments, the environment of deposition, and their source. It was this lack of extended study regarding the sedimentary conditions under which these beds were deposited that attracted the writer to this field.

FIELD METHODS

General statement.—The field work consisted of a detailed study of certain selected localities. These localities were chosen at intervals of 5 to 10 miles along the strike of the outcropping beds, as well as down the dip, where the presence of reëntrants made investigation possible. By using stations spaced at such intervals, it was possible to avoid the collection of overlapping data and yet to allow for the recording of any noticeable lithologic changes that appeared. Because of freshness of exposed surface and accessibility, roadcuts, wherever possible, were selected as sites for detailed study.

At each of the selected localities field counts were made, mineralogical and color specimens were collected. field descriptions were made, the bedding, including measurements of the dip and the strike of bedding planes, was studied, the stratigraphic relations were determined where possible, paleontological specimens were collected, general and specific features were photographed, and samples were collected for laboratory study of texture and shape.

At each of the localities chosen for detailed study a section was measured by hand level to include all beds exposed at the place of outcrop. The purpose was to secure data regarding the general nature of the conglomerate at each station, as well as that of the associated beds. These sections were taken in order to use the completed series as a basis of comparison of the thicknesses, general characteristics, and associations of the conglomerate with other beds from point to point along the outcrop.

The field count consisted of textural, shape, and mineralogical observations that were carried out in the field. This method is crude compared with detailed laboratory analysis, but where laboratory study is impracticable such study is well worth while, and for that reason the following details regarding field counting are presented.

A relatively flat area of typical conglomerate was chosen for the count, and on this smooth surface a 12-inch square was marked out with chalk and this square was further subdivided into four equal parts. For the determination of the size-grade distribution each piece lying within the quarter-square was measured and recorded in its specific grade. (For the sake of simplicity in recording, certain grade ranges were used—0–10 mm. was designated as grade A, 10–20 mm. as grade B, 20–40 mm. as grade C, et cetera.) As each piece was measured it was given a chalk mark to avoid repetition. This procedure is accurate enough to give one a fairly good idea of the textural character of the conglomerate.

After the size-grade determination was completed, estimates of the shapes of the individual pieces were made and recorded according to a fivefold classification: (35) round, subround, curvilinear, subangular, and angular. This phase of the field count is perhaps the least accurate of all because of the fact that ordinarily only one complete cross section of the piece is discernable; nevertheless these data are also useful under certain conditions.

The next step in the field count was the listing of the various colors represented in the included pieces and the number and percentage present in each variety.

The final step was the determination of the kind and percentage of rocks present in the conglomerate. As chert is by far the most predominant type of material represented in the pebbles of this formation, only those other than chert were noted.

Sample collecting.—In a study of this nature where samples are to be collected for the purpose of deriving criteria for the determination of the distance, direction, and mode of transportation of the materials, as well as for lithologic and depositional studies, an important part of the field work is that of collecting samples for laboratory study. In this study all samples that were to be employed in the determination of the direction of size-grade variation and the direction of decreasing angularity were selected from the bases of the formations to insure regularity of choice with respect to position in the bed.

As the samples were to be used for a general study including textural, shape, and mineralogical studies, as well as for porosity tests in certain cases, it was necessary that samples of considerable size be collected.

The general procedure of the collection of samples followed that given by Wentworth (**35**) and Milner (**14**). Numerous methods of notation and labeling of samples have been proposed (**35**). However, the writer found the following method best suited to his needs. Each sample was labeled according to the following form: date, formation name, field name, locality number, position in bed, and sample number. The sample number was so given as to correspond to a page in the notebook where the same form was used. For example, sample number 2^{145} would indicate that the above form plus a brief field description of the sample would be found as item 2 on page 145 of the field notebook.

LABORATORY METHODS

The laboratory work in connection with this study was carried on in the years 1930 and 1931 and consisted of various detailed analytical studies, among which were: analyses of mechanical composition, shape analyses of pebbles, megascopic and microscopic mineral studies, porosity determinations of certain samples, and identification of fossils of the matrix and pebbles.

In addition, a series of detailed studies of the reduction of angularity of rock pieces, similar to those making up the body of the conglomerate beds, were made with an abrasion mill. The mill was charged with fragments of Talihina chert from an outcrop near Atoka, Oklahoma. This material was selected because of its lithologic similarity to the chert of the conglomerates. Chert abrasives were also placed in the charge in quantities similar to corresponding grades in the conglomerate. Accurate analyses of shapes (**24, 25**) and sizes of the various size-grades and of individual pieces were made at various mileages, and conclusions regarding the ratio between the distance of transportation and the rate and amount of abrasion of the pieces were derived therefrom. Correlations were made between the shape analyses of materials from the mill and those of the conglomerate from which estimates were made as to the distance the sediments had been transported.[2]

The conclusions formed with respect to rate of reduction of angularity of rock pieces similar to these that make up the body of the conglomerate beds are as follows: the most pronounced loss of weight in individual pieces occurs within the first 150 miles; loss of weight and angularity in unbroken pieces is very gradual after the first 500 miles are passed; the percentage loss of angularity is appreciably greater than the percentage loss of weight in unbroken pieces; considerable variation occurs in the changes of weight and angularity of pieces of the same lithologic type, and this is more generally true of chert than of quartzite; the period of greatest change in shape shown in various size-grades is between 200 and 300 miles; abrasion is the most active process in the reduction of the larger pieces; materials less than 1 millimeter in diameter are continuously and rapidly formed; and materials of 1–4 millimeters cannot exist in association with materials of the constituency employed in this study because of the grinding action of the larger pieces.

Numerous photographs were made in connection with the experimental studies in abrasion to show the changes in shapes of various particles during the transportation in the abrasion mill. Photomicrographs were made of the various thin sections to show lithological and paleontological types. Porosity tests were made on the Brazos and Turkey Creek sandstones, the method used being that proposed by Buckley (4).

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Professors E. H. Sellards and F. B. Plummer of the Texas Bureau of Economic Geology for their kindly interest, helpful advice and suggestions. He is also particularly indebted to Dr. A. C. Trowbridge of the State University of Iowa for the general supervision of the problem. He is further indebted to Dr. A. C. Tester of the State University of Iowa for the direction of various laboratory projects carried out

---

[2]The apparatus employed in this study is similar to that described by Wentworth (33) and consists of two metal drums lined with wood. These are situated at the two ends of a supporting axis which is turned by a ¼ horsepower electric motor at the rate of 35.5 revolutions per minute. The rock fragments, which are covered by water, roll continuously down the upgoing side of the drums at the rate of 1.92 miles per hour or 46.25 miles per 24 hours.

in the preparation of this paper, and to many others who, by their kindly interest and suggestions, have helped the writer in carrying forward this work. The writer also wishes to express his appreciation to the Graduate College of the State University of Iowa and to the Fort Worth and North Texas geological societies, which organizations, through their financial aid, made possible the completion of this work.

CONGLOMERATES OF THE BRAZOS RIVER INLIER

The conglomerates and sandstones studied in the Brazos River inlier are, in order of age, beginning with the oldest: Brazos sandstone and conglomerate, Turkey Creek sandstone and conglomerate, and Avis sandstone and conglomerate.

BRAZOS SANDSTONE AND CONGLOMERATE

Name and definition.—The Brazos sandstone and conglomerate member of the Mineral Wells formation was named from the excellent exposures of these beds along the Brazos River in Palo Pinto County. This member, consisting of massive, coarse-grained sandstones and chert conglomerates 25 to 50 feet thick, forms a striking escarpment which trends northeast across Palo Pinto County (**16**, p. 138). Throughout the outcrop the sandstone and conglomerate phases are very closely associated, and where one is found the other is usually present in greater or lesser amounts, save for the southern extension, where the member is made up entirely of sandstone. It is of the comglomeratic phase that this paper treats particularly.

The Brazos conglomerate everywhere lies between beds of sandstone. These overlying and underlying sandstones vary from locality to locality and may be massive- or thin-bedded, coarse-, medium-, or fine-grained, cross-bedded or flat lying, made up entirely of a sand grade or composed of sand together with pebbles in varying percentages. They may be essentially quartz in their make-up or may contain considerable quantities of fragmentary chert; friable or strongly indurated; sharply defined or grading into conglomerate; calcareous or non-calcareous; thin (6 feet) or thick (60 feet). In short, they are characteristically heterogeneous.

The conglomerate consists largely of angular to subangular chert fragments, occasional pieces of which have a diameter of 4½ to 5 inches. However, a great many variations in texture, and shape and size of pebbles appear from place to place along the outcrop.

The clastic material that makes up the conglomerate is all siliceous in nature and consists, in the order of decreasing importance, of chert, siliceous clay, quartzite, and quartz. The matrix, consisting of grains that have diameters of less than 2 millimeters, is made up entirely of quartz and chert grains which are bound together by iron oxide and silica. In the upper size-grades of the matrix chert predominates.

The pebbles consist largely of variegated cherts and siliceous clays that present an almost unbelievable number of recognizable types. At Locality 5 (fig. 7A), near Garner in the bed of Dry Creek, 107 distinct types, based on differences in color, texture, and crystallinity, of cherts and siliceous clays were collected in an area of about 15 square feet, and this is typical of the conglomerate.

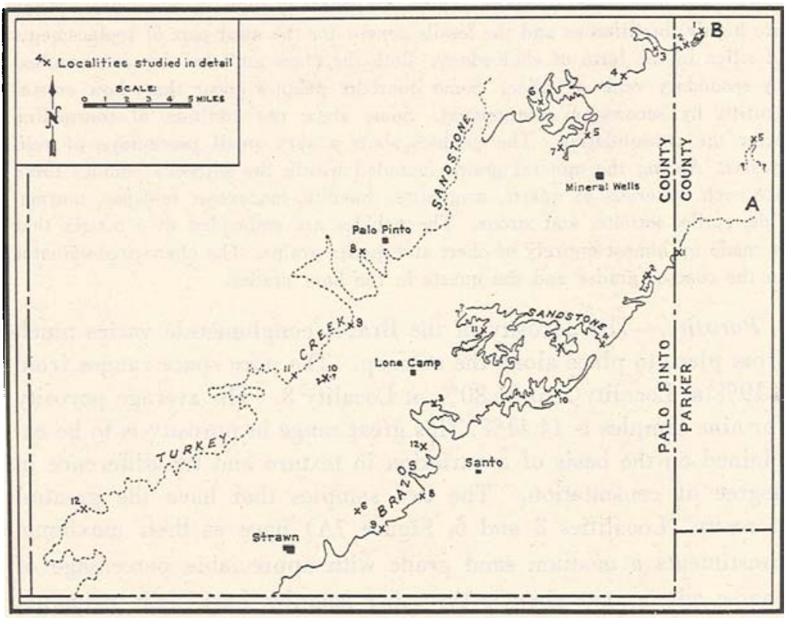


Fig. 7. Sketch map to show outcrop of the Brazos and Turkey Creek conglomerates in north-central Texas and the localities from which samples were collected. Localities numbered as in the text. A, Brazos sandstone and conglomerate outcrop; B, Turkey Creek sandstone and conglomerate outcrop.

Gray is the predominant color in the pebbles of the conglomerate. The yellows and the whites are the next in order of abundance, and then in the order of decreasing abundance appear various shades of red, banded colors, black, and lastly green. The gray, yellow, white, and red are represented among the pebbles of all localities, the banded and black cherts are each present in ten of the localities, and the greens are found only in four localities, and then only in very minor percentages.

The constituent materials of the conglomerate may be summarized as follows:

Chert is by far the predominant material of the pebbles, and is present in almost every conceivable variety. The predominating general colors are, in the order of decreasing importance, gray, yellow, white, red, banded colors, black, and green. The chert ranges from cryptocrystalline through microcrystalline to crystalline in structure, and these structures occur in a variety of combinations. The siliceous clays, second in importance in the make-up of the pebble content, consist of original fragmentary material and secondary silica of a chalcedonic nature. They are generally high in iron oxide. They are highly fossiliferous and the fossils consist for the most part of replacements of silica in the form of chalcedony. Both the chert and the clay are ramified by secondary veins of silica. Some quartzite pebbles occur that show crystal growth by secondary enlargement. Some show the addition of tourmaline after the consolidation. The pebbles show a very small percentage of vein quartz. Among the mineral grains included within the siliceous pebbles there are such materials as quartz, magnetite, ilmenite, leucoxene, feldspar, tourmaline, rutile, sericite, and zircon. The pebbles are embedded in a matrix that is made up almost entirely of chert and quartz grains. The chert predominates in the coarser grades and the quartz in the finer grades.

Porosity.—The porosity of the Brazos conglomerate varies much from place to place along the outcrop. The pore space ranges from 3.19% at Locality 2 to 26.80% at Locality 3. The average porosity for nine samples is 14.41%. This great range in porosity is to be explained on the basis of a variation in texture and the difference in degree of cementation. The two samples that have the greatest porosity (Localities 3 and 6, Figure 7A) have as their maximum constituents a medium sand grade with appreciable percentage of coarse admixture, whereas the other samples have their principal ingredients in the pebble grade. Cementation is a very important factor in determining the amount of water that a rock may hold, and much of this conglomerate is very tightly cemented with silica and iron oxide. Variations in cementation doubtless explain the fact that the finer textured samples have the greatest percentage of pore space. The western localities (3, 6, 8, 9) show greater pore spaces than do the eastern localities (1, 2, 4, 5, 7). The two localities farthest down the dip show a much higher degree of porosity than do the others.

Bedding.—The conglomerate member is characterized by very irregular high-angle cross-bedding throughout and by bedding that is very irregular. Definite bedding planes are essentially lacking, and those which do occur are poorly defined and inextensive. The amount and direction of the dips of various foreset beds in five of these localities are as follows: (localities numbered as in Figure 7 A):

Locality 1: 15° N. 50° E.; 8° N. 40° E.; 4° N. 15° E.; 10° N. 2° W.; 5° N. 21° E.; 13° N. 60° E.; 12° N. 17° W.

Locality 2: 2° N. 45° E.; 8° N. 32° E.; 7° N. 10° E.; 12° N. 22° E.; 11° N. 2° W.; 4° N. 65° E.; 7° N. 18° W.; 9° N. 9° W.; 16° N. 27° E.

Locality 3: 3° N. 80° W.; 6° N. 48° W.; 2° N. 58° W.; 10° N. 12° E.; 6° N. 20° W.; 12° N. 47° W.

Locality 10: 11° N. 68° W.; 4° N. 44° W.; 6° N. 28° W.; 4° N. 18° E.; 16° N. 23° W.; 6° N. 23° E.; 4° N. 51° W.; 13° N. 63° W.; 9° N. 37° W.; 15° N. 41° W.; 9° N. 34° E.; 12° N. 39° W.

Locality 11: 5° N. 10° W.; 4° N. 17° W.; 5° N. 35° W.; 17° N. 27° W.; 3° N. 16° W.; 13° N. 60° E.; 10° N. 30° W.

As shown by these and other localities the majority of the foreset beds have northwesterly dips, and this would indicate that the streams by which these beds were laid down were flowing in a more or less northwesterly direction, at least at the site of deposition.

Shape of pebbles.—Quantitative shape analyses show the Brazos conglomerate to be composed largely of subangular and angular fragments. Figure 9 shows in graphic form typical analyses from Locality 5. Figures derived by averaging the various stages of abrasion (angular, subangular, and curvilinear) for the entire group show the Brazos conglomerate to be composed of materials that are 40.6 per cent angular, 44.1 per cent subangular, 10.1 per cent curvilinear, 4.4 per cent subround, and 0.8 per cent round.

The samples from the various localities show that there is considerable variation in shape of pebbles from place to place, a variation that is by no means regular, either along the strike or down the dip of the beds. The materials, as shown by this series of analyses, do not become noticeably less angular westward (away from the source). This lack of regularity in the variation of abrasion of the rock pieces, however, is not surprising when the limited width of the outcrop and the hardness of the chert materials are considered.

It will be noticed that in the finer grades of a number of the samples the percentage of subround and round grains increases in the smaller grades. Under ordinary conditions this feature would not be expected and it is doubtless explainable by the presence of reworked grains.

Mechanical analyses.—Samples of the conglomerate were collected from eleven localities along the outcrop (fig. 7 A). The results of the mechanical analyses of these samples are as follows:[3]

No. 1. Millsap Mountain on the Mineral Wells-Fort Worth highway, 3 miles west of Millsap, Parker County, thickness 20 feet. The material is poorly sorted. The maximum constituent is in the 8–4 grade; there are considerable quantities of both the coarse and fine admixtures, and a secondary maximum is in the coarse admixture. The distant grades are in the fine admixture.

No. 2. Four miles southeast of Mineral Wells on the D. Mahoney Survey, Palo Pinto County, thickness 20 feet. This sample is poorly sorted, but somewhat better sorted than No. 1. There is a single maximum in this sample which is in the 8–4 grade. In the proximate grades the coarse and fine admixtures are present in about equal amounts. The distant grades occur in the fine admixtures.

No. 3. Ward Mountain, 5 miles northwest of Santo on the Santo-Palo Pinto road, thickness 10 feet. In this analysis the maximum constituent consists of medium sand,[4] and the coarse and fine admixtures are present. The more distant grades occur in the coarse admixture, the most distant grade being made up of pebbles.

---

[3]In the following discussion of the mechanical analyses the terminology of Udden (31) is followed. In this usage the grade present in greatest quantity is referred to as the *maximum constituent* or *grade* or *chief ingredient*, and the two decreasing series of grades on either side of the *maximum grade* are called the *coarse* and *fine admixtures*. In some samples the chief ingredients may be made up of two grades present in approximately equal amounts. The grades adjacent to the *maximum grade* are known as the *proximate grades*, and those made up of particles most different in size from the particles in the *maximum ingredient* are called the *distant grades*. The term *secondary maximum* is applied to a grade present in greater quantity than its adjacent grades but in smaller amount than the *maximum ingredient* and more or less distant from it. A *secondary maximum* may be present in either the *coarse* or the fine *admixture*.

[4]The grade terms used in this paper are those proposed by Wentworth (35) and are as follows: bowlder, 256 mm.; cobble, 64 mm.; pebble, 4 mm.; granule, 2 mm.; very coarse sand grains, 1 mm.; coarse sand grains, ½ mm.; medium sand grains, ¼ mm.; fine sand grain, ⅛ mm.; very fine sand grain, 1/16 mm.; silt particle, 1/256 mm.; clay particle.

No. 4. Inspiration Point, 9 miles south of Mineral Wells on the Mineral Wells-Brazos road, Palo Pinto County, thickness 35 feet. This sample is made up of pieces that are of the sizes of granules and pebbles, the maximum constituent falling in the 16–8 mm. grade (the pebble size). The coarse admixture ranges downward to materials having a diameter of less than 1/16 of a millimeter. There is an indistinct secondary maximum in the fine sand grade of the fine admixture.

No. 5. A short distance west of the town of Garner in the bed of Dry Creek on the Mineral Wells-Garner road, Parker County, thickness 25 feet.

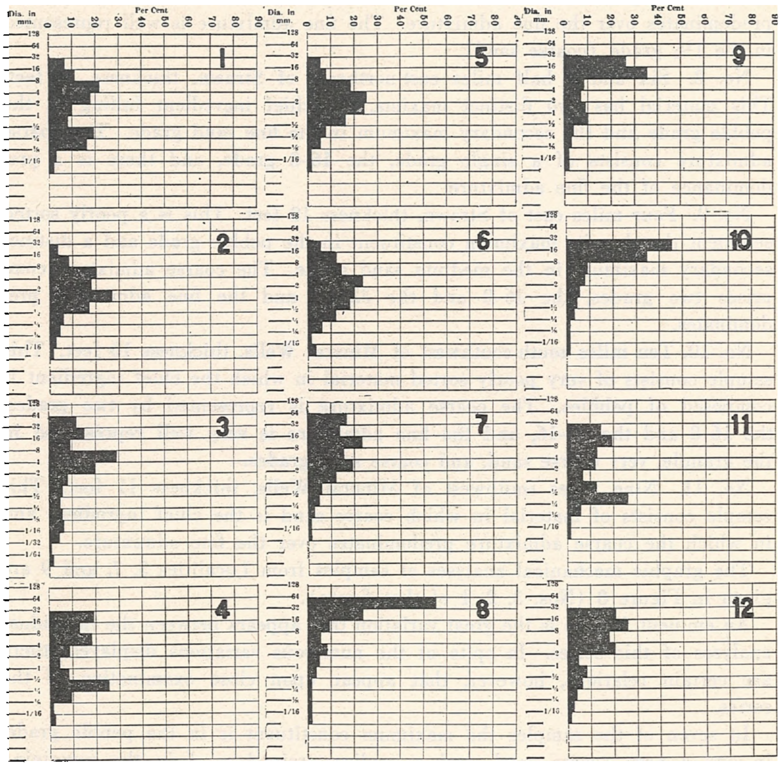


Fig. 8. Mechanical analyses of conglomerates from north-central Texas: No. 1, Brazos conglomerate, Loc. 9 of Figure 7A; No. 2, Brazos conglomerate, Loc. 7 of Figure 7A; No. 3, Brazos conglomerate, Loc. 3 of Figure 7A; No. 4, Turkey Creek conglomerate, Loc. 6 of Figure 7B; No. 5, Turkey Creek conglomerate. Loc. 5 of Figure 7B; No. 6, Turkey Creek conglomerate, Loc. 5 of Figure 7B; No. 7, Rochelle conglomerate, Loc. 4 of Figure 10; No. 8, Rochelle conglomerate, Loc. 1 of Figure 10; No. 9, Rochelle conglomerate, Loc. 2 of Figure 10; No. 10, conglomerate above the Rochelle conglomerate, Loc. B of Figure 10; No. 11. conglomerate below the Rochelle conglomerate, Loc. A of Figure 10; No. 12, Avis conglomerate.

This sample has two distinct maxima. The maximum constituent is in the pebble grade and the secondary maximum in the fine admixture in the medium sand grade. As in No. 4, the coarse admixture constitutes a single grade.

No. 6. Three miles northeast of Strawn, thickness 14 feet. This sample has as its maximum constituent a medium-grained sand, with the coarse admixtures predominating over the fine admixtures. The most distant grades are in the coarse admixtures and reach the pebble grade.

No. 7. Eight miles south-southeast of Mineral Wells, thickness 28 feet. The predominant grades in this sample are the coarse sand and pebble grades, the maximum constituent is a very coarse sand, and the coarse admixture predominates over the fine admixture. The fine admixture is well represented in the 1½ grade (coarse sand).

No. 8. Six and a half miles east-northeast of Strawn, thickness 15 feet. This material has two distinct maxima, the chief ingredient falling in the pebble grade and the secondary maximum in the fine sand grade. The coarse admixture consists of a single grade, the 16–8 grade, and there is a predominance of the fine admixture.

No. 9. Four miles east of Strawn, thickness 18 feet. This is a poorly sorted sediment that has its maximum constituent in the pebble grade and a distinct secondary maximum in the medium sand grade. The coarse admixture comprises two grades, the 16–8 and the 32–16, and the fine admixture predominates.

No. 10. Ten miles south-southwest of Mineral Wells, thickness 10 feet. This sample consists of very poorly sorted material in which the chief ingredient is composed of pebbles. The coarse admixture is represented by two grades, the 16–8 and the 32–16, and the fine admixture is very well represented in the granule, very coarse sand, and coarse sand grades.

No. 11. Nine miles southwest of Mineral Wells, thickness 11 feet. This sample consists of material in which coarse sand is the chief ingredient and in which the coarse admixture predominates over the fine admixture.

The graphic mechanical analyses of samples from Localities 5, 7, and 9 are given in Figure 8 (Nos. 3, 2, 1 of that figure).

An eminent feature is the great variation that appears between the individual analyses of this series. In spite of the numerous variations displayed, there are certain relations, however. that appear upon close examination of the series.

In seven of the samples the maximum constituent is in the pebble grade, in one a very coarse sand, and a medium-grained sand in the remaining three. Five samples present a secondary maximum, one of which consists of pebbles, two of which are medium-grained sands, and two of which are fine sands. Each sample contains a coarse admixture which has somewhat of a variable range. Seven of the coarse admixtures fall entirely within the range of pebbles, one ranges from granules to pebbles, and the remaining three exhibit a range from sand upward to the pebble grade. The combined amounts of the coarse admixtures in the various samples range from 6.1 per cent in Sample No. 8 to 48.0 per cent in Sample No. 7. Each analysis shows a percentage of fine admixture, ranging from 14.3 per cent in Sample No. 6 to

67.3 per cent in Sample No. 8. In the fine admixtures the range grades downward to the silts in every analysis, whereas the upper range varies from 8 mm. (Nos. 4 and 5) down to ¼ mm. (Nos. 3 and 6).

From the above data a general statement regarding the texture of the Brazos sandstone and conglomerate member may be derived. Certain beds in this member are true conglomerates characterized by the presence of rock fragments of pebble size (ranging from 4 to 64 millimeters in diameter) in varying percentages along the outcrop. In a majority of the samples the pebble grade makes up the chief ingredient, whereas the secondary maximum, when present, appears in the fine to medium sand grades in all samples, save one, which occurs in the pebble grade. The pebbles are embedded in a matrix that grades downward through the various sand grades to silt. In all the samples the ingredients show but little tendency toward sorting as to size grades, a characteristic which is usually attributed to an environment of rapid deposition.

Thin sections of pebbles.—Microscopic examination of thin sections that were made from pebbles selected from the various localities reveals certain features that are useful in classifying the materials. Brief descriptions of certain of the sections are given below. The localities referred to are those shown in Figure 7A.

No. 1. Cryptocrystalline to crystalline chert. Locality 4. In the hand specimen this appears to be characterized by alternating bands of cream and light gray. The bands range from .5 to 1 mm. in width. The thin section shows alternating bands of crystalline (the light gray of the palm specimen) and cryptocrystalline (the cream-colored band) silica. A very thin band of chalcedony separates the crystalline from the cryptocrystalline silica.

No. 2. A highly siliceous clay. Locality 4. This is a hard, compact, earthy material that is light gray in color. The surface, which is slightly weathered, shows occasional minute white fossils. This siliceous clay is composed of both cryptocrystalline and microcrystalline silica that is somewhat brownish in color. The material is very fine and even in texture. Scattered through this material are microfossils which have been replaced by crystalline silica. The forms are of two principal types, saucer-shaped and oval (Pl. 12, fig. 1). They are probably radiolarians as they have several features in common with radiolarians figured by Baker and Bowman (2) from the Santiago chert (Devonian).

No. 3. Banded chert. Locality 5. The hand specimen shows two heavy bands, approximately 7 mm. wide. one light gray and the other dark gray. The dark band is the same throughout, but the lighter band is crossed by occasional dark lines and near the contact with the dark gray there are a number of closely spaced, wavy, more or less parallel, white lines.

The thin section shows one band of cryptocrystalline silica, the light gray band of the hand specimen, and one band consisting of stringers, ranging from .19 to .64 mm. in width, of microcrystalline, cryptocrystalline, and crystalline silica. This is the group of wavy, white lines in the hand specimen. The cryptocrystalline parts are brownish-gray in color. There are occasional crystalline structureless spherules distributed throughout the mass. Several crystalline veinlets traverse the section in various directions.

No. 4. Brownish-gray quartzite. Locality 4. This is an iron stained brownish-gray, even-grained, closely cemented quartzite. This section appears as a more or less even-grained quartzite, traversed by a single narrow band of microcrystalline silica. Some of the grains have faces that have been built up by secondary enlargement, but for the most part the mass consists of subangular to rounded quartz grains closely cemented with secondary silica. The cementing silica is stained by iron oxide. The quartz is interspersed by a few more or less rounded grains of magnetite. The section is highly fossiliferous containing sponge spicules, round and oval bodies, some of which are clear while others show a suggestion of structure and possess darkened centers. Other siliceous fragments, possibly organic, are present embedded in a matrix of highly siliceous clay. The greatest length exhibited by the spicules is 0.19 mm.; the spherical bodies are much smaller (Pl. 12, fig. 2). These forms are quite similar to those figured by Adkins and Arick (1) from pre-Comanchean rocks in Bell County.

No. 5. Jasper. Localty 5. This is a siliceous pebble having a reddish-brown center which is surrounded by a lighter band at the outer edges. The material is colorless to pale yellow in thin section and is composed of cryptocrystalline to microcrystalline silica that is colored by iron oxide.

No. 6. Jasper. Locality 1. This siliceous pebble has a deep red body with occasional flecks of smoky gray and a margin of light brown on one boundary. The material is very dense and presents a smooth surface. It is colorless to light brown to dark brown in thin section. The mass as a whole consists of cryptocrystalline and microcrystalline silica that is iron stained. The silica is "peppered" with numerous dark brown iron specks (averaging from .0150 to .0750 mm. in diameter). There are occasional veinlets of microcrystalline silica traversing the section in all directions. A single spine was noted, the body of which had been replaced by crystalline silica.

No. 7. Cryptocrystalline chert. Locality 5. A fine-grained gray to buff colored chert, apparently homogeneous throughout. In thin section the specimen is seen to be very fine-grained, cryptocrystalline to microcrystalline with embedded occasional bits of subangular quartz and feldspar. Some of the quartz grains are encrusted with iron oxide and there are occasional grains of kaolinized feldspar. Certain areas in the chert appear to be more crystalline than the main mass. The entire section is ramified with numerous veinlets of crystalline silica. This siliceous rock is highly fossiliferous and contains numerous single-pronged spines, some two- and three-pronged spicules, a number of round, clear bodies, and a few somewhat crescentic bodies. The spines are by far the most outstanding feature of the section and have a maximum length of 3.8 mm. and an average length of approximately 0.7 mm. C. L. Cooper,[5] has recognized fossils in this section that are possibly conodonts.

No. 8. Siliceous clay. Locality 1. The palm specimen is light gray to dark gray in color. The surface is more or less earthy, though very hard, and appears to be somewhat weathered. This condition is possibly due to the action of acid during the process of disaggregation of the sample of which it was a part. This siliceous material is essentially cryptocrystalline in character, although there is a crystalline network throughout, due to the cutting of the section in all directions by numerous crystalline silica veinlets. Scattered through the material are microfossils made up of silica that is more or less crystalline.

No. 9. Red quartzite. Locality 4. This pebble is even-textured, compact, red quartzite. In thin section the specimen is a very compact, coarse-grained quartzite and shows no secondary enlargement of grains. Although the grain of the rock is predominantly coarse, certain portions are made up of fine materials. The section shows some degree of staining by iron oxide. The rock appears to have been affected by hydrothermal action at some time during its history, as indicated by the fact that certain grains of silica inclose, or are cut by, tourmaline sun-bursts.

No. 10. Brown siliceous clay. Locality 1. This is smooth, fine-grained, even-textured, light brown, siliceous clay. In thin section the material appears as a highly siliceous clay that bears enough iron oxide to give the rock mass a light brown color. The material is predominantly cryptocrystalline. The section is highly fossiliferous and contains several three- and four-pronged spines and occasional structureless spherulitic bodies. These organic structures have been replaced by silica that is more or less crystalline.

No. 11. Cryptocrystalline to microcrystalline chert. Locality 4. A dark gray to dark brown chert pebble that is traversed by occasional crystalline veinlets. In thin section the material is essentially cryptocrystalline, but some more or less isolated patches appear microcrystalline. The section is crossed by several distinctly crystalline veinlets. In this section a few tapered spines were noted and a few globule-like clear bodies, all of which are replaced by silica that is essentially crystalline.

No. 12. Gray quartzite. Locality 1. This specimen is smooth, even-grained, light gray quartzite. In thin section the material is even-textured. The section shows distinct bands of heavy minerals. Among the minerals included in this band are leucoxene, limonite, tourmaline, rutile, and zircon. Some of the quartz grains show growth by secondary enlargement.

No. 13. Pink to gray quartzite. Locality 5. This is a coarse-grained, even-textured, pink to gray quartzite. In thin section it appears as a mass of quartz particles of sizes ranging from 0.01 to 18 mm. in diameter. The coarse and fine grains are arranged in alternate bands. A single, slightly iron-stained chert fragment is present in the section. The original iron oxide cement

[5]Cooper, C. L., personal communication, dated March, 1931.

surrounds some of the grains, which are included in the secondary cement-silica. The section contains a few grains of ilmenite, and one of these is partially altered to leucoxene.

Fossils.—The matrix of the Brazos sandstone and conglomerate contains but few fossils. Plants are present but so fragmentary and poorly preserved as to be scarcely identifiable. At Locality 12 of Figure 7A some marine invertebrates, including *Myalina* sp. and *Productus* sp., have been found. Although this fauna is meager it is significant, indicating marine conditions at this locality.

Of special concern in the present study are fossils found in the transported pebbles of the conglomerate. In the thin sections of certain pebbles a rather diversified collection of micro-organisms was found. In general, this fauna consists of spherulitic bodies that have various structures and symmetry, spine and spicules, and other fragmentary remains, all of which have been replaced by silica in one form or another. The poor state of preservation and the lack of literature dealing with such organisms of pre-Strawn age, makes specific identification of these fossils a very difficult problem, so much so, in fact, that only the most general names may be applied. Most of the fossiliferous pebbles are those that are made up of siliceous clays and not the true chert types. The rounded forms (*Radiolaria?*) have the most widespread occurrence in these pebbles, but the varied types of spines and spicules are rather abundant as well. One of the siliceous clay pebbles contains a number of rounded bodies that are replaced by chalcedony. Under crossed nicols some of these forms show structure that suggests the possibility of their belonging to the *Fusulinidae.* In these particular bodies only a very faint suggestion of the structure is to be seen. The thin sections containing the fossils are described above.

Environment of deposition.—Several features that are typical of this conglomerate point to fluvial transportation of the included materials. The evidences pointing to fluvial transportation are as follows: The characteristic homogeneity as to lithologic types leads to the conclusion that these materials were transported by streams from sources that were not far distant. It is possible, however, that other less resistant materials were originally associated with the chert but were worn out during the course of transportation. The intermingling of pebbles, granules, sands, and silts indicates transportation by streams of considerable velocity and volume; in other words, during transportation there was little or no assortment of materials as to size-grade distribution. The shapes of the pebbles in the conglomerates, as well as those of the grains comprising the matrix, are largely subangular and angular, this being typical of fluvially transported sediments. Pieces that are subject to strong wave action, as beach and littoral material, ordinarily show a much greater degree of rounding than is displayed by the pebbles in the Brazos conglomerate.

The characteristic features of the Brazos conglomerate are summarized below:

	Littoral	Piedmont	Delta	Flood Plain
Homogeneity of lithologic types		X	?	X
Poor assortment		X	X	X
Subangular to angular		X	X	X
Poorly stratified	?	X	?	X
No orientation as to long axes or flattened sides		X	?	X
Long axes of sand lenses parallel to dip		X	X	X
Frequent alternation of coarse and fine beds	X	X	?	X
Constituent materials ranging from silts to pebbles of considerable size		X	?	X
Numerous fore-set beds (cross-bedding)	X	X	X	X
Ripple marks and mud cracks in associated beds	X	X	X	X
Little intercalated clay and shale		X	X	?
More than 25 miles in width	X	X	?	
Irregularities in thickness, bedding, etc., more prominent along strike than dip	X	X	X	?
Tendency toward red color				?
Fragmentary plant fossils		X	X	X
Marine fossils in one locality	X		X	
Grades into normal sandstone	?		X	

After reviewing the criteria for the various types of delta deposits, fluviatile conglomerates, and littoral and piedmont environments as described by Barrell (3), Mansfield (10), Twenhofel (28), and Trowbridge (27), the conclusion is reached that the assignment of a definite environment of deposition in which the Brazos conglomerate was deposited is not justifiable. There are characteristics that are common to piedmont, to littoral, to flood plain, and to deltaic environments of deposition. Apparently the site of deposition was one that was situated at the strand line in such a position that the deposits might be marine at certain times and places and continental at others. Such a condition as this might occur in deltas where deposits are of both a continental and a marine nature, the continental deposits being in the subareal portion and the marine deposits in the subaqueous portion of the delta. Whatever the environment might have been, the deposits were accumulated in close proximity to the sea; the materials were deposited rapidly, and were not subjected to strong wave action and reworking after deposition.

The sediments were carried to their site of deposition by streams that flowed westward. At the close of this paper will be found a discussion of the probable source of the materials of this conglomerate.

THE TURKEY CREEK SANDSTONE AND CONGLOMERATE

Name and definition.—The Turkey Creek member of the Mineral Wells formation, named by Plummer and Moore (**17**, p. 77), was defined by them as a massive sandstone, 10 to 20 feet thick, which forms the first prominent escarpment east of the outcrop of the Palo Pinto limestone. Stratigraphically, this member lies approximately 500 feet above the Brazos sandstone and conglomerate. The location of this sandstone outcrop is shown in Figure 7B.

As in the Brazos member, the sandstone and conglomerate are so closely related that it is impossible to separate the two over any considerable distance. Everywhere they occur together, first one and then the other predominating, except in the northern and southernmost extensions of the outcrop where the member is entirely sandstone.

The thickness of this member varies from 5 to 17 feet as measured at the various localities. No definite statement can be made as to regular changes either along the strike or along the dip of the sandstone. Apparently no such regularity exists.

The Turkey Creek conglomerate is everywhere overlain by sandstone and the underlying beds are also composed largely of sand, but contain clay. These associated sandstones vary greatly within short distances both horizontally and vertically. Among the various features that are present in these associated sandstones the following are listed: coarse grain, medium grain, fine grain, with textural range from sandstone to pebbly sandstone with occasional conglomeratic lenses; massive beds, thin beds, laminations; red, reddish-brown, brown and gray colors; and a range in thickness of from 5 to 46 feet.

The coarse clastic material that is found in the various conglomeratic phases of this member is all of a siliceous nature, and comprises, in the order of decreasing importance, chert, siliceous clay, quartzite, and quartz. The matrices of the conglomerates and the sandstones are essentially made up of quartz grains along with varying amounts of angular chert fragments which are bound together by iron oxide and silica cements. In some of the samples the larger grades of the chert predominate.

The pebbles consist largely of a variegated mass of chert and siliceous clay that present a large number of recognizable types. Forty-one distinct types (based on color, fracture, and crystallinity) were recognized at Locality 6. White pebbles predominate and comprise an average of 78.9 per cent for 8 localities. Gray pebbles are second in the order of abundance and make up an average of 14.7 per cent of the whole, and the other groups, in order of decreasing importance, are yellow, red, black, and green pebbles. It will be noted that the white and gray pebbles are present in the conglomerates of each locality listed; yellow pebbles are present at all except Locality 6; red pebbles and the banded cherts are lacking only at Localities 8 and 10; black pebbles are found at 3 localities; and green pebbles appear only at Locality 5 and then only in slight amount.

It is evident that the Brazos sandstone and conglomerate member presents a far greater variety of color types than does the Turkey Creek member, and furthermore that whereas the grays predominate in the Brazos, their place is taken by the whites in the Turkey Creek member. This fact might have its explanation in the degree of weathering to which these materials have been subjected. Melton (**13**, p. 62) states that the unweathered Talihina chert of the Ouachita area occurs in various shades of translucent dark gray and that weathering has changed it to many shades of light gray, tan, pinkish tan, and white. This might suggest that the materials in the Turkey Creek sandstone member have been more extensively weathered than those in the Brazos conglomerate.

Following is a summary of the characteristics of this conglomerate:

The Turkey Creek sandstone member comprises, in its various phases, true conglomerate, pebbly sandstone, and sandstone. The conglomeratic phase is characterized by rock pieces that range from 4 to 32 millimeters in diameter, with occasional pieces of a larger size. In the pebbly sandstones the pebbles range upward to 16 millimeters in diameter. In a majority of the samples the primary constituents are composed of the medium and fine sand grades. A majority of the secondary maxima occur in the pebble sizes. In the conglomeratic phases the matrices consist of materials that grade downward to silt. Some of the samples, those of the northern and southern extensions of the outcrop, show a tendency toward sorting of materials. The constituent materials are largely subangular and angular. The sand grades include a noticeable percentage of rounded quartz grains and these are probably to be explained by the presence of reworked materials.

Porosity.—The porosity of the Turkey Creek sandstone varies from 10.3 per cent at Locality 5 to 17.2 per cent at Locality 12 and averages 14.6 per cent. Apparently there is no regular variation in the porosity either along or across the strike.

Bedding.—The Turkey Creek sandstone member is characterized by cross-bedding and by bedding planes that are very irregular and ill-defined. The directions and amounts of the dips of certain foreset beds at Localities 1 to 3 and 11 and 12 are as follows (locality numbers correspond to those shown on Figure 7B):

Locality 1: 6° N. 35° E.; 10° N. 20° E.; 7° N. 38° E.
Locality 2: 9° N. 38° E.; 5° N. 21° E.; 3° N. 43° E.; 12° N. 33° E.
Locality 3: 6° N. 7° W.; 10° N. 16° E.; 4° N. 27° E.; 16° N. 14° W.

The data from these and other localities show that the foreset beds have a general northerly dip. Localities 1, 2, and 6 show dips to the northeast, whereas all the rest, save Locality 3, which is equally divided between the two, show northwest dips. The cross-beds dip at angles of 1 to 16 degrees.

Shapes of pebbles.—A composite average of the shapes of pieces for the 12 samples is as follows:

	Per Cent
Angular	43.5
Subangular	43.0
Curvilinear	11.5
Subround	1.7
Round	0.3

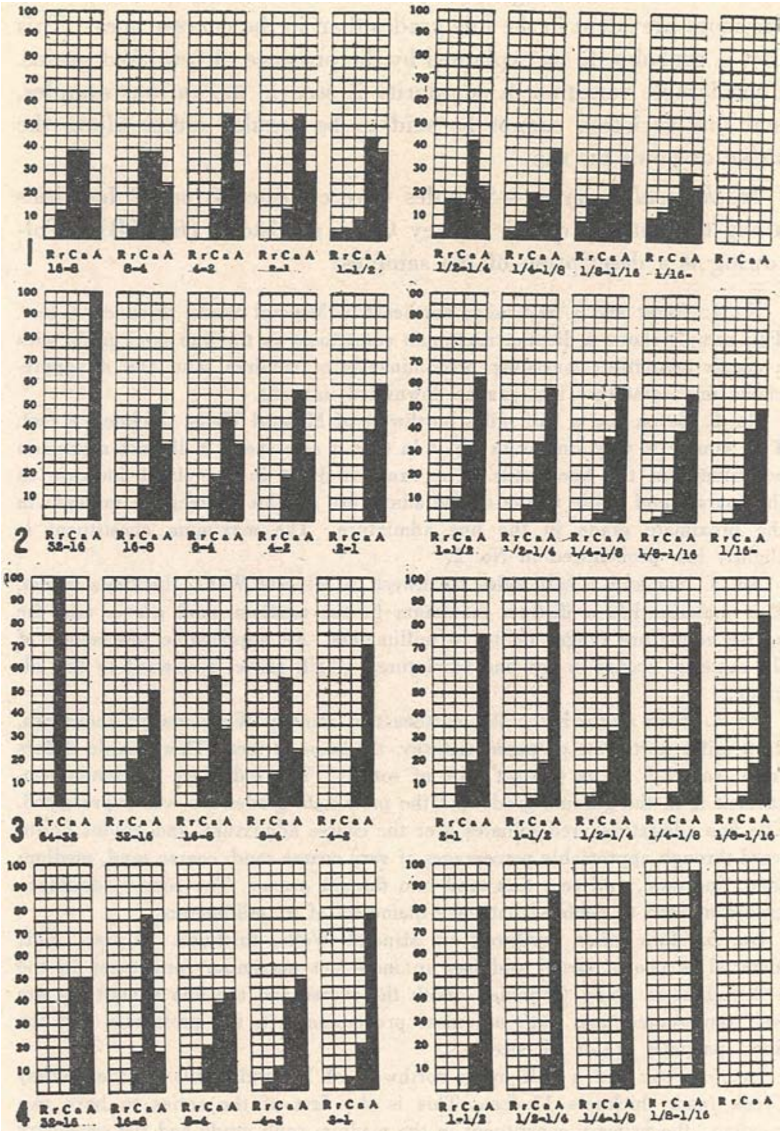


Fig. 9. Shape analyses of pebbles from the north Texas conglomerates: No. 1, Brazos conglomerate; No. 2, Turkey Creek conglomerate; No. 3, Rochelle conglomerate; No. 4, conglomerate lying above the Rochelle.

The more abraded fragments (curvilinear, subround, and round) are more prevalent in the fine grades than in the coarser ones. This fact is probably to be explained by the presence of reworked grains. Considerable variation in angularity is seen in the various samples, and this variation cannot be said to be regular either along the strike or down the dip.

Mechanical analyses.—Samples were collected from 12 localities along the outcrop of the Turkey Creek sandstone (fig. 7B). Following is a description of the samples:

No. 1. Eight and a half miles northeast of Mineral Wells. thickness 5 feet. This sample shows a distinct maximum constituent in the fine sand grade with a coarse admixture consisting predominantly of medium sand and an appreciable fine admixture that grades downward into silt.

No. 2. Seven and a half miles northwest of Mineral Wells, thickness 8 feet. This sample is very similar to No. 1 in that it also shows a distinct maximum constituent in the fine sands. The samples differ in the slight increase in the coarse sand grade in the coarse admixture and an appreciable increase in the proximate grade in the fine admixture. The maximum constituent is slightly less pronounced in No. 2.

No. 3. Six and a half miles northwest of Mineral Wells, thickness 6 feet. This material has a distinct maximum in the medium sand grade, and the coarse admixture ranges up to 16 millimeters. An appreciable percentage of the material occurs in the fine admixtures, which grade downward to the silt grade.

No. 4. Four and a half miles northeast of Mineral Wells toward Jacksboro, 2/10 miles northwest of main highway, thickness 6 feet. This sample differs from Nos. 1–3 in its distinct lack of sorting. The indistinct maximum constituent is in the granule grade and the proximate grades are well represented. The fine admixture predominates over the coarse admixture, and grades downward through appreciable percentages of very coarse sand, coarse sand, medium sand, fine sand, and very fine sand into the silt grade. The coarse admixture grades upward to pebbles that have diameters of 32 millimeters.

No. 5. Two miles northwest of Mineral Wells, thickness 10 feet. This material is poorly sorted and has an indistinct maximum constituent in the 4–2 millimeter grade (granule). Both the coarse and the fine admixtures are well represented, and both are most predominant in the proximate and the finest particles are of silt size.

No. 6. Four and a half miles northwest of Mineral Wells on the Turkey Creek road, thickness 17 feet. This is the first of the series to have two maxima—the primary constituent in the medium sand grade and the secondary maximum in the pebble grade (32–16 millimeters). The pebble and sand grades are in about equal proportions.

No. 7. Two and a half miles northwest of Mineral Wells. thickness 14 feet. This material has medium-grained sand as its primary constituent. The coarse admixture grades upward to the 32–16 millimeter grade which is a rather distant secondary maximum. The largest fine admixture is in the proximate grade, a fine sand. A very small percentage is in the silt grade.

No. 8. Two and a half miles south of Palo Pinto on the Palo Pinto–Santo road, thickness 12 feet. This is a sample of very poorly sorted material that has material of granule size (4–2 millimeters) as its primary constituent. The fine admixture is in the most distant grades and there is a secondary maximum consisting of medium sand. The coarse admixtures are rather well represented and range upward to pebbles that have diameters of 32 millimeters.

No. 9. Five and a half miles toward Santo on the Palo Pinto–Santo road, 2.2 miles southwest of main highway, thickness 12 feet. The mechanical analysis of this material shows the primary constituent to be a medium-grained sand with an appreciable percentage in the coarse admixture which ranges upward to pieces having a diameter of 8 millimeters. The fine admixture consists largely of the proximate grade, fine-grained sand, and grades downward into silt.

No. 10. Four miles west of Lone Camp, thickness 10 feet. This sample has a distinct maximum in the medium sand grade and a predominance in the coarse admixtures, which are represented by appreciable percentages in every grade upward to the 32 millimeter size. The fine admixtures are rather poorly represented, and have their predominance in the fine sand grade.

No. 11. Four and four-tenths miles south of Mineral Wells–Strawn highway toward Gordon, thickness 11 feet. The most nearly perfectly sorted material in the entire series occurs in this sample. The primary constituent, which is fine sand, comprises over 80 per cent of the entire sample. The only appreciable amount of material in the coarse admixture is in the medium sand grade. The very fine sand and silt grades are comparatively well represented.

No. 12. Sixteen and a half miles southwest of Lone Camp, thickness 8 feet. The final sample of the series has many features in common with No. 11. The most outstanding likeness is in their primary constituents, as both show many distinct maxima in the fine sand grade. They are also very similar in their coarse admixtures. The only appreciable differences between the two analyses lie in the slightly smaller percentage in the primary constituent and the larger amount of very fine sand than of silt in the fine admixture of No. 12.

The mechanical analyses of three samples of this conglomerate are given in Figure 8 (Nos. 4, 5, 6 of that figure).

Perhaps the most prominent feature of the series is the presence of essentially pure sandstones at both the northern and southern extensions of the outcrop, with typical conglomerate between. Medium sand comprises the primary constituents in 5 samples, fine sand in 4 samples, and materials of the granule size in the remaining three samples. Four samples exhibit secondary maxima, two of which are in the 32–16 mm., grade, one in the 16–8 mm., and one in the ½–¼ mm. grade. All of the samples have coarse admixtures that show considerable variation in the various samples and range from 4 percent in Number 11 to 65 per cent in Number 6. The grades represented in the coarse admixtures range from ¼ mm. (Nos. 1, 2, 11, and 12) to 32 mm. (Nos. 4, 5, 6, 7, 8, and 10). The least range shown in the coarse admixture is that of Nos. 11 and 12, which range from ¼ mm. to 1 mm., and the greatest range, ½ mm. to 32 mm., in Nos. 6, 7, and 10. Eight of the samples contain pieces of pebble size in varying percentages. Each sample in the series has a fine admixture that grades downward into the silt grade. The coarsest grades in the fine admixture range from 2 mm. (Nos. 4, 5, and 8) down to ⅛ mm. (Nos. 1, 2, 11, and 12). The smallest range shown in the fine admixtures is in Nos. 1, 2, 11, and 12, where this entire sample consists of the grades having a diameter of less than ⅛ mm. The fine admixture varies in amount from 6.4 per cent in No. 10 and 48.4 per cent in No. 5.

Certain beds in this member consist of typical conglomerate. Other beds are pebbly sandstone, in which the materials of the pebble grade are present in very minor quantities, as for instance in sample No. 3. In addition to conglomerate and pebbly sandstone. parts of the member are typical sandstone, as is exemplified in Nos. 1, 2, 11, and 12. In a majority of the samples the primary constituents are composed of the sand grades. None of the series has a pebble grade as its principal ingredient, and only three lie within the granule size. Secondary maxima appear in four samples, three of which are composed of pebbles and the fourth consists of medium sand. In the conglomerate the matrix consists of sands that grade into silt. Nos. 1, 2, 3, 11, and 12 show sorting that is developed to a considerable degree, whereas the remainder of the series shows little tendency to assortment as to size-grade.

Thin sections of pebbles.—Thin sections that were made of pebbles selected from the Turkey Creek sandstone member exhibit certain features that prove useful in classifying the materials. Brief descriptions of some of the sections are given below.

No. 1. Microcrystalline to crystalline chert. This pebble is a light gray to dark gray chert that is crossed by a zone of minute, wavy, more or less parallel, smoky gray lines. In thin section it appears as a more or less mottled mass of microcrystalline and crystalline silica. The main body is light brown to light tan in color, due to iron oxide staining. Occasional structureless, crystalline, spherical bodies are irregularly distributed through the section. These bodies range from .31 to .96 of a millimeter in diameter. In addition to these, there is a single spherical form that has a "honey-comb" structure. This is very similar to the one figured by Adkins and Arick (1, p. 20) from pre-Comanchean cherts occurring in well samples in Bell County, Texas. These bodies are tentatively identified as *Radiolaria.*

No. 2. Cryptocrystalline, microcrystalline, and crystalline chert. In the hand specimen this appears as a light gray to light brown chert showing occasional specks of crystalline silica. The thin section shows this pebble to be composed essentially of pure silica, which is cryptocrystalline, microcrystalline, and crystalline in form. The crystalline silica occurs as irregularly shaped patches that have an irregular distribution throughout the section.

No. 3. Siliceous clay. This specimen is a cream to buff colored siliceous pebble that presents a more or less weathered surface. In thin section this material appears as a siliceous clay that is grayish to light yellow in color. The silica is essentially microcrystalline. A considerable portion of the section is made of what appears to be sponge fragments, which occur in pieces that range from .06 to 2.2 millimeters in length.

The constituent materials of the Turkey Creek member can be summarized as follows: Chert is by far the predominant constituent material in the pebbles. This chert occurs in many varieties. The predominating colors are, in order of their decreasing importance. white, gray, yellow, banded colors, red, black, and green. The chert is partly cryptocrystalline, partly microcrystalline, and partly crystalline. The siliceous clays are second in importance as a constituent material of pebbles and consist of original fragmental material and secondary silica, and are highly fossiliferous. A few quartzite pebbles occur in the conglomerate. The pebbles show a very small percentage of quartz. The pebbles in the conglomerate phase are embedded in a matrix that is composed of chert and quartz grains, in which the quartz predominates, especially in the finer grades. The sand composing the sandstone phase is made up predominantly of quartz.

Fossils.—Two of the pebbles from the conglomeratic phase of this member were found to contain fossils, the descriptions of which are given above. No fossils indigenous to this member were found.

Environment of deposition.—In texture, shape, mineralogy, bedding, and paleontology the Turkey Creek sandstone member is very similar to the Brazos sandstone and conglomerate. The many similarities lead to the conclusion that the history recorded by these two members is very much the same. Apparently there was a recurrence of Brazos River conditions in Turkey Creek time. Field evidence shows that the streams that transported the materials were flowing from the east or southeast. These conditions lead to the conclusion that highlands to the east were the source for these coarse clastic materials.

THE AVIS SANDSTONE AND CONGLOMERATE

The Avis sandstone member named from the town of Avis, in Jack County, north of Jacksboro (17, p. 154), lies at the base of the Thrifty formation and in places rests on the Wayland shale (Graham formation) and elsewhere directly upon the Gunsight limestone (Graham formation). According to Clark (7), the Avis sandstone may be traced along the strike for 100 miles.[6] Its thickness varies from 5 to 50 feet, the greatest thickness being in Jack County

[6]For the outcrop of this member see geologic maps of Jack and Young counties issued by the Bureau of Economic Geology of The University of Texas.

north of Bryson. The conglomeratic phase of the Avis sandstone member was observed 1 mile west of Graham, where it caps an east-facing escarpment.

The conglomerate at this locality is shown by mechanical analysis (fig. 8) to have a primary constituency in the 16–8 millimeter grade. The coarse admixture comprises a single grade, which is present in an appreciable percentage. The fine admixtures are well represented and grade downward from small pebbles to silt. The sand grades that comprise the matrix are fairly well represented.

The constituent materials in this conglomerate are highly angular. The percentage of subround and curvilinear pieces is very small. The three largest grades that are not shown on the plate are also characteristically angular and subangular.

Averages derived from data presented by Clark (7) for 27 localities give the following figures regarding the shapes of pebbles in the Avis conglomerate:

	Per cent
Well rounded	0.0
Partially rounded	0.9
Rounded corners	3.4
Subangular	6.0
Angular	69.0
Flat	20.3

Other averages derived from Clark's figures on color and mineralogy are:

Color—	Per cent
White	69.9
Gray	14.9
Yellow-brown	9.1
Red	5.6
Pink	0.3
Mineralogy—	**Per cent**
Quartz	0.03
Chert	80.05
Shale	17.55
Hematite	.27
Limestone	.03

The Avis conglomerate has several features in common with the Turkey Creek conglomerate in that the predominant color represented in the pebbles of both is characteristically white, and that they both show a high degree of angularity. The deposition of the

Avis clastics was doubtless brought about by a recurrence of conditions similar to those that prevailed during Turkey Creek time.

Clark, who has studied this conglomerate, is of the opinion that the materials of the conglomerate represent a series of alluvial fans which derived their sediments from an old land mass to the east (7).

CONGLOMERATES OF THE COLORADO RIVER AREA

ROCHELLE CONGLOMERATE

Name and definition.—The name Rochelle conglomerate was given by Tarr (**23**, p. 205) to a bed of coarse conglomerate found east of the town of Rochelle and was traced by him from Rochelle northeastward to the Colorado River, along Deep Creek, just east of the town of Milburn. He stated that east of Deep Creek a portion of the conglomerate is buried beneath the Cretaceous and that in this buried portion a change from conglomerate to conglomeratic sandstone takes place, and that to the northeast it may be again traced as a distinctly conglomeratic sandstone band across Pecan Bayou to the Cretaceous. Plummer and Moore (**17**, p. 96) state that the conglomerate near Pecan Bayou closely resembles the Rochelle bed. The writer found that the conglomerate bed in the gravel pit near Pecan Bayou ½ mile north of Brownwood is not typical Rochelle. It does not consist predominantly of chert pebbles, as it does east of Rochelle, but of rounded limestone pieces that are loosely held together in a friable sandstone matrix. The fact that there are several exposures of Cretaceous conglomerates to the south of this one that are very similar lithologically presents the probability that this too is Cretaceous.

The writer has found what he has interpreted to be the Rochelle conglomerate at various points southwest, south, southeast, east, and northeast of Rochelle (fig. 10). The outcrop is discontinuous and indistinct and for that reason the writer's reconnaissance in that area does not warrant a mapping of the outcrop. Three miles southeast of Cowboy (just east of Locality 5) the conglomerate passes beneath the Cretaceous. Two other conglomerates, one lying stratigraphically below and the other above the Rochelle, were noted in this general area (A and B, fig. 10). The lower one might easily be confused with the Rochelle, but detailed study brings out characteristic differences.

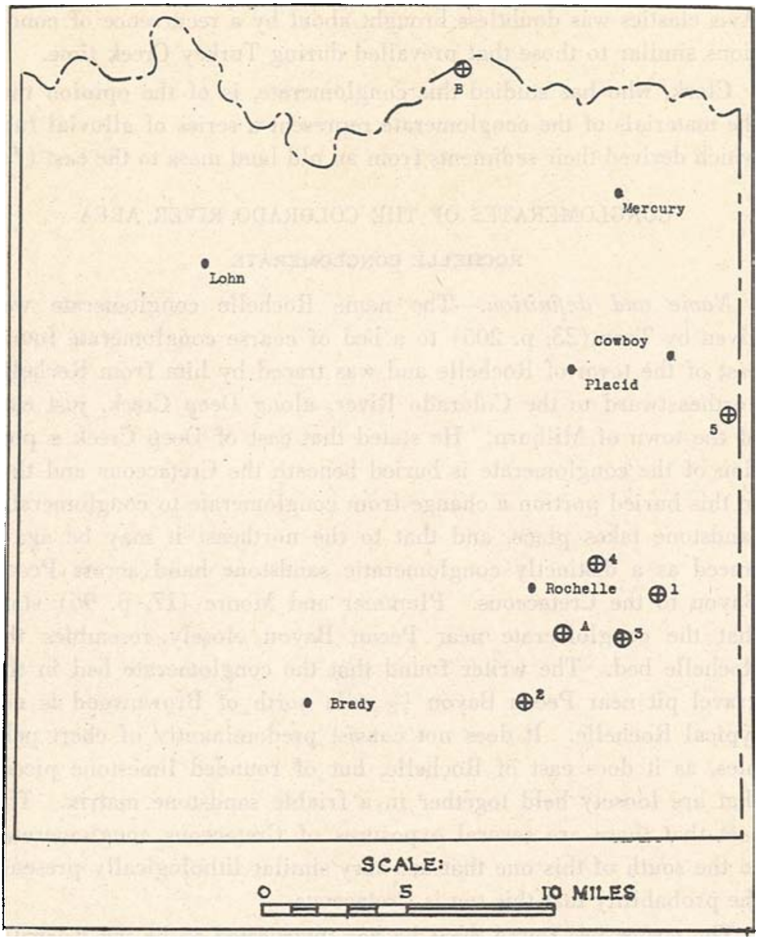


Fig. 10. Sketch map showing localities from which samples of conglomerates were collected in the Pennsylvanian area on the Colorado River.

Localities in McCulloch County at which the Rochelle conglomerate is typically exposed are as follows:

Locality 1. Type locality, 4 miles east of Rochelle on the San Saba road, thickness 20± feet.

Locality 2. Five miles southwest of Rochelle on the old Rochelle-Brady road, thickness 14 feet.

Locality 3. Three and one-half miles southeast of Rochelle, thickness 12 feet.

Locality 4. One mile from the Rochelle-San Saba highway on the old Brownwood road, thickness 8 feet.

Locality 5. Three miles southeast of Cowboy at the McCulloch-San Saba county line.

Locality A is an exposure of a conglomerate below and Locality B of a conglomerate above the Rochelle conglomerate (fig. 10).

The rocks that overlie and underlie the Rochelle conglomerate, where visible, are sandstones varying in thickness from 5 to 26 feet. These related sandstones exhibit variable characteristics such as: light brown, dark brown, reddish-brown, and red colors; massive and thin bedding; medium and coarse textures; true sandstone and pebbly sandstone; and, at some localities, ripple marks.

The constituent material of the Rochelle conglomerate is almost entirely siliceous, and consists, in the order of decreasing importance, of chert, siliceous clay, and quartzite. The matrix is white quartz sand, which in places carries a comparatively high percentage of chert. Plummer and Moore (**17**, p. 96) report fragments of black shale and small pieces of black chert in the matrix which is said to closely resemble material from the Marble Falls formation.

Perhaps even a greater variety of chert is to be found in the Rochelle than in the Brazos conglomerate of the Brazos River valley. At the type locality, 4 miles east of Rochelle, one hundred thirty-five distinct varieties were noted.

The Rochelle conglomerate member comprises a true conglomerate that is characterized by an abundance of coarse materials that are embedded in a matrix that grades downward through the sand grades to a silty material. The predominance of the coarser materials is seen to be within the range of 64 to 4 mm., however, occasional cobbles having diameters of 180 mm. and more are found. The coarse admixtures, when present, are all above the 16 mm. grade.

A composite average of five samples of this conglomerate shows the whole to be 54.2 per cent angular, 34.0 per cent subangular, 11.2 per cent curvilinear, and 0.6 per cent subround. It is seen that the less angular pieces predominate in the coarser materials and that the finer grains are distinctly angular. This doubtlessly indicates the lack of reworked grains in the finer grades.

Mineralogically, the Rochelle conglomerate may be said to be composed of siliceous materials, among which chert fragments predominate among the pebbles and quartz grains among the grades composing the matrix. Occasional siliceous clay, quartzite, and quartz pebbles are found. The general color groups represented are the grays, yellows, greens, whites, blacks, banded, browns, and reds. Green pebbles may be said to be characteristic of this conglomerate.

The characteristic texture of the Rochelle conglomerate is shown in Plate 12, Figure 6. In this particular phase the matrix is quartzitic and is of the same hardness as the included pebbles.

Although numerous colors and color combinations are represented within the pebbles of the Rochelle conglomerate, they may be grouped into eight general classes. The general groups, in their order of decreasing importance, are as follows: gray, yellow, green, white, black, banded colors, brown, and red. The Rochelle may be readily distinguished from the conglomerates of the Brazos River inlier, the Brazos and Turkey Creek members, by the abundance of green chert. It may also be distinguished from the conglomerate underlying it on this basis.

Bedding.—The Rochelle conglomerate is characterized by irregular cross-bedding throughout and true bedding planes are lacking. Directions and the amounts of the dips of various foreset beds at the various localities are as follows:

Locality 1: 3° S. 41° W.; 6° S. 46° W.; 5° S. 48° W.; 8° S. 51° W.
Locality 2: 12° S. 72° W.; 7° S. 83° W.; 4° S. 56° W.
Locality 3: 3° S. 80° W.; 5° S. 73° W.; 4° S. 50° W.; 5° S. 88° W.; 6° N. 86° W.
Locality 4: 5° S. 37° W.; 9° S. 53° W.
Locality 5: 4° N. 87° W.

The above data show that the foreset beds at four of the localities, Nos. 1, 2, 3, and 4, dip in a general southwest direction. In a single locality, No. 5, where only one measurement could be taken, the dip was found to be in a northwesterly direction. The amount of dip varies from 3 to 12 degrees.

Shapes of pebbles.—A graphic representation of the shape analysis of a typical sample of the Rochelle is given in Figure 9 (No. 3 of that figure). A composite average of the whole of the samples, including all size-grades, is as follows:

	Per cent
Angular	54.2
Subangular	34.0
Curvilinear	11.2
Subround	0.6
Round	0.0

It is to be noted that the constituent materials in the pebble grades show a considerably higher degree of abrasion than the smaller pieces. Taking the conglomerate in its entirety, it may be said to be distinctly angular, although the pebbles are usually found to be much less angular than the matrix.

Mechanical analyses.—Mechanical analyses of the Rochelle conglomerate were made from these five localities. The results are described as follows:

No. 1. In this sample the principal ingredient is in the coarsest grade, the 32–64 mm. grade. There is no coarse admixture and the fine admixture ranges downward to the silt grade. The predominance of the fine admixture is larger than ⅛ mm. size. The proximate grade, 32–16 mm., is second to the principal ingredient in importance.

No. 2. This material presents material of the 16–8 mm. grade as the maximum constituent. The coarse admixture constitutes a single grade, that having a range between 32 and 16 mm. The fine admixture grades downward to the silt grade. An indistinct secondary maximum occurs in the fine admixtures in the medium sand grade. The grades between 8 and ¼ mm. are present in approximately equal amounts.

No. 3. A very distinct primary constituent appears in the 16–8 mm. grade. The coarse admixture is made up of the proximate grade, the 32–16 millimeter size. The fine admixtures grade downward to the silt grades, and the particles having a diameter of less than ¼ mm. are present in very small amounts.

No. 4. This is a very poorly sorted material with a somewhat indistinct primary constituent in the 16–8 mm. grade. The coarse admixtures range upward to 64 mm. and the fine admixture down to less than 1/16 mm. The fine admixtures predominate over the coarse admixture.

No. 5. This sample differs from all the rest in that the bulk of the constituent material has a diameter greater than 8 mm. The coarsest material, which is in the 64–32 grade, comprises the principal ingredient. There is no coarse admixture and the fine admixture grades downward to the silt grades. A very indistinct secondary maximum occurs in the medium sand grade.

Perhaps the most notable feature of this series is that the maximum constituents of the sample are in every case in the pebble grade and above 8 mm. in diameter. Samples 3 and 5 show some tendency toward assortment as to size grades. Four out of the five samples have secondary maxima. which are in the medium sand grades in every case. Three of the five samples have coarse admixtures, all of which are materials having a diameter greater than 16 mm.

Mechanical analyses from localities Nos. 1, 2, and 4 are given in Figure 8 (Nos. 7, 8, and 9 of that figure).

The coarse admixtures range from 12.4 to 47.8 per cent of the samples. The fine admixtures range from 32 mm. down to 1/16 mm., and are present in each sample of the series. The fine admixtures are present in varying amounts, ranging from 31.6 per cent to 48.6 per cent. It may be said that the samples in this series have many features that are common to all and that they are much more closely related than are those of the Brazos and Turkey Creek conglomerates.

This member is a true conglomerate characterized by its abundance of coarse materials, which are seen to range upward to 64 millimeters in the mechanical analyses. Occasional cobbles, some having a length of 180 mm., were noticed lying loosely on top of the conglomerate at one locality. The coarse admixtures, when present, are all above 16 millimeters in diameter. The pebbles are embedded in a matrix that grades downward through the various sand grades to silt. Medium sand is the most abundant material in the matrix.

Thin sections of pebbles.—Thin sections were made of three pebbles from the Rochelle conglomerate. Descriptions of these sections are given below.

No. 1. Cryptocrystalline chert. This is a pure white pebble, the surface of which is somewhat weathered, possibly due to the etching by caustic soda during the process of disaggregation.

In thin section this material is shown to be composed of very fine-grained cryptocrystalline chert. The section is essentially homogeneous throughout, save for occasional patches of microcrystalline silica of minute dimension. A few rounded quartz grains are embedded in the mass.

No. 2. Microcrystalline chert. A fine-textured, cream to light gray chert pebble. In thin section it appears as a very fine-grained microcrystalline chert. Scattered throughout the section are a number of more or less oblate bodies which are doubtless the outlines of fossils that have been replaced by silica. For the most part, the replacement material is chalcedonic in nature, but in some cases the silica grades from chalcedony at the periphery to crystalline silica in the center. Certain of the altered areas possess minute iron oxide inclusions. Occasional "shreds" of sericite are present.

No. 3. Siliceous clay. A peculiarly marked pebble in which the main body is grayish blue in color in which numerous buff to cream-colored splotches are included. In thin section the material is seen to be composed of silica that is both original (fragmentary) and secondary. Much of the secondary silica is more or less chalcedonic in nature. Occasional bits of sericite are present. The buff and cream-colored splotches are less highly silicified than the grayish-blue material. Numerous oblate bodies are distributed throughout the section. Most of them are structureless, but several show poorly preserved structures that are like those of *Fusulinidae*. This specimen is identical to one found in the Brazos conglomerate.

Fossils.—It is likely that a study of a number of sections of the included pebbles would show the presence of a distinctive microfauna. Two of the three sections that were made of the pebbles showed fossil forms. These forms are tentatively identified as fusulinids. A more detailed study of the microfauna of this conglomerate bed is reserved for the future. No indigenous fossils were found in the conglomerate.

Environment of deposition.—This Rochelle conglomerate is very similar to both the Brazos and Turkey Creek conglomerates in that they are all three composed of pebbles that are siliceous in nature. The deposits are stream carried, the source being to the northeast.

CONGLOMERATE UNDERLYING THE ROCHELLE CONGLOMERATE

An outcrop of a conglomeratic bed was noted in the bed of a small creek 1½ miles southeast of the town of Rochelle. The location is shown in Figure 10, where it is designated as Locality A. The conglomerate is approximately 12 feet thick at this locality and lies upon a massively bedded sandstone which contains occasional pebbles near its upper limits.

The pebbles were made up entirely of chert, and the following color groups were noted: gray, 72 per cent; white, 22 per cent; green, 2 per cent; brown, 2 per cent; red, 1 per cent; banded colors, 1 per cent.

The mechanical composition of this material, which is graphically shown in Figure 8 (No. 11 of that figure), shows its primary constituent to be a medium sand. A more or less distinct secondary maximum occurs in the 16–8 millimeter grade. The coarsest materials are in the 32–16 millimeter grade.

The constituent materials in this conglomerate are highly angular in the grades below 4 millimeters, and more nearly round in the coarser grades. In the largest grade the materials are almost equally distributed between curvilinear, subround, and round particles.

The conglomerate is cross-bedded, and the dips of various cross beds were noted as follows: 3° S. 80° W.; 5° S. 73° W.; 4° S. 50° W.; 5° S. 88° W.; 6° N. 86° W.

The most distinguishing features between this bed and the Rochelle conglomerate are: the lack of black pebbles, the comparative rarity of green pebbles, and the absence of pieces larger than 32 millimeters in diameter.

CONGLOMERATE ABOVE THE ROCHELLE CONGLOMERATE

On the White Ranch on the Colorado River, seven miles northwest of Mercury, McCulloch County, is an exposure of conglomerate that is possibly a part of the Hog Creek shale,[7] the basal member of the Caddo Creek formation. Although this bed lies above the Rochelle stratigraphically, the two have many characteristics in common. The location of the exposure studied is shown at B of Figure 10.

This upper conglomerate is very similar to the Rochelle in that it is characterized by variegated chert and siliceous clay pebbles. The predominant color groups represented in the pebbles are as follows: red, 0.5 per cent; white, 7.1 per cent; gray, 60.9 per cent; green, 11.6 per cent; banded, 4.1 per cent; brown, 1.0 per cent; yellow, 14.8 per cent.

This conglomerate is shown by mechanical analysis (fig. 8) to be coarse in texture. The primary constituent is in the 32–16 millimeter grade.

SOURCE OF SEDIMENTS

An important problem in connection with these conglomerates is the source of the sediments and the probable distance they were transported.

Sediments derived from the east.—All those who have studied these conglomerates have agreed that their source is from an easterly direction. That the Brazos conglomerate was derived from a source located somewhere to the east or northeast has been proposed by several persons (8, pp. 15–16; 19, p. 1065; 6, p. 572). It is the opinion of the writer that the source was to the east, with a preference for the southeast rather than the northeast. This opinion is based on the following observations:

In the lists of dips of the cross-bedding at the various points along the outcrop (see p. 157) it is shown that essentially all of the forset beds have a westerly dip, and, in a large percentage, a northwesterly dip and this immediately suggests an east or southeast source.

There is a certain regular gradation in the sizes and amounts of coarse materials occurring from east to west. Thus in the three localities that are situated in a general east-west line (Nos. 4, 7, and 11, fig. 7A) there is a distinct change in the maximum constituency, and that the easternmost one,

---

[7]Bullard, F. M., conversation, Aug., 1930.

No. 4, has its maximum constituent in the 16–8 mm. grade, whereas No. 11, the westernmost, has as its maximum constituent material of 1½ mm. while the intermediate one, No. 7, has a maximum constituent in the 2–1 mm. grade. In a distance of approximately 6 miles the maximum constituent in the conglomerate changes from material of the pebble size down to that of a texture of coarse sand. This gradation is also shown by the samples from localities 10 and 3. No. 10, the easternmost, has as its chief ingredient material of the 8–4 mm. grade, whereas the westernmost one has grains of the ½–¼ mm. grade as its maximum constituent. In sample No. 6, the one that is located farthest down the dip, the principal ingredient is found in the ½–¼ mm. grade. Although no well samples have been available for this study, it seems quite reasonable to expect that the conglomerate should pass into normal sandstone within a short distance west of the present outcrop. Judging from the gradation expressed in the east-west suite of samples (Nos. 4, 7, and 11) the change would be expected within the boundaries of Palo Pinto County. In the southwestern extension of the outcrop the beds change to sandstone before their disappearance beneath the Cretaceous. This idea of the gradation into normal sandstone down the dip is also held by others who have had occasion to study it (5, p. 9; 6, pp. 573–575). This gradation of size-grades of the constituent materials and the change from conglomerate to sandstone from east to west is indicative of an eastern source for the materials.

Poorly preserved asymmetrical ripple marks in some of the associated sandstones have a general northwest-southeast trend with their steeper slopes to the north. As the gentler slopes of current ripple marks are invariably up current (28, p. 465), it would seem that the currents that developed them were from the east-southeast.

Tarr (23, p. 205) was of the opinion that the materials of the Rochelle conglomerate were derived directly from the "Silurian" [Ordovician], and Plummer and Moore (17, p. 96) expressed the possibility of their having been derived from old rocks which then outcropped south or east of the present Llano Mountains. However, field evidence shows that the source of the materials included within this conglomerate were brought from some point to the northeast. The source beds of these coarse clastics consisted of a thick series of thin-bedded chert and siliceous shale very much the same as those contributing materials to the conglomerates of the Brazos River inlier. Fewer observations have been made on the other conglomerates, but Clark, who has studied the Avis conglomerate, is of the opinion that it came from the east, and the field evidence of the Turkey Creek conglomerate indicates a northerly direction of flow of the streams at the particular localities studied.

Distance transported.—Other than the work of Shrubsole (**22**), Tolman (**26**), Gregory (**9**), Wentworth (**33**, **34**, **36**, **37**, **38**), and Marshall (**11**, **12**), comparatively little study has been made of the rounding of gravels beyond the simple observation that it takes place. Likewise, little quantitative work has been done on the shapes of pebbles and the lack of exact data in this field has led to the belief on the part of some geologists that shapes of pebbles are of little value in interpreting the history of deposits in which they occur (**28**). The author is of the opinion, however, that the quantitative study of the shapes of rock pieces is well worth-while in interpretative sedimentary studies, and that, in certain studies at least, much history is to be read from shapes of pieces alone. The experimental evidence derived from a laboratory study in which cherts similar to those in these conglomerates were used led to the conclusion that the chert pebbles of the Brazos conglomerate have been carried about 300 miles from thir original source and that the cherts of the Rochelle conglomerate have been moved not quite so far, probably about 250 miles from their original source to their site of present deposition.

These measurements refer to actual distances traveled. It is true, of course, that rock fragments do not travel straight courses in streams, and pieces that have been subjected to the abrading action of streams for an equivalent course of 250 or 300 miles must have traveled a much smaller distance in straight line measurement.

Location and character of source beds.—Outstanding characteristics of these conglomerates bearing on the location of the source rock are: the cherts are similar if not identical to those found in the Ouachita Mountains; the distance traveled as shown by shape of pebbles is no greater for the southern conglomerates than for the northern, possibly somewhat less, and apparently no greater than for cherts of a similar nature in Oklahoma (**13**).

Obviously there is a genetic relationship in the origins of the several conglomerates. The field and laboratory evidence points to a common source. Their agents of transportation and their environment of deposition evidently were the same.

The beds from which these chert materials were derived must have consisted of the most variegated types; they must have been a thick series that consisted of thin chert layers alternating with

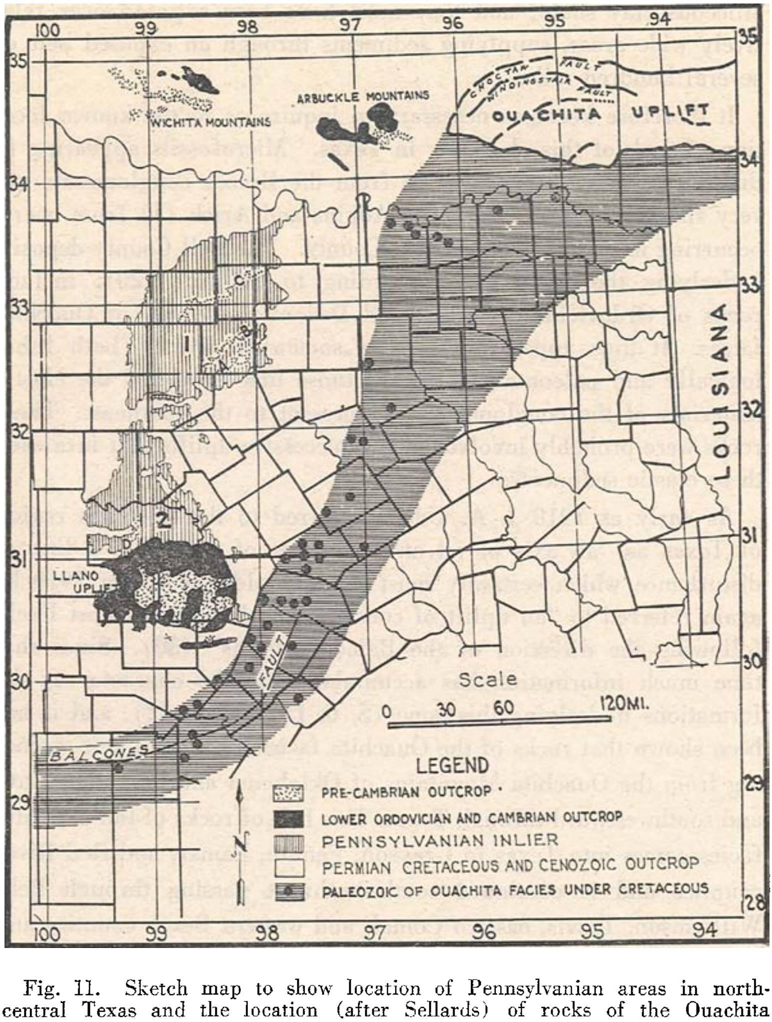


Fig. 11. Sketch map to show location of Pennsylvanian areas in north-central Texas and the location (after Sellards) of rocks of the Ouachita facies, which are regarded as the source beds of these conglomerates. 1, Brazos River inlier; 2, Pennsylvanian area on Colorado River. With the exception of the pre-Cambrian and Cambrian and Lower Ordovician, the formations outcropping north of the Red River (in Oklahoma) are not shown on the map. Likewise, limited exposures of Mississippian at the north and west margins of the Llano uplift in Texas are omitted. The formations (not differentiated on the map) bordering the Pennsylvanian areas are: at the west and north, Permian with some Cretaceous remnants; at the east, Cretaceous, and, in the Gulf Coastal Plain, Eocene and later. At the south of the Colorado River Pennsylvanian area are, as indicated on the map, outcrops of early Paleozoic and of pre-Paleozoic formations.

siliceous clay shale; and they must have been exposed over relatively wide areas, supplying sediments through an exposed belt of several hundred miles.

It therefore becomes necessary to inquire as to the known location of rock of this character in Texas. Microfossils appearing in thin sections of certain pebbles from the Brazos conglomerate are very similar to those figured by Adkins and Arick (**1**) from cherts occurring in well samples in Bell County. The Bell County deposits underlying the Cretaceous, according to Sellards (**20**), include rocks of Ordovician, Silurian, and Devonian age and of Ouachita facies. It thus appears that rocks somewhat similar, both lithologically and paleontologically, to those that furnished the clastic materials of the conglomerate are present to the southeast. These rocks were probably involved in the successive uplifts that furnished these clastic sediments.

As early as 1918 J. A. Udden referred to the Balcones region of Texas as "an axis of an ancient series of rock . . . a line of disturbance which certainly must be very old" (**29**). In 1919 he again referred to "an uplift of considerable dimensions most likely following the direction of the Balcones faults" (**30**). Since that time much information has accumulated on the character of the formations underlying this zone (**5**, **6**. **15**, **18**, **20**, **32**), and it has been shown that rocks of the Ouachita facies underlie a belt extending from the Ouachita Mountains of Oklahoma and Arkansas south and southwestward through Texas. This belt of rocks of the Ouachita facies comes into Texas in Grayson, Fannin, Lamar, and Red River counties and is continued south-southwest passing through Bell, Williamson, Travis, eastern Comal, and western Bexar counties and thence westward to the Marathon region (**21**).

The belt of rocks of the Ouachita facies under the Cretaceous, as thus mapped, approximately parallels the strike of these conglomerates and lies 75 or 100 miles east of their outcrop (fig. 11). These rocks are the only known source that could supply cherts of this character through a belt some hundred miles long, and that they are the source of the materials of these conglomerates is highly probable.

BIBLIOGRAPHY

1. Adkins, W. S., and Arick, M. B., Geology of Bell County, Texas: Univ. Texas Bull. 3016, 1930.
2. Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of Trans-Pecos Texas: Univ. Texas Bull. 1753, 1917.
3. Barrell, Joseph, Criteria for the recognition of ancient delta deposits: Bull. Geol. Soc. Amer., vol. 23, pp. 377–446, 1912.
4. Buckley, E. R., On the building and ornamental stones of Wisconsin, Wisconsin Geol. Surv., Bull. 4, 1898.
5. Cheney, M. G., Stratigraphic and structural studies in north-central Texas: Univ. Texas Bull. 2913, 1929.
6. Cheney, M. G., History of the Carboniferous sediments of the Mid-Continent oil field: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 557–594, 1929.
7. Clark, J. W., A study of the Avis conglomerate, a member of the Thrifty formation in the Cisco group of the Upper Pennsylvanian of north-central Texas: manuscript.
8. Drake, N. F., Report on the Colorado coal field of Texas: Geol. Surv. Texas, 4th Ann. Rept., pp. 355–446, 1892.
9. Gregory, H. E., Note on the shape of pebbles: Am. J. Sc., vol. 17, pp. 300–304, 1915.
10. Mansfield, G. R., The characteristics of various types of conglomerates; Jour. Geol., vol. 15, pp. 550–555, 1907.
11. Marshall, P., The wearing of beach gravels: Tr. New Zealand Inst., vol. 58, 1927.
12. Marshall, P., Beach gravels and sands: Tr. New Zealand Inst., vol. 60, 1929.
13. Melton, F. A., Age of the Ouachita orogeny and its tectonic effects: Bull. Amer. Assoc. Petr. Geol., vol. 14, pp. 57–72, 1930.
14. Milner, H. B., Introduction to sedimentary petrography: London, 1922.
15. Miser, H. D., and Sellards, E. H., Pre-Cretaceous rocks found in wells in Gulf Coastal Plain south of Ouachita Mountains: Bull. Amer. Assoc. Petr. Geol., vol. 15, pp. 801–818, 1931.
16. Plummer, F. B., Preliminary paper on the stratigraphy of the Pennsylvanian formations of north-central Texas: Bull. Amer. Assoc. Petr. Geol., vol. 3, pp. 132–150, 1919.
17. Plummer, F. B., and Moore, R. C., Stratigraphy of the Pennsylvanian formations of north-central Texas: Univ. Texas Bull. 2132, 1921.
18. Plummer, F. B., Pennsylvanian sedimentation in Texas: Illinois Geol. Surv., Bull. 60, pp. 259–269, 1931.
19. Powers, Sidney, Age of the folding of the Oklahoma mountains—the Ouachita, Arbuckle, and Wichita mountains of Oklahoma and the Llano-Burnet and Marathon uplifts of Texas: Bull. Geol. Soc. Amer., vol. 39, pp. 1031–1071, 1928.

20. Sellards, E. H., Rocks underlying Cretaceous in Balcones fault zone of central Texas: Bull. Amer. Assoc. Petr. Geol., vol. 15, pp. 819–827, 1931.
21. Sellards, E. H., Adkins, W. S., and Plummer, F. B., Geology of Texas, vol. 1, Stratigraphy: Univ. Texas Bull. 3232, 1932.
22. Shrubsole, C. A., On the probable source of some of the pebbles of the Triassic pebble-beds of South Devon and of the Midland counties: Quart. Jour. Geol. Soc. (London), vol. 59, pp. 311–333, 1903.
23. Tarr, R. S., A preliminary report on the coal fields of the Colorado River: Geol. Surv. Texas, 1st Ann. Rept., pp. 199–216, 1890.
24. Tester, A. C., and Bay, H. X, The shapometer, a device for measuring the shapes of pebbles: Science, vol. 73, no. 1899. pp. 565–566, 1930.
25. Tester, A. C., The measurement of the shapes of rock particles: Jour. Sedimentary Petrology, vol. 1, no. 1, pp. 3–11, 1931.
26. Tolman, C. F., Erosion and deposition in the southern Arizona bolson region: Jour. Geol., vol. 17, pp. 136–163, 1909.
27. Trowbridge, A. C., The terrestial deposits of Owens Valley, California; Jour. Geol., vol. 19, pp. 706–747, 1911.
28. Twenhofel, W. H., and others, Treatise on sedimentation: Baltimore, 1926.
29. Udden, J. A., and others, Funnel and anticlinal ring structure associated with igneous intrusions in the Mexican oil field: Amer. Inst. Min. Eng., Bull. 133, pp. 92–97, 1918.
30. Udden, J. A., Observations on two deep borings near the Balcones faults: Bull. Amer. Assoc. Petr. Geol., vol. 3, pp. 124–131, 1919.
31. Udden, J. A., The mechanical composition of clastic sediments: Bull. Geol. Soc. Amer., vol. 25, pp. 655–744, 1914.
32. Van der Gracht, W.A.J.M. van Waterschoot, The Permo-Carboniferous orogeny in the south-central United States, Koninklijke Akademie van Wetenschappen te Amsterdam, vol. 27, no. 3, pp. 1–170, 1931. Abst., Bull. Amer. Assoc. Petr. Geol., vol. 15, pp. 991–1057, 1931.
33. Wentworth, C. K., A laboratory and field study of cobble abrasion: Jour. Geol., vol. 27, pp. 507–521, 1919.
34. Wentworth, C. K., Note on a cobble of peculiar shape: Jour. Geol., vol. 32, pp. 524–528, 1921.
35. Wentworth, C. K., Methods in mechanical analysis of sediments: Univ. Iowa Studies in Nat. Hist., vol. 11, no. 11, 1927.
36. Wentworth, C. K., The shapes of pebbles: U. S. Geol. Surv., Bull. 730-C, pp. 91–114, 1922.
37. Wentworth, C. K., The shapes of beach pebbles: U. S. Geol. Surv., Prof. Paper 131–C, pp. 75–83, 1922.
38. Wentworth, C. K., Chink-faceting, a new process of pebble-shaping: Jour. Geol., vol. 33, pp. 260–267, 1925.

PLATES I TO XII

PLATE I

All figures × 40

(Drawings by Jane Titcomb and Faith Patterson)

PLATE V

Figures— *Page*

1–3. *Spiroplectammina rossae* n. sp., x100, Sta. 174–T–6 63
- 1. Holotype; *a*, side view; *b*, end view.
- 2. Side view of holotype in transmitted light.
- 3. Side view of paratype in transmitted light.

4–6. *Ammobaculites expansus* n. sp., x50, Sta. 11–T–3.......... 65
- 4. Side view of holotype.
- 5. Side view of holotype in transmitted light.
- 6. Paratype; *a*, side view; *b*, end view.

7–11. *Ammobaculites midwayensis* n. sp., x50, Sta. 11–T–3 66
- 7. Side view of holotype.
- 8. Holotype in transmitted light.
- 9–11. Paratypes; *a*, side view; *b*, end view.

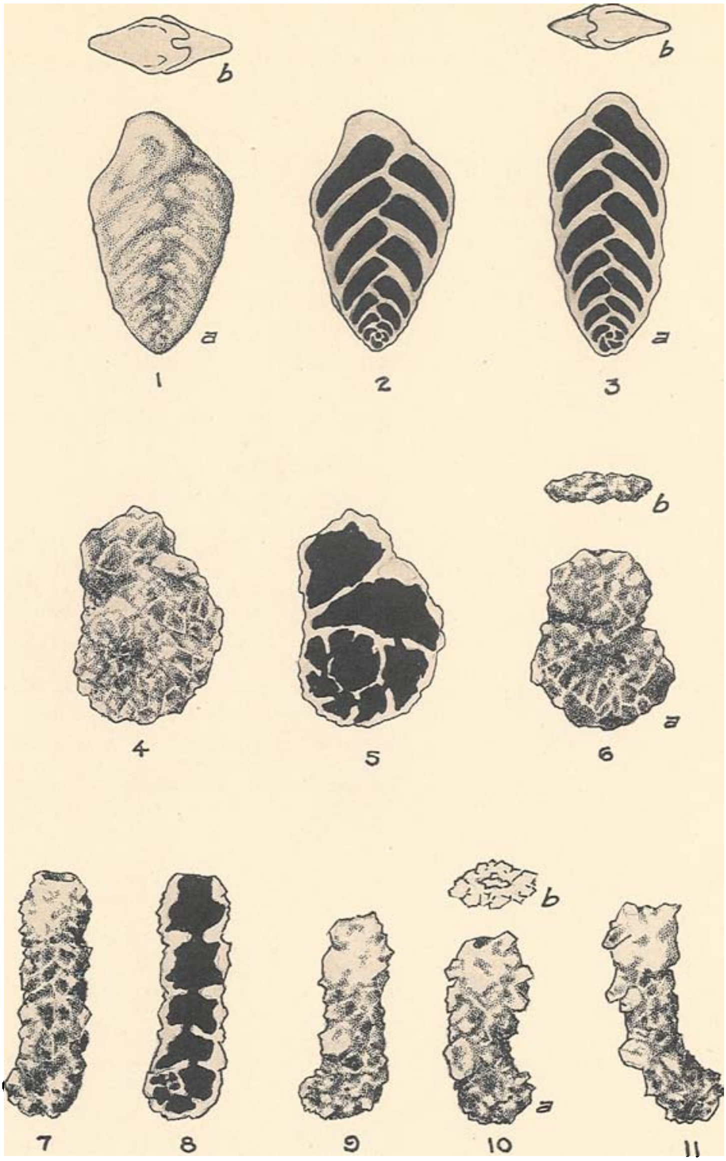

b
b
a
a
1
2
3
b
a
4
5
6
b
a
7
8
9
10
11

PLATE VI

Figures— *Page*

All figures × 10.

Schwagerina sp. from the Big Lake oil field is placed for comparison between *Schwagerina* cf. *fusulinoides* and *Triticites ventricosus*.

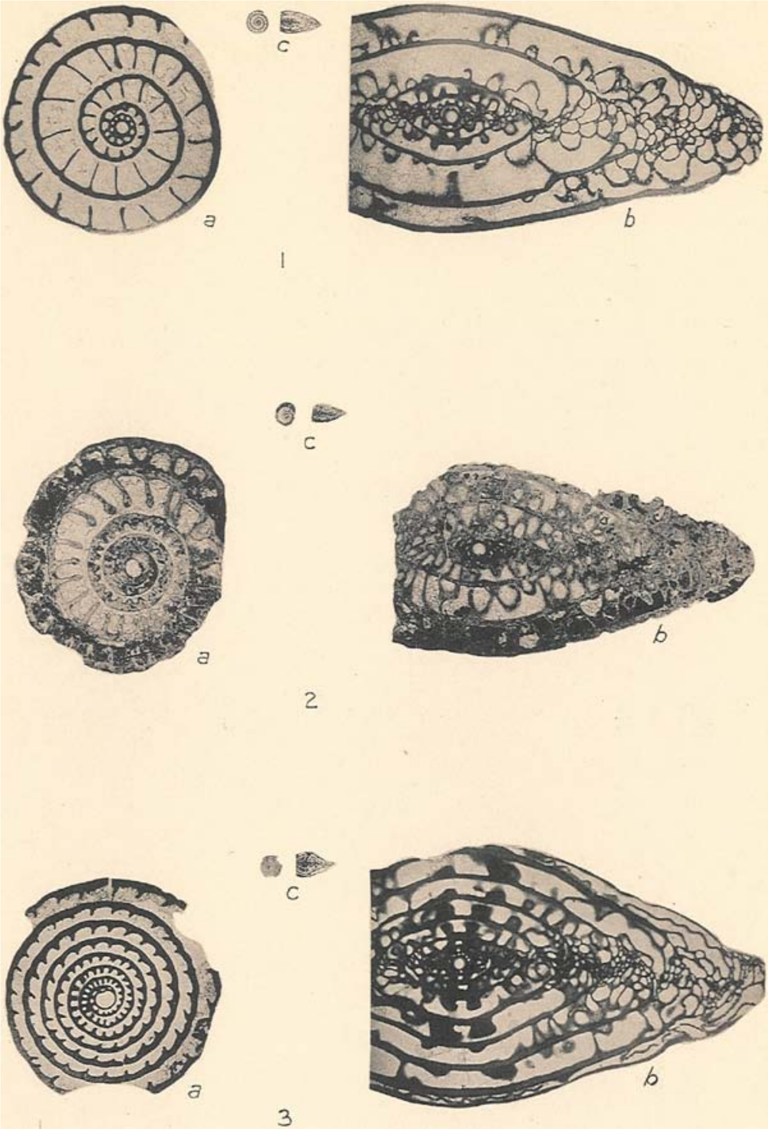

c
a
b
1
c
a
b
2
c
a
b
3

PLATE VII

Figures— *Page*

1–4. *Meandrostia tortacloaca* n. sp., Loc. 1 82–83

1. Exterior of one of the cotypes showing a few ostia and the minute pitting of the eroded surface; × 2.
2. Cotype showing well the baggy appearance of some specimens; × 2.
3. Longitudinal polished section of another specimen showing change in position of cloaca; × 2.65.
4. Transverse section of specimen in fig. 1, showing eccentric position of cloaca; *a*, tracing of *b* to show detail more clearly; × 2.65.

5, 6. *Heterocoelia beedei* Girty, Loc. 1 78

5. Longitudinal polished section of single cell showing small cloacal pores and cloaca. No ostia were cut by the section; ×2.
6. Exterior of single cell showing cloaca extending beyond the cell at both ends, and three of the spoutlike ostia that perforate the cell wall; × 2.

7, 8. *Heterocoelia sphaerica* n. sp., Loc. 1 79

7. Longitudinal polished section of one of the cotypes showing large cloacal pore and cloaca; *a*, tracing of *b* to show more clearly details in structure; × 2.
8. Exterior of the other cotype; × 2.

9, 10. *Meandrostia kansasensis* Girty, Loc. 1 82

9. Uneroded specimen, showing scattered ostia that perforate the outer wall; × 2.
10. Eroded specimen, the removal of the outer wall having exposed the vermiform chambers within the body; × 2.

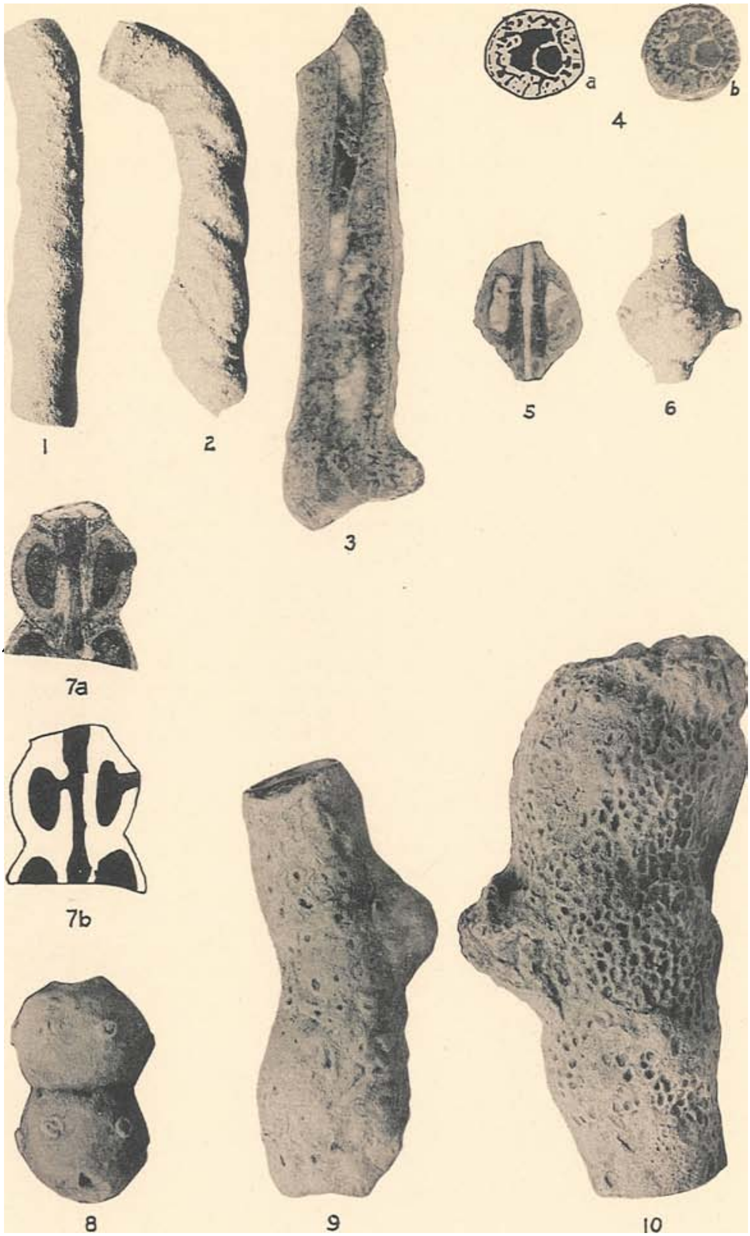
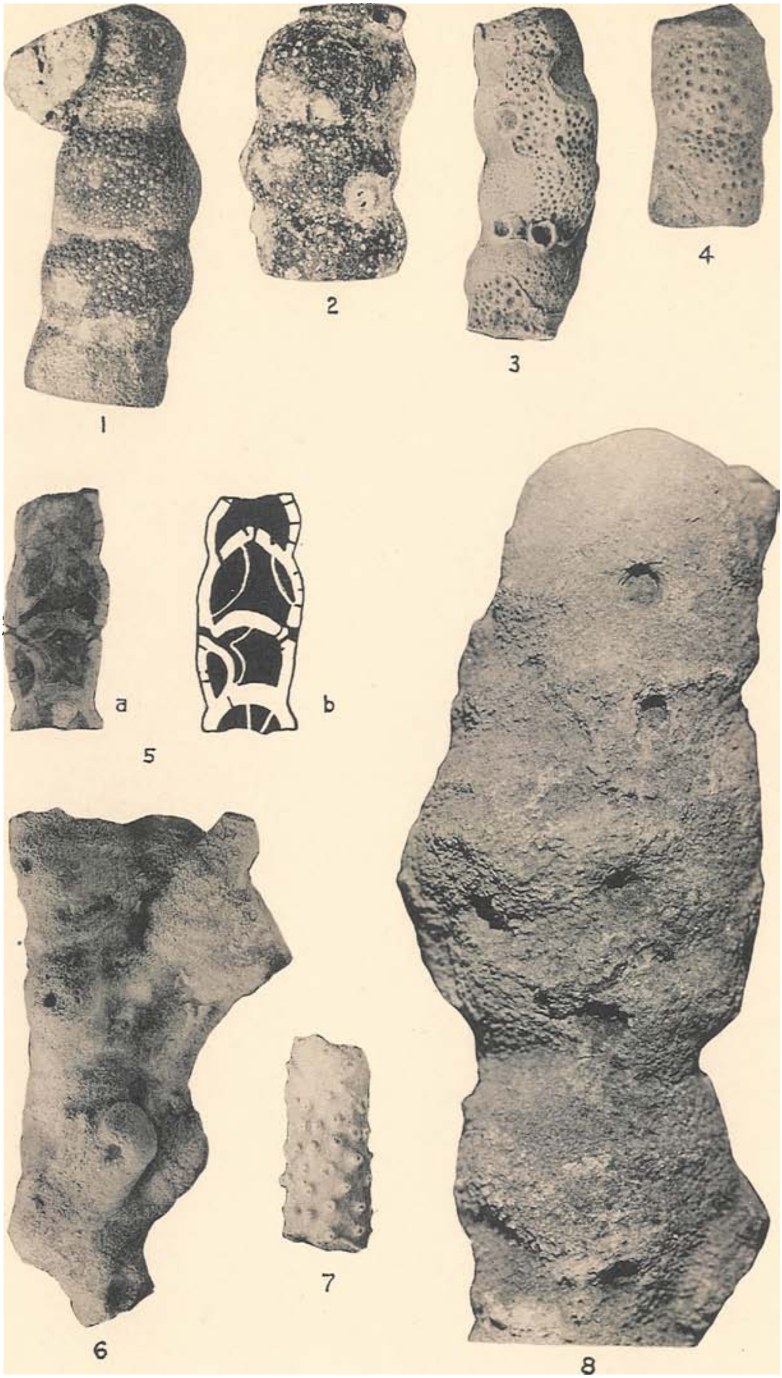

1
2
3
a
b
4
5
6
7a
7b
8
9
10

PLATE VIII


1
2
3
4
a
b
5
6
7
8

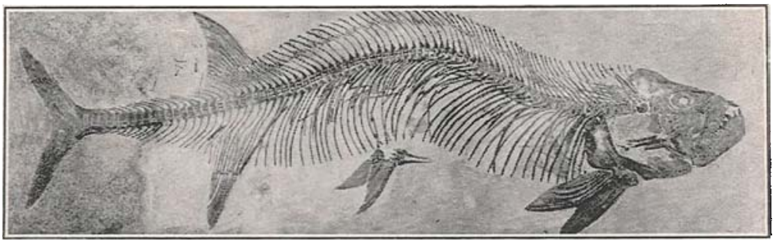


Fig. 1. *Xiphactinus audax* Leidy. This fossil measures 12 feet from the maxilla to the fork of the tail. The pelvic elements and the last nine vertebra are restored. The tail is that of another specimen. The dorsal and anal fins are restored from the imprints of these organs. The restoration in the head region can best be seen in Figure 2. Preparation by L. I. Price under supervision of the author. Page 87.

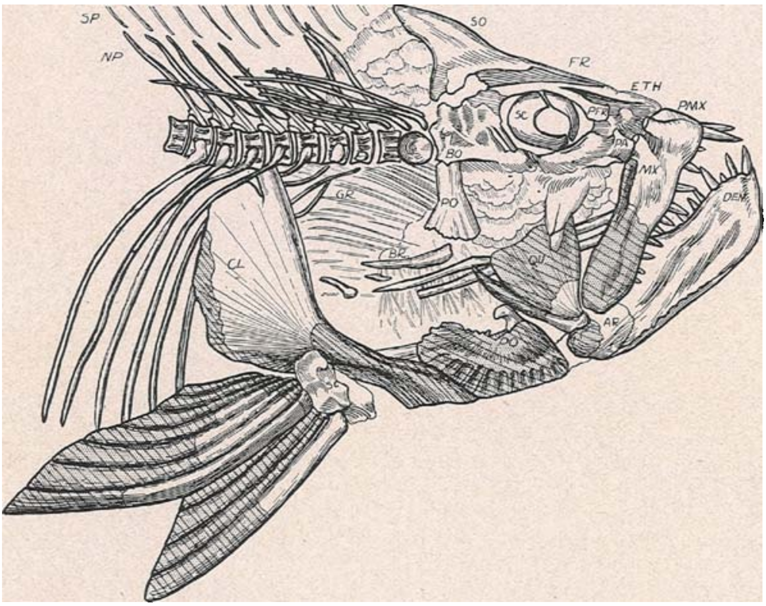
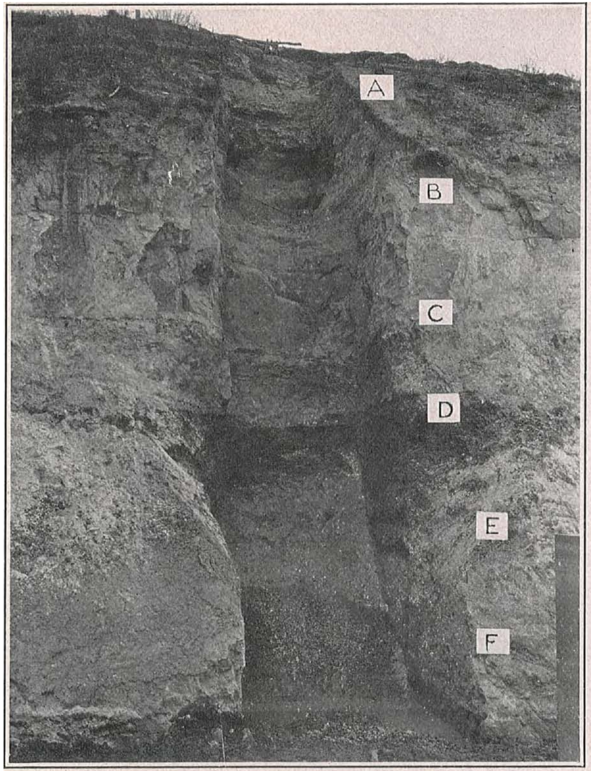
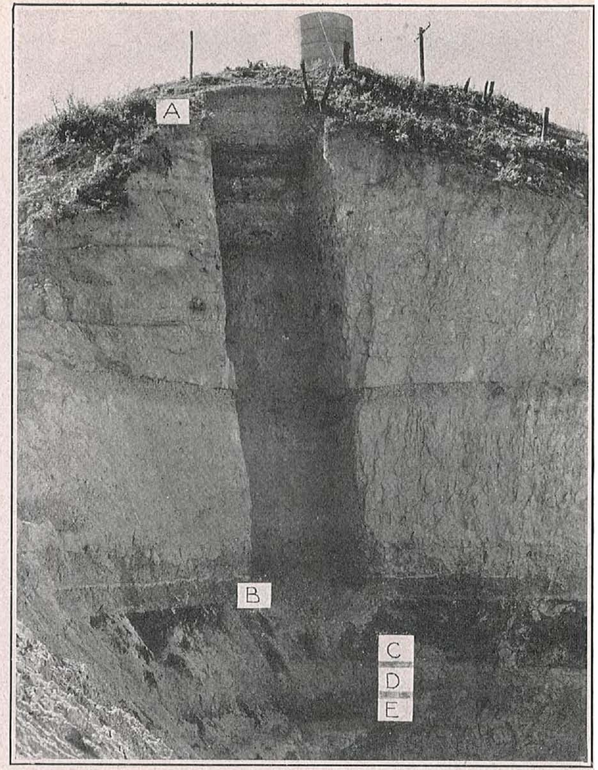


Fig. 2. Skull of *Xiphactinus audax* Leidy, drawn by L. I. Price. The darkened areas are restored. No effort was made to restore the operculum since this would have covered the branchiostegal rays and the gill rakers, both of which are well preserved. Only the bones discussed in this paper are labeled. SO, *supraoccipital*; FR, *frontal*; ETH, *ethmoid;* PMX, *premaxilla*; MX, *maxilla*; PA, *parietal;* PFR, *prefrontal;* SC, *sclerotic;* BO, *basioccipital;* PO, *preopercular*; QU, *quadrate*; AR, *articular*; DEN, *dentary*: BR, *branchiostegal rays*; GR, *gill rakers*; CL, *cleithrum*; SC, *scapula*; NP, *neural spines*. Page 87.

PLATE X



1.



2.

PLATE XI

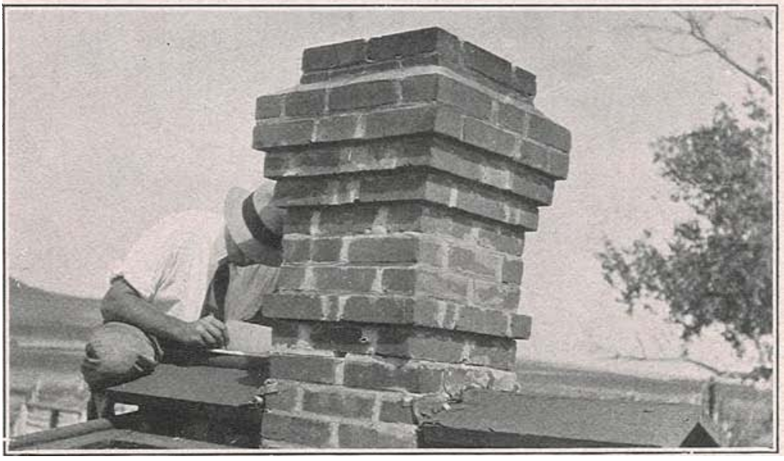
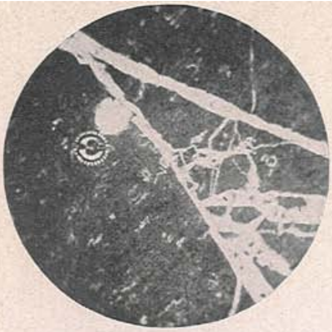


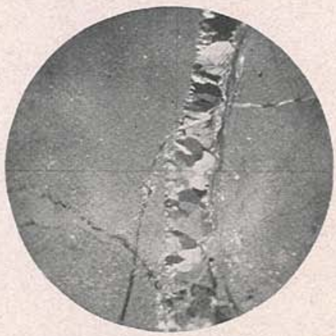
PLATE XII



1

2

3



4

5

6

INDEX