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TERTIARY AND QUATERNARY GEOLOGY OF THE LOWER RIO GRANDE REGION, TEXAS

BY

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TERTIARY AND QUATERNARY GEOLOGY OF THE LOWER RIO GRANDE REGION, TEXAS

By A. C. Trowbridge

INTRODUCTION

FIELD WORK

Most of the data on which this report is based were gathered during three field seasons. In June, July, and August, 1919, the writer was assisted by A. G. Maddren; in part of June and all of July and August, 1920, by W. S. Glock and Lloyd North. In the summer of 1921 a party consisting of E. W. Berry, E. D. Lozano, L. W. Stephenson, E. B. Stiles, and the writer spent a few weeks in the northern part of the region. Berry collected and identified fossil plants from the lower and middle Eocene. Lozano represented the Instituto Geológico de México. Stephenson acted in a general consulting capacity, especially in regard to the relations between the Cretaceous and the Tertiary. Stiles was primarily interested in the collection of typical formational samples for microscopic analysis by the bureau of economic geology of the University of Texas. While this field work was being done, few subsurface data were available, roads passable by car were few and far between, and roadside exposures were scarce, but since then the development of a number of oil and gas fields, in connection with which nearly 2,000 holes were drilled and many new roads were built and others were graded, has made available a large number of well logs and samples, rendered parts of the region easily accessible, and opened many new exposures. A large amount of work was also done by commercial geologists, which led to new opinions, and a few of these were published. In order to check his conclusions by the mass of new material, to add to the report these new surface and subsurface data, and to confer with commercial geologists on the problems involved, the writer visited the region again in August, 1927. Several days of this visit were spent in company with Lloyd North.

Julia Gardner and the writer visited Live Oak County for a day in March, 1929, in order to check some of the factors involved in the classification and correlation of the uppermost Eocene, Oligocene, and lower Miocene beds.

In all the field work reconnaissance methods were used, and no claim is made that the results are such as might be expected from a detailed survey. It is hoped, however, that this report will serve as a basis for future detailed investigation, whether commercial or purely scientific.

ACKNOWLEDGMENTS

All the field work except that of 1927 and 1929 and most of the work of preparing the report was done under the direction of T. Wayland Vaughan, whose advice and help have been invaluable.

The invertebrate fossils collected were identified by Julia Gardner and the fossil plants by E. W. Berry. A number of well logs were obtained from the bureau of economic geology of the University of Texas, through Dr. J. A. Udden and later through Dr. E. H. Sellards, both of whom have cooperated with the Federal survey in other features of the work. Messrs. Alexander Deussen, the late E. T. Dumble, and C. L. Baker have been of great assistance by freely giving information obtained through their own work in this and adjacent regions, both in Texas and in Mexico. Mr. R. P. Baker kindly furnished certain well logs, and Mr. Lloyd North has made available many samples, photographs, and subsurface maps prepared by him and his assistants, covering all the main oil and gas fields of the area.

The Humble Oil & Refining Co. also contributed many logs, samples, and other data through its geologists, Mr. Olin G. Bell and Mr. F. W. Getzendaner.

Much information has been obtained indirectly through reviews of 85 books and articles by more than 40 writers, to all of which reference is made in the text or footnotes. Much of the reviewing was done by W. S. Glock, who continued to serve as an assistant for several months after the end of the field season in 1920. A. G. Maddren served similarly during the winter of 1919-20. The analyses of sedimentary samples were made in the sedimentation laboratory of the University of Iowa by Max Littlefield and later by Harry Fields and Victor H. Jones.

Some samples and analyses were furnished by Mr. Gordon Damon, of the University of Texas.

PREVIOUS WORK IN SOUTHWESTERN TEXAS

Late in the eighteenth century and early in the nineteenth century, general exploration was carried on in southwestern Texas and adjacent regions. Geologic observations were recorded along with notes bearing on other phases of natural history. The results of some of this work were published.[1]

[1] Bartram, William, Travels, Philadelphia, 1791. James, E. P., Geological sketches of the Mississippi Valley: Philadelphia Acad. Sci. Jour., vol. 2, pp. 326-329, 1822; Remarks on the sandstone and floetz trap formations of the western part of the valley of the Mississippi: Am. Philos. Soc. Trans., new ser., vol. 2, pp. 191-215, 1825. Holley, Mary, Texas, Baltimore, 1833; Lexington, Ky., 1836. Moore, F., jr., Description of Texas, Philadelphia, 1840; 2d ed., New York, 1844. Kennedy, William, Texas, London 1841; New Orleans, 1844.

In 1846 Roemer started publishing on southwestern Texas, and by 1848 he had ready a geologic map of the whole State.[2] He collected, identified, and described fossils from southern Texas and drew the Cretaceous-Tertiary line in a general way as it is known.

The Santa Fe expedition in 1850 was not fruitful geologically, although reports including some geologic notes were made to Congress.[3]

In connection with the United States-Mexico boundary survey, 1848–1855, considerable geologic work was done, the results of which were published by Schott,[4] Conrad,[5] Hall,[6] Parry,[7] and Bailey.[8] The papers here cited refer only to the immediate vicinity of the Rio Grande.

Beginning in 1859 and continuing for several years, B. F. Shumard, as State geologist, published a series of articles on the geology of Texas, in some of which reference is made to the lower Rio Grande region.[9]

Shumard was followed as State geologist by Moore,[10] who "sketched" the geology of Texas. The work of Shumard, Moore, and Buckley[11] overlapped. Buckley's articles in particular are notable for their comprehensive character and general accuracy, considering the conditions under which the work was done.

In 1869 Roessler[12] summarized the geology of Texas, as then known, discussed the Cretaceous and Tertiary of the State, and mentioned mammalian fossils taken from the banks of the Rio Colorado and the Rio Brazos.

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[2] Roemer, Ferdinand, A sketch of the geology of Texas: Am. Jour. Sci., 2d ser., vol. 2, pp. 358–365 1846; Contributions to the geology of Texas: Idem, vol. 6, pp. 21–28, 1848; Texas, Bonn, 1849; Die Kreidebildungen von Texas, und ihre organischen Einschlüsse: Am. Jour. Sci., 2d ser., vol. 17, pp. 150–151, 1854; Mittheilungen an Professor Bronn gerichtet: Neues Jahrb., 1853, pp. 39–44.

[3] Michlin, N. J., Reconnaissance from Corpus Christi to the Leona: 31st Cong., 1st sess., Ex. Doc. 4, pp. 7-13, 1850. Marcy, R. B., Report on the Santa Fe expedition: 31st Cong., 1st sess., S. Ex. Doc. 64, pp. 169–227, 1850.

[4] Schott, Arthur, Geology of the lower Rio Bravo del Norte: Mexican Boundary Survey, vol. 1, pt. 2, pp. 28–48, 1857; Geology of the lower Colorado region: Idem, pt. 3, pp. 92–99.

[5] Conrad, T. A., Description of Cretaceous and Tertiary fossils: Idem, vol. 1, pt. 2, pp. 141-174.

[6] Hall, James, Geology and paleontology of the boundary: Idem, vol. 1, pt. 2, pp. 101-140.

[7] Parry, C. C., Geological features of the Rio Grande Valley from El Paso to the mouth of the Pecos River: Idem, vol. 1, pt. 2, pp. 49–61.

[8] Bailey, J. W., Microscopic examination of some earths: Idem, vol. 1, pt. 2, p. 24.

[9] Shumard, B. F., First report on the geology of Texas, Geol. and Agr. Survey Texas, 1859; Observations upon the Cretaceous strata of Texas: St. Louis Acad. Sci. Proc., vol. 1, pp. 582–610, 1857; Miocene of Texas: St. Louis Acad. Sci. Trans., vol. 2, pp. 140–141, 152, 1860; The primordial zone of Texas, with descriptions of new fossils: Am. Jour. Sci., 2d ser., vol. 32, pp. 213–221, 1861; Descriptions of new Cretaceous fossils from Texas: Boston Soc. Nat. Hist. Proc., vol. 8, p. 809, 1862.

[10] Moore, Francis, Geological sketch of Texas: Texas Almanac, vol. 3, pp. 91–99, 1859.

[11] Buckley, S. B., Preliminary report of survey of Texas, 1866; Geological resources of Texas: Texas Almanac, vol. 10, pp. 63–66, 1866; Rivers and water powers of southwestern Texas: Idem, pp. 69–70; Mineral resources of Texas: Idem, pp. 79–82; Texas State Geologist First Ann. Rept., p. 61, 1874; Second Ann. Rept., 1876.

[12] Roessler, A. R., On the geology of Texas: Geol. Soc. London Quart. Jour., vol. 25, pt. 2, pp. 5–6, 1869.

The next name which stands out among writers on the geology of Texas is that of Hilgard, who in 1871 published a short paper,[13] followed in 1881 by another.[14] In these articles he described and interpreted the Tertiary and Quaternary marine sediments on the Gulf border.

Heilprin,[15] in and about 1884, identified Claiborne fossils at Laredo, traced the Cretaceous-Tertiary line (incorrectly) southward to a point on the Rio Grande just below the mouth of the Pecos River, and summarized in his book all that was then known of Texas Tertiary geology.

Loughridge,[16] writing chiefly from an agricultural point of view, published, also in 1884, a short account of the geology of Texas, in which he mentions exposures on the Rio Grande, especially in its lower course.

In 1888 Owen included in his first administrative report[17] some notes on the counties near the Rio Grande, especially those in which both Cretaceous and Tertiary beds are exposed, and mentioned for the first time the Carrizo sandstone. In another article[18] he expressed the belief that the deposits that are now known as the Reynosa (="Uvalde") formation were of glacial origin and derived from Mexican mountains.

Until recently perhaps Hill,[19] partly in conjunction with Vaughan and others, had written more than any other geologist relative to the

[13] Hilgard, E. W., Geological history of the Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 2, pp. 391–404, 1871.

[14] Hilgard, E. W., Later Tertiary of Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 22, pp. 58–65, 1881.

[15] Heilprin, Angelo, Notes on fossils from Laredo: Am. Naturalist, vol. 18, p. 334, 1884; Tertiary geology of the eastern and southern United States: Philadelphia Acad. Nat. Sci. Jour., vol. 9, pt. 1, pp. 115–154, 1884; Contributions to the Tertiary geology and paleontology of the United States, Philadelphia, 1884.

[16] Loughridge, R. H., Geology of Texas: Tenth Census, vol. 5, pt. 1, pp. 17–23, 653–831, 1884.

[17] Owen, J., Texas Geol. Survey First Rept. Progress, 1888.

[18] Owen, J., Notes on the geology of the Rio Grande Valley: Geol. and Sci. Bull., vol. 1, No. 2, 1888.

[19] Hill, R. T., Salient geologic features of Travis County, Tex.: Austin Statesman, Dec. 15, 1886; Present knowledge of the geology of Texas: U. S. Geol. Survey Bull. 45, pp. 387–467, 1886: Texas section of the American Cretaceous: Am. Jour. Sci., 3d ser., vol. 34, pp. 287–309, 1887; Geologic story of the Colorado River: Am. Geologist, vol. 3, pp. 287–299, 1887; Events in North American Cretaceous history illustrated in the Arkansas-Texas division of the southern United States: Am. Jour. Sci., 3d ser., vol. 37, pp. 282–290, 318–319, 1889; Am. Assoc. Adv. Sci. Proc., vol. 38, pp. 243–244, 1889; Geographic features of Texas: Am. Geologist, vol. 5, pp. 9–29, 1890; Notes on the geology of the Southwest: Am. Geologist, vol. 7, pp. 366–370, 1891; Classification of the topographic features of Texas; Cretaceous rocks of Texas and their economic uses: Texas Geol. Survey First Ann. Rept., pp. 103–104, 1889; The Tertiary formation of western Texas: Am. Naturalist, vol. 25, pp. 49 et seq., 1891; A deep artesian boring at Galveston, Tex.: Am. Jour. Sci., 3d ser., vol. 44, pp. 406–409, 1892; Geologic evolution of the nonmountainous topography of the Texas region: Am. Geologist, vol. 10, pp. 105–115, 1892; Physical geography of the Texas region: U. S. Geol. Survey Top. Atlas, Folio 3, 1900; The Coast Prairie of Texas: Science, new ser., vol. 14, pp. 326–328, 1901; Topography and geology of the Black and Grand Prairies in Texas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, 666 pp., 1901; Gypsum deposits of Texas: U. S. Geol. Survey Bull. 223, pp. 68–73, 1904. Hill, R. T., and Penrose, R. A. F., jr., Relation of the uppermost Cretaceous beds of the eastern and southern United States and the Tertiary-Cretaceous parting of Arkansas and Texas: Am. Jour. Sci., 3d ser., vol. 38, pp. 468–473, 1889. Hill, R. T., and Dumble, E. T., Igneous rocks of central Texas: Am. Assoc. Adv. Sci. Proc., vol. 38, pp. 242–243, 1890. Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 193–322, 1897; The Lower Cretaceous Gryphaeas of the Texas region: U. S. Geol. Survey Bull. 151, 139 pp., 1898; U. S. Geol. Survey Geol. Atlas, Nueces folio (No. 42), 1898.

geology of the lower Rio Grande region. Primarily, however, he worked on the Cretaceous rather than the Tertiary.

In 1887 and 1888 White[20] wrote on the coal at Eagle Pass and Santo Tomas and on the Laramie deposits partly as related to southern Texas. He considered all the coal to be of Cretaceous age.

In 1889 Penrose and Dumble made a boat trip down the Rio Grande, from Eagle Pass almost to the mouth of the river. The results were first published by Penrose.[21] This work might be said to represent the first step toward modern and accurate location, description, and interpretation of the Tertiary of the lower Rio Grande region. In this paper previous work is outlined, the topography is briefly described, the Cretaceous-Tertiary line is located (incorrectly) on the Rio Grande 3 miles below the Webb-Maverick County line, and many Tertiary sections on the Rio Grande are given. During several years after his trip with Penrose, Dumble continued working in this and adjacent areas and published a number of valuable papers bearing more or less directly on the region described in the present report.[22]

Dumble is easily the most prolific modern writer on the Tertiary of southwestern Texas. Kennedy[23] is another Texas geologist who has written on the lower Rio Grande region, although his interests have been chiefly in the Gulf Coastal Plain of eastern Texas.

During the years of greatest activity of Hill, Dumble, and Kennedy, Harris served as collector and identifier of invertebrate faunas and did independent work on the Midway and lower Claiborne formations and on coastal salt domes.[24]

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[20] White, C. A., The age of the coal in the Rio Grande region: Am. Jour. Sci., 3d ser., vol. 33, pp. 18-20; 1887: Relation of the Laramie group to earlier and later formations: Idem, vol. 35, pp. 432-438, 1888.

[21] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Survey First Ann. Rept., pp. 3-101, 1890.

[22] Dumble, E. T., Review of Texas geology as developed by the work of the Survey: Texas Geol. Survey First Ann. Rept., pp. xxix-lxxiv, 1890; Report of the State geologist for 1890: Texas Geol. Survey Second Ann. Rept., pp. 5-88, 1891; Report on the brown coal and lignite of Texas, pp. 17-243, 1892; Geology of the middle Rio Grande: Geol. Soc. America Bull., vol. 3, pp. 219-230, 1892; Cenozoic deposits of Texas: Jour. Geology, vol. 2, pp. 549-567, 1894; Notes on the Texas Tertiaries: Texas Acad. Sci. Proc. for 1894, pp. 23-27; Cretaceous of western Texas and Coahuila: Geol. Soc. America Bull., vol. 6, pp. 375-388, 1895; Volcanic dust in Texas: Science, new ser., vol. 1, pp. 657-658, 1895; Some Texas oil horizons: Texas Acad. Sci. Proc., vol. 2, pp. 87-92, 1897; The geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, pp. 913-987, 1902; The Tertiary of the Sabine River: Science, new ser., vol. 16, pp. 670-671, 1902; The middle and upper Eocene of Texas: Texas Acad. Sci. Trans., vol. 11, pp. 50-51, 1909; The Carrizo sands: Idem, pp. 52-53; The occurrence of gold in the Eocene deposits of Texas: Am. Inst. Min. Eng. Bull. 70, pp. 1021-1024, 1912; Some events in the Eocene history of the present coastal area of the Gulf of Mexico in Texas and Mexico: Jour. Geology, vol. 23, pp. 481-498, 1915; The problem of the Texas Tertiary sands: Geol. Soc. America Bull., vol. 26, pp. 447-476, 1915; Tertiary deposits of northeastern Mexico: California Acad. Sci. Proc., 4th ser., vol. 5, pp. 163-193, 1915; The geology of east Texas: Texas Univ. Bull. 1869, 1918; Origin of the Texas salt domes: Am. Inst. Min. Eng. Bull. 142, pp. 1629-1636, 1918; A revision of the Texas Tertiary section with special reference to the oil-well geology of the coast region: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 424-444, 1924.

[23] Kennedy, William, Report on eastern Texas: Texas Geol. Survey Second Rept. Progress, pp. 55-69, 1891; Texas clays and their origin: Science, new ser., vol. 22, pp. 297-300, 1893; Coastal salt domes: Southwestern Assoc. Petroleum Geologists Bull., vol. 1, pp. 34-59, 1917. Hayes, C. W., and Kennedy, William, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 212, 1903.

[24] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, No. 2, 1895; No. 4, 1896; The salt domes of Texas and Louisiana: Science, new ser., vol. 27, pp. 347-348, 1908; The geological occurrence of rock salt in Louisiana and east Texas: Econ. Geology, vol. 4, pp. 12-34, 1909; The St. Maurice formation: Bull. Am. Paleontology, vol. 6, 1912.

In much the same way Cope[25] investigated the vertebrate faunas of the State, including some in the southern part.

Vaughan[26] has also done a considerable amount of work along the lower Rio Grande. In addition to field work in preparation for the publications cited, in October and November, 1913, he accompanied Matson on a wagon trip from Laredo to Brownsville. The results of this last piece of work have not been published, but the field notes have been available to the writer of the present report.

Udden worked in the northern part of the Rio Grande region,[27] before becoming director of the bureau of economic geology of the University of Texas, and since then he has published, with assistants, a review of the geology of the State.[28]

The lower Rio Grande region is included in a report on ground water by Taylor.[29]

A large amount of field work has been done in southwestern Texas by C. L. Baker while engaged with the Bureau of Economic Geology and more recently in the employ of oil companies, but few of the results of this work have been published.

Stephenson has for some years been investigating the Cretaceous formations of southwestern Texas and has described the Cretaceous-Eocene line in this region.[30]

For some years Deussen[31] has investigated the stratigraphy, structure, water resources, and oil and gas supplies in the Gulf Coasta Plain of Texas. Most of the territory on which he has reported lies between the Brazos and Nueces Rivers, although he has done much work in eastern Texas and some work between the Nueces and the Rio Grande.

25 Cope, E. D., Remarks on the geology about Laredo, Tex.: Am. Naturalist, vol. 18, p. 753, 1884; Paleontology of the Vertebrata: Texas Geol. Survey Third Ann. Rept., pp. 251–259, 1891; A contribution to a knowledge of the fauna of the Blanco beds in Texas: Philadelphia Acad. Nat. Sci. Proc., 1892, pp. 226–229.

26 Vaughan, T. W., Asphalt deposits of western Texas: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 5, pp. 930–935, 1896; Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, 1900; U. S. Geol. Survey Geol. Atlas, Uvalde folio (No. 64), 1900.

27 Udden, J. A., A sketch of the geology of the Chisos country, Brewster County, Tex.: Texas Univ. Bull. 93, 1907; Report on a geological survey of the lands belonging to the New York & Texas Land Co. (Ltd.) in the upper Rio Grande embayment in Texas: Augustana Library Bull. 6, pp. 51–107, 1907.

28 Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1916.

29 Taylor, T. U., Underground waters of the Gulf Coastal Plain of Texas: U. S. Geol. Survey Water-Supply Paper 190, 1907.

30 Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pp. 155–192, 1914.

31 Deussen, Alexander, Cement resources and industry of Texas: The Tradesman, vol. 56, pp. 46–49, Chattanooga, Tenn., 1906; Notes on Texas clays: U. S. Geol. Survey Bull. 470, pp. 302–351, 1911; Geology and underground waters of the southern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, 1914; Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, 1924. Deussen, Alexander, and Dole, R. B., Ground waters in LaSalle and McMullen Counties, Tex.: U. S. Geol. Survey Water-Supply Paper 375, 1906.

In 1912 G. C. Matson investigated the Tertiary beds in the area between the Nueces and the Rio Grande, to complete to the border the work of Deussen, but the results were not published.

In 1918 Ashley[32] reported on the coal in Webb county, with a view to suggesting its uses for war purposes.

Recent activities of the Bureau of Economic Geology of the University of Texas have resulted in papers by Liddle,[33] Sellards,[34] Bailey[35] and Plummer.[36]

In 1923 a preliminary paper on the lower Rio Grande region[37] was published in advance of the preparation of the present complete report. The discovery of oil and gas in larger quantities than before in Webb and Zapata Counties in 1921 has led to renewed activity on the part of commercial geologists and the publication of three or more papers.[38]

GEOGRAPHY

LOCATION

The area included in this report is that part of the West Gulf Coastal Plain between the Brazos River and the Rio Grande, the geologic examination of which was left not quite finished by Alexander Deussen upon his resignation from the United States Geological Survey in 1913. Deussen's report (Professional Paper 126) covers the area from the Brazos River to a line running a short distance west of Uvalde, in Uvalde County, to Carrizo Springs, in Dimmit County, and continuing southeastward, touching the southwest corner of La Salle County near Encinal, past Hebbronville, in Jim Hogg County, to the Gulf, passing south of Falfurrias, in Brooks County, and Sarita, in Willacy County. The region described in the following pages, which may best be called the lower Rio Grande region, slightly overlaps the area mapped by Deussen and is bounded on the southwest by the Rio Grande, on the east by the Gulf, and on the north and

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[32] Ashley, G. H., The Santo Tomas cannel coal, Webb County, Tex.: U. S. Geol. Survey Bull. 691, pp. 251-270, 1918.

[33] Liddle, R. A., Geology and mineral resources of Medina County: Texas Univ. Bull. 1860, 1918.

[34] Sellards, E. H., Geology and mineral resources of Bexar County: Texas Univ. Bull. 1932, 1919; Notes on the oil and gas fields of Webb and Zapata Counties: Texas Univ. Bull. 2230, 1922.

[35] Bailey, T. L., The geology and natural resources of Colorado County: Texas Univ. Bull. 2333, 1923; Extensive volcanic activity in the middle Tertiary of the south Texas Coastal Plain: Science, new ser., vol. 59, pp. 299-300, 1924; The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, 1926.

[36] Plummer, H. J., Foraminifera of the Midway formation: Texas Univ. Bull. 2644, 1926.

[37] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, pp. 86-107, 1923.

[38] Wrather, W. E., The Mirando Oil Co. well, Zapata County, Tex.: Am. Assoc. Petroleum Geologists, Bull., vol. 5, pp. 625-636, 1921. Jones, R. A., The relation of the Reynosa escarpment to the oil and gas fields of Webb and Zapata Counties, Tex.: Idem, vol. 7, pp. 532-545, 1923. Getzendaner, F. M., Geologic section of Rio Grande embayment, Texas, and implied history: Idem, vol. 14, No. 11, pp. 1425-1437, 1930.

northwest by the Cretaceous-Eocene line as mapped by Stephenson,[39] which extends from a point on the Rio Grande about 3 miles upstream from the Webb-Maverick County line in northerly and northeasterly directions to the Nueces River at Pulliam.

The area within these boundaries amounts to about 13,000 square miles, which is about one-twentieth of the State of Texas. It includes the extreme southern part of Uvalde County, most of the western part of Zavala County, the west half of Dimmit County, the eastern part of Maverick County, all of Webb County except the northeastern part, the extreme southwest corner of Duval County, all but the extreme north edges of Jim Hogg, Brooks, and Kenedy Counties, and all of Zapata, Starr, Hidalgo, Willacy, and Cameron Counties. (See pl. 1.)

The lower Rio Grande region is traversed by the Southern Pacific Railroad from San Antonio through Uvalde and from Falfurrias to McAllen; the San Antonio, Uvalde & Gulf Railroad from Uvalde to Crystal City and Carrizo Springs; the International-Great Northern Railroad from San Antonio to Laredo; the Texas-Mexican Railway from Corpus Christi to Laredo; the St. Louis, Brownsville & Mexico Railway from Houston to Brownsville and from Harlingen to Rio Grande City; the Asherton & Gulf Railway from Bart (Artesia Wells post office) to Asherton; and narrow-gage lines of the Rio Grande Railway from Brownsville to Point Isabel and the Rio Grande & Eagle Pass Railway from Laredo north along the river to Minera.

There are also excellent automobile roads from San Antonio to Uvalde and from Uvalde to Carrizo Springs; from La Pryor, Crystal City, and Carrizo Springs to Eagle Pass; from Corpus Christi and Sarita to Laredo; and from San Antonio through Falfurrias and the sand belt south of Falfurrias to connect with the "Valley Road," which connects Brownsville with Rio Grande City and other "valley" points. There is also an automobile road from Laredo up the Rio Grande for 35 miles to Palafox. A highway in process of construction connects Laredo with Rio Grande City. There are fair roads from Hebbronville to the river at Zapata, Rio Grande City, and Mission. A network of poor ranch roads will take the careful driver of a light car almost anywhere, except during the infrequent rainy seasons. Horse-drawn vehicles can go anywhere at any time.

CLIMATE

The lower Rio Grande region lies in a zone of semiaridity, relatively high temperature, and fairly strong and constant east winds.

[39] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pl. 15, 1914.

SKETCH MAP OF TEXAS SHOWING THE LOWER RIO GRANDE REGION IN RELATION TO THE TOPOGRAPHIC PROVINCES

Adapted from Hill and Vaughan.

93804—32 (Face p. 8.)

Rainfall.—The following tables showing rainfall were compiled from statistics of the United States Weather Bureau:

Rainfall at stations in the lower Rio Grande region, by months

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual (mean)
La Parra, Kenedy County	11	1.00	1.79	1.87	1.95	2.27	1.69	2.95	2.36	3.17	2.41	2.01	0.98	24.55
Brownsville, Cameron County	39	1.33	1.39	1.27	1.31	2.15	2.28	1.88	2.80	5.62	3.21	2.20	1.45	26.89
Fort Ringgold, Rio Grande, Starr County	37	.81	.29	.95	1.03	2.37	1.96	1.38	1.87	3.13	1.57	.83	.77	17.46
Fort McIntosh, Laredo, Webb County	39	.80	1.03	.98	1.79	2.38	2.10	1.94	2.71	2.75	1.16	1.02	1.09	19.75
Encinal, La Salle County	12	.55	2.47	.96	2.28	3.90	3.12	2.53	1.94	2.86	1.35	1.19	.77	23.92
Uvalde, Uvalde County	22	.78	1.45	1.81	2.04	2.92	2.54	2.73	2.81	2.40	1.85	1.52	1.17	24.02
Eagle Pass, Maverick County	38	.71	.81	1.11	1.60	3.11	2.44	1.76	2.59	3.31	1.58	1.10	.80	21.01

As shown in the above table, points near the coast, such as La Parra and Brownsville, receive more rain than points inland. The precipitation is irregularly distributed, so that even in the wetter portions there is no certainty of raising crops without irrigation.

Eagle Pass had 7.03 inches of rain in 1893, 14.05 inches in 1901, 3.63 inches in 1909, 18.3 inches in 1924, and 18.56 inches in 1930. Precipitation at Laredo ranged from 4.31 inches in 1901 to 36.38 inches in 1903, 15.63 inches in 1929, and 23.99 inches in 1930. In a single month, August, 1879, 12.59 inches of rain fell at Laredo. The years 1916, 1917, and 1918, were relatively dry for the whole region, but the drought was broken in 1919 by almost 12 months of abundant rain. Although no records were broken at Eagle Pass or Laredo in 1930, a fall of 4.10 inches at the former place and 6.74 inches at the latter was recorded for October, 1930, and the precipitation for the year as a whole was comparatively high. On the average September is the wettest month and January the driest.

Clear, brilliant weather is the rule in the region, but occasional thunderstorms travel across the country, and from many of them the rainfall is very great. Arroyos that have been dry for months thus come to contain for a few hours roaring and impassable torrents.

The semiaridity of the region is partly due to its location just south of a belt of permanent high atmospheric pressure. The air in this belt is descending and moving toward the Equator on its south side, becoming warmer as it moves. Thus the relative humidity decreases, giving rise to evaporation rather than to precipitation. This condition is favored also by the winds, which, during the summer at least, blow steadily from the Gulf. The land being warmer than the sea

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during the summer, the air gets warmer as it moves, and evaporation results.

Temperature.—The temperature of the region is in harmony with its latitude and the influence of the adjoining land and sea. The southernmost point, near Brownsville, is in latitude 26°, which is the southernmost point in the United States except the south tip of Florida, which is less than 1° nearer the Equator. The north side of the lower Rio Grande region is at about 29° or about 2° south of the north boundary of Florida. The following table was compiled from statistics of the United States Weather Bureau:

Temperature (°F.) at stations in the lower Rio Grande region, by months

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual (mean)
Brownsville, Cameron County	47	59.1	62.8	68.5	73.7	78.6	82.5	83.8	83.7	80.3	74.4	67.5	61.5	73.0
Fort Ringgold, Rio Grande, Starr County	46	57.7	61.6	70.1	76.5	81.5	87.1	88.7	86.2	81.6	74.8	66.1	59.5	74.3
Fort McIntosh, Laredo, Webb County	43	55.1	60.4	68.5	75.5	81.2	85.4	87.1	86.7	82.1	73.4	63.4	56.0	73.4
Eagle Pass, Maverick County	27	52.5	57.7	66.0	72.5	99.9	84.9	86.6	86.1	80.5	71.4	60.6	53.4	71.0

The 60° F. isotherm for January passes through the northern part of the region and the 70° isotherm through the southern part. The general weather map, however, shows that both these lines turn northeastward over Florida, indicating slightly higher winter temperatures there than in Texas. This is doubtless due to the peninsular character of Florida, the land being kept warm in winter by the sea, which almost surrounds it. The average July temperature for the whole Rio Grande region is between 80° and 90°, the same as for the whole of Florida. The average annual temperature for the whole lower Rio Grande region is not far from 72°, and the mean temperature for January is about 56°. Vaughan[40] reports frost and ice on November 3, 1912, on a terrace of the Rio Grande 13 miles from Zapata. The following low temperatures were recorded in January, 1930:

	°F.		°F.
Eagle Pass	12	Rio Grande	19
Carrizo Springs	13	Mission	20
La Pryor	10	Mercedes	22
Uvalde	10	Harlingen	22
Sabinal	9	Brownsville	24

[40] Vaughan, T. W., field notes of 1912.

Killing frost extended to the lower Texas coast during the cold wave of January 17–18 and again during the last week of the month.

Wind.—The prevailing wind throughout the region is from the southeast. This wind, which is of the monsoon type, is not so persistent in the winter as in the summer. During the summer the land is heated more than the Gulf, rendering the air lighter over the land than over the water. Barometric gradients are thus established from Gulf to land. That the winds are due to unequal heating is made clear by the fact that they blow most strongly during and for a few hours after the daily periods of maximum heating and are the weakest during the early morning hours, when insolation is at a minimum.

During the autumn, winter, and spring strong north winds are fairly frequent. They are doubtless due to strong high-pressure areas or anticyclones which pass from west to east over the Northern States, occasionally following a more southerly path than usual. The air moves out in all directions from these high-pressure areas, forming north winds south of their centers.

POPULATION

The climatic conditions described above determine the main industry of the lower Rio Grande region, which is grazing. Only in the years of more than average precipitation can ordinary agriculture be carried on successfully, and those years are not predictable. Dry farming has not been tried extensively, but whether it would prove continuously successful where there are such great extremes is doubtful. Where irrigation is possible, on the Rio Grande from Fort Sam Fordyce to the Gulf and on patchy terraces farther upstream the land is divided into small farms, and cotton, corn, kafir corn, grapefruit, oranges, lemons, bananas, and garden truck for the early markets are raised. The citrus fruits and bananas can probably be grown successfully, however, only in the lower part of the valley, where the southern latitude and low altitude prevent disastrous frosts. Other irrigation projects than those drawing water from the Rio Grande have been tried, but most of them have failed. There is some irrigation from wells near Falfurrias. The Nueces River is a source of water for a moderate amount of irrigation just outside the region, in Zavala and Dimmit Counties, though the water used in the Winter Garden comes almost exclusively from deep wells.

Large ranches, some of them containing a million acres or more, devoted to the breeding and raising of cattle, sheep, and goats, are the rule in this region. So long and severe are the occasional droughts, such as that of 1916–1918, that even the grazing industry may suffer.

The population at the last two censuses was as follows:

Population of the lower Rio Grande region in 1920 and 1930, by counties

County	Total		Per square mile		County	Total		Per square mile	
	1920	1930	1920	1930		1920	1930	1920	1930
Uvalde	10,769	[a] 12,945	6.8	8.1	Brooks	4,560	5,901	4.7	6.1
Zavala	3,108	10,349	2.3	7.7	Starr	11,089	11,409	8.2	8.5
Maverick	7,418	6,120	5.9	4.9	Hidalgo	38,110	77,004	23.4	49.5
Dimmit	5,296	8,828	3.9	6.5	Willacy [b]	1,033	10,499	.8	18.3
Webb	29,152	42,128	9.1	13.1	Kenedy	--------	701	--------	.5
Zapata	2,929	2,867	2.8	2.8	Cameron	36,662	77,540	26.2	92.3
Jim Hogg	1,914	4,919	1.7	4.3					

[a] Preliminary population figures subject to correction.
[b] Part of Willacy County set off as Kenedy County since the census of 1920.

The average density of population in 1930 was 17.1 to the square mile; the average for the State was 22.2.

DRAINAGE

The drainage lines of the lower Rio Grande region are shown in Plate 7. The northern part of the region, as far south as the latitude of Laredo, contains the Rio Grande-Nueces River divide. All this land is well drained. For 100 miles below Laredo a strip from 15 to 20 miles wide is drained by the Rio Grande and its tributaries.

The delta below Samfordyce is so flat, the soil is generally so porous, and the river is depositing so much of its sediment that it breaks up into numerous distributary channels. Water that falls on the surface here either stands until it sinks in or evaporates or it flows off to the Gulf through the Rio Grande or one of its distributaries. In the coastal portion of the region, from Hebbronville east, shallow intermittent and obscure independent drainage channels have been established. Little water from these channels, however, reaches the Gulf, for it flows only after the heaviest rains and even then loses itself in shallow lagoons or in grassy flats within a short distance. In fact, the water table is slowly rising, to the serious concern of the engineers. The large rectangular tract lying between this independent drainage area on the north and the Rio Grande on the south and in general covered by drifting sand is totally without surface drainage.

RIO GRANDE

The Rio Grande, formerly called the Rio Bravo Del Norte,[41] rises near the crest of the Continental Divide in the San Juan Mountains of Colorado and flows for more than 1,200 miles first southerly and then southeasterly to the Gulf of Mexico east of Brownsville. It

[41] Schott, Arthur, Geology of the lower Rio Bravo del Norte: United States-Mexico Boundary Survey, vol. 1, pt. 2, pp. 28-48, 1857.

constitutes the international boundary between the United States and Mexico for 900 miles, from a point a short distance above El Paso to the Gulf.

After it emerges from the San Juan Mountains much of its volume during the summer is diverted for irrigation in the San Luis Valley, Colorado, and in New Mexico or is lost through evaporation and seepage. Elephant Butte Reservoir, on the river in southern New Mexico, capacity 2,600,000 acre-feet, stores its winter and flood run-off, thereby providing water for irrigation in the El Paso region and to some extent regulating the stream discharge down to its mouth. Precipitation increases from about 10 inches a year at El Paso to almost 25 inches at the mouth of the Rio Grande, and consequently enough water is brought in by the Texas and Mexico tributaries to sustain a permanent flow of considerable volume through the lower Rio Grande region.[42]

The largest single tributary to the Rio Grande throughout its course is the Pecos River which rises in Moro County, N. Mex., and flows 500 miles or more to its mouth in Val Verde County, Tex., about 85 miles up the Rio Grande from Eagle Pass. The main tributaries to the Rio Grande from the Texas side within the region under discussion are, in order downstream, San Ambrosio Creek, San Lorenzo Creek, Arroyo Santa Isabella, Arroyo Chacon, Dolores Creek, El Burro Creek, Arroyo Valeno, Arroyo del Tigre, and Los Olmos Creek. The main distributary on the delta is the Rio Colorado, of which a secondary distributary is the Resaca de los Fresnos. There are two main tributaries from Mexico, the Rio Salado, which joins the Rio Grande opposite Zapata, Tex., and the Rio San Juan, which enters a few miles above Rio Grande City.

NUECES RIVER

The Nueces River with its tributaries drains the northeastern part of the region. Of the 315 miles of its length from its source in Edwards County, Tex., to Corpus Christi Bay, only about 5 miles is within the lower Rio Grande region. It enters the region at the Cretaceous-Eocene line of contact at Pulliam, on the Uvalde-Zavala County line, and leaves it 5 miles below in flowing southeastward across the line connecting Uvalde and Carrizo Springs. (See pl. 7.) From this point it flows southward for 40 miles in a course generally parallel with the east border of the region and at a distance nowhere greater than 7 miles. East of Carrizo Springs it turns to the east, but its tributaries find their sources in this region almost as far southeast as Hebbronville.

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[42] For discharge data on the Rio Grande see U. S. Geol. Survey Water-Supply Papers 358, 388, 408, 438, 458, 478, 508, 528, 548, 568, 588, 608, 628, 648, 668, and 688.

In that portion of its course which lies within and adjacent to the lower Rio Grande region, the Nueces River is discontinuous and intermittent. It flows as a continuous surface stream only during and for a few days or at the most a few weeks after periods of abundant precipitation. During practically the whole summer of 1919 it flowed with considerable volume, but in the drier seasons, such as that of 1921, the water during the greater part of the time stands in warm, clear pools, many of them deep, but with connecting circulation through the underlying gravel.[44]

The principal tributaries to the Nueces River system from the west that drain the lower Rio Grande region, named from north to south, are Turkey, Chaparrosa, Elm or Chacon, Picoso, Peña, San Roque, and Parida Creeks. These are all intermittent and generally small but become torrential after rains. The chief independent streams east of Hebbronville are Palo Blanco Creek and Arroyo Buluarte, which flow into Laguna Salado.

TOPOGRAPHY

GENERAL FEATURES

In 1898 Hill and Vaughan,[45] in describing the topography of southern Texas, recognized the Balcones fault scarp running through Bexar, Medina, Uvalde, Kinney, and Val Verde Counties and considered it the line of separation between the Edwards Plateau on the north and the Rio Grande Plain on the south. The lower Rio Grande region lies wholly in the Rio Grande Plain, the general topography of which is described in the paper cited. The Balcones fault lies 20 to 75 miles north of the Cretaceous-Eocene line. (See pl. 1.)

That portion of the Rio Grande Plain which is included within the lower Rio Grande region slopes gently from the Cretaceous-Eocene line southward and eastward to the Gulf. The average altitude of the northern boundary south of Uvalde is 800 to 850 feet. The highest point in the region is Sand Mountain, 16 miles southwest of Uvalde, an erosion remnant of the resistant Carrizo sandstone, which overlaps older Tertiary formations in this locality. The altitude of its top is 968 feet, and it stands nearly 100 feet above its immediate surroundings. Batesville Hill, 12½ miles east of Sand Mountain and a few miles outside the region, has an altitude of 964 feet. The tops of such eroded volcanic plugs as the Taylor Hills, Mount Inge, Sulphur Mountain, and Allen Hill, a few miles north of the region,

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[44] Records of the discharge of the river at Cinonia, Zavala County, are given in U. S. Geol. Survey Water-Supply Papers 438, 458, 478, 508, 528, 548, 568, and 608.

[45] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 199-212, 1898.

are still higher, Allen Hill reaching an altitude of 1,286 feet. The highest point in the Anacacho Mountains, about 18 miles northwest of the northwest edge of the region, is 1,349 feet above sea level. The general plain surface at Uvalde is 910 feet above sea level. The Nueces River enters the region at an altitude of 775 feet and leaves it at about 715 feet. The Rio Grande crosses the landward border of the region in southern Maverick County at an altitude of about 600 feet. The maximum relief near the landward side of the region is therefore more than 700 feet.

Where the region is crossed by the International-Great Northern Railroad, between Encinal and Laredo, the altitude averages about 575 feet and ranges from 900 feet or so on the highest points to about 400 feet at the Rio Grande. In a line between Hebbronville and Rio Grande City, roughly parallel with the Gulf coast and about 80 miles from it, the average altitude is about 450 feet and the total relief does not exceed 350 feet. West of this line the relief is due to the erosive work of the Rio Grande and the Nueces and their tributaries and of fluvial waters that do not reach any main drainage line. Beginning a few miles east of this line and extending to the Gulf, aggradational conditions prevail and the high plain and the erosional valley of the Rio Grande are lacking. The average altitude along a line from Falfurrias to Donna, 50 to 60 miles from the coast, is about 130 feet, but the relief does not exceed 60 feet. Where the region is crossed by the St. Louis, Brownsville & Mexico Railway along a line 20 to 30 miles from the Gulf, the average altitude is not more than 30 feet. The relief here is represented by the height of low dunes. The immediate coastal area consists topographically of an almost flat plain sloping imperceptibly to Laguna Madre, which is a tidal flat behind a barrier known as Padre Island. The Laguna Madre is practically dry in many places during periods of low tide or offshore winds, and the water does not normally exceed 10 feet in depth at any place or time. The barrier island would be submerged when the stronger east winds blow but for the low dunes that have been piled up by the wind almost continuously along it. On the average the Rio Grande Plain, neglecting its local irregularities, slopes toward the Gulf at the rate of about 5 feet to the mile.

TOPOGRAPHIC DIVISIONS

BASIS OF SUBDIVISION

The region between the Nueces and Brazos Rivers and to some extent eastern Texas consists topographically of a series of low structural plains along the strike of the Gulfward-dipping and least resistant formations, separated by parallel cuestas caused by the outcropping edges of the formations of superior resistance. The configuration of the surface is due to the differential erosion of unequally resistant and slightly tilted beds. These plains and cuestas constitute the topographic divisions of the region and are so described by Deussen.[46]

In the lower Rio Grande region, where a large part of the topography is controlled by the Rio Grande, where owing to semiaridity degradational action is relatively weak, and where much of the bedrock surface is obscured by drifting sand, delta deposits, and the like, these structural topographic features are not so conspicuous. The Bordas scarp, however, which is itself one of the most conspicuous topographic features of the region and separates two major plains, is of structural origin, is a cuesta, and is a continuation of one of Deussen's cuestas in the area north of the Nueces. There are also structural subdivisions of the major divisions within the region.

It seems best for the purposes of this report to base the topographic division of the lower Rio Grande region upon a combination of drainage, structure, position, and surficial characters. On this basis nine divisions are recognized—the breaks of the Rio Grande, the Nueces Basin, the Dentonio Plain, the Aguilares Plain, the Bordas scarp, the Hebbronville Plain, the sand belt, the Rio Grande Delta, and the Gulf coast. Plate 2 shows these divisions in their proper relationships.

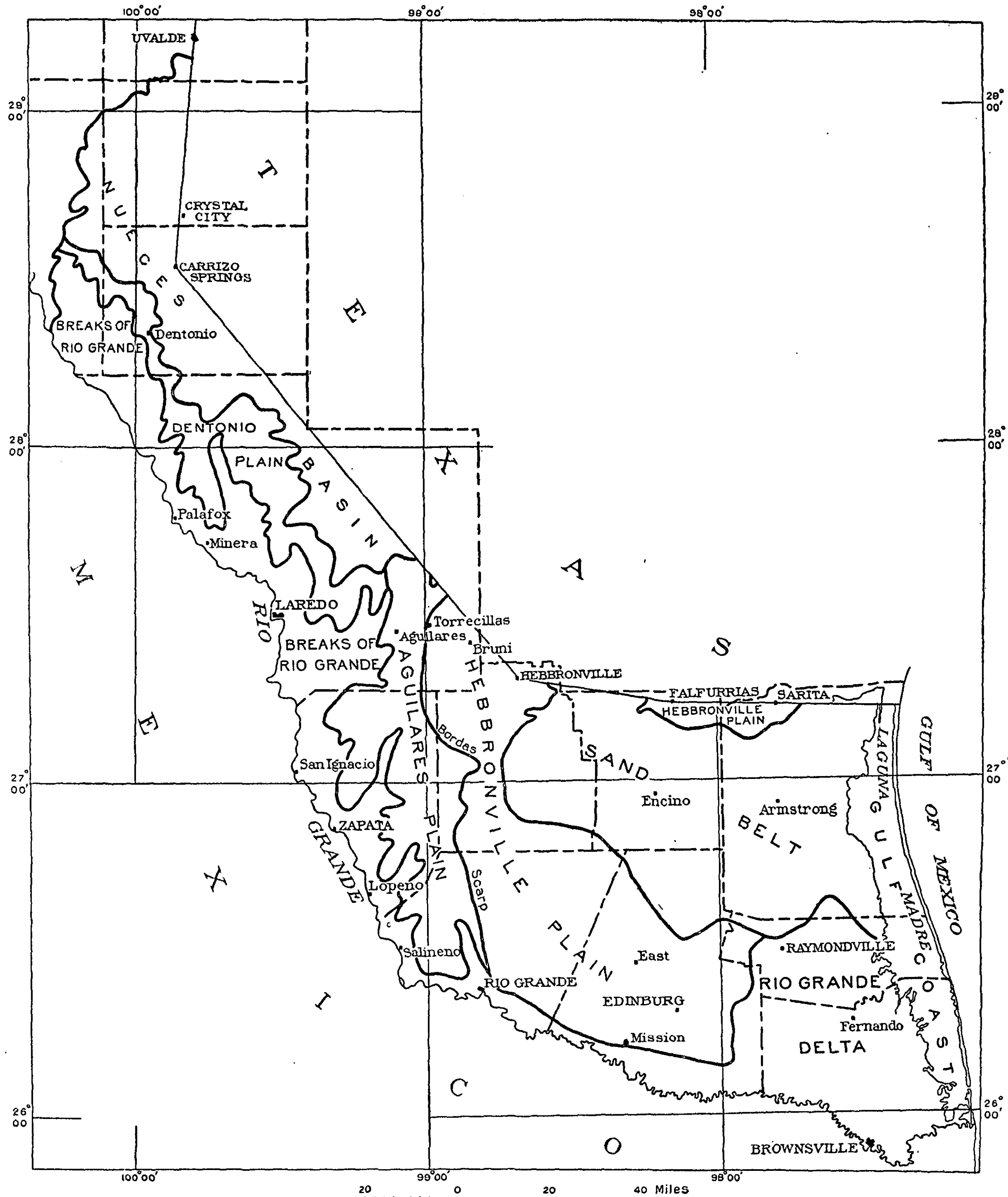
BREAKS OF THE RIO GRANDE

From Penitas, where the erosional valley of the Rio Grande ends and the delta begins, to the Cretaceous-Eocene line the surface near the river is broken by the valleys of its tributaries. This is the roughest portion of the region and is commonly known as the breaks of the Rio Grande.

The width of the belt depends upon and varies with the length of the tributary streams and the distance from their mouths at which they are or have been actively eroding. The tributaries do not average more than 15 miles in length. Because most of them have only shallow valleys in their upper courses, the breaks are confined to an even narrower belt. In some places the unbroken surface of the plain extends almost to the rim of the Rio Grande gorge and the breaks consist only of the immediate valley walls. In many places the eastern border of this belt is indefinite and is arbitrarily drawn on the map. As shown in Plate 2, the width of the belt ranges from 1 to 15 miles and averages about 7 miles.

As a rule the relief and the roughness in this area decrease downstream with the decreasing altitude of the general surface. Both also

[46] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 2–12, 1924.



MAP OF THE LOWER RIO GRANDE REGION SHOWING TOPOGRAPHIC DIVISIONS

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vary from place to place with changes in character of the rock. Where the underlying rock is sandy and porous there are few streams and few valleys, and the surface is correspondingly less cut up than where clay and shale crop out. Where the Rio Grande and its tributaries have cut into hard rocks their valleys are deeper and narrower than elsewhere, and the relief and roughness are correspondingly conspicuous.

The immediate valley of the Rio Grande varies both in width and depth. In many places the profile from the top of the bluff to the edge of the river is broken by silt terraces, which rise from 20 to 75 feet above river level. There is here a valley within a valley, the inner one with silt walls being of later origin than the outer one, the walls of which rise almost or quite to the level of the general surface. In other places the terraces have been cut away and the river washes the bases of precipitous bluffs. In such places the walls of both trenches coincide. The Rio Grande bluffs at the contact between Cretaceous and Tertiary strata are about 100 feet high. The depth of the valley at the mouth of San Lorenzo Creek is 62 feet; south of the Chupadero ranch, 80 feet; 3 miles above the Bigford ranch, 122 feet; at the mouth of Concillos Creek, 110 feet; at the pumping plant below Palafox, 125 feet; 1 mile below the mouth of Espada Creek, 93 feet; at the mouth of Sambarieto Creek, 100 feet; 5 miles below La Perla, 125 feet; 1 mile below Zapata, 94 feet; at Ramireno, 70 feet; at Santa Margarita, 57 feet; just above Roma, 129 feet; at Roma, 64 feet; and at La Loma de la Cruz, below Rio Grande City, 82 feet. From Rio Grande City the bluffs decline uniformly in height to Penitas, where they end. Below Samfordyce, however, the walls of the valley are so low and indefinite that depth can hardly be assigned.

The figures given above are the heights of the immediate river bluffs only. Everywhere there is a gradual rise from the rim of the valley to the higher land back from the river, in most places an ascent of 50 to 100 feet within a mile. Many hills in this area stand 250 feet or more above the river. Big Apache Hill, 7 miles above Palafox, has an estimated altitude of 730 feet, and the Rio Grande, just a mile away, is below 500 feet. There is a hill only 5 miles northeast whose altitude is estimated to be 820 feet. A relief of 300 feet or more within a few miles is, however, exceptional.

Plate 4, *A*, is a view of the Rio Grande and its bluffs. It is notable that the bluffs are much more nearly continuous and much steeper on the Texas side than on the Mexico side of the river. The valley is asymmetric, with gentle streamward slopes on the south and much steeper ones as a rule on the north. This difference is doubtless due to the fact that the river flows generally southward and that the formational dips are to the east. In its downward cutting the river has tended to shift down the dip, according to a well-known principle.

The valleys of the main tributary streams are as deep at their mouths as the Rio Grande bluffs are high. Consequently, their maximum depths range from a few feet to 125 feet, and they become shallower toward the heads of the tributaries. The valley of Concillos Creek 5 miles northeast of the Bigford ranch house and about an equal distance from its mouth is 40 feet deep and 125 yards across. The walls are of rock and gravel and are clearly defined. The flood plain is flat and wide but is cut by a channel 15 feet deep. This is a fair average for tributary valleys in this topographic division.

The breaks of the Rio Grande might be roughly subdivided topographically into north-south belts, on the basis of differences among the outcropping formations. In the westernmost of these minor belts, from the Cretaceous-Eocene line to San Ambrosio Creek, the surface contours are controlled by the erosion of the relatively nonresistant and homogeneous Indio formation. The surface is therefore subdued. The Midway outcrop does not cover a sufficient area to affect the topography materially. The more resistant Carrizo sandstone forms a westward-facing escarpment through the San Pedro and Chupadero ranches to the Rio Grande at the old Sullivan place. Between this Carrizo ridge and the mouth of Espada Creek the Bigford formation is at the surface. Because of its lenses of sandstone in clay and shale, the surface here is more than usually irregular in a small way, even for the breaks. Between Espada and Sambarieto Creeks the river cuts the strike of the Mount Selman formation obliquely. This formation consists chiefly of clay but has enough beds and lenses of hard sandstone to form high bluffs along the river and mesalike remnants and canyonlike valleys away from the river. From a point on the Rio Grande 8 miles above Laredo downstream to Ramireno, a distance of 75 miles, the course of the river and the strike of the strata are so nearly parallel that the Cook Mountain formation crops out the whole way in the Rio Grande bluffs and for a distance back from the river, decreasing from 7 miles above Laredo to nothing at Ramireno. This formation, which is as a whole more than ordinarily resistant, includes several very hard beds. Consequently this portion of the breaks is unusually rough, and north-south ridges or cuestas facing west are not uncommon. East of the Cook Mountain belt and farther from the river is the Cockfield belt, which occupies the eastern part of the breaks for many miles and comes to the river between Ramireno and Roma. This whole belt, even including the river-border portion, has relatively slight relief. Between Roma and Rio

Grande City the river flows in an easterly direction, practically with the dip. In this distance of only 14 miles the breaks are the result of the dissection of the Fayette, Frio, and Oakville formations. The Fayette forms westward-facing cuestas marking the border of the Cockfield belt, the Frio clay expresses itself in low, gentle river bluffs and broad, open tributary valleys, and the Oakville forms the lower slopes of bold bluffs. Between Rio Grande City and Samfordyce the bluffs and breaks are capped with the resistant Reynosa formation underlain by Oakville sandstone, clay, and ash. These conditions give rise to a distinctive mesa type of topography. Below Samfordyce the Lissie gravel dips gently downstream and correspondingly the bluffs become lower and lower until they disappear.

One of the most conspicuously rough portions of the breaks, aside from the Rio Grande bluffs, is the Cerrito Blanco group of hills, which occupy an area of about 1 square mile 6 miles northeast of Santo Tomas, in Webb County. These hills are conspicuous from all directions except the south, where a continuous ridge hides them. They stand 60 to 75 feet above their surroundings. With flat tops and precipitous slopes they constitute mesas of the Great Plains type. A 16-foot bed of sandstone in the Mount Selman formation caps 38 feet or more of clay, which is also Mount Selman. The beds dip about 2° southeast. Arroyo Santa Isabella and its tributaries from the west have been the chief agents of erosion, although rain water, wind, and gravity have aided. The hills are bordered on the northwest by a cuesta ridge, of which the northwest side is steep and marked by the outcropping edge of a hard sandstone ledge, and the southeast side conforms with the dip.

Because of the good drainage and rough surface of the breaks of the Rio Grande, travel in this portion of the region is difficult. Except in the few places where creeks are bridged at crossings, roads are impassable after rains. With each shower the creeks wash away the improvements across them, and much work on the crossings must be done to keep them passable even between rains.

But it is in the breaks of the Rio Grande that the best, deepest, and most numerous exposures of the rock formations of the region are found. It is doubtful if there is a better series of workable sections of coastal Tertiary and Quaternary rocks in America than those along the Rio Grande. A typical view in this belt is shown in Plate 4, *B*.

NUECES BASIN

The eastern portion of that part of the region north of Laredo is drained by the Nueces River and its tributaries. The area of the basin of this stream within the region is shown in Plate 2.

On the whole the valleys of the Nueces and its tributaries are broader and shallower than those in the breaks of the Rio Grande. They are partly filled with silt of Pleistocene age, and the deposits in many of them are so thick that the silt almost buries the low divides. The valleys are thus broad, flat, low-lying silt plains separated obscurely by only slightly higher, gentle-sided divides. The silt plain in the Nueces Valley is more than 7 miles wide at latitude 29°, and that in the valley of Turkey Creek at the same latitude is nearly 2 miles wide. Farther south these plains merge, forming a surface at least 10 miles wide on the west side of the Nueces. On this plain is the large Pryor ranch and the town of La Pryor. The west border of the plain is inconspicuous.

Steep slopes, however, are not lacking in the Nueces Basin. In places the valleys are narrow and the streams have cut gorgelike trenches in the rocks underlying the silt. It is presumed that in these places, the silt during its period of deposition buried divides or the noses of divides between tributaries. Later the streams intrenching their wandering courses were locally superimposed upon these higher rock surfaces. The Nueces itself in practically all the area treated in this report occupies a steep-sided though generally flat-bottomed valley 35 or 40 feet deep and 400 to 1,000 feet wide. Just north of the crossing of the Uvalde-La Pryor road there is a rock section a third of a mile long and more than 50 feet high. Even where the Nueces is intrenching itself without having reached bedrock, the silt-walled valley is narrow, deep, and steep-sided.

About a mile northeast of Crystal City, just outside the region here considered, the Nueces River divides downstream into two channels, the western of which is known as Espantosa Lake, although in periods of high water it flows vigorously over falls and rapids. (See pl. 4, *C*.) At 15 miles below this point the two channels reunite. Both these streams flow in sharply defined valleys. The Espantosa Valley at the road and railroad crossings 2 miles south of Crystal City is 180 feet wide and 54 feet deep. The Nueces Valley proper in this vicinity is similar. This division and reunion dates back to the time when the streams began to intrench themselves after deposition of the silt ended. The parent stream was divided on the depositional flat, and the divisions were both maintained after rejuvenation.

The traveler going from La Pryor westward on either the old or the new Eagle Pass road crosses the valleys of all the main tributaries to the Nueces. East of Chaparrosa Creek there is a considerable area of flat upland underlain by gravel. This surface is not more than 20 feet above the streams. Chaparrosa Creek occupies a valley 15 feet deep and 500 feet wide. Palo Blanco Creek likewise flows in a broad, indefinite draw, less than 15 feet deep. Elm or Chacon

Creek is here flowing on bedrock and has a definite channel not more than 50 feet wide and 20 or 25 feet deep. The valleys of Picoso, Peña, and other creeks farther south are not conspicuous topographically. About 2½ miles east of the Van Cleve ranch the surface between Picoso and Chacon Creeks is flat and in places swampy, though gravel appears in spots. The general surface is not more than 15 feet above drainage level.

DENTONIO PLAIN

A narrow and irregular area of high land, here called the Dentonio Plain, separates the Rio Grande drainage system from that of the Nueces. In some places the heads of the valleys on both sides of the divide are so close together that the divide can be represented by a line. In other places there are surfaces 2 or 3 miles wide in which there is little or no drainage and which can be assigned neither to the breaks of the Rio Grande nor to the Nueces drainage basin.

The topography in this strip is distinctive. It is well represented at and near Dentonio, in Dimmit County, from which it is named; in an area that centers 14 miles southwest of Carrizo Springs and south of the English or Red ranch; and in an area west of the Espejo ranch and 25 miles south of Carrizo Springs. In these areas and in others not so representative the surface is high and untouched by drainage, being almost as flat as the silt plains in the Nueces Basin. The plain supports practically no brush but is an open prairie where grass is the only vegetation. The surface material is sandy, but there is no deep sand.

AGUILARES PLAIN

That portion of the region lying between the north boundary and Rio Grande City and between the breaks of the Rio Grande and the Bordas cuesta is here known as the Aguilares Plain. It lies south and east of the Nueces Basin and the Dentonio Plain. Its drainage goes entirely to the Rio Grande, but the drainage lines are in valleys so shallow and the general surface is so little dissected that it is topographically distinct from the breaks of the Rio Grande. The line separating the two divisions on Plate 2 is drawn more or less arbitrarily, however. The Bordas scarp sharply marks the east edge of the area. The plain is confined to southeastern Webb County, eastern Zapata County, and extreme western Jim Hogg County. In Starr County its southward extension is cut off by the breaks. It is named for the town of Aguilares, on the Texas Mexican Railway, 26 miles east of Laredo and 7 miles west of the foot of the Bordas scarp. Aguilares is in about the middle of the plain east and west, and the topography in and around this village is typical of that of the plain as a whole.

The Aguilares Plain is a southward continuation of the Frio and Wellborn Plains and Yegua Prairie of Deussen.[47] In the lower Rio Grande region this surface is not topographically divisible into three portions, although it is underlain here as farther north by the three formations or their equivalents for which Deussen's divisions were named.

The surface of the plain is not rough. Its gentle southward and eastward slope toward the Gulf is broken only by the shallow valleys of the heads of the Rio Grande tributaries, the many low hills due to the outcrops of lenses slightly superior in resistance to the almost ineffective agents of subaerial erosion, and scattered depressions scooped out by the wind with corresponding slight elevations where the material from the depressions was piled. Few square miles in the plain have a relief of as much as 50 feet, and some parts, so far as the eye can see, are actually flat. However a gentle waviness is the rule.

The configuration of the plain is typical not only in the neighborhood of Aguilares but for 3 or 4 miles around the Callaghan ranch, east of Cactus in Webb County, and in the vicinity of the Jennings gas field and the Miraflores ranch, in Zapata County. The land near the Callaghan ranch is notably flat, and no well-defined streams flow across it. The soil, derived from the underlying Cockfield formation, is dark gray or black. Vegetation is sparse, and low grasses predominate. Mesquite is rare, and prickly pear is practically lacking.

From the Salomoneno ranch northward through the Jennings gas field and the Miraflores ranch, westward to Caballos Tank, northeastward to Aguilares, and eastward to the foot of the Bordas scarp there is a gently rolling, poorly drained surface in which rock exposures are rare. Salomoneno Creek is intermittent and occupies an arroyo 10 feet deep except near the west border; other drainage lines are less definite, and their depressions are even more shallow. The most conspicuous hill in this district is Cerrito Prieto, 5½ miles southwest of Aguilares, which stands out prominently 20 feet above the plain on the east and 45 feet above the bed of Cerrito Creek on the west and north.

BORDAS SCARP

Next to the Rio Grande gorge the Bordas scarp is the most prominent topographic feature of the lower Rio Grande region. It crosses the northeast border of the region 7 miles northeast of Oilton (formerly Torrecillas), about 38 miles east of Laredo, and 100 miles from the Gulf, and from this point it extends southwestward to a position just west of Oilton, southward to Ojuelos, and thence in a somewhat irregular course generally southward and a little eastward to enter

[47] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 9–10, 1924.

the breaks of the Rio Grande north of Rio Grande City, where it is cut through by the river. In general the scarp follows the course of the base of the Reynosa formation. It passes west of the San Miguel ranch house, west of La Mesa, and 1 mile north of the Felipe Cuellar ranch house. It crosses the Hebbronville-Randado road 2 miles west of the Jesus Maria ranch house and passes east of Guerra. It cuts the Hebbronville-Roma road northwest of Cuevitas and thence slants to the east of the Rio Grande City road north of El Sauz. (See pl. 2.)

In 1906 Veatch[48] suggested the name "wold" for ranges of hills produced by differential erosion on slightly inclined sedimentary strata and called the gentle dip slopes on one side "cuestas" and the steeper opposite slopes "escarpments" or "bajadas." In 1914 Deussen[49] accepted this terminology and applied it to some of the elevations of the Texas Coastal Plain; but the term "cuesta" has come into general use as applied to the whole upland, including the dip slope on one side of the crest and the steep slope or escarpment on the other,[50] and this usage is followed in the present paper.

The Bordas scarp is the west face of a cuesta on the Reynosa formation. The resistance of this formation to erosion is due not so much to superior hardness of rock as to great porosity and a covering of loose sand. Water that falls on the Reynosa surface east of the scarp sinks in almost immediately, and there is little chance for erosion. The formation dips eastward very gently, its surface forming the Hebbronville Plain, described below, and its edge making the scarp where, with the Oakville sandstone, it holds up the softer and more impervious Frio clay. North[51] who has surveyed the Bordas scarp in detail from the Rio Grande to and beyond the San Antonio River, in Dewitt County, states that the scarp continues as far as the limestone or caliche in the Reynosa formation goes and that the scarp ends farther northeast where there is no more caliche in the Reynosa, and from this he concludes that the porous caliche is the main cause of the resistance of the Reynosa formation and is thus indirectly the primary cause of the scarp itself. The resistance of the Oakville and Reynosa formations is also increased locally by the formation of siliceous rock masses, beds, and cylindrical pipes.

According to Jones[52] the Bordas or Reynosa escarpment has resulted partly also from faulting, but subsurface data do not bear

[48] Veatch, A. C., Underground water resources of Long Island: U. S. Geol. Survey Prof. Paper 44, pp. 28-30, 1906.

[49] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, p. 15, 1914.

[50] Martin, Lawrence, Physical geography of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 36 p. 42, 1916.

[51] North, Lloyd, personal communication, February 6, 1928.

[52] Jones, R. A., The relation of the Reynosa escarpment to the oil and gas fields of Webb and Zapata Counties, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 7, p. 543, 1923.

this out, at least for that portion of the cuesta within the region under discussion. There are a few minor faults on or near the scarp, but most of them are oblique to the strike of the beds and to the trend of the scarp and seem to have no genetic relation with the scarp.

Sloping steeply westward and almost imperceptibly eastward from its crest, the Bordas cuesta is conspicuous only if viewed from the west, but in such a view through almost its total length in the region it looms on the sky line, even if the observer is 10 miles or more distant. Its average height above the surface of the Aguilares Plain is 60 or 70 feet. In some places it is so low that it is difficult to locate precisely, and in others it is more than 100 feet high. It does not consist of a single escarpment but is broken along its west side into a series of tablelike hills that have been isolated from the main upland. (See pl. 5, *A*.)

HEBBRONVILLE PLAIN

What is here designated the Hebbronville Plain is the southward continuation of the Alice and Reynosa Plains of Deussen.[53] It is the cuesta of which the Bordas scarp forms the west edge. This plain extends from Hebbronville southward to the breaks of the Rio Grande and is bounded on the east by a large area of drifting sand and by the Rio Grande Delta. (See pl. 2.) It slopes about 10 feet to the mile eastward from its western border, where it is 60 to 70 feet higher than the Aguilares Plain. Its surface is slightly dissected in its western part and has been somewhat roughened throughout by wind action. On the whole, however, it is more nearly flat than any division described above. The sandy soil and scattered exposures of white limestone and gravel are characteristic. Vegetation is sparse in the sandier portions but of considerable luxuriance where the sandy soil is thin and the limestone is near the surface. The land is good for grazing and in wet seasons affords excellent crops, especially of cotton. Some of the roads in this district are sandy and therefore difficult to travel, but there is a good road from Hebbronville to Randado and Rio Grande City.

SAND BELT

Lying chiefly in Kenedy, Willacy, Brooks, Hidalgo, and Jim Hogg Counties is an area of about 2,800 square miles in which the bedrock surface is practically everywhere covered by wind-blown sand. As shown in Plate 2, it lies south and southeast of Hebbronville and south of Falfurrias and Sarita. La Parra is on the west edge of a northward extension of the sand belt to Baffin Bay. From Alta Vista, in Jim Hogg County, it extends eastward to the coast. The south boundary is north of El Sauz, Raymondville, and El Tule and

[53] Deussen, Alexander, op. cit., pp. 7-8.

south of Yturria, Jesus Maria, and Cipres. It measures 55 miles along the coast southward from Baffin Bay and 75 miles from east to west. The St. Louis, Brownsville & Mexico Railway crosses the belt in a north-south direction and has the ranch stations of Armstrong Norias, Rudolph, and Yturria. The Southern Pacific Railroad also crosses the sand belt between Falfurrias and Edinburg.

A road has been built by Brooks and Hidalgo Counties from Falfurrias through Encino to El Tule and Edinburg. Elsewhere travel in the sand belt is well-nigh impossible except by light wagon or on horseback.

The surface configuration in this belt is that characteristic of areas in which wind and vegetation compete, the wind tending to shift sand and the vegetation tending to hold it. In some places dunes are forming and migrating. In others grass, live oak trees, and brush have gained a foothold, and the dunes are dormant. The relief of the surface is measured by the height of the dunes and the depth of the "blow-outs" and does not exceed 25 feet on the average and 75 feet as a maximum. Part of the surface is almost flat, but the larger part is hilly. Most of the dunes are in ridges, elongated in a northwesterly direction. Topographic details in the sand hills are shown on the maps of the Saltillo Ranch and Tarida Ranch quadrangles published by the United States Geological Survey. Plate 5, *B*, shows the topographic and vegetal conditions that prevail in this area. In the sand belt watermelons are grown extensively, but cattle raising and dairying are the chief industries. There is a butter factory of considerable size at Falfurrias, but most of the land utilized by the industry lies north of the sand.

RIO GRANDE DELTA

Between the sand hills and the Rio Grande, below the gorge and the breaks of the Rio Grande and extending from the Hebbronville Plain eastward to the Gulf is the Pleistocene and Recent delta of the Rio Grande. (See pl. 2.) This portion of the region is popularly known as the "valley." It includes practically all of Cameron County and about half of Hidalgo County.

With the exception of a low ridge, known as the Mission Ridge, on which are Mission, McAllen, San Juan, Pharr, and Donna, and a small area west of Raymondville, the whole surface is subject to flood. The land is poorly drained by the Rio Grande and its distributaries, the Rio Colorado, and the Resaca de los Fresnos. In times of ordinary high water the Rio Grande breaks bank as far upstream as Penitas and floods back to low terraces on the south side of the Mission Ridge. Water that stands permanently in abandoned channels or resacas makes its way from one to the other and finally enters the Rio Colorado. During excessive floods, which come once or twice in a decade, the water breaks through the ridge on both sides of Mercedes and submerges practically all the land north to the sand belt.

Except for some low terraces with almost imperceptible walls and a few "clay buttes," the delta surface is practically flat. The topographic maps of the Mission and San Juan quadrangles published by the United States Geological Survey, which have a 5-foot contour interval, afford an excellent picture of the surface configuration. The Mission Ridge is as much as 155 feet above mean Gulf level and about 60 feet above the mean level of the Rio Grande. The channel of the Rio Colorado is in places 40 feet deep and steep-walled. North and east of Brownsville occur conspicuous hills and ridges known as "clay buttes," some of which are 30 feet high.

The surface materials in the delta are clay, silt, and sand. The roads become very dusty during dry seasons. The deciduous vegetation consists chiefly of thick mesquite and prickly pear. The valley is thickly settled, however, and large areas have been cleared. Pumping plants on the Rio Grande furnish water for irrigating cotton, citrus fruits, etc.

GULF COAST

Padre Island, a narrow dune-covered sand barrier, separating the Laguna Madre from the Gulf, is continuous from Corpus Christi Bay to the mouth of the Rio Grande. The island does not exceed a mile in width, but the Laguna Madre is 4 to 10 miles wide. The dunes are generally not more than 10 feet high. They are on or near the middle line of the barrier and are flanked by tidal and storm sand flats. On its landward side the Laguna Madre has low banks where the waves have cut into the coastal plain in time of storm. Plate 6, *A*, illustrates the topography of the coastal belt.

STRATIGRAPHY

GENERAL FEATURES

The classification and correlation of the rocks of the Gulf Coastal Plain are difficult. Practically all the formations bear strong resemblances lithologically. The Indio, Bigford, and Mount Selman are lignitic; the Fayette and Oakville carry heavy beds of volcanic ash; all contain gypsiferous clay; many are glauconitic; concretions range practically throughout the section from bottom to top; there are unconformities within formations as well as between them; not all the rocks are consolidated, and few of them are firm; some of them are marine, some palustrine, and some terrestrial in origin. The character and distribution of the Tertiary and Quaternary sediments depend chiefly on the advances and retreats of the seas of the periods when these sediments were laid down. It is likely that while marine deposits were being made here, terrestrial sediments were in process of deposition elsewhere—for example, at Tampico, in eastern Texas, or in Alabama. Thus a marine formation may grade laterally into beds of eolian or fluvial origin, and vice versa. All textural subdivisions are in the form of lenses rather than in continuous beds of uniform thickness. They grade into one another vertically and horizontally. Thus a section in one locality may not be duplicated a mile away. There are also overlaps in which young formations are spread in tonguelike areas far beyond their known main districts of outcrop. In addition to all this, surface exposures are rare, except in the breaks of the Rio Grande, and until the oil and gas fields were developed, beginning in 1921, authentic and complete logs of wells were few.

The best key to the stratigraphy is afforded by the fossils. The faunas and floras of the several groups and formations on the Atlantic and East Gulf Coastal Plains, and even in eastern Texas, have been sufficiently well recognized and described to warrant correlation with formations in the lower Rio Grande region, in which many of the same fossil animals and plants are found. Not all the formations are fossiliferous, and in some the fossils are not distinctive, but by determining carefully through laboratory analysis the slight lithologic differences, by discriminating as to the significance of stratigraphic breaks, by tracing beds from one locality to another, and by checking these phases with the fossils, it is possible to classify and correlate the formations with some degree of confidence. At least the classifications of others relating to this or neighboring regions can be checked up and accepted, rejected, or modified. It is hoped that the divisions named, correlated, and described in the following pages will serve at least as a starting point for later and more detailed work than was permitted by the reconnaissance methods used in the present survey.

The strata of the lower Rio Grande region dip generally eastward toward the Gulf at slightly higher angles than the slope of the land surface. Consequently, except for two or three exceptional overlaps, there is a regular progression from the older formations in the northern part of the region to the younger formations near the Gulf. The gradient of the Rio Grande being less than the dip of the beds, the river flows over younger and younger formations as it approaches the Gulf. Each successive formation crops out in a belt roughly normal to the direction of dip and roughly parallel with the Gulf shore line.

The Tertiary and Quaternary rocks of the region are classified as follows:

Tertiary and Quaternary rocks of lower Rio Grande region

System	Series	Group	Formation	
Quaternary.	Recent.		Coastal deposits. Wind-blown sand. Fluviatile deposits.	
	Pleistocene.		Beaumont clay. Lissie gravel.	Terrace deposits.
Tertiary.	Pliocene (?).		Reynosa formation.	
	Miocene.		Oakville sandstone.	
	Oligocene (?).	Vicksburg (?).	Frio clay.	
	Eocene.	Jackson.	Fayette sandstone.	
		Claiborne.	Cockfield formation. Cook Mountain formation. Mount Selman formation.	
		Wilcox.	Bigford formation. Carrizo sandstone. Indio formation.	
			Midway formation.	

CRETACEOUS-EOCENE LINE

Stephenson[54] reported in 1914 on the contact between rocks of Cretaceous and Tertiary age in southwestern Texas, following the work of Vaughan,[55] who had in 1900 located and described the contact at more than one place. Because of the thoroughness with which this earlier work was done, the writer gave relatively little attention to this line of contact, although he visited all the sections described by either Vaughan or Stephenson, several of them in company with Stephenson in 1921. The contact, at least between the Rio Grande and the Nueces River, is essentially as Stephenson describes it, but minor changes in the mapping have resulted from the recent more detailed work of Jewell, Getzendaner, Miss Gardner, and others. The details of the line of contact shown in Plates 3 and 7 were supplied by Mr. Getzendaner.[56]

[54] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pp. 169–181.

[55] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, pp. 34–36, 1900; Geol. Atlas, Uvalde folio (No. 64), 1900.

[56] Getzendaner, F. M., personal communication, January 19, 1928; Geologic section of Rio Grande embayment, Texas, and implied history: Am. Assoc. Petroleum Geologists Bull., vol. 14, fig. 1 and p. 1433, 1930.

The change from Upper Cretaceous rocks, represented by the Escondido formation, to Tertiary rocks, represented here by lower Eocene strata of Midway and Wilcox age, is not marked by any notable lithologic change. Strata of the two systems are similar, although, according to Stephenson, there is more glauconite in the Eocene than in the Cretaceous. Stephenson[57] found evidence of physical unconformity in Texas, and so did Baker[58] on the Mexican side of the border, but the systemic significance of such unconformities is difficult to recognize, especially in parts of the geologic column where local unconformities are common. The faunal break, however, is great, and its significance is unquestionable. Not a single species is common to the faunas below and above the break, and many genera that occur in the Cretaceous are missing in the Eocene. As Vaughan[59] pointed out in 1900, it is clear that the unconformity at this horizon is really great, even though lithologically and stratigraphically it appears insignificant. In the Rio Grande region a long time must have elapsed between the end of the recorded Cretaceous and the beginning of the recorded Eocene.

The suggestion was made by Scott[60] on the basis of the supposed identity of *Hercoglossa danica* and *Enclimatoceras ulrichi* that at least the lower part of the Midway of Texas might be correlated with the Danian, which is by most European geologists considered uppermost Cretaceous. The unconformity at the base of the Midway would in that case represent only a break between the uppermost Maestrichtian Escondido and the lowermost Danian Midway. Miss Gardner[61] considered such a long-range correlation on the basis of a single species unwarranted. In view of the facts that there are many other well-known Eocene forms in the Midway and that no species and few genera are common to the Escondido and the Midway, the unconformity at the base of the Midway in southwestern Texas is interpreted as a great gap separating the Cretacious and Tertiary systems and not a mere break between two formations of the Upper Cretaceous.

Rio Grande sections.—The best exposures of the contact are in the bluffs on the Texas side of the Rio Grande 3 to 10 miles above the Maverick-Webb County line, west and south of the Windmill ranch. The writer has nothing to add to Stephenson's description and interpretation of these sections.[62]

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57 Stephenson, L. W., op. cit., pp. 169–176.

58 Baker, C. L., personal communication.

59 Vaughan, T. W., op. cit. (Bull. 164), pp. 35–36.

60 Scott, Gayle, On a new correlation of the Texas Cretaceous: Am. Jour. Sci., 5th ser., vol. 12, pp. 157–161, 1926; Études stratigraphiques sur les terrains crétacés du Texas: Univ. Grenoble Annales, 1926.

61 Gardner, Julia, On Scott's new correlation of the Texas Midway: Am. Jour. Sci., 5th ser., vol. 12, pp. 453–455, 1926.

62 Stephenson, L. W., op. cit., pp. 169–176.

According to Baker[63] the Cretaceous-Eocene contact is exposed in at least three places within 6 miles of the Rio Grande on the Coahuila side at Cerrito Prieto, a low bluff about three-quarters of a mile from the Rio Grande, where the Arroyo del Caballero joins the main valley (1, pl. 3); on the west wall of the Rio Grande Valley three-quarters of a mile downstream from the mouth of the Arroyo del Caballero (2, pl. 3); and on the Arroyo del Amole about 6 miles upstream from the Trinidad ranch house (3, pl. 3). At each of these localities there is an erosional as well as a faunal unconformity. The line of contact is irregular; Escondido layers of different ages form the basement on which the Eocene rocks were laid; the contact is marked by an irregular band of glauconite of darker color than the glauconite in the Eocene above or the Cretaceous below; and the basal Eocene beds contain pebbles, cobbles, and even boulders derived from the underlying Escondido formation.

Nueces River sections.—Vaughan's section at Pulliam[64] (4, pl. 3) is as follows:

Section at Waxy Falls, above Pulliam ranch

	Ft.	in.
10. Flint gravel; lower rocks not exposed	8	
9. Coarse-grained, laminated, and cross-bedded yellow sandstone	2	
8. Soft yellow sandstone and clay	25	
7. *Ostrea cortex* embedded in clay and consolidated into a firm ledge[65]	2	
6. Laminated yellow sandy clays	3	6
5. Soft ledge, composed largely of fragments of oyster shells	1	
4. Soft laminated yellow sandy clays	3	
3. Soft fine-grained sandstone, in many places distinctly crossbedded and containing some asphaltum	10	
2. Asphaltum-bearing sandstone—soft sandstone impregnated with asphaltum	5	
1. Bluish clays to water's edge	2	
	61	6

No. 10 is probably Pleistocene; 9 and 8 are referred to the Eocene (Myrick formation); 7 to 1 are Cretaceous (Pulliam formation).

Another exposure of the petroliferous sandstone and underlying shale occurs on the east wall of the Nueces Valley at the Pulliam ranch house and in the stream bed just north of the house.

In 1924 Deussen[66] redescribed this same section, interpreted it as being all Cretaceous except the gravel and silt of No. 10, and presented evidence that the Cretaceous strata have been arched and faulted.

Frio River sections.—The Cretaceous-Eocene line of contact on the Frio River (5, pl. 3) is described by Vaughan.[67] Here the lowermost

[63] Baker, C. L., personal communication.

[64] Vaughan, T. W., U. S. Geol. Survey Geol. Atlas, Uvalde folio (No. 64), p. 3, 1900.

[65] According to Vaughan the base of the Eocene is at the top of layer 7.

[66] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 40, 1924.

[67] Vaughan, T. W., op. cit., p. 2.

Eocene strata are of Midway age and are fossiliferous, as on the Rio Grande. Stephenson[68] lists the fossils taken from these beds. There is a large amount of reworked Cretaceous material, including small pebbles, shark teeth, and fragments of *Ostrea cortex*, in the basal glauconitic beds of the Eocene.

TERTIARY SYSTEM

EOCENE SERIES

MIDWAY FORMATION

Definition and correlation.—The term Midway was used in 1886, by Smith and by Aldrich,[69] and in 1887, by Smith and Johnson,[70] for the lowest Tertiary strata at Midway Landing, Wilcox County, Ala., or for the basal part only of the Midway formation as commonly understood for 30 years.

In Texas strata of this age were first called "Basal or Wills Point clays" by Penrose.[71] Later Harris [72] correlated the two formations on stratigraphic, lithologic, and paleontologic grounds and fully described the Midway formation, as the name is now understood. Deussen [73] summarized the literature of the Midway to date in 1914 and again in 1924.

In Medina County, Tex., Liddle [74] recognized a Midway group subdivided into what he designated the Elstone and Squirrel Creek formations, but in the lower Rio Grande region the strata of lower Midway age constitute a single formation. As explained on page 29, Scott in 1926 suggested that the Midway of Texas might be Upper Cretaceous rather than lower Eocene, but this correlation has not been established.

Distribution.—Partly because the Midway is the thinnest of all the Tertiary formations in southern Texas but also because it is overlapped by the Indio and Reynosa formations, it crops out only in a small area. As shown in Plates 3 and 7 it appears at the surface only in a narrow strip in southern and eastern Maverick County. It is exposed in the base of the Rio Grande bluffs 2 miles north of the Maverick-Webb County line (6, pl. 3), where it lies under the Indio

[68] Stephenson, L. W., op. cit., p. 177.

[69] Smith, E. A., Alabama Geol. Survey Bull. 1, p. 14, 1886; Aldrich, T. H., idem, p. 60.

[70] Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee and Alabama Rivers: U. S. Geol. Survey Bull. 43, p. 62, 1887.

[71] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Survey First Ann. Rept., p. 19, 1890.

[72] Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 8, 9, 22, 1894; On the geological position of the Eocene deposits of Maryland and Virginia: Am. Jour. Sci., 3d ser., vol. 47, pp. 303–304, 1894; The Midway stage: Bull. Am. Paleontology, vol. 1, No. 4, pp. 11–13, 1896.

[73] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 30–31, 1914; Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 41, 1924.

[74] Liddle, R. A., The geology and mineral resources of Medina County: Texas Univ. Bull. 1860, pp. 74–81, 1918.

formation. On the north side of the river, at the big bend east of the Blesse ranch house, the whole bluff, which is unusually low at this point, consists of Midway rocks. At White Bluff, straight north and across the river from the Blesse ranch house, at the end of the fence extending southwest from the Windmill ranch (7, pl. 3), the Midway formation appears in the uppermost 12 feet of a 105-foot bluff. From this point it appears above the Cretaceous and under gravel of the Reynosa formation for a distanc of 5 miles up the Rio Grande, in some places at or near the top of the river bluffs and in others in the valleys of tributary streams or on bordering slopes. Still farther north, west of the old Indio ranch house, although obscured by gravel of the Reynosa formation which overlies it, the Midway belt of outcrop is about 1½ miles wide. West of the Glass ranch the formation crops out between the Cretaceous on the west and the Indio formation on the east in a belt about 2 miles wide. North of this the belt of outcrop bends to the east, touches the northwest portion of Dimmit County and the southwest corner of Zavala County, and still farther north narrows in a northwesterly direction and is cut out by an overlap of the Indio just south of Chilipetin tank, in northeastern Maverick County.

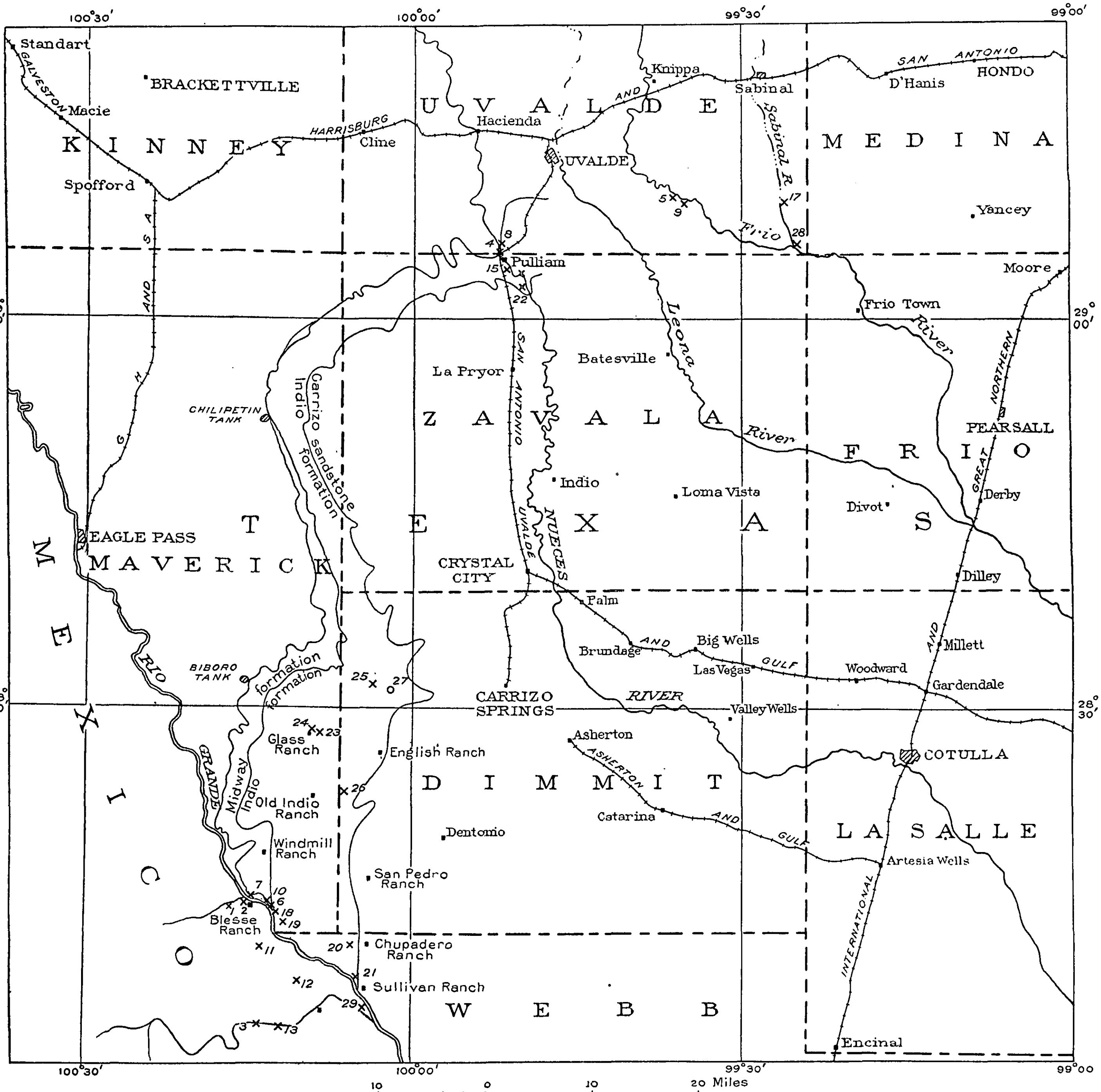
On the Frankie ranch, however, there is one outcrop where the overlap is apparently incomplete. About 1¼ to 1½ miles up Chaparrosa Creek from the crossing of the Eagle Pass-Uvalde road, on the west side of the creek, a bluff rises about 20 feet above the stream bed. A bed containing *Ostrea cortex* crops out at the base, and dark-red banded Indio sandstone caps the bluff to a thickness of 10 feet. Below the Indio sandstone a highly calcareous sandstone or sandy limestone, yellowish gray and locally fossiliferous, forms a discontinuous ledge about 2 feet thick. The interval between the limestone and the bed containing *Ostrea cortex* is concealed. Although none of the poorly preserved casts collected can be referred to common Midway species, the lithologic character of the matrix and the field relations suggest the Midway.

About halfway between the Pulliam ranch and the Widow Cook ranch on the east side of the Nueces River in southern Zavala County, southwest of Uvalde (8, pl. 3), a thin bed of greensand and glauconitic limestone lies between the Cretaceous and the undoubted Indio.

Although the Midway formation has a meager distribution at the surface in the lower Rio Grande region, it is well known in Coahuila and Nuevo Leon, Mexico, south of the Rio Grande;[75] on the Frio River, in southeastern Uvalde County;[76] and it appears in a continuous

[75] Dumble, E. T., Tertiary deposits of northeastern Mexico: California Acad. Sci. Proc., 4th ser., vol. 5, No. 6, pp. 178-181, 1915. Baker, C. L., unpublished manuscript. Vaughan, T. W., U. S. Geol. Survey Geol. Atlas, Uvalde folio (No. 64), p. 2, 1900. Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, p. 177, 1914.

[76] Liddle, R. A., The geology and mineral resources of Medina County: Tex. Univ. Bull. 1860, pp. 74-81, 1918.



SKETCH MAP SHOWING THE CRETACEOUS-EOCENE LINE OF CONTACT, THE DISTRIBUTION OF THE MIDWAY AND INDIO FORMATIONS, AND THE LOCATION OF EXPOSURES DESCRIBED belt of outcrop from eastern Uvalde County to southwestern Arkansas.[77] It crops out over at least fairly wide areas in all of these places except in the lower Rio Grande region.

Lithology.—The Midway formation consists chiefly of shale but includes lenses and layers of sandstone and limestone. At the base of the formation in some places there are thin and discontinuous beds of conglomerate containing abraded fragments of rock and fossils derived from the underlying Escondido formation. Heavy ledges of limestone overlie the conglomerate or form the basal beds where there is no conglomerate. The limestone is gray, compact, and in some places crystalline, and it contains fossils. The beds are at few places more than 1½ feet thick and are interbedded with greenish-gray sand 1 to 2 feet thick. The shale is generally dark, and some beds are black, but the colors include green, brown, gray, bluish gray, and blue. Some of the beds are notably pure, but many are sandy or silty and gypsiferous. No single bed is more than 40 feet thick. The sandstone is gray, yellowish, brownish, or greenish and is irregularly and thinly bedded. Many beds are micaceous, and some are glauconitic. Most of them are rather soft, but some are firm. The sandstone varies in texture but is generally fine grained. Throughout the formation, but chiefly in the shale, there are numerous concretions, which range in diameter from 6 inches to 10 feet, are generally flat or biscuit shaped, and consist chiefly of limestone. Many are septaria, or "turtle stones." Some of the smaller ones are pyritized, some are clay ironstones, and some consist of iron carbonate.

Stratigraphic relations.—The unconformable relations between the Midway and the Cretaceous have already been described. There is also a time break at the top of the Midway where this formation is overlain by strata of Wilcox age. The unconformable contact between the Midway and the Wilcox is well exposed at the north end of the westward-facing bluff of the Rio Grande in southern Maverick County, 2½ miles north of the Webb County line (6, pl. 3), and on the west wall of the valley of the Frio River at Bob Evans's apiary ("Myrick's lower apiary" in the Uvalde folio), in Uvalde County, 12 miles east of the lower Rio Grande region as here mapped (9, pl. 3). In each of these sections the line between the Midway and Wilcox formations is the edge of an erosional surface, and the basal Wilcox is conglomeratic, the pebbles being worn fragments, fossils, and concretions of iron carbonate derived from the underlying Midway. There is a great unconformity between

[77] Sellards, E. H., The geology and mineral resources of Bexar County: Tex. Univ. Bull. 1932, pp. 54–57 1919. Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 40–46, 1924. Dumble, E. T., The geology of east Texas: Texas Univ. Bull. 1869, pp. 31–37, 1918.

the Midway and the Reynosa, the gravel of the Reynosa having been deposited on a surface which bevels the Midway and all other Eocene strata.

Thickness.—As the dip of the Tertiary formations may not be entirely deformational but may have been in part original, the usual methods of determining thickness from the outcrops are of no great value. Furthermore, the full thickness of the Midway formation is probably nowhere exposed, because of the Wilcox overlap. Only where the Midway has been drilled through for oil or water and where its base and top can be determined from the log or from samples of the core can its true thickness be estimated. According to the log of the L. E. Hanchett test well, 10 miles west of Carrizo Springs, as interpreted by C. L. Baker, the formation is 194 feet thick. Wells drilled west of Carrizo Springs in Dimmit and Maverick Counties by the Humble Oil & Refining Co., as interpreted by Getzendaner,[78] show thicknesses of the Midway formation as follows: Sullivan No. 1 well, 325 feet; City National Bank No. 1 well, 319 feet; Sullivan No. 5A well, 370 feet; Sullivan No. 11 well, 250 feet; and Sullivan No. 14A well, 295 feet. According to Jewell,[79] who detailed the Escondido, Midway, and lower Wilcox on the Indio ranch, the thickness of the Midway there is 199 feet. The average of all available estimates of its thickness outside of the Rio Grande region but near it is 216 feet.

Fossils.—More species of fossil invertebrates are found in the Midway (see pls. 30–33) than in any other Tertiary formation in the region, with the single exception of the Cook Mountain formation, in which fossils are at least fairly abundant. In the Midway most of the layers yield a few fossils to careful search, and some carry fossils in abundance, though the number of species is restricted. The most conspicuous genus is *Venericardia,* of which there are seven species. These forms generally occur in the limestone or as casts in the clay members. The presence of *Turritella* and *Ostrea* of the types abundant in the lower Eocene of Alabama and the cephalopod *Enclimatoceras vaughani*[80] is also worthy of special note. A single block of petrified wood containing a new species of marine worm, *Teredo maverickensis,*[81] was taken from the Midway on the Rio Grande in southern Maverick County. Jewell[82] found a fairly persistent fauna (35 species) consisting of small echinoids, echinoid spines, *Teredo maverickensis* Gardner, *Volutocorbis limopsis* (Conrad), and abundant *Enclimatoceras* in oxidized greensand, the top of which is separated

[78] Getzendaner, F. M., personal communication, Aug. 26, 1927.
[79] Jewell, W. R., personal communication to Julia Gardner, July 20, 1923.
[80] Gardner, Julia, New species of Mollusca from the Eocene deposits of southwestern Texas: U. S. Geol. Survey Prof. Paper 131, p. 115, pl. 33, 1924.
[81] Idem, p. 114, pl. 32, fig. 11.
[82] Jewell, W. R., op. cit.

from the base of the Wilcox by 27 feet of dark friable shale. Also, according to Jewell, the *Venericardia whitei* Gardner constitutes a fairly constant horizon marker 71 feet above the Cretaceous-Eocene contact and 128 feet below the Midway-Wilcox contact. Mrs. Plummer[83] has described more than 125 species of Foraminifera that were found in samples of Midway sediments collected north and northeast of San Antonio, Tex.

The megascopic fossils collected from the Midway formation of this and neighboring districts by the writer and others include 13 corals, a new echinoid, the bryozoan *Conopeum damicornis* Canu and Bassler, and more than a hundred Mollusca, many of them new. Some of the previously described species are as follows:

Conopeum damicornis Canu and Bassler.
Cucullaea texana Gardner.
Ostrea pulaskensis Harris.
Ostrea crenulimarginata Conrad.
Modiolus (Brachidontes) saffordi (Gabb).
Amusium (Parvamussium) alabamiense Aldrich.
Venericardia smithii Aldrich.
Venericardia whitei Gardner.
Venericardia alticostata Conrad.
Venericardia hesperia Gardner.
Teredo ringens Aldrich.
Teredo maverickensis Gardner.
Volutocorbis limopsis (Conrad).
Neptunea (Cyrtochetus) constricta Aldrich.
Pyrula cf. P. juvenis Whitfield.
Cypraea cf. C. estellensis Aldrich.
Turritella cf. T. humerosa Conrad.
Natica cf. N. limula Harris.
Natica perspecta Whitfield?
Enclimatoceras vaughani Gardner.

Rio Grande sections.—Stephenson[84] has described most of the Midway exposures on the Rio Grande, but one is worthy of additional description.

Section of the Midway formation on the Rio Grande bluff 4¼ miles south of Windmill ranch and 2 miles east of Blesse ranch house (10, pl. 3)

[Pl. 6, *B*]

	Feet
Shale	7
Iron concretions	1
Shale	5
Concretionary sandstone	1
Blue-black shale with abundant *Venericardia smithii*	12
Concretionary iron bed containing *Venericardia smithii*	1
Dark-gray shale containing disk-shaped iron concretions and a few gastropods	25
Thin and irregularly bedded sandstone, interbedded near the top with a sandy shale	15
	67

[83] Plummer, H. J., Foraminifera of the Midway formation in Texas: Texas Univ. Bull. 2644, 1926.

[84] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pp. 169–176, 1914.

A short distance downstream from this section, all the members of which are Midway, and almost continuous with it (6, pl. 3), both Midway and Wilcox beds are exposed. This section was described by Stephenson,[85] who recognized an unconformity but did not certainly determine whether the overlying beds are Midway or Wilcox. The dark shale with interbedded sandy limestone ledges (d of Stephenson's section) is Midway. Unconformably above it lie heavier, lighter-colored sandy and shaly beds (e of Stephenson), which belong with the Indio formation of the Wilcox group. The details of this contact are illustrated photographically in Plate 6, *C*.

Baker[86] describes the Midway strata in Coahuila, across the Rio Grande from southern Maverick County and northern Webb County, Tex., as follows:

> Beds of the basal Midway are exposed on the road crossings of the two small creeks between Cerrito Prieto and Trinidad houses (11, 12, pl. 3), where there are thin beds of very sandy and fossiliferous limestone interbedded with greenishy laminated sands. On the south side of the valley of the second creek (12, pl. 3) the upper Midway consists of green clays with large green-brown limestone concretions. The Midway-Wilcox contact on the Arroyo del Amole comes about 4 miles upstream from Trinidad ranch house (13, pl. 3). The bluff on the north side of the creek shows at the base 3 feet of blue-gray clayey laminated sands succeeded by 70 feet of green-gray sandy clays with specks of glauconite, casts of marine fossils and cannon-ball septarian lime and iron carbonate concretions, the latter sometimes aggregated into a thin bed. The clay weathers green brown and contains secondary selenite. Above it comes basal Wilcox cross-bedded buff, iron-stained sandstone, forming a prominent north-south escarpment dipping east. Beween the Midway lower limestones and the upper clays comes a member of fine greenish sandstone weathering brown and sometimes cross-bedded.

Frio River sections.—About 12 miles east of the eastern boundary of the area covered by this report, on the west wall of the valley of the Frio River at Bob Evans's apiary (9, pl. 3), is a section exposing two Eocene formations between river level and the top of a 60-foot bluff. The lower 20 feet is composed of calcareous and argillaceous brownish and yellowish-gray sandstone, with a large number of spheroidal and irregular concretions of more calcareous material. The rock is not highly fossiliferous, but a large *Enclimatoceras* and numerous gastropod and pelecypod remains were collected from it. This rock is Midway. Above this and separated by an irregular line and thin conglomeratic beds is 30 to 40 feet of coarse-grained gray consolidated cross-bedded noncalcareous sandstone, without concretions and without fossils. This sandstone is Wilcox, probably belonging to the Indio formation. (See pl. 8, *A*.)

Origin.—The Midway formation is marine, as shown by its lithology and its contained fossils. It records the advance of an early

[85] Stephenson, L. W., op. cit., p. 172, pl. 17, *A*.

[86] Baker, C. L., op. cit.

Tertiary sea over the surface of Cretaceous rocks at the end of a long period of time during which the Cretaceous rocks were subjected to subaerial processes. At the end of the Midway epoch the sea withdrew, and more time elapsed before the deposition of sediment was renewed in the Wilcox epoch.

WILCOX GROUP

NAME AND CORRELATION

Generally nonmarine strata amounting to almost 1,000 feet in thickness in some places, lying above the Marine Midway and below the Marine Claiborne have been long recognized both in the East and West Gulf Coastal Plains and in the Mississippi embayment. To these strata the terms "Lignitic," "Sabine," "Sabine River," "Timber Belt," and Wilcox have been applied. The history of these and other formation names and the correlation of the strata in different places have been given by Deussen,[87] who explains that the term Wilcox, first used by Crider [88] in 1906, is the only unobjectional one, and within the last 15 years practically no other name has been applied to these strata.

SUBDIVISIONS

The post-Midway and pre-Claiborne beds have been included within a single formation in most places, but in others they have been recognized as a group divided into formations to which local names are given.

On stratigraphic and paleontologic grounds the Wilcox group in this region was subdivided in 1923 [89] into three formations, named in ascending order the Indio formation, the Carrizo sandstone, and the Bigford formation. (See footnote 8, p. 52).

INDIO FORMATION

Name.—The strata overlying the marine Midway formation and underlying the Carrizo sandstone are now designated the Indio formation. These strata were formerly known as the Wilcox formation, for they were believed to represent all the deposits of Wilcox age in this region. As explained in the preceding paragraph, however, more detailed studies led to the discovery that the Wilcox deposits as here developed consist of three formations, of which the Indio is the lowest one. The Indio formation was named from the Indio ranch, in Maverick and Dimmit Counties, which includes most of the area of outcrop of the formation within this region.

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[87] Deussen, Alexander, Geology and underground waters of the southwestern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 38-39, 1914.

[88] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 25-28, 1906.

[89] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, pp. 91-92, 1923.

Lithology.—Although it is made up of an intricate mixture of sediments, the Indio formation consists chiefly of thin-bedded and laminated argillaceous sand and arenaceous shale but includes some layers of massive clay and lenses and layers of sandstone. The clay and shale are greenish or bluish gray and light chocolate-brown, and most of them are gypsiferous. The sandstone is gray, yellow, green, and brown, is not notably cross-bedded, and is of various textures. It includes also some beds of lignite and many calcareous arenaceous concretions, most of them flat, biscuit-shaped, or millstone-shaped.

Distribution.—The Indio formation crops out in the Rio Grande region in a belt 8 to 11 miles wide, in western Dimmit County, southeastern Maverick County, and northwestern Webb County, where it is exposed in practically its full thickness.

There are few exposures north of Dimmit County, except on the Nueces River below the Pulliam ranch house, and it was thought[90] that the outcrop was cut out in turn by an overlap of Carrizo sandstone on the Cretaceous. Getzendaner[91] believes that the outcrops in Dimmit County and southeastern Maverick County and on the Nueces River in northern Zavala County are connected by a narrow belt of outcrop, and there is a narrow but continuous belt of low flat ground here, affording few exposures, separating outcrops of Cretaceous on the west, northwest, and north from outcrops of Carrizo sandstone on the east, southeast, and south. (See pls. 3 and 7.)

Thickness.—The thickness of the Indio recorded in the Hanchett wells, in Dimmit County, is 648 feet, but as the sites of these wells are west of the eastern boundary of the formation, this figure does not represent the full thickness. According to Getzendaner,[92] well No. 1 of the City National Bank penetrated 815 or 877 feet of Indio strata, and this represents the full thickness of the formation in this locality.

Fossils.—Strata of lower Wilcox age on the Sabine River have long been known to contain marine fossils,[93] but the marine fossils in the Wilcox in southwestern Texas were not recognized for some years. Oysters that have been thought to be *Ostrea crenulimarginata* and to belong in the Midway have now been found to be *Ostrea multilirata*[94] (see pls. 34, 35) and to belong in the Indio, and marine Foraminifera, including *Nodosaria*, *Textularia*, and *Globigerina*, together with the

[90] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 90 and pl. 28, 1923.

[91] Getzendaner, F. M., Geologic section of Rio Grande embayment, Texas, and implied history: Am. Assoc. Petroleum Geologists Bull., vol. 14, No. 11, fig. 1, 1930.

[92] Getzendaner, F. M., personal communication, Aug. 26, 1927.

[93] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River; U. S. Geol. Survey Prof. Paper 126, p. 47, 1924.

[94] Gardner, Julia, New species of Mollusca from the Eocene deposits of southwestern Texas; U. S. Geol. Survey Prof. Paper 131, pp. 109-110, 1923; The restoration of *Ostrea multilirata* Conrad, 1857: Washington Acad. Sci. Jour., vol. 16, p. 513, 1926.

gastropod *Levifusus* cf. *L. trabeatoides*, have been found associated with the oysters at a number of places in Dimmit County.

In the City National Bank well No. 1–A arenaceous Foraminifera were found at 331, 381, 406, and 531 feet above the base of the Indio formation; in the City National Bank well No. 2–A at 200, 550, and 575 feet above the base; and in City National Bank well No. 3–A at 256, 324, 681, and 715 feet above the base. At 681 feet above the base of the formation a piece of large oyster, possibly *O. multilirata*, occurred with the Foraminifera.[95]

According to Jewell[96] there are marine fossils representing 24 species about 190 feet above the base of the Indio in southern Maverick County.

All the marine molluscan fossils so far known in the Wilcox of Texas (see pls. 34–39) are described and interpreted by Miss Gardner,[97] who finds that faunas from Bexar and Wilson Counties are of upper Wilcox age and closely related with the marine faunas at Sabinetown, on the Sabine River, and that the Maverick County fauna of Jewell is lower Wilcox and of about the same age as faunas from Pendleton, on the Sabine River, and from Greggs Landing, Ala. From this she concludes that the Indio strand line must not have been seriously interrupted from the Rio Grande to the Alabama River.

Fossil leaves were found on the west wall of the valley of the Nueces River a mile below the Pulliam ranch (15, pl. 3), on the east wall of the valley of the Nueces River at the big bend 1¼ miles above the Uvalde-La Pryor road crossing (16, pl. 3), in the clay pit at the end of the unused aerial tram south of Elmendorf, Bexar County, and at the Schuddemagen ranch, 10 miles south of Sabinal, Uvalde County (17, pl. 3). The last two localities are outside the area mapped on Plate 7. The list of identified species includes *Anona ampla* Berry, *Anona eolignitica* Berry, *Cyperites* sp. Hollick, *Ficus mississippiensis* Berry, *Nectandra* sp., *Oreodaphne obtusifolia* Berry, *Rhamnus coushatta* Berry, *Sabalites grayanus* Lesquereux, and *Sapindus linearifolius* Berry. (See pl. 36.)

Rio Grande sections.—The Indio formation is exposed at a number of places on the Rio Grande between the section of the Midway-Wilcox unconformity 2 miles above the Maverick-Webb County line and the old Sullivan place, south of the Chupadero ranch.

The section 2 miles above the Maverick-Webb County line (6, pl. 3), which is described on page 36 and which shows both probable Midway and the Indio formation, is further illustrated in Plate 8, *B*.

[95] Getzendaner, F. M., personal communication, Aug. 26, 1927; Geologic section of Rio Grande embayment, Texas, and implied history: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 1434, 1930.

[96] Jewell, W. R., personal communication to Julia Gardner, July 20, 1923.

[97] Gardner, Julia, Fossiliferous marine Wilcox in Texas: Am. Jour. Sci., 5th ser., vol. 7, pp. 141–145, 1924.

Section at mouth of first creek above Bluff Crossing on the Rio Grande (just south of point 6, pl. 3)

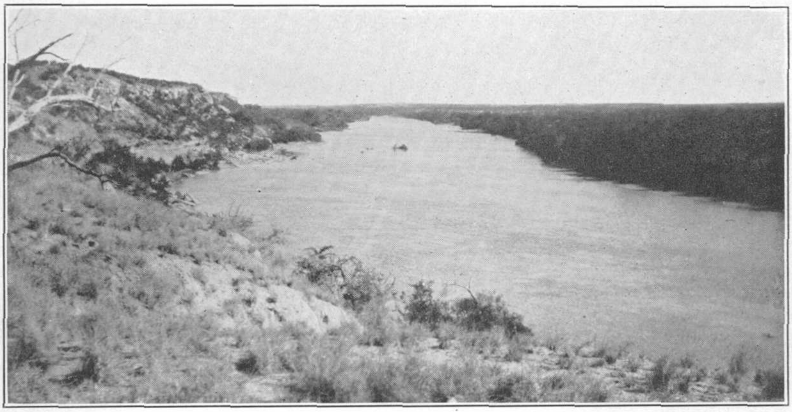
	Feet
Indio formation:	
Gypsiferous shale.	
Coarse-grained micaceous sandstone, unevenly thin-bedded, containing numerous flakes of black carbonaceous material	10–15
Probably Midway formation: Dark-gray shale with discus-shaped limy iron concretions that have been fractured and contain secondary calcite and pyrite	4

The line of contact between the lower shale and the overlying sandstone is irregular, suggesting unconformable relations. The lower shale, which is notably unlike the shale above the sandstone and the shale of the Indio formation in general, is probably of Midway age, although no fossils were found in it; apparently this section affords another exposure of the Midway-Wilcox unconformity which is so well seen a quarter of a mile farther up the river. (See p. 36.) The sandstone of this section is charged with water, which sprays out when the rock is struck with a hammer. There is a bubbling spring of bitter water from the sandstone just above its contact with the shale, around which the sandstone is coated with a white powder that is bitter to the taste.

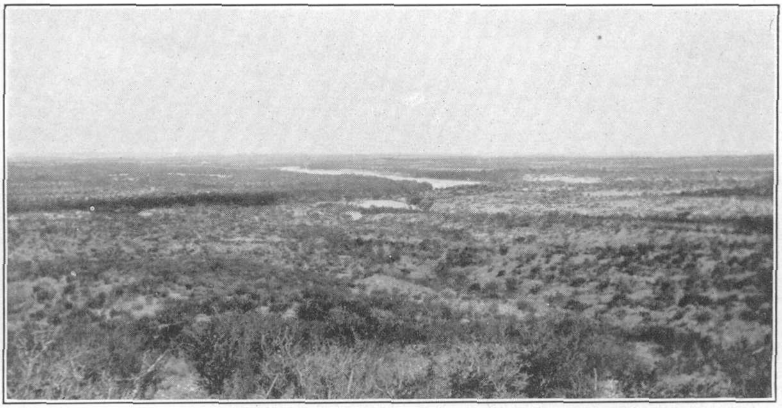
Section of Indio formation 1½ miles above Bluff Crossing on the Rio Grande (18, pl. 3)

	Feet
Single layer of sandstone characterized by irregular seams of hematite along planes of cross-bedding	5
Thick-bedded massive and flaggy sandstone	20
Scaly, wavy laminated sandy shale, dark gray and purplish	15
Sandstone, evenly bedded as a whole but with a few thin sets of indefinite cross beds; ripple marks conspicuous	15
Wavily bedded sandy shale containing thin lenses of resistant sandstone, some of which are coated with white, powdery, bitter material	2
Concealed by talus of heavy blocks aud slabs of sandstone to top of terrace along Rio Grande	25

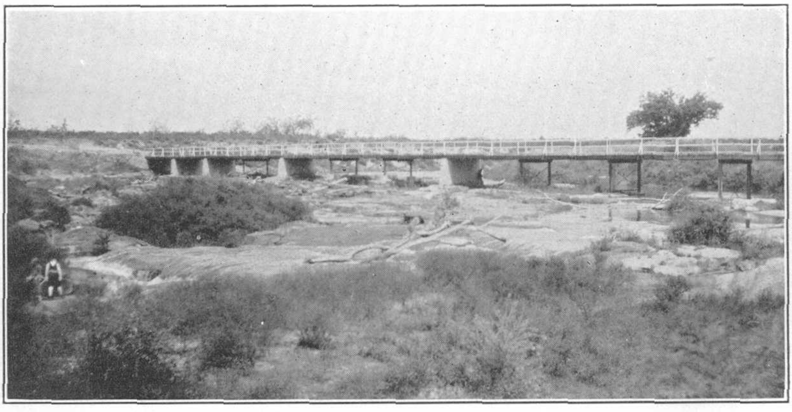
No bedrock is exposed on the Rio Grande between Bluff Crossing and the mouth of San Ambrosio Creek, the valley wall consisting for this distance of a high silt terrace. There is, however, an interesting exposure less than a mile from the river in the bed of the unnamed creek that heads near the Windmill ranch, where the creek is crossed by the road between the Chupadero and Windmill ranches, 9.3 miles west of the Chupadero ranch (19, pl. 3). There about 8 feet of thin-bedded soft argillaceous sandstone containing several large but squat calcareous sandstone concretions is exposed. The concretionary material, though sandy, effervesces freely with acid, but the sandstone does not effervesce. The calcium carbonate has



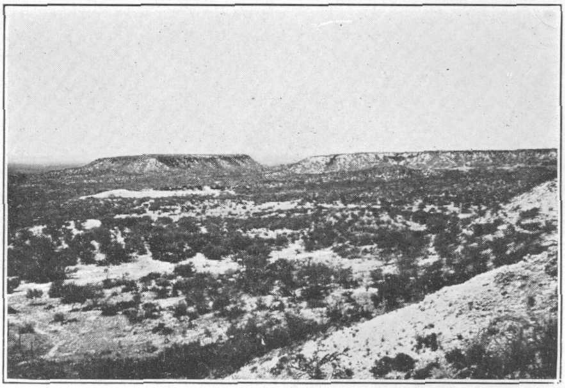
A. THE RIO GRANDE BELOW THE MOUTH OF CONCILLOS CREEK



B. BREAKS OF THE RIO GRANDE BELOW THE WINDMILL RANCH

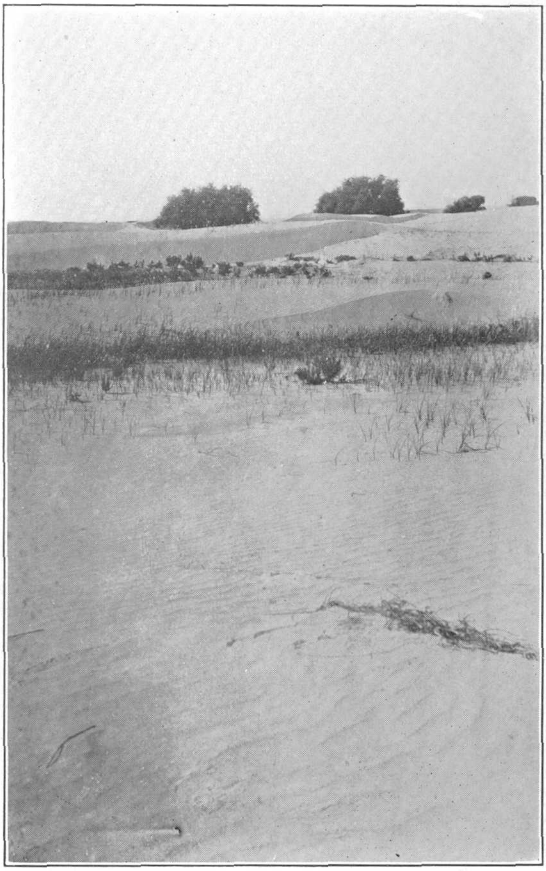


C. ESPANTOSA LAKE EAST OF CRYSTAL CITY IN TIME OF FLOOD



A. THE BORDAS ESCARPMENT IN THE MIRANDO VALLEY OIL FIELD

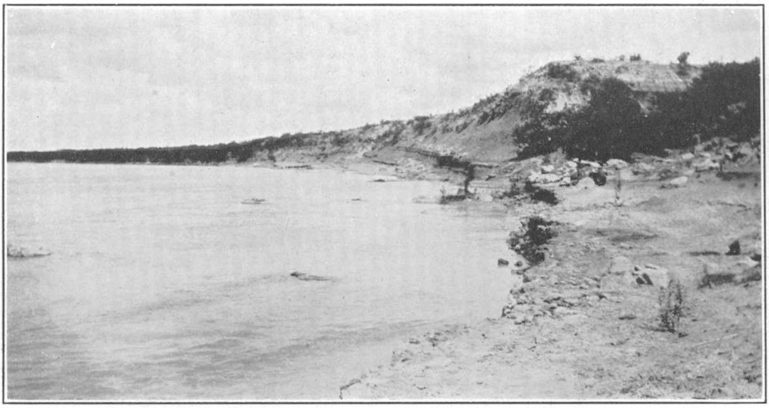
Photograph by W. S. Glock.



B. MIGRATING DUNES IN THE SAND BELT

Photograph by Lloyd North.

A. THE GULF COAST SOUTHEAST OF RAYMONDVILLE
Photograph by W. S. Glock.



B. MIDWAY FORMATION IN THE BEND OF THE RIO GRANDE EAST OF BLESSÉ RANCH

WILCOX-MIDWAY UNCONFORMITY AT THE BEND OF THE RIO GRANDE BELOW BLESSÉ RANCH HOUSE been concentrated only in certain sandy beds, and the bases and tops of these beds mark the bottoms and tops of the concretions, so that their diameter parallel to the bedding is several times their thickness normal to the bedding. The result is a form similar to that of a millstone. One of the concretions is 6 feet in diameter measured horizontally and 1½ feet measured vertically.

Several sections in the Indio formation are exposed in the valley of San Ambrosio Creek west of the Chupadero ranch. At the road crossing (20, pl. 3) flaggy iron-cemented sandstone crops out, with round iron concretions half an inch in diameter, gray selenitic clay, and a 2-inch layer of iron weathering concentrically to form thin bands of various shades.

About 1,000 feet downstream from the road crossing and 2¼ miles from the Rio Grande, on the east wall of the valley of San Ambrosio Creek, there is a 40-foot vertical face for a horizontal distance of 250 feet. The beds consist of thin-bedded, wavily laminated ripple-marked sandstone and shale. There is little pure sandstone and equally little pure shale; the sandstone is shaly, and the shale is sandy. Thin beds can be traced continuously for 150 feet in the cliff. Where the sand beds are ripple marked the shallow troughs of the ripples have been filled with shale in such a way as to cause scales to form and break out. The sandstone is micaceous. No fossils were found in this section. The strata dip 3°-4° NE.

Between the mouth of San Ambrosio Creek and the old Sullivan place (21, pl. 3) there is a bluff of the Rio Grande from 40 to 80 feet high. Heavy sandstone ledges of the Carrizo formation grade downward through somewhat thinner and more distinctly bedded sandstone and dark-gray clay into thin-bedded sandy shale of the Indio practically identical with that which crops out 2 miles to the north and west, as described in the last paragraph. There is no evidence of unconformity between the Carrizo and the Indio at this place. Perhaps these two formations are unconformable only where the Carrizo overlaps the upper part of the Indio, and in this locality the full thickness of the Indio is represented.

Nueces River sections.—Between the railroad crossing at Pulliam and the old Uvalde-La Pryor road crossing, a distance of about 5 miles, the Indio formation is exposed in several places along the Nueces River. Except for the thin bed described on page 32, which may be Midway, there is no Midway between the Indio and the Cretaceous on the Nueces River, the Midway outcrop having been eliminated either by faulting or by overlap. Some of the Indio sections are capped by thin layers of the Carrizo and a short distance below the Uvalde-La Pryor road crossing the Indio dips under the

Carrizo. The structure here is complex, reversed dips and faults of small throw being fairly common.

All these sections have been described by Vaughan[98] and Deussen.[99] The materials exposed in the thickest and best section, which is at Bee Bluff on the east side of the river, on the outside of the big bend, about 2 miles above the Uvalde-La Pryor road crossing (16, pl. 3), consist of very thin-bedded and laminated sandstone and sandy shale with at least three beds of lignite coal. The sandstone is noncalcareous. The section is remarkable for the evenness and uniformity of stratification lines, as illustrated in Plates 9 and 10. At the lower end of Bee Bluff the Indio formation is unconformably overlain by the Carrizo sandstone as shown in Plate 10, *A*. Berry found three species of fossil leaves in this section, all of Wilcox age.

A section five-eighths of a mile above the road crossing (22, pl. 3) is shown in Plate 9, *C*. In a section 1 mile below the Pulliam ranch house (15, pl. 3) Berry found and later identified *Anona ampla* Berry, *Anona eolignitica* Berry, *Cyperites* sp. Hollick, *Oreodaphne obtusifolia* Berry, *Sabalites grayanus* Lesquereux, and *Sapindus linearifolius* Berry. (See pl. 36.)

Sections containing Ostrea multilirata.—Strata belonging stratigraphically about in the middle of the Indio formation are exposed at two places near the Glass ranch house.

Section a quarter of a mile east of the Glass ranch on the road to the English ranch (23, pl. 3)

	Ft.	in.
Oyster bed (*Ostrea multilirata* Conrad) consisting entirely of shells, more or less broken	2	3
Bluish-gray shale		4±
Thin-bedded soft gray fine-grained sandstone	6±	

Section at tank a quarter of a mile north of the Glass ranch (24, pl. 3)

	Ft.
Oyster bed (*Ostrea multilirata* Conrad)	3±
Sandy shale and shaly micaceous sandstone interbedded; both weather and break into scales or irregular plates	10

Analyses of samples taken from the exposure at the tank are given on page 47.

The occurrence of oysters about 12 miles west of Carrizo Springs (25, pl. 3) has been reported by Udden,[1] Matson,[2] and Baker.[3] By all these observers the oyster was identified as *O. crenulimarginata*, but Miss Gardner has included Matson's collection from this place in

[98] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields in Texas: U. S. Geol. Survey Bull. 164, p. 49, 1900.

[99] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 55, 1924.

[1] Udden, J. A., field notes.

[2] Matson, G. C., field notes.

[3] Baker, C. L., personal communication.

Ostrea multilirata Conrad.[4] (See pls. 34, 35.) The outcrop is not far northwest of the L. E. Hanchett wells Nos. 1 and 2, in the eastern part of Green Davidson's Comanche pasture, and the oyster bed dips under the well site, where it is probably represented in the log below by a foraminiferal zone 125 to 148 feet below the surface.

There is another exposure of this oyster-bearing bed 8 miles northwest of the San Pedro ranch on the Maverick-Dimmit County line, about 6 miles south by southeast from the Glass ranch exposures (26, pl. 3), and the bed may be continuous between these two places. The rock with which the oysters are associated is not well exposed, but from surface indications it is clay or shale. Near by there is also thin-bedded shaly sandstone.

Subsurface sections.—An almost complete section of the Indio formation, including foraminiferal beds near the middle of the formation, as well as of the Midway and of some Cretaceous formations, is obtained from the Hanchett wells.

Logs of L. E. Hanchett wells 1 and 2, Dimmit County, 10 miles west of Carrizo Springs (27, pl. 3)

[Descriptions by subsurface department of Bureau of Economic Geology of the University of Texas interpretation by C. L. Baker; log furnished independently by J. A. Udden and C. L. Baker]

	Feet
Tertiary:	
Wilcox—	
Mostly gray marl, with sand, sandstone, and clay	0–110
Sandstone, gray, mostly soft, with some loose sand at top and bottom. Marine Foraminifera from 125 to 148 feet (*Nodosaria, Textularia, and Globigerina*)	110–148
Clay, gray, limy and silty, with some gray limy sandstone. Clay slakes in water	148–175
Clay and sand, dark gray, with mica particles and lignite. Clay slakes in water	175–245
Sandstone, gray and mica bearing, with silty clay and lignite	245–251
Sandstone, gray, fine grained, with mica and lignite	251–300
Sand, fine, gray, micaceous. Some lignite at base	300–323
Clay, silty, and sand, fine, gray, micaceous	323–344
Sandstone, soft, light gray, micaceous; some clay and lignite	344–372
Clay, dark gray, silty; slakes in water; some lignite	372–378
Sandstone, soft, fine grained, gray, micaceous and lignitiferous, some of it with black clay streaks	378–402
Clay, gray, silty, with black lignitic layers	402–436
Sandstone, soft, fine grained, light gray, limy, micaceous and with darker lignitic layers	436–452
Clay, brownish, dark and light gray, silty; slakes in water	452–480
Clay like preceding, with sandstone of dark lignitic and light micaceous layers	480–490

[4] Gardner, Julia, New species of Mollusca from the Eocene deposits of southwestern Texas: U. S. Geol. Survey Prof. Paper 131, p. 110, 1923; On the restoration of *Ostrea multilirata* Conrad: Washington Acad. Sci. Jour., vol. 16, pp. 513–514, Nov. 18, 1926.

	Feet
Tertiary—Continued.	
Wilcox—Continued.	
Clay, dark, very fine, with slip joints	490–500
Clay, dark brown and lignitic, with some silt	500–526
Sandstone, fine, soft, gray; some clay, mica flakes and lignite in layers	526–559
Clay, gray, silty, with thin layers of light-gray mica-bearing sand	559–578
Sandstone, soft, fine grained, light gray, with thin layers of lignitic shale	578–592
Clay, blackish brown, silty, with darker hard lumps	595–615
Silt, brownish black, with a little clay, mica, and lignite	615–625
Clay, brownish gray, lignitic; some sand and mica	625–635
Sand, fine, gray, with lignite and mica	635–648
Midway—	
Clay, dark gray, silty	648–710
Clay, gray, silty, with some fine greenish gray sand	710–720
Clay and silt, gray, with a little mica and gray sand	720–730
Clay, gray, silty, with greenish-gray limy sandstone	730–750
Clay, dark gray; some sandstone below 800 feet	750–836
Greensand, from almost black to dark grayish green; a gritty rock, soft, white, or grayish, with black mica, may be volcanic ash; and limestone, light gray, crystalline	836–842
Cretaceous:	
Escondido—	
Clay, gray, silty and limy, with some soft greenish-gray sandstone	842–895
Silt, marly, gray; some greensand and mica	895–910
Sandstone, fine grained, gray, with lime, greensand, and mica	910–950
Marl, dark gray, silty, with greensand	950–990
Shale, dark gray; some greensand and quartz sand	990–1, 010
Silt, dark gray, marly, with greensand, mica, and some gray sandstone (in lower part)	1, 010–1, 030
Sandstone, light gray, fine, with some dark gray marly silt, also greensand	1, 030–1, 070
Sandstone, light gray, with some silt, greensand, and mica	1, 070–1, 190
Shale and sandstone, dark gray, marly; some greensand and mica. Sandstone fine grained. Little coal at 1,420 feet. Base of Escondido comes between 1,410 and 1,420 feet	1, 190–1, 470
San Miguel—	
Sandstone, gray, some coal and mica	1, 470–1, 490
Sandstone and shale, gray; some mica	1, 490–1, 520
Sandstone, gray, and shale, dark gray; much asphalt; gas somewhere here	1, 520–1, 550
Sandstone, gray, and shale, dark gray; some mica and greensand	1, 550–1, 560
Sandstone, gray, fine, with mica. A little asphalt between 1,570 and 1,580 feet	1, 560–1, 600
Sandstone, gray, with some lignite. Asphalt at 1,630 feet	1, 600–1, 640
Shale, dark gray, marly. Fossil shells at 1,660 feet; some lignite with fossil shells at 1,720 feet	1, 640–1, 740

Cretaceous—Continued.

San Miguel—Continued.

	Feet
Shale, gray, marly, and sandstone, limy, fine, gray; some lignite and asphalt	1, 740–1, 750
Sandstone and shale, gray; some lignite at bottom	1, 750–1, 770
Sample shows dark blue-gray clay containing fine sand	1, 800
Sample shows blue-gray fine sandy clay. Cast of very small *Cardium*. A little light-gray sandstone	1, 900
Clay, rather compact, dark gray, with much lime and considerable very fine sand	1, 950–1, 990
Sample similar to that at 2,090 feet but with less pyrite and more secondary calcite	2, 000
Medium dark blue-gray clay and light-gray cemented fine quartz sand. Sand apparently occurs in thin interbeds. Pyrite fairly abundant. Below 2,085 feet clay becomes sandier and sand becomes coarser. Artesian sandstone bearing salt water at 2,115 feet, fairly coarse, almost entirely made up of quartz grains, cemented by calcite	2, 090
Sandstone, finer and of a brownish tint from limonite stain	2, 135
Gas	2, 135–2, 140
Alternations of lighter-gray fine soft sandstone and dark blue-gray sandy clay. Cement of sandstone is $CaCO_3$. Some oil-bearing sand	2, 140–2, 170
Medium-grained quartzose sand; salt water with artesian pressure. Sand becomes finer below 2,185 feet. Considerable lime in the cement. Gas in this or succeeding member	2, 170–2, 215
Light-gray friable sandstone, medium grained. Base of San Miguel	2, 220–2, 240
Light gray-blue very fine and flocculent clay, limy. A little asphalt at 2,258 feet. Some very light gray volcanic ash at 2,283 feet	2, 240–2, 283

Sections outside the region.—The lower Wilcox section on the Frio River in Uvalde County (9, pl. 3) has been described on page 36.

Stephenson [5] has described a section on Elm Creek, 11 miles south of Sabinal (17, pl. 3), in the eastern part of Uvalde County, in which he recognizes the Midway and Escondido formations. In pockets on the upper surface of the limestone assigned to the Midway he found oysters which have now been identified as *O. multilirata* Conrad. A single fossil leaf was found in the member directly above the limestone and identified by Berry as *Rhamnus coushatta* Berry, a Wilcox form. Because of these two fossils, neither of which has ever been found in the Midway and the first of which is characteristic of the Indio in this region, member No. 5 of Stephenson's section is taken out of the Midway and placed in the Indio formation.

[5] Stephenson, L. W., Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, p. 173, 1914.

On the east side of Sabinal Creek 4 miles in a straight line below the Schuddemagen ranch (28, pl. 3) is an exposure of heavy black-weathering hard ledges of calcareous sandstone indurated almost to quartzite, with inconspicuous yellow silty and sandy beds between. No fossils were found here, but small iron concretions are plentiful. This section probably belongs with the Indio formation.

Baker[6] has described the Indio formation and its relations with the Carrizo near the Rio Grande on the Mexican side, across from the Chupadero ranch. He applies the older term Wilcox to what is called in this report the Indio formation. His descriptions of the sections are as follows:

Wilcox Eocene.—The Wilcox is rather well exposed along the lower 8 miles of the Arroyo del Amole, which enters the Rio Grande just opposite the Chupadero ranch house. The basal beds are sands and sandstone, light gray and buff, often cross-bedded. Higher up are sandstones, sands, sandy clays, and clays. The sandstones vary from laminated to massive and are often cross-bedded and ripple marked. The sandy clays are often carbonaceous and are thinly laminated. There are here clays characteristic of the Wilcox wherever the writer has seen that formation west of the Mississippi, unctuous joint slip clay, a blue-gray when unweathered but weathering a rich brown on the Amole. The clays contain some beds of sphaerosiderite, now altered largely to limonite, and the mineral is also found in septarian concretions. The little lignite seen is in very thin beds. The sandstones often carry clay ball pebbles. All the above different materials are interbedded.

Unconformity between Wilcox and Carrizo.—The last bluff on the Arroyo del Amole is on the southeast side about a mile above its junction with the Rio Grande (29, pl. 3.) On the upstream side the Wilcox consists of brown and gray sands and sandstones and carbonaceous sandy shales. The downstream part of the bluff is Carrizo massive buff cross-bedded soft sandstone. The strata are practically horizontal along the line of the bluff. The contact between the two formations dips 10° N. and transgresses a thickness of 40 feet of the Wilcox in the exposed part and undulates along the eroded surface of the Wilcox This line of unconformity shows the greatest relief of any ever seen anywhere in the Eocene of the Gulf Coastal Plain. It should be recalled that the Carrizo at most places in Texas is an overlapping formation.

Laboratory analyses.—The results of laboratory analyses of samples from the Indio of this region are given below.

Analysis of basal conglomerate of the Wilcox group on the Frio River at Bob Evans's apiary (sample 02161) (9, pl. 3)

Mineralogy and lithology.—Quartz; feldspar (abundant); plagioclase and orthoclase (more weathered than fresh); zircon (crystal faces apparent); calcite; volcanic ash in small quantities below ⅛ millimeter in diameter; fish remains; chiefly teeth; soluble in acid, probably $CaCO_3$ and $CaPO_4$; other minerals unidentified. Sandstone, grains ½ millimeter in diameter, ferruginous, fragments from preexisting formations.

Size.—On boiling with 18.5 per cent HCl 37 per cent was dissolved. Mechanical analysis of the insoluble residues resulted as shown in Figure 1.

[6] Baker, C. L., unpublished report.

Shape.—Only a few of the grains above ¼ millimeter in diameter show evidence of abrasion. Finer material is all angular.

Cement.—The cement is soluble in acid and appears to be primary. It is probably $CaCO_3$.

Bedding.—The conglomerate layer is discontinuous and consists of small dark pebbles or pellets and many worn and unworn shark teeth.

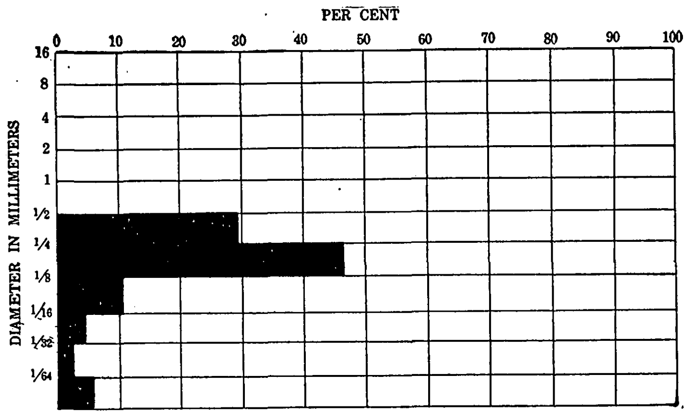


FIGURE 1.—Mechanical analysis of insoluble residue from sample 02161

Analysis of material 6 feet below oyster bed at tank a quarter of a mile north of the Glass ranch (sample 02168) (24, pl. 3)

[See section on p.42]

Mineralogy and lithology.—Quartz, 80 per cent; feldspars, 10 per cent; $CaCO_3$, 5 per cent; muscovite, kaolinite, limonite, tourmaline, and zircon, 5 per cent. The mineral composition is notable for a high percentage of quartz, a relatively large amount of muscovite, and rarity of heavy minerals. The sample contains little amorphous clay.

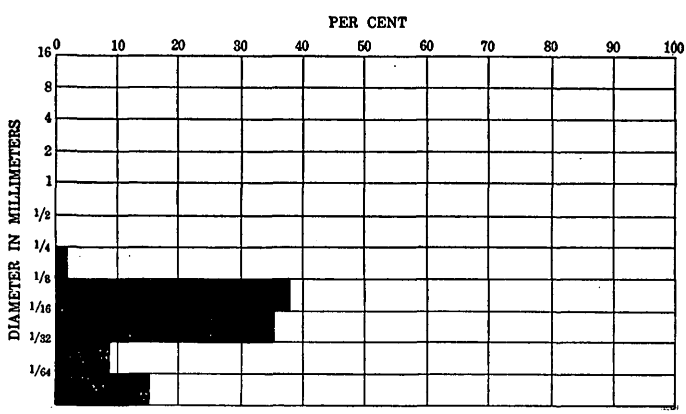


FIGURE 2.—Mechanical analysis of insoluble residue from sample 02168

Size.—For mechanical analysis of residues after solution of 5 per cent of sample in 18.5 per cent HCl see Figure 2.

Shape.—Very angular. Quartz grains show fractures. Mica flakes lie flat parallel to bedding planes.

Packing and pore space.—Grains not closely packed. Interstices filled with finer material and $CaCO_3$.

Cement.—Rock friable as a whole but breaks up in resistant aggregates cemented with $CaCO_3$.

Color.—Yellowish gray; darker along bedding planes. Yellow color probably due to oxidation of iron on account of rock being more permeable to water.

Organic remains.—Small fragments resembling wood fiber occur sparingly. No fish remains and no Foraminifera.

Analysis of material 10 feet below the oyster bed at tank a quarter of a mile north of the Glass ranch (sample 02169) (24, pl. 3)

[See section on p. 42]

In all respects similar to sample 02168 except for texture.

Size—See Figure 3.

Fossils.—Specifically unidentified Foraminifera occur in this sample.

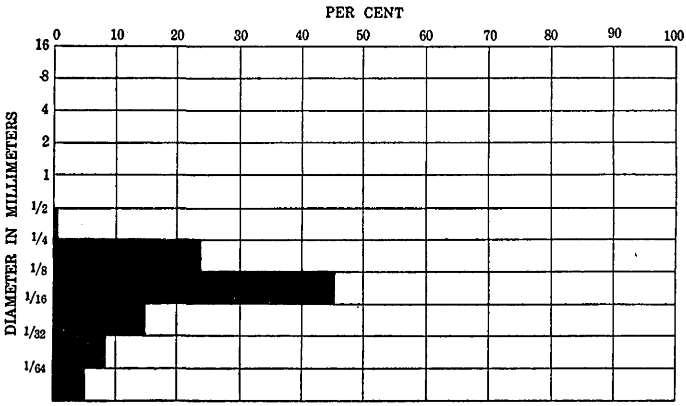


FIGURE 3.—Mechanical analysis of residue after dissolving 7 per cent sample of 02169 with HCl

Analysis of a series of samples from a single section of the Indio formation near the Maverick-Webb County line (19, pl. 3)

[Samples collected by E. B. Stiles and furnished by the Bureau of Economic Geology of the University of Texas. Analyzed by Max Littlefield]

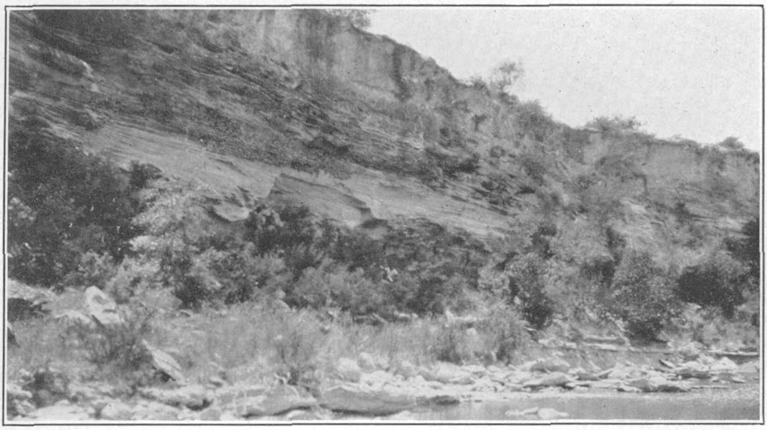
As shown in Figures 4–9 the sediments are progressively finer from bottom to top of the section.

Color.—All samples gray-black. Some staining by limonite in joints and in bedding planes.

Bedding.—Lamination more apparent on samples from upper part of section. Lower part more massive.

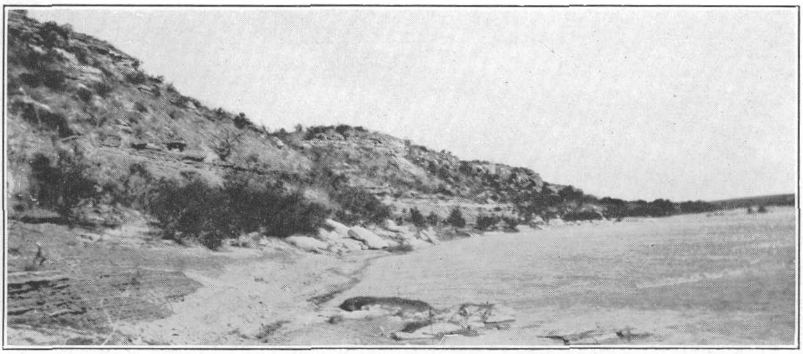
Mineral content.—Feldspar abundant, but less than 10 per cent of grades above 1/32 millimeter. Glauconite abundant down to 1/64 millimeter and probably below. Except in sample 02098 glauconite makes up 10 per cent of samples. Mica, chiefly muscovite and altered biotite, common in coarser grades of some samples. Limonite present but secondary. Some carbonized plant fragments.

Interpretation.—It is clear from the evidence of unconformity at the base of the Indio that deposition was interrupted in this region after the Midway beds had been laid down, that weathering and erosion followed, and that deposition was resumed at the beginning of the Indio epoch. It has long been thought that the Indio formation (Wilcox of previous publications on this area) was wholly of non-marine origin, but the foregoing descriptions demonstrate that in the

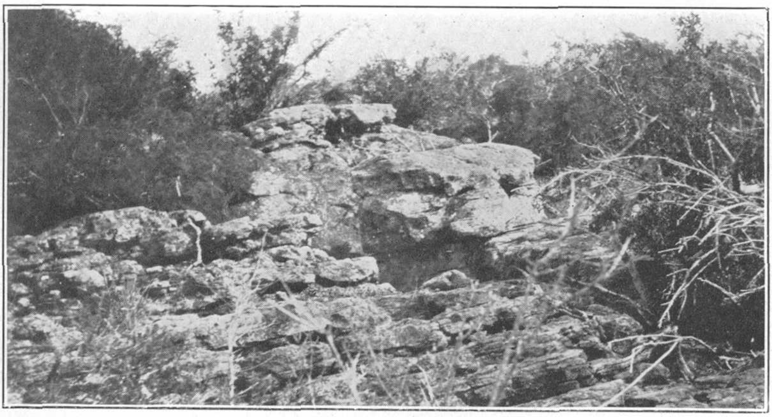


A. WILCOX-MIDWAY UNCONFORMITY ON THE FRIO RIVER AT BOB EVANS'S APIARY

Photograph by L. W. Stephenson.

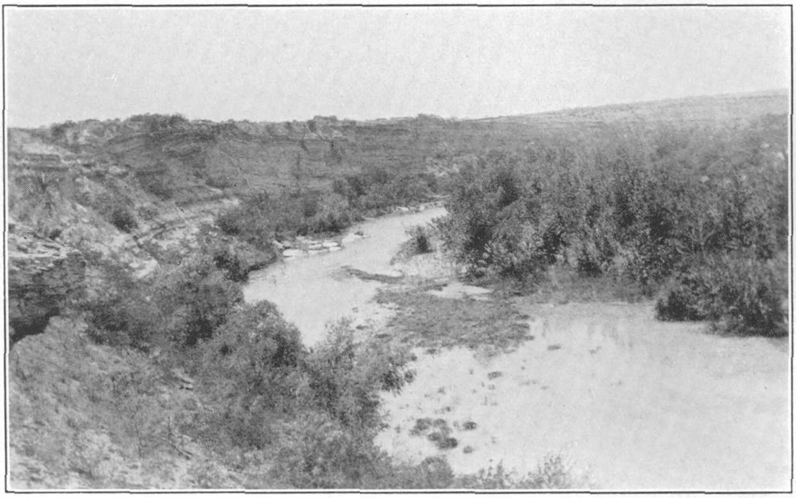


B. MIDWAY AND WILCOX STRATA IN THE BEND OF THE RIO GRANDE BELOW BLESSÉ RANCH

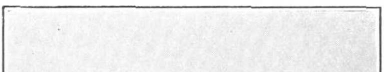


C. QUARTZITE IN CARRIZO FORMATION ON A HILL 1 MILE SOUTHEAST OF THE FLOWER RANCH, IN DIMMIT COUNTY

Photograph by A. G. Maddren.



A. INDIO STRATA IN THE BEND OF THE NUECES RIVER BELOW PULLIAM



B. FAULT IN THE INDIO FORMATION AT BEE BLUFF, 2 MILES ABOVE THE UVALDE-LA PRYOR ROAD CROSSING ON THE NUECES RIVER

Photograph by A. G. Maddren.

C. INDIO FORMATION FIVE-EIGHTHS OF A MILE ABOVE THE UVALDE-LA PRYOR ROAD CROSSING ON THE NUECES RIVER

Photograph by A. G. Maddren.

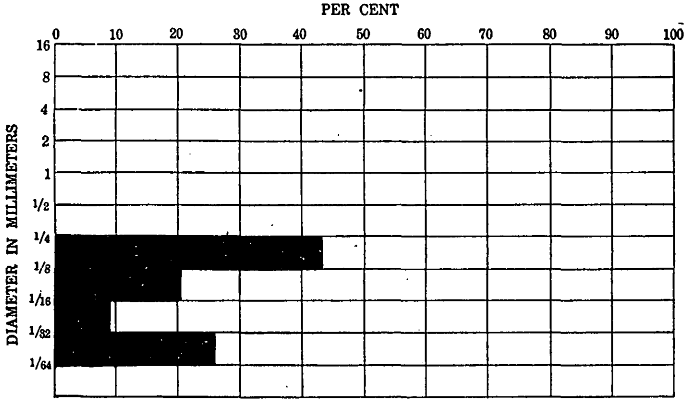


FIGURE 4.—Mechanical analysis of sample 02097, *from* base of section of **Indio formation** near Webb-Maverick County line

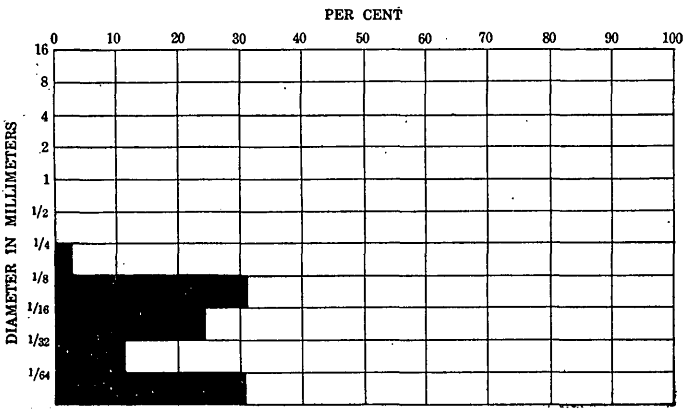


FIGURE 5.—Mechanical analysis of sample 02095, 5 feet above base of section of **Indio** formation near Webb-Maverick County line

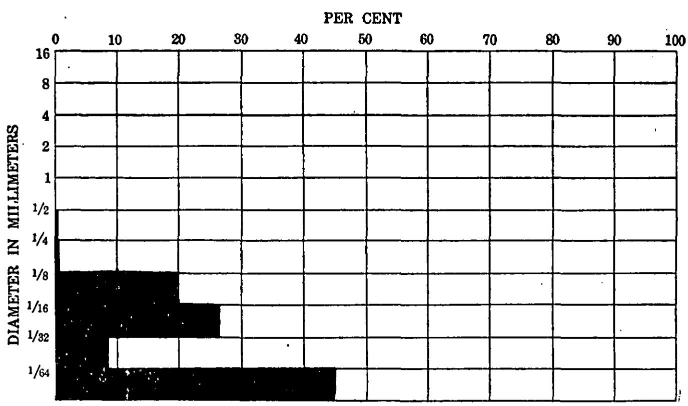


FIGURE 6.—Mechanical analysis of sample 02093, 10 feet above base of section of Indio formation near Webb-Maverick County line

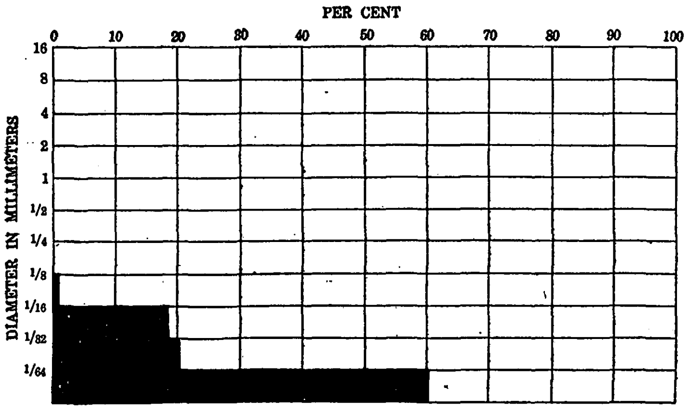


FIGURE 7.—Mechanical analysis of sample 02094, 18 feet above base of section of Indio formation near Webb-Maverick County line

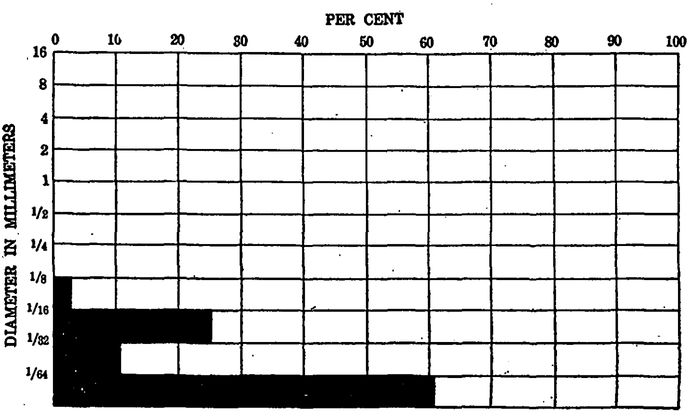


FIGURE 8.—Mechanical analysis of sample 02096, 26 feet above base of section of Indio formation near Webb-Maverick County line

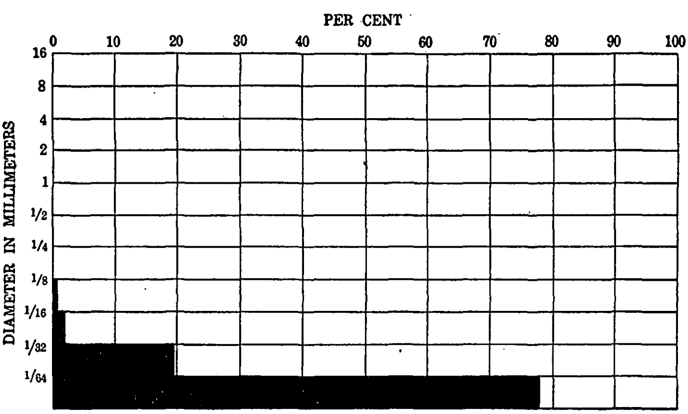


FIGURE 9.—Mechanical analysis of sample 02098, 34 feet above base of section of Indio formation near Webb-Maverick County line

lower Rio Grande region it is at least partly marine. The evidence for this conclusion is to be found in the Foraminifera obtained in the Hanchett and National City Bank wells, the associated oyster beds, and the marine fossils near the base of the formation. Along the Sabine River in northeastern Texas and in Bexar, Wilson, Guadalupe, Caldwell, and Bastrop Counties strata of Indio age contain marine fossils.

The interbedded shale and sandstone in more or less definite and continuous beds, the general absence of lens and pocket structure, the relatively fine texture and low textural range, the basal fish remains and glauconite, and the cross-bedding and ripple marks in parts of the formation that do not contain marine fossils indicate that these beds also, even though not marine, were deposited close to a strand line. The lignite recorded in the well logs and laboratory analyses suggests the presence of lagoons such as those which occur back of strand lines. The formation is doubtless partly marine and partly nonmarine and was deposited on both sides of a shore line on low land and in a shallow sea. The shore line probably oscillated back and forth slowly during Indio time.

The source and conditions of derivation and transportation of the sediments are not entirely clear, although tentative conclusions are warranted. The presence of original and unweathered minerals within the formation, including the feldspars, the micas, and zircon, suggests that mechanical disruption and transportation kept ahead of chemical weathering. This could have been accomplished if the areas of erosion at the sources of sediment were high and the climate not too warm or too moist.

There is no known source nearer than the mountains of Colorado, New Mexico, and northern Mexico for the large amount of quartz and feldspar and smaller amounts of zircon and other materials which this formation contains. Although the constituent grains are angular, it is thought that they might have been transported so far by streams, for they are no more angular than the grains of quartz, augite, and other minerals that make up bars offshore from the mouths of the Mississippi River and that were transported still greater distances. The grains in the Indio formation, like those in the Mississippi Delta bars, are so near in size to the lower limit of water rounding that they could have been transported great distances without noticeable rounding. Especially would the crystal edges of the zircon be preserved in spite of transportation for long distances.

The Cretaceous rocks of the Edwards Plateau, immediately to the west and northwest, consist chiefly of cherty limestone and shale, which would not furnish the crystalline quartz and feldspar of the Indio formation. This area may have contributed sediment to the streams that flowed across it, transporting their loads from the mountains to the Gulf, but most of the large and heavy pieces of chert would be left, and most of the dissolved carbonates from the limestone and the collodial clay from the shale would be carried out to sea and distributed widely beyond the coastal border. It is not probable that the known Cretaceous rocks of the plateau were covered with sandy rocks of later Cretaceous or early Eocene age that were entirely removed in the derivation of the Indio and later Eocene formations.

Although the flora collected from the Indio is too scanty for certain and detailed ecologic conclusions, most of the plants, according to Berry,[7] are coastal types of warm-temperate climates, such as grow in low coastal areas in which are lagoons and barriers. The gypsum in the formation suggests aridity or semiaridity, but the evidence is not conclusive, for the gypsum appears to be secondary wherever it is seen in sections. The special significance of the peculiar flattened concretions and the bedded iron ore is not clear.

CARRIZO SANDSTONE [8]

Classification.—Owen [9] first recognized a sandy phase of the Eocene overlying the "Lignitic" (Indio formation of this report) and stated that it had a thickness of 200 feet and cropped out "from a point on the Nueces River south of Uvalde to a point 10 miles west of Carrizo Springs, thence south to the Rio Grande." He named it the Carrizo sandstone.

Vaughan in 1900,[10] following the original definition of Owen, included in the Carrizo sandstone only the sandstones cropping out west of Carrizo Springs, and in 1912 [11] he regarded the Carrizo formation as a transgressive phase of the Wilcox.

Dumble has mentioned the Carrizo sands in a number of papers. In 1894 [12] he described a series of red and white sands with clay seams in the upper part of the "Lignitic," which he correlated with the Carrizo sands of Owen and the Queen City beds of Kennedy.[13] Again,

[7] Berry, E. W., personal communication.

[8] When this report was prepared the Carrizo and Bigford formations were confidently referred to the Wilcox group on the basis of fossil plants. Within the past two years the opinion has been growing both among petroleum geologists, who have done a great deal of detailed field work in Texas, and among several geologists of the United States Geological Survey, that the Bigford is the shallow-water representative of marine Claiborne beds in central and northeastern Texas to which Miss Ellisor has applied the name Reklaw member, and that both the Carrizo and Bigford will probably prove to be of Claiborne age, instead of Wilcox, and on the new geologic map of Texas will be so classed.

[9] Owen, J., Report of geologists for southern Texas: Texas Geol. and Min. Survey First Rept. Progress or 1888, pp. 70–74, 1889.

[10] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, pp. 37–54, 1900.

[11] Vaughan, T. W., in Willis, Bailey, and others, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 726, 1912.

[12] Dumble, E. T. Cenozoic deposits of Texas: Jour. Geology, vol. 2, pp. 549–567, 1894.

[13] Kennedy, William, The Eocene Tertiary of Texas east of the Brazos River: Philadelphia Acad. Nat. Sci. Proc. for 1895, p. 135, 1896.

in 1902 Dumble[14] described sandy beds constituting the upper of two members of the "Lignitic" and underlying the "Marine beds" of the lower Claiborne, giving sections on Antascosa Creek in Bexar and Medina Counties, on the International-Great Northern Railroad in Medina and Frio Counties, on the Leona and Nueces Rivers in Zavala County, and on the Rio Grande in northern Webb County. At Carrizo Springs he included in his Carrizo sand not only the Carrizo of Owen and Vaughan, which crops out west of the town, but also all the shaly and limy strata cropping out at and for 8 miles east of the town and underlying the lower Claiborne, now represented by the base of the Mount Selman formation. He correlated the most sandy beds in all sections described with Carrizo sands of Owen and Vaughan and with the Queen City beds of Kennedy in eastern Texas. In this paper evidence of a Carrizo overlap is also presented.

Later Dumble[15] considered the Carrizo to belong in the base of the Claiborne and to be the equivalent of the "Buhrstone" (Tallahatta formation) of Alabama. The evidence stated is that the Carrizo differs lithologically from and lies unconformably on the "Lignitic" and on the Midway by overlap and that it has the "position and composition" of the "Buhrstone." Its stratigraphic relations with the Claiborne were not given. In 1915[16] and again in 1918[17] he repeated this classification, calling attention to what he believed was the erroneous assignment of the Carrizo to the upper part of the Wilcox in most of the reports on eastern Texas.

In their latest review of the geology of Texas Udden and his assistants[18] mention the fact that Vaughan and others regard the Carrizo as of Wilcox age but mistakenly correlate the Carrizo of western Texas with the Queen City of eastern Texas and assign a Claiborne age to the "Queen City-Carrizo." Later evidence has established the Queen City well above the Carrizo and separated from the Carrizo by the marine equivalent of the Bigford. The assignment of the Carrizo to the Claiborne was continued by Liddle[19] in Medina County, where the formation overlaps the older Eocene formations to the Cretaceous.

Before 1923, therefore, when the preliminary report on this region[20] was published, it had become customary to include within the Carrizo

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[14] Dumble, E. T., Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., New Haven meeting, October, 1902, pp. 10, 11, 14, 16, 17, 19; The Tertiary of the Sabine River; Science, new ser., vol. 16, pp. 670–671, 1902.

[15] Dumble, E. T., The Carrizo sands: Texas Acad. Sci. Trans., vol. 11, pp. 52–53, 1911.

[16] Dumble, E. T., Tertiary deposits of northeastern Mexico: California Acad. Sci. Proc., 4th ser., vol. 5, pp. 176–177, 1915.

[17] Dumble, E. T., The geology of east Texas: Texas Univ. Bull. 1869, pp. 61–64, 1918.

[18] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, p. 91, 1916.

[19] Liddle, R. A., The geology and mineral resources of Medina County: Texas Univ. Bull. 1860, pp. 87–93, 1918.

[20] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, pp. 85–107, 1923.

sandstone the shaly and limy beds at and east of Carrizo Springs and to assign to this formation a lower Claiborne age. But the discovery that in the Rio Grande sections there are beds several hundred feet thick that are not primarily sandy, which lie stratigraphically above the Carrizo sandstone and below the Mount Selman, the oldest Claiborne formation, and that the shaly beds under the sandstones, the sandstones themselves, and the shaly and limy beds above the sandstones all contain plants of supposed Wilcox age led to the recognition of the Carrizo sandstone as the middle of three formations of the Wilcox group.[21] In the preliminary report the Bigford beds were taken out of the Carrizo on the Rio Grande, and the shaly and limy beds at and east and north of Carrizo Springs were left in the Carrizo, and the Bigford formation was said to pinch out south of Asherton.[22]

Although in 1924 Deussen[23] correlated the Carrizo sand with the Wilcox group, he still followed Dumble in including within it all the beds from the base of the Carrizo sandstone to the base of the Mount Selman and thus included in the Carrizo much that is described in this report as Bigford.

In 1929 the name Carrizo was used for an eastern Texas sand and referred to the basal Mount Selman,[24] though there is no recorded attempt to establish the synchroneity of this sand with that cropping out in the vicinity of Carrizo Springs, Dimmit County.

The question has been raised outside of the area of this report, and before it can be decided the relationship of the type Carrizo sandstone of southern Texas to marine beds elsewhere must be established. Further delay in the publication of this report while the question is being considered does not seem justified.

Classification and correlation of the Carrizo and Queen City beds have in the past been made with great difficulty and great possibility of error because of the total absence of fossils in the Queen City and the lack of knowledge of the occurrence of fossil plants in the Carrizo, but it is now clear that the Carrizo is not to be correlated with the Queen City, as contended by Dumble, but is older than the Queen City. Miss Ellisor[25] and Wendlandt and Knebel[26] agree that the Queen City is younger than the Carrizo.

[21] Trowbridge, A. C., op. cit. (Prof. Paper 131), pp. 89-93.

[22] Idem, p. 92 and pl. 28.

[23] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 57, 1924.

[24] Ellisor, A. C., Correlation of the Claiborne of east Texas with the Claiborne of Louisiana: Am. Assoc. Petroleum Geologists Bull., vol. 13, No. 10, pp. 1335-1345, 1929. Wendlandt, E. A., and Knebel, G. M., Geology of east Texas, with a discussion on salt movements and with special reference to the Mount Sylvan salt dome (read before Am. Assoc. Petroleum Geologists, Mar. 24, 1929).

[25] Ellisor, A. C., op. cit., p. 1342.

[26] Idem, p. 1355.

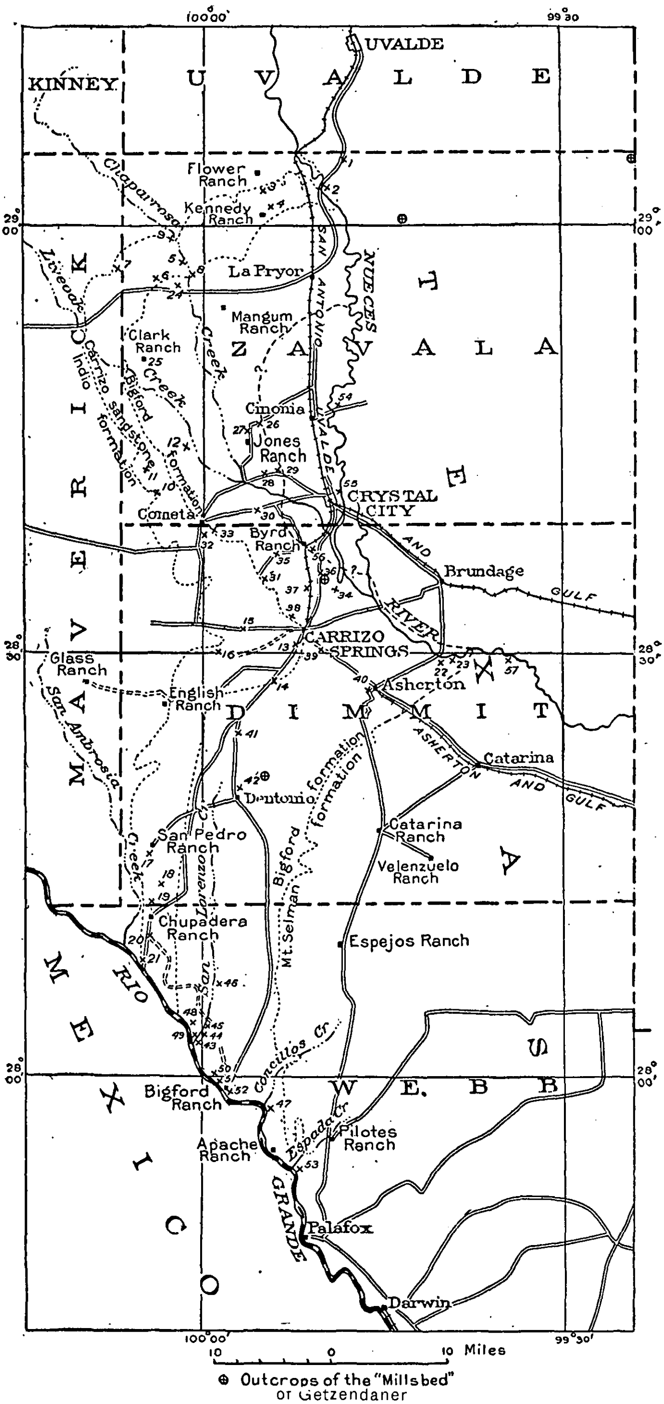

FIGURE 10.—Sketch map showing the distribution of the Carrizo, Bigford, and Mount Selman formations and the location of exposures described. Numbers refer to locations mentioned in the text

Distribution.—The distribution of the outcrops of the Carrizo formation is shown on Plate 7 and Figure 10. In some localities neither the bottom nor the top of the formation can be located exactly, because of the lack of good exposures, and the boundary lines on Plate 7 and Figure 10 represent merely the nearest approximations to these lines of contact that are possible at this time.

The belt of outcrop is about 3½ miles wide in Webb County and southern Dimmit County, 7 miles wide at one place in west-central Dimmit County, 6 miles wide at one point in northern Dimmit County, about 5 miles wide on the average in northeastern Maverick County and northwestern Zavala County, and 2 miles wide where it is crossed by the Nueces River in northern Zavala County.

Stratigraphic relations.—The Carrizo sandstone in western Zavala County and eastern Maverick County was regarded by Vaughan[27] as a transgressive phase of the Wilcox, and this interpretation appears to be supported by the field evidence.

A marked unconformity between the Indio and the overlying Carrizo is indicated at the lower end of Bee Bluff, on the east bank of the Nueces River, at the big bend, about 3 miles downstream from the Pulliam ranch house. Not only is the line of contact irregular, but balls of Indio clay are reworked in the basal Carrizo sands. A basal conglomerate was also seen in a Carrizo exposure on the west bank of the Nueces. An unconformity at the base of the Carrizo was observed by Getzendaner[28] at the type locality on Pena Creek 5 miles west of Carrizo Springs. There is, however, no evidence of unconformity at the outcrop at the old Sullivan ranch house on the Rio Grande. Unconformable relations in Mexico have been described by Baker (see p. 46) and at certain points north of the Nueces in Texas by Deussen.[29] The Carrizo, Indio, and Bigford floras are similar, seemingly indicating that there is no great time break either below or above the Carrizo.

Character.—The Carrizo formation is much more sandy than the other formations of the Wilcox group, the Indio and the Bigford, and the beds of sandstone in the Carrizo are more firmly cemented, some of them being crystallized into quartzite. Many of the sandstones are highly ferruginous, but some are gray or white, colors denoting little or no iron. The sand and the sandstone are characteristically cross-bedded. Owing to inequalities in the firmness of the cement, erosion has in some places produced castellated forms,

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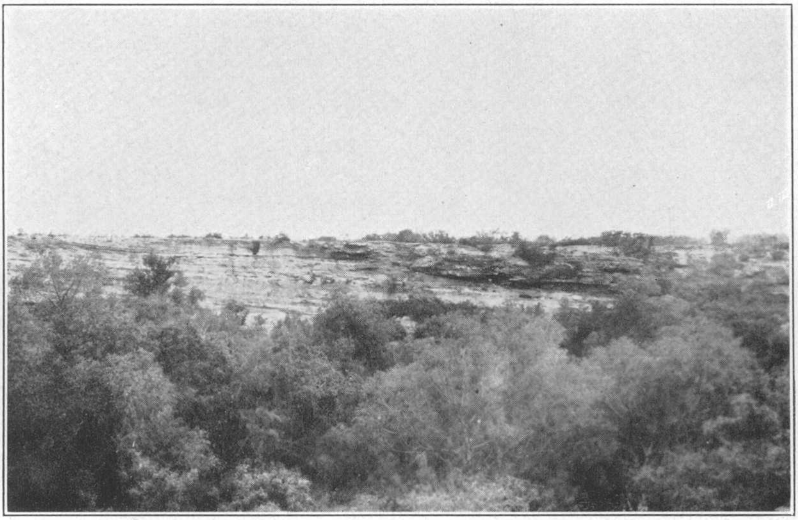
[27] Vaughan, T. W., in Willis, Bailey, and others, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 726, 1912.

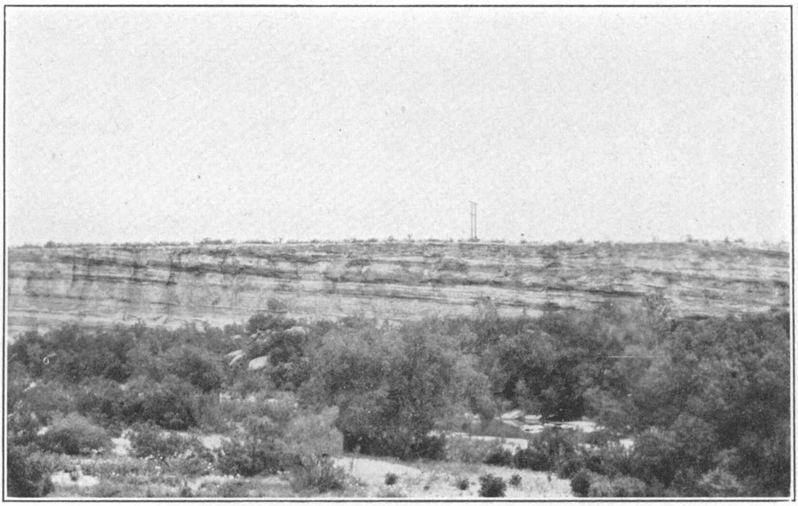
[28] Getzendaner, F. M., Geologic section of Rio Grande embayment, Texas, and implied history: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 1435, 1930.

[29] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 58, 1924.



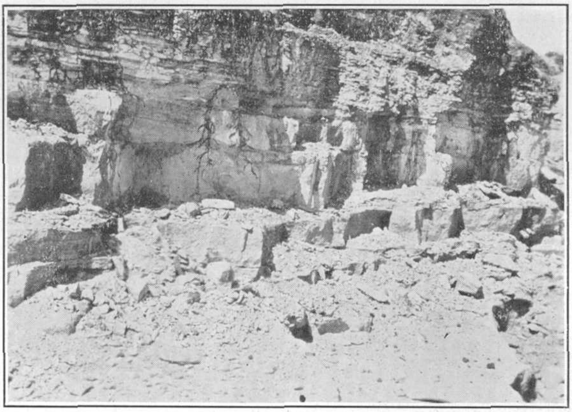
A. INDIO FORMATION UNCONFORMABLY OVERLAIN BY CARRIZO SANDSTONE AT BEE BLUFF, NUECES RIVER

The Carrizo appears in the upper part of the bluff, in somewhat more than the right half of the picture, and is characterized by massive irregular bedding, in contrast to the even thinner bedding of the Indio formation. Photograph by L. W. Stephenson.



B. EVENLY BEDDED SAND AND CLAY OF INDIO FORMATION AT BEE BLUFF

A short distance upstream from the part of the bluff shown in *A*. Photograph by L. W. Stephenson.



A. CARRIZO SANDSTONE IN THE BELL QUARRIES, WEST OF CARRIZO SPRINGS

Photograph by Fox Co., San Antonio.

B. CARRIZO SANDSTONE AT THE OLD SULLIVAN PLACE, SOUTH OF THE CHUPADERO RANCH notably south of the old Chupadero ranch, in northwesternmost Webb County. The sandy beds vary greatly in texture but are for the most part coarse grained. Interbedded with the sandstone are a few thin beds of clay, shale, and limestone and in one or two places very thin layers of hematite and cone-in-cone claystone.

Fosssils.—No invertebrate or vertebrate fossils have been found in the Carrizo sandstone. Poorly preserved fragments of plants have often been noted, but the flora was not critically studied until 1921, when E. W. Berry accompanied the writer to the field and made collections. Identifiable leaves were found in a short arroyo in the east wall of the Nueces River valley three-quarters of a mile below the old Uvalde-La Pryor road crossing (locality 2, fig. 10). The list given below shows, according to Berry, that the Carrizo is of Wilcox and not of Claiborne age, a conclusion which is in harmony with the lithology and stratigraphy of the sandstone and the associated beds. These are all well-known middle and upper Wilcox forms.

Banksia puryearensis Berry.
Eugenia grenadensis Berry.
Gleditsiophyllum eocenicum Berry.
Mespilodaphne coushatta Berry.
Myrcia vera Berry.
Persea longipetiolata (Hollick) Berry.
Sabalities grayanus Lesquereux.

There is a significant similarity between this list and the list of fossil plants taken from the Indio formation about 4 miles up the Nueces (p. 42).

Fossil plants, all well-known upper Wilcox species, were collected from the Bell quarries southwest of Carrizo Springs (13, fig. 10), and identified by E. W. Berry as follows:

Acrostichum sp.
Anona ampla Berry.
Anona wilcoxiana Berry.
Canavalia eocenica Berry?
Cassia tennesseensis Berry.
Cinnamomum vera Berry?
Dryophyllum tennesseensis Berry?
Ficus mississippiensis (Lesquereux) Berry.
Heteracolyx new species.
Nectandra pseudocoriacea Berry.
Oreodaphne obtusifolia Berry.
Oreodaphne puryearensis Berry.
Palmocarpon butlerensis Berry.
Sabalites grayanus Lesquereux.
Sophora wilcoxiana Berry (pl. 37).
Sterculia wilcoxensis Berry.

Thickness.—The thickness of the Carrizo sandstone west of Carrizo Springs, as estimated by Owen,[30] is 200 feet, and this may be taken as its approximate average thickness for this region. Where the formation is cut by the Rio Grande in Webb County its thickness is estimated at 118 feet. North of this region greater thicknesses are assigned.

Sections in northwestern Zavala County.—The Carrizo sandstone crops out at a number of points south and southwest of Uvalde and west and northwest of La Pryor. Because of the downstream dip of the beds the rocks of the Carrizo sandstone are found farther north on the uplands bordering the river than in the river bed itself. About 3 miles northeast of the McDaniel ranch, 10 miles south by west of Uvalde on the road to La Pryor (1, fig. 10), there is a ledge of brown and black quartzite, a ferruginous sandy rock which belongs with the "Myrick formation" of Vaughan[31] and with the Carrizo of this report. Although in this exposure the rock appears to be in a lens or nodular mass, there is a persistent layer of it in the neighborhood, for similar rock occurs in the Nueces River bluff for half a mile, beginning a quarter of a mile below the road crossing, crosses the river three-quarters of a mile below the crossing, and is traceable in dovetailing lenses from this point in a northwesterly, westerly, and southwesterly direction for a distance of more than 2 miles, to and beyond the San Antonio, Uvalde & Gulf Railroad. Traced farther west it is found to be at essentially the same horizon as the rock at Sand Mountain and near the Kenedy and Flower ranches. (See pl. 8, C.) The rock in the river bed contains iron concretions and hardened clay balls. Results of the laboratory study of this quartzite are given on page 61.

The quartzitic phase is overlain in the bed of the Nueces River and in adjoining bluffs about three-fourths of a mile below the crossing of the Uvalde-La Pryor road (2, fig. 10) by 15 feet of material, some of which is blue-black clay and some irregular irony limy shale. The clay and shale are leaf bearing, and Berry has identified the species listed on page 57 from the east wall of the Nueces Valley.

Directly overlying the clay and shale in at least one place a mile below the crossing and outcropping in several places in the bluffs within a mile downstream from that point is 50 feet or more of soft gray and brown cross-bedded ferruginous coarse-grained sandstone containing in some layers irregular areas of concretionary iron oxide 2 or 3 feet across. Although the beds of shale in this section are thicker than those included elsewhere within the Carrizo sandstone of this report, the thick, coarse-grained sandstone over the shale appears to be Carrizo, and therefore the whole section is put tentatively in the Carrizo.

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[30] Owen, J., op. cit., p. 72.
[31] Vaughan, T. W., U. S. Geol. Survey Geol. Atlas, Uvalde folio (No. 64), pp. 2-3, 1900.

About 1 mile southeast of the Flower ranch house (3, fig. 10) is a conspicuous hill on whose slopes are exposed coarse-grained, irregularly bedded quartzitic sandstone and quartzite. (See pl. 8, *C*.) Exposed surfaces of these rocks are glazed. Some of the quartz grains are half the size of a small pea and are angular or subangular. The outcrop is not continuous, and these rocks must be distributed irregularly throughout this part of the formation. The quartzite gives place to sandstone both parallel and normal to the bedding planes.

About three-quarters of a mile northeast of the Kenedy ranch (4, fig. 10) there is an exceptionally extensive outcrop on another hill, locally known as Sand Mountain. The hill is 50 feet high, more than a quarter of a mile long east and west, and 50 yards across. The rock here is not in the same stratum as that on the hill at the Flower ranch, and probably neither hill is elongated parallel with the formational strike. More than likely they are held up by irregularly silicified parts of the formation. This hill also is composed of ferruginous quartzitic sandstone. There is more iron in the cement than on the other hill. The sandstone is coarsely gritty in part and is nowhere fine grained. It is strongly cross-bedded in members 6 to 12 inches thick. The rock is of a dull reddish-brown color and weathers out into blocks 10 to 20 feet on a side. It shows tubular holes, pits, and channels due also to weathering. Irregular iron concretions are abundant.

Three other outcrops of the quartzitic phase were seen, one 2 miles a little east of north of the house on the Mangum farm (5, fig. 10), where the rock is hard, gritty quartzite with much iron; another half a mile south of the same house in a field (6, fig. 10), where the rock is similar but not so extensively exposed; and a third 4 miles west and north of this same house (7, fig. 10), where the rock is a hard, roughly weathered quartzite, in which there are beds resembling jasper. The jasperlike beds were not seen elsewhere in the region.

On Chaparrosa Creek, beginning 1 mile north of the La Pryor-Eagle Pass road (8, fig. 10) and extending upstream for 2 miles, are abundant exposures of Carrizo sandstone, without quartzite, shale, limestone, or concretions. The sandstone is soft, friable, coarse grained, and cross-bedded. Sets of crossed beds 1 foot thick are separated by thin partings, which are essentially horizontal. The crossed beds in the different sets dip in different directions and at different angles. In most places the rock is almost pure silica, but some parts of it are ferruginous.

Section of Carrizo sandstone on Chaparrosa Creek in the southeastern part of the Nancy Bailey property (9, fig. 10)[32]

	Feet
Indurated yellow sandstone cemented by crystalline lime, which in places shows globular 1 to 2 inch concretionary centers, white (in yellow?), ripple bedded	2
Soft fine-grained sandstone	1½
Alternating 2-inch layers of clay and sandstone	1½
Soft sandstone, fine grained, yellow and gray	2
Clay with sand, yellow and red streaks	1
Sandstone, soft	2½
Clay, with some half-inch layers of yellow material	15

Sections west of Crystal City.—About 15 to 18 miles west of Crystal City and near the road to Eagle Pass are exposures of the Carrizo formation. One outcrop noted is 100 yards east of the bench mark where a branch road leads off to the Van Cleve ranches (10, fig. 10). The rock is soft brown cross-bedded sandstone similar to that on Chaparrosa Creek farther north. About 1½ miles northwest of Van Cleve's Picoso ranch, on Picoso Creek (11, fig. 10) are exposures of gray and brown calcareous sandstone, and 1½ miles east of the entrance to the Van Cleve ranches (12, fig. 10) is a small exposure of quartzitic sandstone.

Sections near Carrizo Springs.—The best exposures near Carrizo Springs are in the Bell quarries, southwest of the town on the road to Dentonio. One quarry that has furnished sandstone for buildings in Carrizo Springs is 1.3 miles from the town, and another is a quarter of a mile farther west, on the Bell homestead (13, fig. 10). Most of the sandstone here is fairly pure, but some of the layers are shaly. It is oxidized on the surface but gray just below the surface in most layers. (See pl. 11, *A*.) The fossil plants listed on page 57 were collected from these quarries.

About half a mile south of Bell's house, in the road, is an outcrop of flaggy cross-bedded sandstone. Farther south on the same road, 5 miles from Carrizo Springs (14, fig. 10), there is a large exposure of cross-bedded sandstone with about 8 feet of shale on top.

Soft coarse-grained sandstone crops out for 100 yards along the Pena, a northward-flowing stream 5.8 miles west of Carrizo Springs (15, fig. 10). The rock exposed there is cross-bedded, dark gray, and ferruginous.

Reddish-brown sandstone appears 2½ miles northeast of the Yett ranch (16, fig. 10), where the road to Carrizo Springs turns north to cross a sandy creek bottom. A fifth of a mile farther east sandstone intricately cross-bedded in thin sets of beds is exposed on the roadside. The cross-beds here dip in all directions, and all the beds in the lower part of the section are ripple-marked.

[32] Udden, J. A., field notes.

Sections on and near the Rio Grande in Webb and Dimmit Counties.—Half a mile west and south of the San Pedro ranch (17, fig. 10) white cross-bedded sandstone, a 3-inch layer of hematite showing excellent cone-in-cone structure, clay, and sand are exposed. Cathedral Rock, 3 miles south of the San Pedro ranch (18, fig. 10), is 30 feet high and consists of coarse cross-bedded sandstone with large veins of bluish-white quartz.

Section of Carrizo sandstone on hill near Cathedral Rock, Dimmit County

	Feet
Ferruginous sandstone	5
Clay, not exposed	30
Brown sandstone	20
Gray, thinly laminated sandstone and clay	4
Gray concretionary massive sandstone	4

Section of Carrizo sandstone 1½ miles north and west of Chupadero ranch (19, fig. 10)

	Ft.	in.
Gray concretionary sandstone	10	
Interlayered brown and gray sandstone	10	
Gray shale with a few slabs of gray to brown sandstone	8	
Smooth gray sandstone, brown on surface		4
Gray shale	1	
Gray shaly sandstone, cross-bedded	2–4	
Gray sandstone in thin slabs	10	

At and around the Chupadero ranch the surface is very sandy. About 1½ miles south of the house (20, fig. 10) is an irregular basin rimmed by outcropping sandstone and with many castlelike hills of sandstone standing conspicuously on its floor. The sandstone, which is about 25 or 30 feet thick, is medium grained, light gray or brown, and massive but with irregular stratification and concretionary lines, so that it weathers irregularly. Locally the sandstone pillars are yellow. The sandstone is friable but in places casehardened.

The cross-bedded, irregularly consolidated sandstone continues south to the old Sullivan place (21, fig. 10), where it forms a prominent bluff 30 feet high on the Rio Grande. (See pl. 11, *B*) A large spring issues at the base of the bluff, probably controlled by Indio shales, which dip so as to bring their surface just about to river level at this place.

Laboratory analyses.—The following analyses represent samples from the Carrizo sandstone.

Analysis of quartzite from Carrizo sandstone in bed of Nueces River three-quarters of a mile below the Uvalde-La Pryor road crossing (sample 02163) (2, fig. 10)

Bedding.—Specimen indicates that formation is massive. Slight hint of bedding in differential distribution of iron, but this may be due to other causes. Fractures across grains.

Mineralogy and lithology.—Quartz angular for the most part; only a few rounded grains. Needles of rutile included in some grains. Feldspar abundant (12.7 per cent), mostly orthoclase, fresh and weathered in about equal proportions. Other minerals in too small grains to be distinguishable. Iron oxide plentiful as coating on each grain and as crack filling. Infiltrated silica fills cracks and has to a slight extent recrystallized the quartz grains. Concentric agatelike structure in places where silica has filled interstices 1/10 millimeter in diameter. A fragment of quartzite was strongly heated for 10 minutes in the blast-lamp flame and was immediately doused in water. The cementing silica and that silica which had recrystallized turned milky white, showing clearly the relation of the infiltrated to the original material. Another sample similarly heated and allowed to cool in air did not turn white on infiltrated material. The infiltrated material has the same refractive index as quartz and recrystallizes with grains of quartz. Cement insoluble in NaOH; hence it could not be opal. Sample slightly calcareous.

Size and shape.—Grains 15 to 20 per cent rounded. Angular but not as markedly so as the finer samples. Prevailing size ½ to ¼ millimeter. Some grains, well rounded, with diameter of 2¼ millimeters were seen in hand specimen. Very little fine material.

Packing and pore space.—Rock originally had considerable pore space, but pores have been secondarily filled, so that rock is now very compact.

Color.—Brown with lighter spots due to fracture of flakes.

Weathering.—Weathered surface has hard black crust due to increased degree of oxidation of the iron. This, no doubt, makes the formation very resistant.

Analyses of Carrizo sandstone on Rio Grande at Sullivan ranch house (21, fig. 10).

Sample 02250

Lithology and mineralogy.—Buff-colored, slightly friable sandstone. The grains consist of 96 per cent quartz, 2 per cent feldspar, and 1 per cent chert. The cement is calcareous and makes up 22 per cent of the sample.

Size and shape.—Mechanical analysis (fig. 11) shows that more than 80 per cent of the sand grains are fine (¼–⅛ mm.) and that the sediment is unusually well sorted. About 45 per cent of the grains are angular, 45 per cent subangular, and 10 per cent subround. There are no well-rounded grains.

Sample 02251

Lithology and mineralogy.—A very friable brown sandstone. There is practically no cement. One per cent soluble in 40 per cent HCl. Quartz makes up 99 per cent of the grains.

Size and shape.—This is medium sand with finer and coarser admixtures (fig. 12). It is not so well sorted as No. 02250. Nearly 25 per cent of the grains are curvilinear, nearly 35 per cent subround, more than 25 per cent subangular, and about 10 per cent angular.

Sample 02252

Lithology and mineralogy.—Light brown, poorly cemented sandstone, 1.4 per cent soluble in acid. Quartz makes up 90 per cent of the grains, feldspar 8 per cent, and muscovite and biotite 2 per cent.

Size and shape.—Fine sand with coarser and finer admixtures (fig. 13). Grains are about 30 per cent angular, 40 per cent subangular, 25 per cent subrounded and 5 per cent curvilinear.

Sample 02253

Lithology and mineralogy.—Friable sandstone, 1 per cent soluble in acid. What cement there is is ferruginous. Grains are 97 per cent quartz and 2 per cent feldspar. Heavy minerals make up 0.4 per cent.

Size and shape.—Medium sand with finer admixtures. Well sorted (fig. 14); 35 per cent angular, 45 per cent subangular, 17 per cent subround, 3 per cent curvilinear.

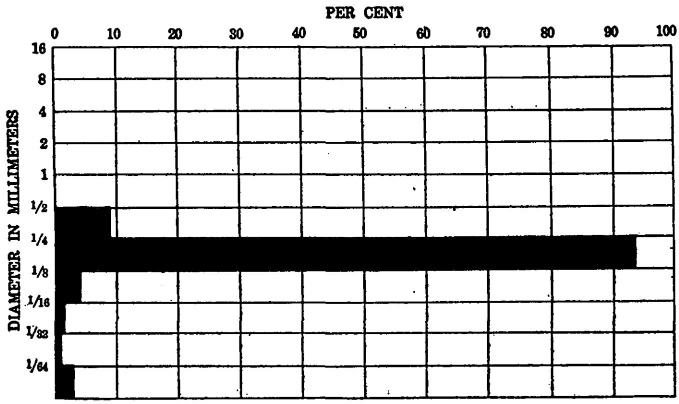


FIGURE 11.—Mechanical analysis of sample 02250

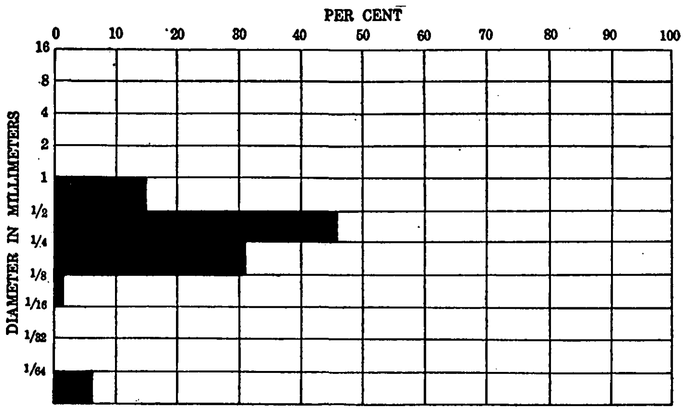


FIGURE 12.—Mechanical analysis of sample 02251

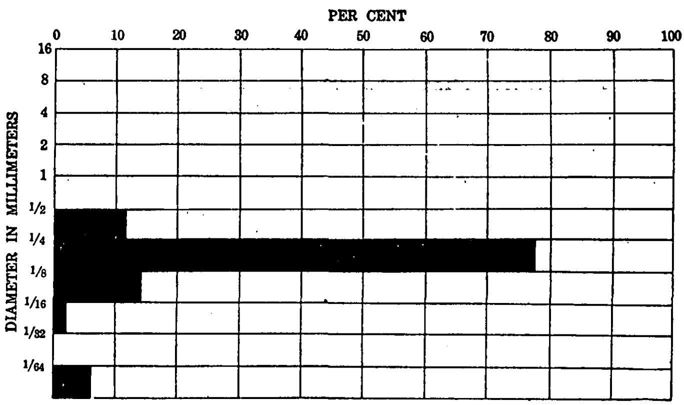


FIGURE 13.—Mechanical analysis of sample 02252

Sample 02254

Lithology and mineralogy.—Bedded, compact sandstone; alternating bands of coarse and fine material, 1.5 per cent soluble in acid. Small amount of cement is calcareous and ferruginous. More than 99 per cent of grains are quartz; 0.5 per cent heavy minerals.

Size and shape.—Very fine sand with fine and medium sand and coarse and fine silt and clay admixtures (fig. 15). Grains are angular, subangular, and subround in about equal proportions.

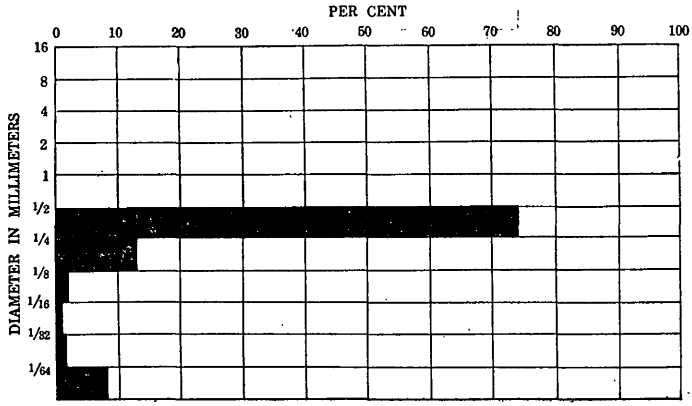


FIGURE 14.—Mechanical analysis of sample 02253

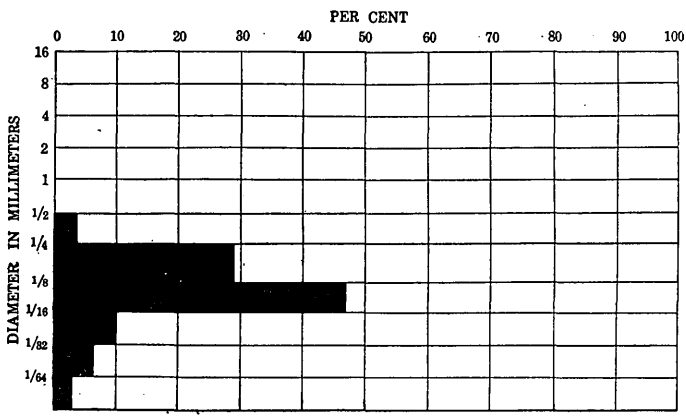


FIGURE 15.—Mechanical analysis of sample 02254

Origin.—Lying unconformably upon the Indio formation but made up of sediments similar in many respects to those of the Indio, the Carrizo sandstone was doubtless deposited under conditions that followed with only a temporary interruption the conditions of Indio time. The Carrizo, like the Indio, was probably derived from crystalline rocks exposed in the Cordilleran region 500 miles or more west of the site of deposition, although Cretaceous sandstones closer at hand may have contributed notably also. The sediments were transported across the plateau country east of the mountains, to be deposited on low flats on the landward side of a shore line and in shallow lagoons and bays. Laboratory analyses show that the Carrizo sands contain less silt and clay than those of the Indio and that on the whole the sand grains are better rounded. This suggests eolian action. The sands presumably were sorted out from the beaches and tidal flats by the wind and deposited on the near-by lands. The absence of undoubted marine fossils and the presence of curled leaves also suggest terrestrial or tidal flat rather than marine or estuarine conditions during the time of deposition.

BIGFORD FORMATION [33]

Name and distribution.—Since Dumble included in the Carrizo all the strata up to the base of the "Marine beds" no formation had been recognized between the Carrizo and the Mount Selman until 1923, when the writer [34] presented evidence that these two formations are separated south of Carrizo Springs by beds of clay, thin-bedded sandstone, and lignite that consist so largely of clay that they can not be called Carrizo sandstone. To these strata was applied the name Bigford, from the Bigford ranch, practically the only habitation in their belt of outcrop, where the beds are best exposed. The belt of outcrop is about 10 miles wide in Webb County and about 8 miles wide in the latitude of Carrizo Springs. (See fig. 10.) Getzendaner [35] recognizes the Bigford also and has traced it as far east as the eastern part of Frio County.

Character.—Lithologically the Bigford formation consists chiefly of clay of many colors and subordinate quantities of gray, green, and brown sandstone, which is at most places not cross-bedded. It contains many beds of lignite, a few of them more than 20 inches thick, and some lens-shaped concretionary masses. However, some seams as much as 8 feet thick have been reported. It contains few paper shales and sands, such as occur in the Indio, and few thick coarse-grained cross-bedded and commonly quartzitic sands, such as occur in the Carrizo. It contains also many beds, lenses, and irregular bodies of yellow limestone, and some thin beds of hematite. Most of the clays are selenitic. Cone-in-cone structure is fairly common in the beds of fine texture, in which calcareous and argillaceous material are mixed in about equal proportions.

Relations to adjacent formations.—Although the Bigford formation is at least fairly distinct lithologically, its contacts with the Carrizo below and the Mount Selman above can be exactly located in only a few places. It appears in some places to grade conformably

[33] See footnote 8, p. 52.

[34] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 92, 1923.

[35] Getzendaner, F. M., op. cit., pp. 1436-1437.

downward into the Carrizo without stratigraphic break. The relations between the Bigford and the overlying Mount Selman formation are not well known, but dissimilarity of floras suggests unconformity.

Thickness.—The Bigford formation in the lower Rio Grande region ranges in thickness from about 340 to about 700 feet.

Fossils.—A small collection of fossils was taken in 1924 from a point 0.6 mile N. 52° E. from the schoolhouse at Dentonio. They were identified by Miss Gardner as *Ostrea* sp., *Anomia* sp., *Cerithium* sp., and fish scales. In addition to some unidentifiable casts of pelecypods, gastropods, and ostracodes reported by North[36] to occur in sandstone and shale 6 miles southeast of Carrizo Springs and about 2½ miles north of Asherton, specifically unidentifiable fossils have been taken from the Bigford formation at a number of other localities reported by Getzendaner[37] in northern Dimmit County and southern Zavala County, one of them within 1½ miles of Carrizo Springs. Fossil leaves were collected from the formation on Concillos Creek, in Webb County, and these were identified by E. W. Berry, who correlated them with the Wilcox group. (See p. 71.)

Nueces River sections.—Although the Bigford has not previously been recognized as distinct from the Carrizo outside the region of this report, several outcrops on the Nueces River are believed to belong to this formation. According to Miss Gardner, the Bigford is the outcropping formation on this river for about 8 miles (air line) downstream from a faulted Carrizo contact a mile above the mouth of Mustang Creek. The northern Bigford-Mount Selman contact falls below the Batesville-La Pryor road crossing; the Bigford is again crossed by the river due east of Carrizo Springs, so that the Bigford-Mount Selman contact is intercepted by the river at two places, one a few miles above the Brundage-Asherton road crossing known as Dunlap Bridge and the other a mile or so below the bridge. The synclinal interval of 20 to 25 miles between the northern and southern outcrops of the Bigford is occupied by the Mount Selman formation. Although only about 2 miles of the upper part of this course of the river is within the lower Rio Grande region, all of it is within easy reach from the east side of the region at La Pryor, Crystal City, and Carrizo Springs, and some of the exposures were visited.

The Bigford strata seen down the Nueces are well exposed on the south side of the river at and below Dunlap Bridge, where the river is crossed by the Brundage-Asherton road (22, fig. 10). By the roadside there are interbedded layers of fine-grained almost

[36] North, Lloyd, personal communication.

[37] Getzendaner, F. M., personal communication, August 26, 1927.

white soft and friable quartz sandstone; beds of gray and bluish-gray shale; thin beds of iron ore, jointed and weathering concentrically between the joints; irregularly ferruginized sandstone; and concretions, lenses, and beds of yellow septarianized limestone. An analysis of the sandstone is given on page 74.

Section of Bigford formation a quarter of a mile below Dunlap Bridge on Nueces River (23, fig. 10)

	Ft.	in.
Sandstone and sandy shale	40	
Interbedded clay and sandy clay	10	
Iron ore that fractures into rectangular pieces about the shape and size of commercial whetstones, which weather into concentric bands very fine and closely spaced		2
Interbedded clay and sandy clay	10	
Iron-ore layer similar to that above		2

Sections west of La Pryor.—Between mileposts 10 and 11 west from La Pryor and about 1 mile west of Chaparrosa Creek in an eastward-facing slope (24, fig. 10) there are beds of shale, soft yellowish or gray sandstone, and thin sandy concretionary limestone showing cone-in-cone structure. Most of the material is bluish-gray clay of good quality. This section is close to the base of the Bigford formation.

On the Clark ranch about 16 miles west and south of La Pryor (25, fig. 10) and at several points on the old Eagle Pass road between the ranch and La Pryor there are shallow exposures of Bigford in which limestone is conspicuous. The limestone is compact and crystalline where unweathered but is coated thickly by soft impure limestone containing irregular stringers of calcite. In some places the limestone is sandy and interbedded with shale. Similar rocks are exposed south of the Rutledge ranch, about 2 miles northeast of the Clark ranch.

Sections west of Crystal City.—About a mile east of the northern of the two Jones ranch houses (26, fig. 10) an old road crosses a rather conspicuous hill that has abundant outcrops of ochre-yellow compact fine and even-grained limestone. On this hill is a very distinct fault plane, traceable by a small ridge of uptilted vertical beds for 100 feet or more and trending N. 22° W. About 700 feet east of the exposure mentioned is a higher, wider, and longer hill composed of alternating beds and more or less confused lenticular areas of yellowish limestone, calcareous sandstone, and weathered gray shale. The shale and some of the limestone bear great quantities of selenite in secondary bodies. The limestone, sandstone, and shale are all in this same formation. The sandstone is soft and friable, contains some lime, and appears to lie in irregular beds, now much disturbed by faulting and consequent shearing. The limestone is yellowish, especially on weathered surfaces. Most of it is firm and of uniform texture, with dendritic markings and with what appear to be fine clay stringers running through it. A sample of the limestone was analyzed, with the results given on page 75. Poorly preserved fossil leaves, stems, and wood occur in these rocks, but none were identifiable.

Eastward from these ridges there are a number of poor exposures of this same yellow limestone in the old road from the Jones ranch to New California.

Two miles north of the southern of the two Jones ranch houses (27, fig. 10) there is an outcrop of the same fine-grained yellow limestone that occurs so abundantly southwest of La Pryor.

Section of Bigford formation 8¼ miles northwest of Crystal City (28, fig. 10)

	Feet
Flaggy sandstone, ferruginous brown to yellow, some layers of which are fairly hard and others soft and crumbly like maple sugar	10
Sandy clay shale	8–10

At 8 miles northwest of Crystal City, where a small creek crosses an old road (29, fig. 10), there is an outcrop of brown ferruginous soft sandstone, apparently without shale, in which irony concretions occur.

On a low hill south of the Eagle Pass road 8 miles west of Crystal City (30, fig. 10) the sandstone of the Bigford is exposed. Most of the rock is soft ferruginous cross-bedded sandstone, but there are two layers 6 feet apart and each 5 inches thick of fine-grained argillaceous limestone. One of the limestone beds shows excellent cone-in-cone structure. About half a mile northeast of this locality there is an outcrop of sandstone interbedded with sandy shale, some layers of which are cemented to make thin, platy layers of limonite.

About 6½ miles northwest of Carrizo Springs on the road to Cometa (31, fig. 10), there is a small exposure of hard crystalline quartzitic sandstone with some limy layers.

A mile south of Cometa, on Pendencia Creek (32, fig. 10), there is an exposure of peculiarly cross-bedded sandstone overlain by bluish-gray clay. (See pl. 12, *A*.) About a mile east of this point and south of Pendencia Creek (33, fig. 10) similar rock crops out on the east side of the Carrizo Springs-Cometa road. The rock here is gray to buff and consists of sandy, shaly beds breaking up into plates and scales half an inch to 1 inch thick along the bedding, with a single interbedded concretionary layer of hard, compact crystalline arenaceous limestone.

For 4 miles southeast from the Cometa-Crystal City road toward Byrd switch, shale, sandstone, and yellow limestone similar to the strata on the old Eagle Pass road west of La Pryor are exposed at several points.

There is rock bottom at the Espantosa Lake crossing of the Winter Garden road (34, fig. 10). Most of the rock is fine-grained gray sandstone, but there is also some shale in which there are septaria of drab limestone recemented with calcite.

On a hill 3 miles west by south of Byrd switch (35, fig. 10), 25 feet high on the south face, the strata are fairly well exposed. Most of the rock is sandstone in alternating beds of coarse-grained oxidized rock and fine-grained gray material. Under all, but doubtless interbedded, are clay shale and sandy shale, not well exposed. There is more of the coarse-grained than of the fine-grained sandstone. Some of the softer and more shaly layers of sandstone contain a few hard banded, almost quartzitic concretionary masses as much as 6 feet in diameter.

Sections around Carrizo Springs.—The formation can not be said to be well exposed in the vicinity of Carrizo Springs, and yet there are a number of sections that are worthy of description.

About 6 miles north of Carrizo Springs on the road to Crystal City (36, fig. 10) there is a bed of soft gray fine and even-grained sandstone 15 to 20 feet thick overlying a bed of clay.

A ledge of yellow limestone comes out in the wall of a shallow drain 2½ miles south of Byrd switch (37, fig. 10). It does not appear to be in a continuous bed, and its structure is doubtless concretionary.

At 2½ miles northwest of Carrizo Springs on the road to Cometa (38, fig. 10) beds of gray and brown sandstone and sandy shale crop out.

The formation is poorly exposed in the town of Carrizo Springs. The total thickness of strata exposed is 10 to 15 feet. In one exposure in the north edge of the town gray sandstone contains lenses of gray limestone 15 to 30 inches long and 3 to 4 inches thick. Below these beds is 1 to 1½ feet of sandy limestone.

Section of Bigford formation 1½ miles east of Carrizo Springs (39, fig. 10)

	Feet
Red and yellow ferruginous sand and sandstone in thin beds	10
Yellow sandstone with some clay layers and some brown nodules	15

Sections at Asherton.—As explained on page 54, the section exposed in the southwestern part of Asherton (40, fig. 10), described and pictured by Deussen[38] as a part of the Carrizo sandstone, is here put in the Bigford. The meager exposures of clay, sandstone, and yellow limestone west of the town on the road to Carrizo Springs bear strong resemblance to the outcrops of Bigford strata west and southwest of La Pryor.

[38] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 59, pl. 21, *A*, 1924.

Sections near Dentonio.—At the forks of the road north of Dentonio about 9 miles north of the Dimmit-Webb County line (41, fig. 10) fine-grained oxidized sandstone and shale occur in a shallow wash. The surface rock around Dentonio (42, fig. 10) is a rather soft and roughly flaggy sandstone in irregular plates 2 or 3 inches thick. This sandstone overlies a deposit of gypsiferous clay shale in which the local valleys have been cut. The sandstone caps the high, flat inter, stream areas. There are some lignitiferous layers in the lower shale and about 3 miles from Dentonio prospect holes have been sunk 40 to 45 feet to a coal bed. These rocks lie close to the bottom of the Bigford formation and are probably the near equivalents of similar strata near the mouth of San Lorenzo Creek.

Shallow exposures between Dentonio and Asherton show that the Bigford beds there contain more clay and limestone than sandstone. A sample of the so-called Mills bed of Getzendaner[39] from the Dentonio scarp on the Dentonio-Asherton road contains cross sections of white corals and is 96.5 per cent soluble in acid.

The material between Dentonio and the Bigford ranch house is not well exposed, but to judge from the few exposures and from the road cuts it appears that the strata are alternating sandstone, clay, and argillaceous sandstone belonging near the middle of the Bigford formation.

San Lorenzo Creek sections.—Several sections are exposed on San Lorenzo Creek.

Section of Bigford formation in north bank of San Lorenzo Creek about half a mile from the Rio Grande (43, fig. 10)

	Feet
Silt soil	4–5
Flint gravel	3
Thin-bedded sandstone	3
Massive light-gray sandstone	5
Thin-bedded sandy shale	5
Shaly sandstone	3
Gray shale, somewhat carbonaceous with sandy streaks of laminae	10
Massive sandstone	3
Carbonaceous shale with sandy streaks	3
Flaggy sandstone	5
Thin-bedded sandy shale	4
Massive sandstone underlain by shale in which stream has eroded	6

[39] Getzendaner, F. M., Geologic section of Rio Grande embayment, Texas, and implied history: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 1436, 1930.

Section of Bigford formation 1 mile above the mouth of San Lorenzo Creek on the northwest bank (44, fig. 10)

	Feet
Thin-bedded sandy shale grading up into sandier heavier beds at the top of the bluff	10
Dark-gray carbonaceous selenitic clay shale, thinly laminated, with a few limy iron concretions	15–18
Massive medium-grained irregularly bedded sandstone in bed of stream	1+

Farther up the creek, where the lower road between the Bigford and Chupadero ranches crosses it (45, fig. 10), there are massive to flaggy sandstones, 15 to 20 feet thick, and large calcareous concretionary masses, overlain by shale upstream and underlain by shale downstream.

At the upper road crossing (46, fig. 10) massive sandstone crops out, overlain by 15 feet or more of selenitic shale and associated with at least one bed of yellow limestone similar to that in the Bigford farther north.

Concillos Creek sections.—Just above the mouth of Concillos Creek on the southwest side and almost continuous with the Rio Grande section (47, fig. 10) the following section is exposed:

Section of Bigford formation on Concillos Creek near its mouth

	Ft.	in.
Flaggy sandstone		6–8
Clay shale	8	
Concretionary sandstone	2–3	
Clay shale	10–11	
Unevenly bedded sandstone	3–5	
Shale with carbonaceous matter near base and a thin layer of lignite	18–25	
Irregular sandstone bed, maximum thickness	2	6
Clay shale	6–12	
Sandstone	2–3	
Shale with sandy bands to creek level	6–8	

A collection of fossil plants was made near the mouth of Concillos Creek, near locality 47, Figure 10, and identified by E. W. Berry as follows (see pl. 37):

Anacardites grevilleafolia Berry.
Banksia puryearensis Berry.
Canna eocenica Berry.
Cassia marshallensis Berry.
Cyperites sp. Hollick.
Inga wickliffensis Berry?
Juglans schimperi Lesquereux.
Mimosites variabilis Berry.
Mimusops mississippiensis Berry.
Myrica wilcoxensis Berry.
Sabalites grayanus Lesquereux.
Sophora wilcoxiana Berry.

Berry reports that this is a Wilcox flora, distinctly older than that in the base of the Mount Selman formation, which is of Claiborne age.

Section of Bigford formation on Concillos Creek about a quarter of a mile above its mouth

[Pl. 12, *B*]

	Ft.	in.
Flint gravel and soil	2	
Brown loamy subsoil	4	
Gray clay	6	
Dark-gray thin-bedded sandy shale	1	3
Dark-brown carbonaceous (lignitic) sandy shale		6
Sandy clay shale	1	6
Massive light gray-brown flaggy sandstone	3	
Clay shale		8
Flaggy evenly and thinly bedded sandstone	1	6
Sandy clay shale	3	
Sandstone and sandy shale interbedded in 2 to 6 inch bands	4	
Massive sandstone much pitted by erosion in bed of creek.		

The first section on Concillos Creek below the crossing of the road between the Bigford and Apache ranches is illustrated in Figure 16 and Plate 13, *B*.

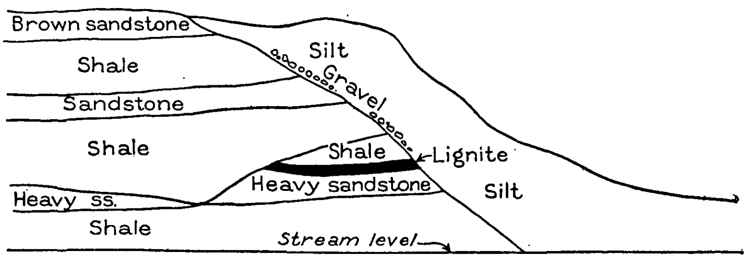
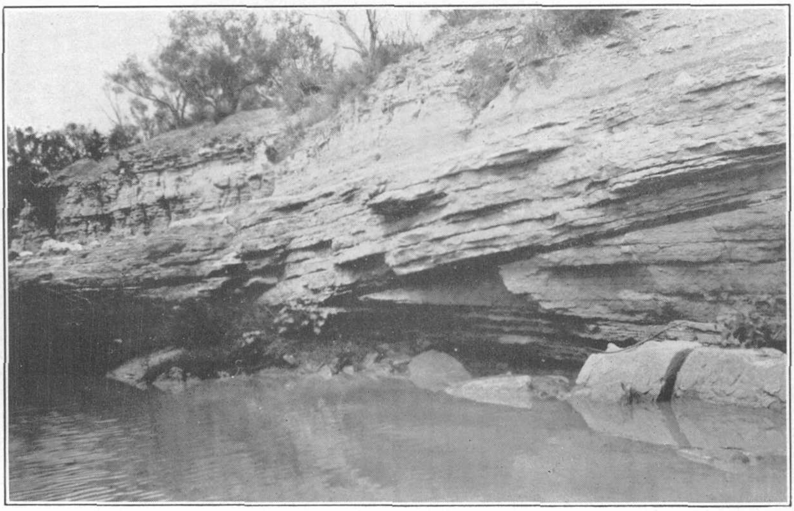


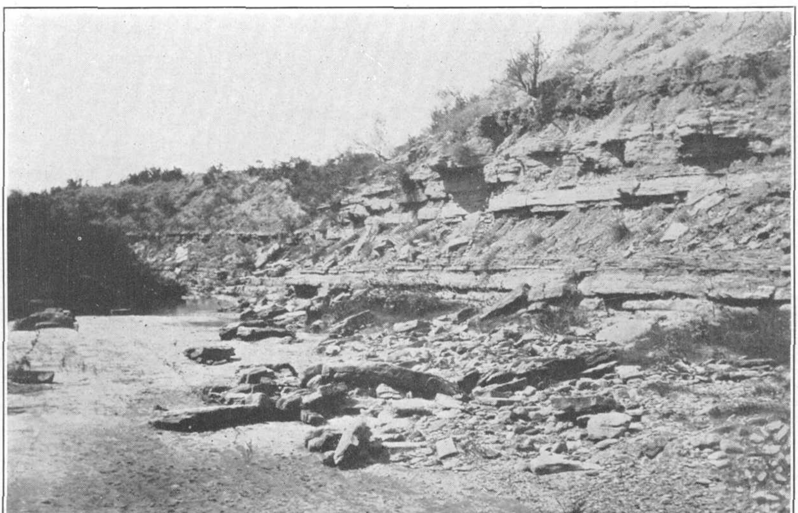
FIGURE 16.—Diagrammatic sketch of the first exposure of the Bigford formation on Concillos Creek below the Bigford-Apache ranch road crossing

An erosional unconformity occurs here within the Bigford formation between two sets of beds of clay, sandstone, lignite, and lignitic clay. Results of laboratory analyses of the sandstone and shale below the unconformity and the brown shale above the unconformity are given on pages 76–78. Fossil leaves occur in clay both below and above the unconformity, but are best preserved in the higher strata. The leaves listed specifically on page 71 were collected from this exposure above the unconformity.

Rio Grande sections.—The best exposures of the Bigford formation are in bluffs on the Rio Grande between a point 2 miles above the mouth of San Lorenzo Creek, where the formation lies on the Carrizo, and a point below the mouth of Espada Creek, where it underlies the Mount Selman. (See fig. 10.)

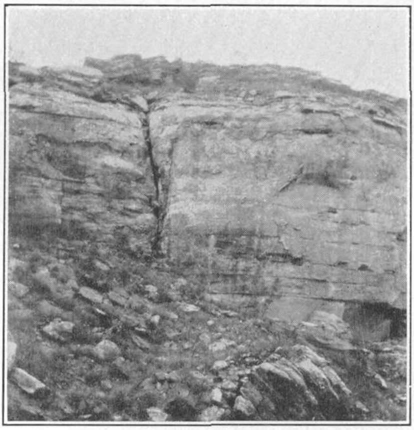


A. SANDSTONE IN THE BIGFORD FORMATION A MILE SOUTH OF COMETA

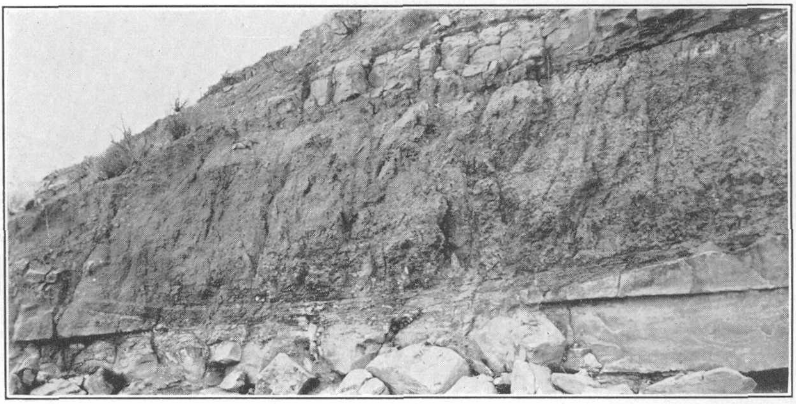


B. INTERBEDDED SHALE AND SANDSTONE OF THE BIGFORD FORMATION ON THE EAST BANK OF CONCILLOS CREEK ONE-FOURTH MILE ABOVE ITS MOUTH

Photograph by A. G. Maddren.

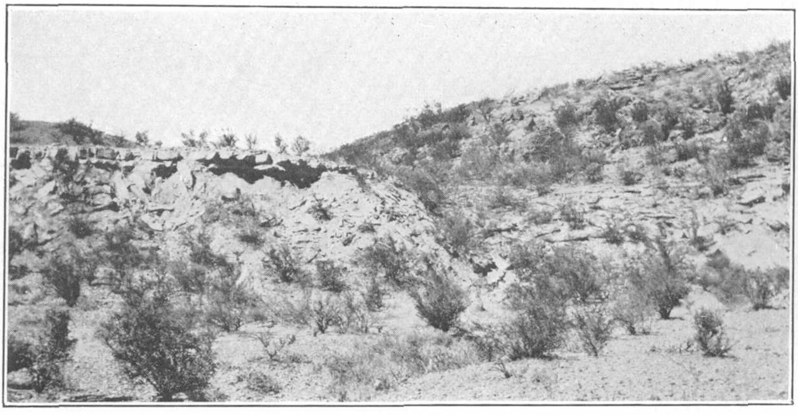


A. SANDSTONE IN MOUNT SELMAN FORMATION CAPPING THE BLUFF AT PALAFOX



B. SECTION ON CONCILLOS CREEK JUST BELOW THE CROSSING OF THE BIGFORD RANCH-APACHE RANCH ROAD

Showing an unconformity within the Bigford formation.



C. MOUNT SELMAN STRATA AT SAN PEDRO HILL, NORTH OF PALAFOX

Section of Bigford formation on the Rio Grande 1½ miles above the mouth of San Lorenzo Creek (48, fig. 10)

	Ft.	in.
Top of bluff.		
Massive flaggy to platy sandstone forming overhanging ledges	20	
Shale grading upward into sandy shale and sandstone	25	
Massive sandstone with shale partings	7	
Gray shale	3	
Shale parting		10
Sandy shale	4	
Gray shale	1	
Sandstone		10
Coal, hard, brittle, bright, with cubical and conchoidal fractures		18–20
Carbonaceous shale	1	
Blocky sandstone	2	6
Concealed by talus	20	
Silt terrace	20	

This section represents strata which lie very close to the base of the Bigford formation.

Between this section and the mouth of San Lorenzo Creek (49, fig. 10) a pronounced bluff exposes bedrock on the river side of an alluvial terrace. Sandstone is interbedded with selenitic clay and shale and with bands of carbonaceous shale. These strata overlie the coal described in the above section.

Section of Bigford formation 2½ miles upstream from Bigford ranch house (50, fig. 10)

	Ft.	in.
Gravel	5	
Shaly, limy ferruginous sandstone, with some sandy shale and some iron concretions	33	
Eight-inch layers of compact buff limestone and fractured and recemented bluish-gray sandy shale with selenite	10	
Gray scaly sandstone with wavy seams of shale	31	6
Concretionary lens of buff limestone and cone-in-cone rock		6
Shaly scaly sandstone with interbedded sandy shale	21	
Concealed	21	
Sandstone ledge to river level		4

These beds belong stratigraphically not far above those at and above the mouth of San Lorenzo Creek, and some of them are duplicated in the section next described.

Section of Bigford formation at end of fence 1¾ miles above Bigford ranch house (51, fig. 10)

	Feet
Silt	15
Massive sandstone	5
Shaly sandstone	15
Concealed	5
Blue-gray shale with iron concretions	4
Argillaceous and micaceous sandstone	16

Section of Bigford formation at Bigford ranch house (52, fig. 10)

	Ft.	in.
Light-gray sandy silt	30	
Tough calcareous sandstone	15	
Cone-in-cone rock		2
Micaceous sandstone	10	
Concealed	5	
Sandstone	2	

From a point a quarter of a mile below the watering place at the Bigford ranch house to the mouth of Concillos Creek, a distance of about 2 miles, there are no outcrops on the Rio Grande at a high river stage. A river bluff just below the mouth of Concillos Creek (47, fig. 10) exposes the upper part of the Bigford formation. (See pl. 4, *A*.) The exposed strata consist of alternating layers of hard massive sandstone averaging 10 feet in thickness and dark-gray shale averaging 15 feet.

Section of Mount Selman and Bigford formations 1 mile below the mouth of Espada Creek (53, fig. 10)

	Feet
8. Sandstone, brown, with conspicuous calcareous sandstone concretions	9
7. Selenitic shale and thin beds of soft sandstone	10
6. Even-layered ferruginous sandstone	7
5. Gray shale with a continuous seam of selenite at the top	3
4. Shaly sandstone	2½
3. Wavily laminated light-brown selenitic shale	6
2. Heavy cross-bedded gray sandstone	11
1. Concealed by silt and talus to river level	47

According to Dumble this section contains the "Carrizo-Marine" contact, which is the same as the Bigford-Mount Selman contact of this report. There is no conspicuous line of separation, and yet there is a difference in bedding between the sandstone of No. 8 and that of No. 2 and there is a sharp line of demarcation between Nos. 5 and 6. At least No. 8 is believed to be Mount Selman, and Nos. 2 and 3 and perhaps Nos. 4 and 5 are Bigford.

Laboratory analyses.—Five samples which were taken from exposures of Bigford strata in and near the region treated in this report were subjected to study in the sedimentation laboratory.

Analysis of Bigford sandstone at south end of Dunlap Bridge over the Nueces River between Brundage and Asherton (22, fig. 10) (sample 02167)

Bedding.—No bedding apparent. Fractures in sugary, friable chunks.

Mineralogy and lithology.—Quartz. Feldspar very abundant (17.1 per cent). Ratio between fresh and altered material is variable in different spots on slide Grains show about even ratio. Slide suggests that part of alteration occurred after deposition as sandstone. Muscovite, zircon, tourmaline. Very few dark-colored minerals.

Size.—The sandstone was broken up on cardboard with a spoon and sieved, with results shown in Figure 17. This sample has a notably low textural range, for it consists largely of very fine sand with subordinate amounts of fine sand and coarse silt and contains no coarse or medium-sized sand and no fine silt or clay.

Shape.—Predominately angular. Very few rounded grains in any grade.

Packing and pore space.—Well packed—that is, has "shaken down" appearance. Pore space small and contains no clay.

Cement.—Apparently no cement; held together by packing. No iron present, as burned sample remained gray.

Color.—Light gray. Color very uniform except on weathered surface, which is darker, owing to lichens, etc.

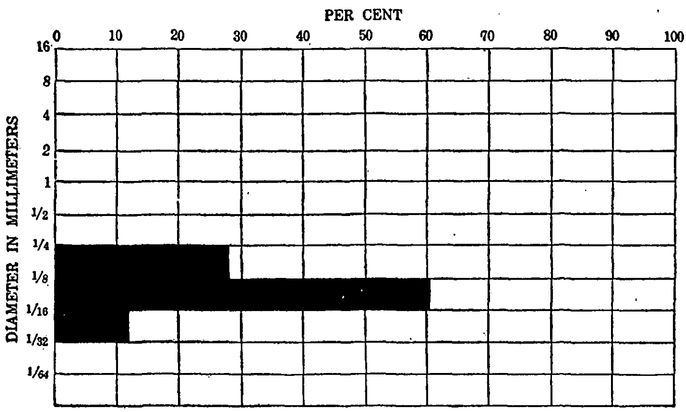


FIGURE 17.—Mechanical analysis of sample 02167

Analysis of limestone from Bigford formation at old road a quarter of a mile east of northern house on Jones ranch (26, fig. 10) (sample 02165)

Bedding.—No bedding planes apparent. Discontinuous slightly wavy lamination made evident by black or white lines. Black due to manganese; white to lime. Breaks with conchoidal fracture into thin chips.

Mineralogy and lithology.—Quartz (with inclusions of rutile); feldspar, 8.7 per cent; orthoclase and plagioclase, abundant, more altered than fresh; muscovite, zircon, garnet, tourmaline. Soluble in 18.5 per cent HCl, 63.5 per cent. Some clay, but most of fine material is crystalline. Particles are embedded in fine matrix and are evenly spaced. The $CaCO_3$ does not appear to be crystalline. Manganese dendrites are common on surface of specimen. Pyrolusite (MnO_2) is the mineral. It is soluble in HCl, hence is a part of the soluble percentage. Heavy minerals very scarce.

Size.—The mechanical analysis of the residues after solution in acid resulted as shown in Figure 18.

Shape.—Quartz predominantly angular in all grades. The grade ⅛–1/16 millimeter has a few rounded grains (2 per cent by count of 200). This is unusual, as material so fine is seldom rounded. Feldspar very angular, as a larger proportion is fresh than in other samples examined. Other minerals scarce and are generally in irregular fragments. Material is scattered through matrix, and grains do not touch one another.

Porosity.—Rock is fine grained and compact.

Cement.—Cement is $CaCO_3$. Very firmly cemented. Was certainly primary.

Color.—Yellow-brown with streaks of black and white. Yellow color due to iron. Burns to a dark brick red. Residuum would doubtless be red.

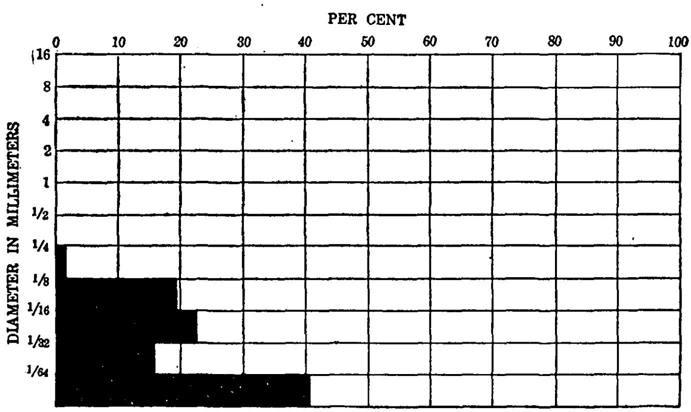


FIGURE 18.—Mechanical analysis of residue of sample 02165

Three samples were taken from the Bigford exposure on Concillos Creek described on page 72 and analyzed in the sedimentation laboratory.

Analysis of sandstone below the unconformity in the Bigford formation as exposed on Concillos Creek next below the crossing of the Bigford-Apache ranch road (sample 02172)

Bedding.—Bedding planes irregular, with bumpy relief of 5 millimeters; are not parallel and suggest ripple marks. Fractures into irregularly rectangular blocks.

Mineralogy and lithology.—Quartz; feldspar abundant, many altered grains; mica not abundant; heavy minerals present in abundance; glauconite present but rare.

Size.—Figure 19 shows the results of mechanical analysis of this sandstone, which is made up chiefly of fine and very fine sand but includes a considerable percentage of silt and clay.

Shape.—All very angular. Glauconite more angular than is usual in this mineral.

Cement.—Held together by clay. Sharp edges are maintained.

Pore space.—Uniform and filled with clay.

Color.—Bluff with slight greenish cast.

Fossils.—No Foraminifera or other microfossils.

Analysis of shale below the unconformity in the Bigford formation on Concillos Creek (sample 02173)

Bedding.—Bedding surfaces not parallel but look as if specimens had been deformed by squeezing. Ripple marks. Color bands, due to varying degrees of oxidation, seem to indicate bedding, but fracture does not follow them exactly. Breaks into roughly cubical and rectilinear blocks.

Mineralogy and lithology.—Quartz, mica, feldspar more abundant than of sample 02172, heavy minerals present in exceptional quantity. Few grains in glauconite in irregular fragments that look as if they have been transported. Not a markedly glauconitic sandstone.

Size.—The results of mechanical analysis are given in Figure 20.

Shape.—All angular except mica flakes.

Packing and pore space.—A little pore space but fairly compact because of shaly character.

Cement.—Held together by clay. Friable in large pieces, but small fragments resist disintegration.

Color.—Bands of olive-green and of greenish buff. Green tinge predominates, and rock as whole is green-gray.

Fossils.—Two Foraminifera were found.

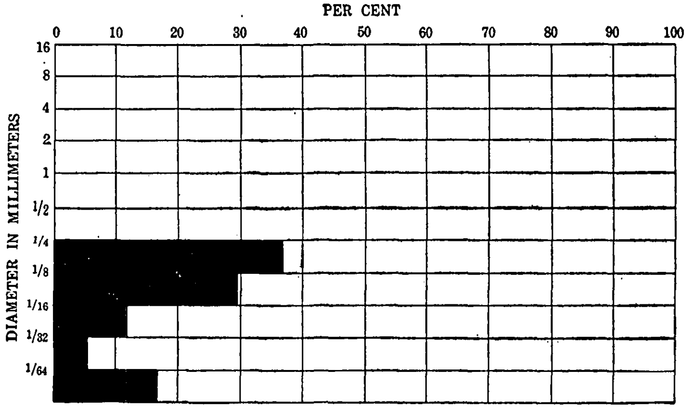


FIGURE 19.—Mechanical analysis of sample 02172

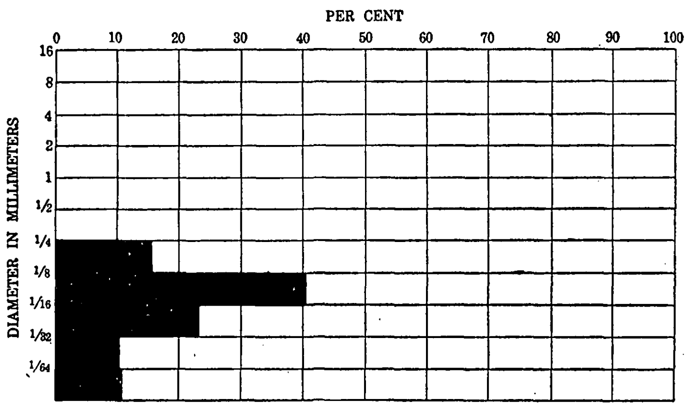


FIGURE 20.—Mechanical analysis of sample 02173

Analysis of brown shale above the unconformity in the Bigford formation on Concillos Creek (sample 02174)

Bedding.—Lamination lines are visible as dark streaks against a slightly lighter background. As fragment is disintegrated the laminations are shown to be waving and the structure lenticular in lenses 4 to 5 millimeters thick. This may be due to shear lines or fissures developed after consolidation. Breaks into irregular fragments, which show shale cleavage, but only in small degree. Bedding surfaces contain imprints of plant fragments, very much broken up.

Mineralogy and lithology.—Quartz, feldspar, mica very abundant, numerous brown plates, which are probably plant shreds; clay in great abundance.

Size.—In order to make mechanical analysis sample was broken up by boiling with NaOH, and deflocculation was accomplished by washing and boiling with Na_2CO_3. The results of analysis are shown in Figure 21.

Shape.—Quartz very angular. Organic matter in flakes and shreds.

Orientation.—Mica and vegetable shreds oriented parallel to bedding in both slide and specimen.

Packing and pore space.—Very compact rock, probably impervious where not cracked. Specimen shows that formation has many cracks, which are lined with either oxidized matter or matter brought from another formation.

Cement.—Held together by clay.

Color.—Blackish gray with buff surface stains in bedding planes.

Analyses of samples from the Bigford formation at spring 7 miles below Sullivan ranch house

Sample 02260

Lithology.—A friable aggregate of well-sorted sand grains, 0.8 per cent soluble in acid. The small amount of cement is calcareous.

Mineralogy.—Light minerals, quartz 79 per cent, plagioclase 20 per cent; heavy minerals, 0.7 per cent, unidentified.

Size.—Medium sand with finer admixture (fig. 22); well sorted.

Shape.—Angular 42 per cent, subangular 35 per cent, subround 26 per cent, round 2 per cent. This sample is similar in most respects to the sandstones of the Carrizo.

Sample 02259

Lithology.—Platy, ferruginous, calcareous yellow to brown sandstone, 4.5 per cent soluble in acid.

Mineralogy.—Quartz 55 per cent, sericite 25 per cent, biotite 11 per cent, feldspar 5 per cent, unidentified heavy minerals 0.4 per cent.

Size.—Poorly sorted, a mixture of coarse, medium, fine, and very fine sand, coarse and fine silt, and clay (fig. 23).

Shape.—Angular 35 per cent, subangular 51 per cent, subround 4 per cent.

Origin.—Although the Bigford formation contains a considerable amount of glauconite in many places and two specimens of Foraminifera were discovered in sample 02173, from one of the Concillos Creek sections, the formation is not thought to be, primarily at least, of marine origin. Both the glauconite and the Foraminifera may wel have been derived from the reworking of the Midway or Escondido formations, over which the strata of the Wilcox group lie unconformably. A few Foraminifera may also have been carried inland from the sea by birds, amphibians, reptiles, or mammals.

The general scarcity or absence of marine or even estuarine fos sils indicates terrestrial origin. It is probable, however, that the sea was not far distant on the east when these rocks were laid down, that the plain of deposition was not much above sea level, and that the deposition was caused and controlled by proximity to the shore line.

The angularity of the grains, as indicated by the analyses of almost all the samples, suggests that water rather than wind was the chief

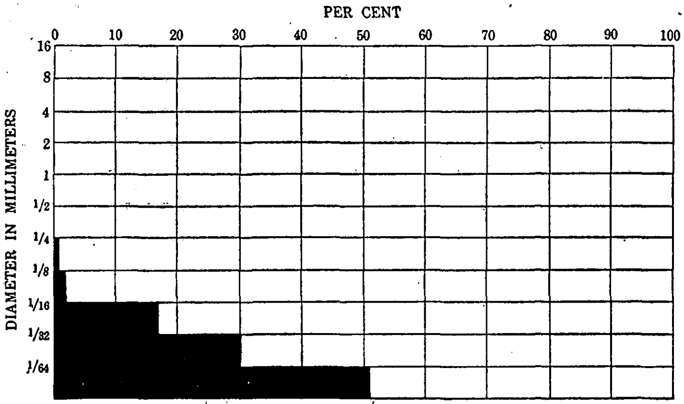


FIGURE 21.—Mechanical analysis of sample 02174

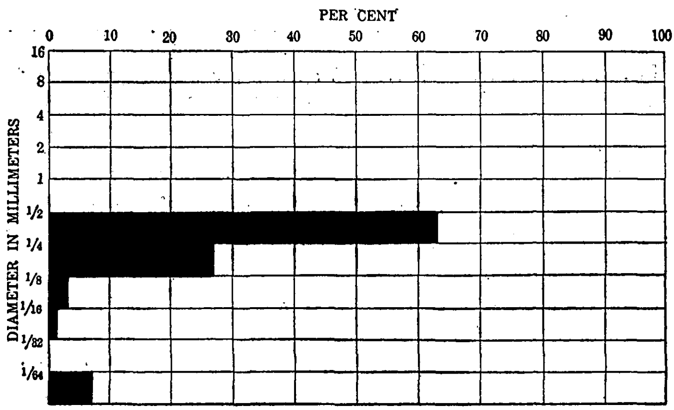


FIGURE 22—Mechanical analysis of sample 02260

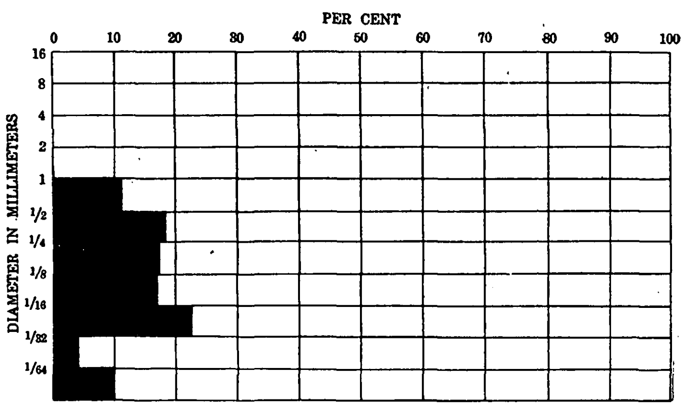


FIGURE 23.—Mechanical analysis of sample 02259

agent of transportation and deposition. Sample 02260, however, contains 2 per cent of rounded grains, indicating some wind action. The textural fineness and the low textural range of the deposits indicate that the transporting waters were sluggish and therefore unable to carry the coarser grades. The relative rarity of heavy minerals, especially in the coarser grades, implies that the limit of transportation was controlled not only by size but also by high specific gravity, or else that there were few heavy minerals at the source.

Not only were there streams flowing into and through the coastal area of deposition, but there must have been also extensive, if temporary and shallow, bodies of standing water, in which vegetation accumulated for the formation of lignite. The unconformity on Concillos Creek records an alternation of deposition and erosion, at least locally. It is not thought, however, that there were long breaks in deposition or that erosion occurred over wide areas even for short periods of time.

It is believed that the clastic materials of which the Bigford formation is composed were brought down by streams from the west. The trans-Pecos mountains and the high plains and plateaus north and west of the Balcones escarpment, all doubtless contributed sediment to the coastal zone. So low was the land and so slowly did the streams flow that the coarser and heavier materials were left behind. But the transportation and accumulation were not accomplished so slowly or the conditions of temperature, humidity, and vegetation were not such as to prevent the feldspars from traveling the whole way without being chemically decomposed.

The origin of the limestone that is so conspicuous in this formation is conjectural. The fact that less than 63 per cent of its material is $CaCO_3$, except in a sample of the so-called Mills bed of Getzendaner, of which 96.5 per cent is soluble in acid, the rest being suspended quartz, feldspar, muscovite, garnet, zircon, tourmaline, and pyrolusite indicates that the limestone itself is original. Certainly not all of it is concretionary. It is likely that there were small inclosed basins adjoining the shore line, which contained shallow water intermittently. When they dried up in dry seasons, the contained carbonates were deposited along with the mechanically suspended sediments. The thin seams of gypsum may have had a similar origin. Perhaps some of it was deposited in the form of caliche.

No attempt is made to explain the cone-in-cone structure, which is more prevalent in the Bigford than in any other formation of the region.

CLAIBORNE GROUP

[Characteristic fossils, pls. 41-45]

The Claiborne age of some of the Eocene formations in Texas has long been recognized. The correlation is made not only on lithologic and paleontologic grounds but also because of continuity along the strike, except for the wide alluvial belt in the valley of the Mississippi River, from the type section on the Alabama River at Claiborne, Ala., through Mississippi and Louisiana to Texas. The strata are also traceable from the Sabine River, on the east border of Texas, to the Rio Grande, without loss of stratigraphic, lithologic, or paleontologic identity.

In the lower Rio Grande region the Claiborne group has been divided into the Mount Selman, Cook Mountain, and Cockfield ("Yegua") formations, named in chronologic order from oldest to youngest.

MOUNT SELMAN FORMATION

Name.—Strata overlying the "Lignitic" were first described by Johnson [40] in 1889. In 1892 Dumble [41] recognized the "Yegua formation," and in the same year the term Mount Selman was for the first time applied by Kennedy [42] to the lower portion of the "Marine beds," which lay on the "Lignitic" and under the "Yegua" (Cockfield). The name was taken from the town of Mount Selman, in Cherokee County, Tex. At the same time Kennedy applied the term Cook Mountain to the upper part of the "Marine beds," supposedly lying between the Mount Selman and the "Yegua." It was therefore in 1892 that the Mount Selman formation as now understood was first defined. It then included the rocks lying on the "Lignitic" and under the Cook Mountain. In 1894 Dumble,[43] following an earlier paper by Kennedy, described the "Marine beds" lying between the "Lignitic beds" and the "Yegua" and recognized the two lithologic and faunal divisions without naming the Mount Selman and Cook Mountain formations. In 1914 Deussen [44] recognized the Mount Selman formation, lying on the Wilcox and under the Cook Mountain, and made it the basal formation of the Claiborne group. In eastern Texas the Mount Selman formation was reported in 1918 by Dumble,[45] still as the lower part of the "Marine beds," conformably overlying the so-called Carrizo (in reality the younger Queen City) and conformably underlying the Cook Mountain formation.

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[40] Johnson, L. C., The iron regions of northern Louisiana and eastern Texas: 50th Cong., 1st sess., H. Ex. Doc. 195, pp. 19-21, 1889.

[41] Dumble, E. T., Report on the brown coal and lignite of Texas, pp. 148-154, Texas Geol. Survey, 1892.

[42] Kennedy, William, A section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico: Texas Geol. Survey Third Ann. Rept., pp. 52-54, 1892.

[43] Dumble, E. T., Cenozoic deposits of Texas: Jour. Geology, vol. 2, pp. 549-567, 1894.

[44] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 37-56, 1914.

[45] Dumble, E. T., The geology of east Texas: Texas Univ. Bull. 1869, pp. 61-65, 1918.

Correlation.—According to Deussen[46] the Mount Selman and Cook Mountain formations of Texas taken together are correlated with the lower Claiborne St. Maurice formation of Louisiana (which was later divided by Spooner[47] into the Cane River, Sparta, and St. Maurice restricted) and the Tallahatta formation plus the Lisbon formation of Mississippi and Alabama.

Whether the Mount Selman formation of this report is the exact equivalent of the Mount Selman of Wendlandt and Knebel[48] in east Texas, with its divisions into Carrizo, Reklaw, Queen City, and Weches, remains to be determined. (See p. 52)

Character.—The chief constituent of the Mount Salem formation in the Rio Grande region is clay, and exposed sections of it are therefore rare except at places along drainage lines where thin ledges of sandstone and limestone hold up the clay in vertical faces. There are large flat areas where the formation is not exposed but where the shallow surficial drainage channels are so universally clayey that the underlying formation must be chiefly if not entirely clay or shale. The sections exposed probably exaggerate the proportion of sandstone in the formation, for they occur only where lenses of the most resistant materials are most abundant. The clay is gray, black, greenish gray, and bluish gray where fresh and yellow or buff where weathered. Some of the beds are sandy, and some are limy, but most of them consist chiefly of stiff, compact clay, plastic and sticky when wet, and hard but with a fracture like that of starch when dry. The beds of clay contain a large quantity of gypsum in lenses, beds, stringers, joint fillings, and irregular crystal aggregates. Most of it is the transparent platy variety, but some masses of bladed crystals are known.

The sandstone, which is most abundant near the base of the formation, occurs in layers and lenses, some of them 25 or 30 feet thick for short distances. The sand is coarse, medium, and fine, most of it is micaceous, and some is glauconitic. The beds are fairly well consolidated but are not quartzitic. The formation includes a few thin lenses of gray limestone. Coal, both lignitic and bituminous, is a common constituent of the Mount Selman.

The Mount Selman formation contains throughout, from bottom to top, many calcareous concretions, chiefly in the clay and shale. Most of them are composed of compact fine-grained pure, almost lithographic limestone. On the outside they are pale yellowish-gray or buff; on the inside they are light chocolate-brown or gray. Nearly all of them are septarian, and the fractures are filled with

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[46] Deussen, Alexander, op. cit. (Water-Supply Paper 335), p. 51.

[47] Spooner, W. C., The interior salt domes of Louisiana: Am. Assoc. Petroleum Geologists Bull., vol. 10, p. 227, 1926.

[48] Wendlandt, E. A., and Knebel, G. M., Lower Claiborne of east Texas, with special reference to Mount Sylvan dome and salt movements: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 1351, 1929.

calcite. They are of diverse sizes and forms. The smallest are about the size of a pea, and the largest are 6 feet in diameter; some are cylindrical, resembling pipe stems, some are biscuit-shaped,

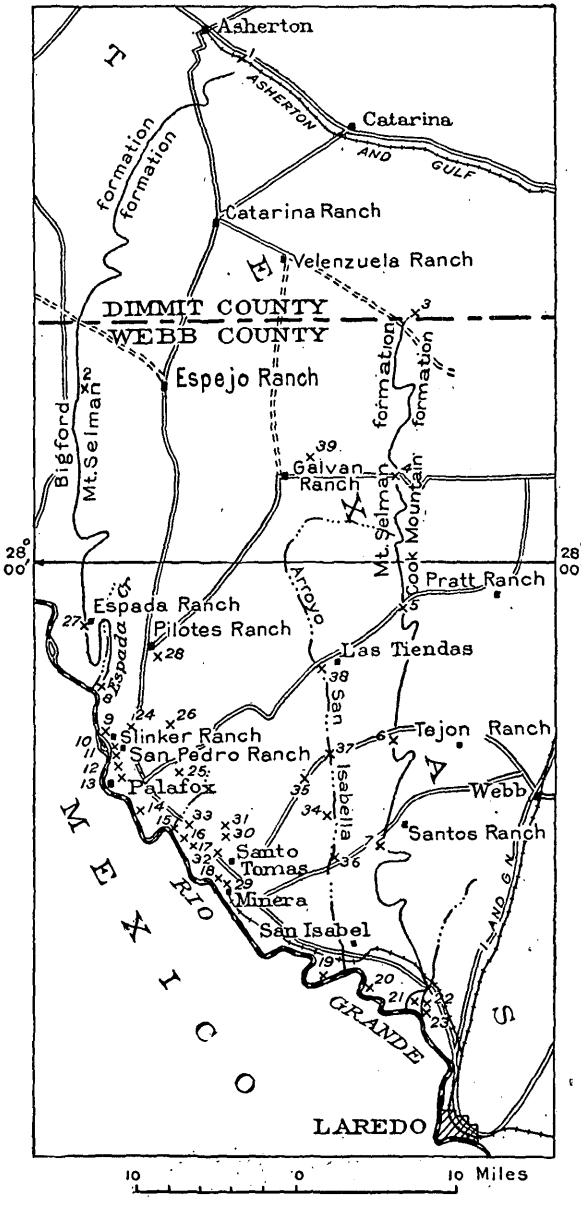

FIGURE 24.—Sketch map showing the area of outcrop of the Mount Selman formation and the location of the exposures described

and some are nodular and extremely irregular. The average concretion is a foot in diameter and spheroidal.

Distribution.—The surficial distribution of the Mount Selman formation is shown on Plate 7 and Figure 24. The formation extends downstream along the Rio Grande from a point 6 miles above Palafox to the mouth of Sambarieto Creek, about 8 miles above Laredo, a distance of about 26 miles measured in a straight line. The course of the river is irregularly oblique to the strike, however, and this distance is not a measure of the width of the belt of outcrop, which has a nearly uniform width of about 16 miles. The western boundary of the formation, which is the Claiborne-Wilcox line of contact, is not sharply defined. In general it follows the line that separates beds of clay, sandstone, and lignite that contain only rarely and locally a few concretions and carry a Wilcox flora (the Bigford formation) from beds of gypsiferous, highly concretionary clay interbedded with beds of sandstone and limestone carrying unmistakable though few and fragmentary marine fossils and a Claiborne flora. This line is determinable with a fair degree of accuracy between the Asherton & Gulf Railway and the Rio Grande. The railway crosses it 3½ miles southeast of Asherton (1, fig. 24), where sandy Wilcox strata give place to flat-lying Mount Selman clay. Between Dentonio and the Catarina ranch no sharp line of division can be made out between the Mount Selman formation on the east and the Bigford on the west, and yet both the surface materials and the topography within a few miles of the ranch are different from those nearer Dentonio. West of the Espejo ranch the line is recognizable within a very short distance of the Brown ranch house (2, fig. 24), just east of which the basal beds of the Mount Selman formation are poorly exposed and west of which there is a high, flat prairie, not sandy, similar to that near Dentonio. About 5 miles northeast of the Bigford ranch and a mile east of Concillos Creek the Bigford-Mount Selman boundary is marked by a prominent westward-facing escarpment. Strata poorly exposed in the bed of Espada Creek at the Espada ranch are believed to be at or near the base of the Mount Selman, and the rocks exposed just west of the creek appear to belong in the Bigford. The Bigford-Palafox road crosses this boundary about a mile northwest of San Pedro Hill.

The Mount Selman-Cook Mountain line, on the east side of the belt, separates the Mount Selman material from the sandy, highly fossiliferous, red-weathering Cook Mountain formation, which stratigraphically overlies the Mount Selman. This line is much more easily traced than the boundary at the base of the Mount Selman. It is easily recognizable on the northeast border of the region mapped, at the base of a westward-facing escarpment 7½ miles southeast of the Velenzuela ranch house (3, fig. 24). The road leading west from Encinal crosses it approximately at the tank 4 miles east of the Galvan ranch (4, fig. 24), and the road leading southeast from Encinal crosses it at a point between 7 and 8 miles west of the Pratt ranch and about 4 miles northeast of Las Tiendas (5, fig. 24). From this point the boundary is traceable in a southerly direction near the ranch grounds of H. H. Jeffries, crossing the Webb-Palafox road about 5 miles west of the Tajone ranch (6, fig. 24), the Webb-Tordillo road about 2 miles east of Tordillo settlement (7, fig. 24), and the Rio Grande & Eagle Pass Railway at Sambarieto Creek and following this creek to the Rio Grande.

The whole area in which the Mount Selman formation comes to the surface is characterized by a gently undulatory topography with clay-loam soils and sparse vegetation. These conditions are typically illustrated between the Espejo and Catarina ranches, between the Espejo and Pilotes ranches, between the Pilotes ranch and Palafox, near Las Tiendas, east of Palafox, and near Tordillo.

The Mount Selman formation is known to extend westward in the trough of the broad syncline that crosses the district around Crystal City. Several outcrops of the formation have been observed on the Nueces River, but the Bigford-Mount Selman boundary line is imperfectly known in this synclinal area.

Thickness.—Jennings well No. 2, in Zapata County, seems to have penetrated between depths of 3,380 and 4,270 feet 890 feet of the Mount Selman formation, but as all the formations thicken down the dip the thickness of the Mount Selman where it crops out is probably less than this. On the basis of computed thickness per mile of distance measured parallel with the dip and the width of the belt of outcrop in this direction, the average thickness of the formation in this region is about 618 feet. Deussen[49] assigns to it a thickness of 600 to 700 feet in the area next north of the lower Rio Grande region.

Fossils.—The definition and identification of the Mount Selman formation paleontologically are difficult because of the rarity and poor state of preservation of the fossils. Scanty and fragmental invertebrate forms including *Cornulina armigera* Conrad, *Cytherea* sp., *Ostrea* sp., *Volutocorbis petrosa* (Conrad), *Protocardia* sp., and *Venericardia planicosta* Lamarck have been collected from the formation in a very few places outside the lower Rio Grande region.

Berry[50] lists a Mount Selman flora (see pl. 40) made up of the following species:

Apocynophyllum grevilleafolium.
Apocynophyllum texensis?
Citrophyllum eocenicum.
Coccolobis clairbornensis.
Fagara claibornensis.
Ficus newtonensis.
Geonomites claibornensis.
Gleditsiophyllum eocenicum.
Mespilodaphne columbiana.
Mespilodaphne caudata.
Mimosites georgianus.
Myrcia trowbridgi.
Oreodaphne inequilateralis.
Sapindus georgianus.
Thrinax eocenica?

[49] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 60, 1924.

[50] Berry, E. W., The middle and upper Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 92, p. 32, 1924.

Exposures.—Although the Mount Selman formation, owing to its large content of clay, is not exposed in thick sections in many places within the lower Rio Grande region, in the bluffs and breaks of the Rio Grande there are a number of exposed sections of considerable thickness, and even far from the river, in the area of the Rio Grande-Nueces divide and in the Nueces Basin, there are some shallow exposures in hillsides, stream banks, and roads.

Rio Grande sections.—The Mount Selman formation is exposed in the Rio Grande bluffs and in the beds of the mouths of tributary streams from a point about 1 mile below the mouth of Espada Creek, 5 miles above Palafox, downstream to the mouth of Sambarieto Creek, 9 miles above Laredo. Although the dip is very gentle, the river flows in a course that is oblique to the dip, and the exposures are not many miles apart, no complete section of the formation can be worked out. The unexposed strata probably exceed in total thickness those that are exposed.

The section about a mile below the mouth of Espada Creek (8, fig. 24), which probably includes the basal beds of the Mount Selman overlying the uppermost beds of the Bigford formation, is described on page 74. About half a mile east of this section there is a 60-foot rise to higher land, in which there is much iron in concretions, seams, and stains, many limestone concretions, at least one 10 to 15-foot layer of shale, and several beds of limy sandstone.

Section of Mount Selman formation at end of fence a quarter of a mile above Slinker ranch (9, fig. 24)

	Ft.	in.
Weathered, scaly, shaly sandstone	7	
Massive hard sandstone	5	3
Shaly sandstone	3	
Soft ferruginous sandstone	3	
Light-gray clay with one 3-inch bed of sandstone	4	
Definitely cross-bedded sandstone in sets about 1 foot thick, coarse to medium grained, light gray or buff	11	

The base of this section is not many feet stratigraphically above the top of the section a mile below the mouth of Espada Creek, and these same strata are probably represented in the poor exposure east of that section.

About half a mile north of the Slinker ranch and slightly higher in the formation the upper part of the wall of the main valley exposes black and brown ferruginous sandstone, a little shale, evenly bedded 2-foot layers of hard sandstone, and some limy beds.

Sandstone exposed in the arroyo between the Slinker and San Pedro ranches has been so irregularly infiltrated with resistant iron that it appears to be irregularly bedded, but it is not.

At the San Pedro ranch house (10, fig. 24) the exposed rock consists of a heavy ledge of irony and sandy limestone 10 feet thick, with softer, friable light-gray, yellow, and brown sandstone below. The lower three-fourths of the bluff is concealed, but the fragments suggest the presence of a bed of clay.

At the ranger camp 1½ miles above Palafox (11, fig. 24) 25 feet of massive bluff-forming calcareous sandstone overlies 12 feet of pure clay shale. The shale is probably the same as that concealed at the San Pedro ranch.

In the Creek bed between the Palafox cemetery and the Alexander ranch (12, fig. 24) are exposed 6 feet of sandstone and shale in alternating beds 1 to 2 feet in thickness. Elongated cylindrical iron concretions resembling pipestems lie in the sandstone normal to the bedding. There are also limestone concretions, most of which are flattened and twisted in such a way as to conform to the beds in which they lie. They consist of hard, compact chocolate-colored limestone, some of which is so fine grained as to be almost lithographic. The concretions are septarianized but do not break easily. They contain veinlets of calcite, and their surfaces are coated with mica. One of the sandstone ledges contains abundant poorly preserved plant remains, including fragments of bark, stems, leaves, and palm rays. These remains (pl. 40) were identified by Berry [51] as follows:

Apocynophyllum grevilleafolium Berry.
Coccolobis clairbornensis Berry.
Ficus newtonensis Berry.
Geonomites claibornensis Berry, n. sp.?
Myrcia trowbridgi Berry, n. sp.

Berry states that this flora is typically Claiborne in its facies.

Lying stratigraphically above the strata exposed in the river bluffs and at higher altitudes east of the rim of the river gorge within 2 or 3 miles north and northeast of Palafox are many exposures of massive calcareous sandstone with thin seams of sandy shale and a few thin layers of cross-bedded sandstone. The massive beds, which are 12 to 15 feet thick, contain irregular iron concretions that cause the rock to weather irregularly into rough, pitted forms. In a westward-facing hill three-quarters of a mile northeast of Palafox and in the road 1.3 miles northeast of the ranger camp fragmental and unidentifiable molluscan fossils were found. Similar fossils occur in the flagstones at the Palafox store.

[51] Berry, E. W., op. cit., p. 14.

Section of Mount Selman formation in bluff three-fourths mile east-northeast of Palafox (13, fig. 24)

	Feet
13. Massive flaggy sandstone at top of knoll	5
12. Shale	10
11. Massive calcareous sandstone, fossiliferous	8
10. Sandy shale and flaggy sandstone	10
9. Clay shale with iron concretions	20
8. Flaggy sandstone	10
7. Dense fine-grained buff to dark-gray limy sandstone with iron layers	20
6. Clay shale with limy concretions	5
5. Sandy shale	5
4. Thin-bedded or flaggy sandstone	10
3. Massive to thin-bedded sandstone	25
2. Concealed by talus blocks of No. 3	30
1. Alluvial terrace from level of Rio Grande	70

The sandstone of No. 3 is soft and sugary and is gray in the unweathered state but turns to buff-brown and even bright hematitic red on the outcrop. The gray dense limestone concretions in No. 6 are from 1 to 3 feet in diameter. Some are disklike, and some are almost spherical. The massive sandstone of No. 11 is shown to be calcareous upon test with HCl, and it contains distinct fragments of shells, which appear to be thin bivalves from half an inch to 1 inch in dimensions, but no identifiable specimens were procured. No. 13 is illustrated in Plate 13, *A*, and an analysis of a sample from it is given on page 101.

Section of Mount Selman formation at lower pumping station 1½ miles below Palafox (14, fig. 24)

	Feet
Gravel	1
Shale with limestone concretions	2–4
Sandstone	25
Shale	6
Massive sandstone with some thin-bedded and cross-bedded sand near top	30
Pure clay shale	12
Shaly sandstone	4–6
Concealed by large blocks of sandstone from above	40

The 30-foot sandstone is the thickest and most massive single layer of sandstone seen in the Mount Selman formation of the region.

Shale and sandstone layers belonging stratigraphically higher than the top of the section at the pumping station are exposed in the higher hills east of the river bluffs. Limestone concretions are found in both shale and sandstone but more commonly in the shale. The concretions are diverse in size and shape, but the average is perhaps a foot in longest diameter and so flattened that the diameter normal to the bedding is about one-half the diameter parallel with the bedding. Inside they are hard, compact, fractured and recemented, calcareous, and chocolate-brown. Calcite fills the cracks and cuts the limestone in thin seams. The shale is selenitic and fairly free from sand.

The next sections noted downstream are at and near the mouth of Llave Creek. A fresh exposure was seen on the north wall of the creek valley one-eighth of a mile from the Rio Grande (15, fig. 24), where the stream in flood had recently cut laterally and exposed in a vertical face 10 feet of fairly pure shale at the bottom with a few 1-inch sandy layers; 6 feet of alternating shale and sandstone; and at the top 8 to 10 feet of heavy sandstone beds. The shale beds in the lower division are 1½ inches thick on the average. Embedded in them in such a way as to bend the shale bedding planes up and down around them are lenses of limy sandstone concretions shaped like tree trunks. Smaller, stemlike nodules of iron run through the concretions. Selenite or gypsum, which is abundant in the shale, lies for the most part flat in the partings, both in small crystals and in flat sheets. There is some gypsum also in joints. In the 6 feet of alternating sandstone and shale the sandstone is hard and forms lenses 4 to 8 inches thick, which thin out within short distances in both directions and dovetail. The sandstone at the top is almost white, pure, glistening, and cross-bedded. These strata are underlain by another layer of sandstone over which the creek falls just below.

The Rio Grande bluff a quarter of a mile below the mouth of Llave Creek (16, fig. 24) affords no good exposures. The topmost ledge is cross-bedded sandstone with many large calcareous concretions. Below this is soft thin-bedded sandstone, underlain by shale that is poorly exposed.

About 3 miles northwest of Minera (17, fig. 24), at the west edge of a ridge, there is a sharp nose bare of vegetation. Here 3 feet of sandstone caps 25 feet of clay. In the clay are numerous concretions, the largest a foot in diameter, roughly spheroidal or oval, light buff on the outside and light chocolate-brown within, consisting of limestone that is almost lithographic in texture and density. Some of them are septarianized, and some are partly hollow and lined with drusy and crystalline gypsum. These materials are fairly typical of the concretionary clays of the Mount Selman formation as a whole.

Section of Mount Selman formation in Rio Grande bluff just above Minera station (18, fig. 24)

	Ft.	in.
13. Clay shale	20	
12. Massive to flaggy buff sandstone	20	
11. Clay shale	25	
10. Thin-bedded sandstone	3	
9. Clay shale	20	

	Ft.	in.
8. Bony shale, brown to black	1	
7. Coal	1	3
6. Shale, bony (parting)		2–3
5. Coal	1	8
4. Bony shale	1	
3. Clay shale	15	
2. High silt terrace	50	
1. Low, narrow silt terrace from river level	15	

The sandstone of No. 12 as exposed in this bluff appears to have been deposited in a depression, so that it forms a lenticular body thickest at the center and thinning toward the edges. It is, however, a continuous and definite member at about 50 feet above the 20-inch coal bed of the district.

At a ranch pumping station about 2 miles above the mouth of Arroyo Santa Isabella (19, fig. 24) there is a series of rapids in the river. At water level a 5-foot bed crops out that consists of hard gray to green cross-bedded ripple-marked and concretionary sandstone and has a southerly dip. At another point in the upper rapid there is an arch of about 30 feet span and 5 feet high, in the axis of which shale is uncovered by the river. At a second rapid 200 yards downstream a bed of sandstone separates two layers of green shale.

It is reported that a thin bed of coal is exposed in the river bed during periods of low water just below the mouth of Arroyo Santa Isabella and that a 14-inch layer of coal was penetrated at the county bridge across this creek 30 feet below the bridge floor. On the east bank of Arroyo Santa Isabella midway between the railway and the county-road bridge gray clay shale crops out along the stream for 100 yards and has an exposed thickness of 15 feet, with a 2-foot bed of flaggy sandstone 7 feet above water level. The shale contains numerous large calcareous, septarian concretions.

Section of Rio Grande bluff 2 miles southeast of Santa Isabel station (20, fig. 24)

	Feet
Reynosa formation (gravel, loose cobbles 1 to 8 inches in diameter)	1–3
Mount Selman formation:	
Gray clay and shale, gypsiferous	15–20
Gray cross-bedded and evenly bedded sandstone	4
Gray sandy shale	10
Gray sandstone	6
Gray shaly sandstone	3
Gray sandy shale	20
Massive soft gray sandstone with fragments of oyster shells	10
Gray gypsiferous clay and shale	40–50
Gray massive soft sandstone containing spheroidal concretions 2 to 3 feet in diameter	40
Silt terrace above the Rio Grande	60

Section of Mount Selman formation near mouth of Sambarieto Creek (21, fig. 24)

	Ft.	in.
Gravel cemented by calcium carbonate except at surface, where it is loose and stained	10	
Massive and indefinitely bedded sandstone of variegated color, unequally resistant and weathering to form shallow caves	34	
Concealed	15	9
Hard massive sandstone, in layers 1 to 8 inches thick, without concretions	7	
Laminated sandy shale and shaly sandstone	1	3
A single massive layer of brown sandstone with some small iron concretions and a few large limestone concretions	4	
Irregularly bedded to massive brown micaceous sandstone, with numerous small, irregular iron concretions	10	6

The top of this section is very close to the top of the Mount Selman formation, but no part of the Cook Mountain is represented in it.

The transition from the Mount Selman up into the Cook Mountain occurs a quarter of a mile above the mouth of Sambarieto Creek in the east wall of its valley (22, fig. 24). Here there is a cliff composed chiefly of sandstone but including several short, thin lenses of fossiliferous limestone. The lowest of these lenses is only 2 inches thick and 5 feet long in the face of the cliff. At 15 feet higher in the section is a second limestone lens 1 foot thick in the middle and 6 feet long, which contains fragmentary and unidentifiable oysters together with other pelecypods and abundant pieces of wood.

Section of Mount Selman formation at mouth of Sambarieto Creek (23, fig. 24)

	Feet
Massive sandstone weathering into caves on the cliff	11
Evenly bedded sandstone and shale in thin beds	6
Sandy shale	4
Massive sandstone	15
Thin-bedded sandstone, shale, and limestone.	

Because of the high stage of water when this part of the area was studied it was not possible to make a complete section of the bluff on the Rio Grande just below the mouth of Sambarieto Creek. The lower 40 feet of this bluff appears to duplicate the section just given. Above this is a considerable thickness of massive sandstone. About 30 feet from the top of the bluff there is a continuous oyster bed at least a foot thick, above which there is a 2-foot bed of white clay similar to that seen elsewhere in the basal portion of the Cook Mountain formation. The clay is overlain by beds of sandstone and shale to the base of a 15-foot bed of limestone-cemented gravel, which caps the bluff. At least the upper 30 feet of this section below the gravel capping is Cook Mountain. The base is probably Mount Selman, and between the two are transition beds.

Inland sections in lower part of the formation.—A number of fair Mount Selman exposures were seen in the belt of outcrop between the Rio Grande and the northeast border of the lower Rio Grande region. Only the better of these are here described. For convenience the exposures representing strata in the lower portion of the formation are separated from those in the middle and upper portions.

Section of Mount Selman formation on San Pedro Hill (24, fig. 24)

	Feet
Coarse gravel capping hill	0–3
Red and brown sandstone	45
Flaggy sandstone	3
Clays and shales	27

This section is illustrated in Plate 13, *C*. Samples were taken from each of the Mount Selman beds in this section and analyzed, with the results shown on pages 99–101.

Complete and detailed sections of about the lower half of the Mount Selman formation were made available some years ago by prospect drillings about 3 miles southeast of Santo Tomas and at the Pilotes ranch. The records quoted below were made by D. D. Davis and given by Vaughan[52] in his report published in 1900.

Log of prospect drilling No. 2 of Cannel Coal Co., southeast of Santo Tomas

[By D. D. Davis]

	Thickness		Depth	
	Ft.	*in.*	*Ft.*	*in.*
Gravel	5		5	
Clay and sandstone	4		9	
Brown shale	1	6	10	6
Yellow sandstone	8	6	19	
Impure coal (Santo Tomas seam)	2		21	-
Gray shale	23		44	
Brown shale	1	4	45	4
Coal		8	46	
White sandstone	10		56	
Gray shale	7		63	
Sandstone	9		72	
Clay	3		75	
Sandstone	8		83	
Mixed shale and sandstone; marine mollusks	7		90	
Limestone; fossil shells	1		91	
Slate [shale]	4		95	
Sandstone	14	6	109	6
Slate [shale]	1	5	110	11
Coal (San Pedro coal seam)	1	11	112	10
Clay shale (San Pedro coal seam)	2		114	10
Coal (San Pedro coal seam)	1	7	116	5
Sandstone	13	7	130	
Slate [shale]	5		135	
Sandstone	4		139	
Slate [shale]	2		141	
Sandstone	15		156	
Slate [shale]	4		160	
Sandstone	4		164	
Slate [shale]	3		167	

	Thickness	Depth
	Ft.	*Ft.*
Sandstone	39	206
Slate [shale]	3	209
Sandstone	16	225
Clay	2	227
Slate [shale]	3	230
Sandstone	10	240
Shale	29	269
Sandstone	2	271
Shale	10	281
Tough shale	39	320
Sandstone	2	322
Shale	6	328
Sandstone	12	340
Shale	16	356
Sandstone	44	400
Shale	4	404
Sandstone	14	418
Slate [shale]	6	424
Sandstone	11	435
Shale	11	446
Limestone	1	447
Shale	9	456
Sandstone	5	461
Shale	3	464
Sandstone	12	476
Shale	6	482
Sandstone	3	485
Shale	5	490
Sandstone	10	500

[52] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, pp. 41–44, 1900.

Log of prospect drilling No. 6 of Cannel Coal Co., at Pilotes ranch

[By D. D. Davis]

	Thickness		Depth			Thickness		Depth	
	Ft.	*in.*	*Ft.*	*in.*		*Ft.*	*in.*	*Ft.*	*in.*
Soil	10		10		Clayey sandstone	6		174	
Gravel	2		12		Shale clay	2		176	
Yellow shale clay	16		28		Sandstone	8		184	
Blue shale clay	16		44		Tough shale	4		208	
Clayey sandstone	2		46		Bony coal		6	208	6
Blue shale clay	28		74		Clay	1	6	210	
Bony coal		8	74	8	Brown sandstone	5		215	
Brown shale clay		4	75		Bony coal	1	3	216	3
Blue shale clay	5		80		Brown shale clay	3	9	220	
Brown shale clay	4		84		Brown clayey sandstone		9	220	9
Coal		10	84	10	Coal		3	221	
Brown sandstone		4	85	2	Brown sandstone	6	2	227	2
White sandstone	4	10	90		Coal	1	8	228	10
Coal	1	11	91	11	Bone		2	229	
Bone		4	92	3	Striped brown sandstone	1	8	230	8
Light-brown shale	1	9	94		Bony coal	1	4	232	
Tough shale	13		107		Bone		6	232	6
Shale clay	10		117		Blue shale clay	4		236	6
Bone		6	117	6	Bone		2	236	8
Bony clay		6	118		Coal		9	237	5
Bone	1		119		Bone		7	238	
Shale clay	6		125		Sandstone	6		244	
Sandstone	6		131		Brown shale	2		246	
Tough shale	14		145		Brown sandstone	8		254	
Sandstone	4		149		Blue shale clay	1		255	
Clayey sandstone	4		153		Sandstone	7		262	
Clay	3		156		Blue shale clay	6		268	
Shale clay	12		168						

In drilling No. 2 the materials recorded include about 43 per cent clay and shale, 50 per cent sandstone, less than 0.5 per cent limestone, and more than 1 per cent coal and bone. In drilling No. 6 the proportions are, shale and clay, 62 per cent; sandstone, 26 per cent; coal and bone, 4.3 per cent; and no limestone. Although the base of the Mount Selman formation is not recognizable in the records, it is probable that the alternating beds of clay and sand penetrated in the lower parts of both drillings include strata in the upper part of the Bigford. These drillings indicate that the lower half of the Mount Selman formation is an aggregate of interlensed rather than interlayered sand, clay, and coal and that clay and sand are included in approximately equal proportions.

About 4 miles east of Palafox (25, fig. 24) a 12 to 15 inch coal bed was mined in 1919 by Coleman & Johnson for fuel to supply their two pumping plants on the Rio Grande. Although the coal bed crops out in the bed of Llave Creek 100 yards east of the mine, it is roofed in the mine shaft by 20 to 25 feet of fine to medium grained, irregularly bedded and flaggy sandstone. The coal is underlain by 15 to 20 inches of bone and bony shale, and this is underlain by another sandstone. There are a few limonite concretions in the upper sandstone.

Secton of Mount Selman formation 5 miles northeast of Palafox (26, fig. 24)

	Ft.	in.
Brown sandstone, cap rock	3–4	
Concealed	20	
Gray clay	5	
Interbedded clay and thin sandstone	1	
Gray sandstone, much jointed	1	2
Gray clay		6
Gray sandstone		4
Greenish clay	25	

The brown sandstone at the top of this exposure is highly concretionary and contains calcite locally. It weathers irregularly to variegated red and purple.

In the bed of Espada Creek at the Espada ranch (27, fig. 24) basal Mount Selman beds consist of hard massive sandstone with large lenslike and millstone-shaped concretions similar to those found elsewhere at this horizon. Where the road from the Espada ranch to the Pilotes ranch passes the division fence there are many small, septarianized concretions in shale and buff lenses of limestone in shale and soft sandstone. About 1½ miles west of the Pilotes ranch a thin ledge of sandstone caps 10 feet of gray shale in low hills. Over the sandstone is more shale containing a few flattened yellow and buff limestone concretions.

The hills within half a mile south and southeast of the Pilotes ranch are composed chiefly of selenitic shale but are capped and terraced by more resistant sandstone and limestone ledges. The sandstone layers are interbedded with shale and are themselves noticeably argillaceous. The limestone beds are sandy. The highest of these hills affords the best exposures, and the following section was measured there:

Section of Mount Selman formation on hill half a mile southeast of Pilotes ranch (28, fig. 24)

	Feet
Hard massive sandstone	21
Gray clay and shale	15
Sandy fine-grained gray or buff limestone	5
Thinly interbedded shale and sandstone	5
Stiff gray selenitic clay shale	25

At the Pintos ranch a small stream has cut through a tank dam and exposed 9 feet of shale below the dam. The shale is gray and contains numerous iron concretions, some of which, shaped like logs, lie parallel with the bedding, and others the size of pipestems cross the bedding. There are also a few small spheroidal septarianized limestone concretions.

Many exposures of lower Mount Selman beds occur in the district around the head of Concillos Creek about midway between the Pilotes and Espejo ranches. The common beds here are sandy and concretionary shales with some sandstone ledges, but one conspicuous layer or series of lenses is made up almost entirely of limestone concretions. This layer is about 1 foot thick and consists in places of oblate spheroidal bodies of limestone separated from one another by vertical joints. Perhaps these are not true concretions but results of concentric weathering of jointed blocks.

Several ledges of sandy limestone are poorly exposed on the hillside in the road just east of the Brown ranch and three-quarters of a mile N. 75° W. from the Espejo ranch, (2, fig. 24). All the layers effervesce freely in acid. The rock is compact and crystalline and on fresh surfaces is pink. In the lower part of the exposures are numerous rounded limestone concretions in a sandy limestone matrix.

Inland sections in middle part of formation.—A number of notable exposures in the middle part of the formation away from the Rio Grande are described below.

Section of Mount Selman formation in arroyo just north of Minera (29, fig. 24)

	Ft.	in.
Crystalline pebbles with calcareous matrix	3	
Green shale	2	
Gray sandstone		6
Gray shale with some concretionary sandstone	2	
Brown concretionary cross-laminated sandstone	3	
Green shale	7	
Brown fissile shale	2	
Brown and yellow shale interbedded with green shale	8	
Coal	2	
Brown fissile shale	1	
Blue to green thinly laminated shale with some sandy layers 1 inch thick and some soft concretions	10	
Brown fissile shale		9
Green shale	5	
Brown fissile shale		6
Green shale	1	
Concealed	10	
Thinly laminated cross-bedded sandstone	2	
Green clay	1	
Thinly laminated gray shale	2	

Section of Mount Selman formation 3 miles north of Minera (30, fig. 24)

	Feet
Thinly laminated shaly sandstone	3
Greenish-gray sandy clays	10
Bony coal	2
Gray clay	2

Section of Mount Selman formation 4 miles north of Minera (31, fig. 24)

	Ft.	in.
Concealed	10	
Concretionary sandstone	2	
Buff sandy clay	9	
Brown shale	1	
Green shale	7	
Dark carbonaceous shale	6	
Light-brown shale	1	
Coal	1	2
Carbonaceous shale	5	
Green shale	15	
Carbonaceous shale	1	
Gray shale	4	
Dark-gray shale	6	

Generalized section of Mount Selman formation near Santo Tomas

	Feet
Clay shale grading upward into sandy shale and thin, flaggy sandstone	4
Sand with purple mottling and a few tubes of sand	4
Sandy clay and shale with large plates of gypsum on top	20
Sandstone, irregularly bedded	8
Concretionary and septarian limestone	1
Sandstone	5

Section of Mount Selman formation half a mile northwest of Santo Tomas (32, fig. 24)

	Ft.	in.
Coarse gravel	3	
Stiff brown clay	3	
Thin-bedded, platy sandstone with ferruginous and calcareous sandstone concretions	4	
Gray shale weathering into thin plates	9	
Thin-bedded, platy sandstone with clay partings, obscure plant markings, and iron concretions	2	6
Light-bluish and light-greenish shale, partly concealed, with one or more sandy layers 4 inches thick and much secondary selenite	29	

Section of Mount Selman formation one-third mile south of Llave Creek on the east side of the Santo Tomas-Perronne road (33, fig. 24)

	Ft.	in.
Medium-grained quartz sandstone interbedded with shale containing almost continuous seams of selenite	5	
Compact dark-gray shale without sandstone or abundant gypsum	23	
Lignite		6
Shale	2	
Shaly sandstone	1	6
Selenite in large plates	7	

North of Llave Creek, west of Las Tiendas and the Galvan ranch, and in the neighborhood of the Velenzuela ranch many shallow exposures in roads and arroyos indicate that the middle portion of the

Mount Selman formation in this part of the region consists chiefly of clay or shale but includes subordinate lenses or layers of impure sandstone.

Inland sections in upper part of formation.—There are a few good exposures in the upper part of the Mount Selman formation in addition to those on the Rio Grande, already described.

Section of Mount Selman formation on easternmost hill of Cerrito Blanco group (34, fig. 24)

	Feet
Gravel	1
Mount Selman formation:	
Compact brownish clay shale completely filled in its basal 2 or 3 feet with masses of aggregates of long blade-shaped crystals of selenite	9
Gray and bluish-gray sandstone with many nodules and irregular areas stained with iron and with much gypsum in seams, especially near the base	16
Compact gray and brown shale, sticky where wet and jointed where dry, without sandy layers, containing much gypsum in continuous seams or layers especially in the upper 5 feet	38

Although the layers described above contain no concretions where best exposed, many compact spheroidal septarial limestone concretions occur in shale stratigraphically below this section in one of the lower hills of the Cerrito Blanco group.

From washes, hillsides, and other shallow exposures around Uña de Gato tank (35, fig. 24), it is judged that the Mount Selman formation there consists chiefly of clay or shale with some thin beds or lenses of sandstone. At the Cannell road crossing of Arroyo Santa Isabella (36, fig. 24), it is judged that the Mount Selman formation there consists chiefly of clay or shale with some thin beds or lenses of sandstone, and for half a mile upstream a ledge of concretionary ferruginous sandstone crops out in the bed of the stream. Where the Santo Tomas road crosses Arroyo Santa Isabella (37, fig. 24), 5 feet of light-blue and gray shale was exposed by the erosive action of the high water of 1919. The bluish beds are on top and are sandy; the gray beds below are more nearly pure.

Section of Mount Selman formation at Las Tiendas (38, fig. 24)

	Ft.	in.
Gray sandstone, weathering red, and hard gray concretions, interbedded with gray clay	12	
Thin-bedded gray sandstone	1	2
Green clay	4	

One mile east of the Galvan ranch (39, fig. 24), in a shallow wash, several feet of selenitic clay is exposed, containing numerous concentrically weathering septarial limestone and calcitized concretions, which average about a foot in diameter and are nearly spherical. The concretions break to pieces along joints, and some of them contain geodelike crystals and drusy material.

Sections on and near the Nueces River.—Several exposures of clay and sandstone on and near the Nueces River in the synclinal area in the vicinity of Crystal City are tentatively referred to the Mount Selman formation.

The first observed exposures down the Nueces from the Carrizo exposures at locality 2, Figure 10, are at a point east of Cinonia, or New California, where the river is divided into two deep, steep-sided channels for about a mile. In the eastern of the two gorges (54, fig. 10) is an exposure of 7 feet of black selenitic shale, weathering gray, that contains lenticular bodies of soft ferruginous sandstone.

A mile east of Crystal City, in the bed of Espantosa Lake (55, fig. 10), there is below the bridge massive cross-bedded gray and brown sandstone, containing in certain parts numerous clay pebbles from a quarter of an inch to 3 inches in diameter. Within the sandstone there are a few odd, loglike bodies, the origin of which is not clear. Lying above the sandstone and forming a low bluff above the bridge is an intricately interbedded and otherwise mingled series of bluish-gray shale with selenite and lime concretions, bedded and concretionary yellowish limestone with stringers of calcite, and thinly laminated, soft gray shaly sandstone.

On Carimanche Slough near its junction with Espantosa Lake (56, fig. 10) yellow ferruginous concretionary limestone crops out in association with gray fine-grained sandstone. The concretions are ferruginous and yellow on the surface but light chocolate-colored inside and have septarian structure with calcite joint fillings.

Another section exposing beds that closely overlie beds referred to the Bigford formation occurs on the southwest bank of the Nueces River 2¾ miles below the Dunlap Bridge, as follows:

Section of Mount Selman formation on Nueces River 2¾ miles below Dunlap Bridge (57, fig. 10)

	Ft.	in.
Clay loam	4	
Iron ore		4
Sandy shale	1	
Iron ore		2
Sandy shale	5	
Fairly pure brown lignite with black streaks	1	
Bony lignite	1	
Gray clay, to river level	2	

The beds exposed in the stream bank are overlain in the higher bluffs by heavy ledges of sandstone containing numerous iron concretions about the size of marbles. Although the lowest three beds resemble the Bigford beds exposed in other localities, the overlying sandstone resembles rock in the base of the Mount Selman elsewhere, and the whole section is tentatively referred to the Mount Selman.

Laboratory analyses.—A number of samples from the Mount Selman formation were analyzed in the laboratory, with the results given below.

Analysis of sandstone from Mount Selman formation at road crossing of Espantosa Lake a mile east of Crystal City (55, fig. 10) (sample 02200)

Bedding.—Thin bedded.

Size.—As shown in Figure 25, this is a very fine grained sandstone with a large admixture of fine sand and smaller amounts of medium sand, silt, and clay.

Shape.—Grains mostly angular in all size grades.

Porosity.—Very compact.

Cement.—Firmly cemented with $CaCO_3$. Soluble in HCl 49.3 per cent.

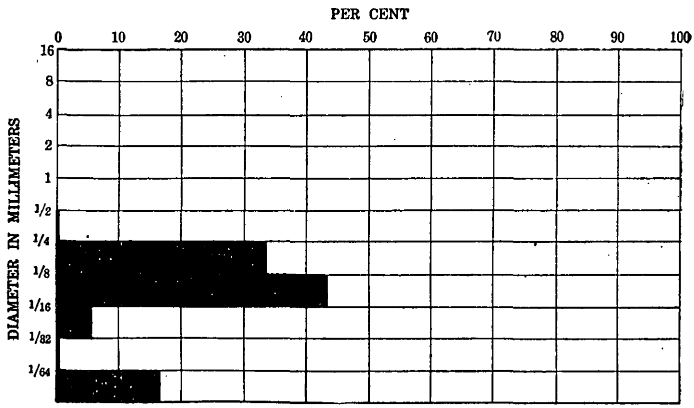

FIGURE 25.—Mechanical analysis of insoluble residue of sample 02200.

Mineralogy and lithology.—Almost pure quartz sand containing a small amount of feldspar and a small percentage of heavy minerals, including in order of abundance magnetite, staurolite, garnet, leucoxene, zircon, rutile, tourmaline, and spinel.

Analysis of sample from clay member of Mount Selman formation at San Pedro Hill (24, fig. 24) (sample 02175)

[See pl. 13, *C*.]

Bedding.—Only after moistening polished surface with HF, horizontal bedding planes show on specimen. Breaks like starch into small chips. Conchoidal fracture when large piece is broken out. Shines when rubbed with finger.

Mineralogy and lithology.—Quartz, feldspar mostly fresh, mica abundant in the larger grades, plant remains replaced by limonite, volcanic ash, very clean; even fine grades are clearly crystalline, little amorphous clay remains after washing, friable in fragments ½ to 5 millimeters.

Size.—The mechanical analysis (fig. 26) shows that 79.4 per cent is finer than 1/64 millimeter in diameter and that the sample ranks as clay rather than silt.

Shape.—Larger pieces of volcanic ash less than 1/4 millimeter in diameter show abrasion; "spun glass" is absent.

Color.—Yellowish gray.

Organic remains.—None except obscure plant impressions and remains.

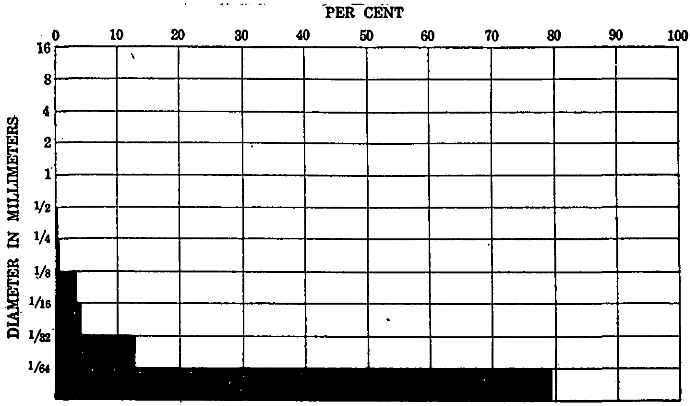

FIGURE 26.—Mechanical analysis of clay sample 02175, deflocculated by boiling with Na_2CO_3

Analysis of sample from sandstone overlying clay of Mount Selman formation at San Pedro Hill (sample 02176)

Bedding.—Bedded horizontally in laminae 2 to 3 millimeters thick. Bedding planes practically parallel and irregular with small relief. Breaks into roughly rectilinear blocks. Has sugary fracture.

Mineralogy and lithology.—Quartz, feldspar (fresh and altered orthoclase and plagioclase), zircon, tourmaline, muscovite, plagioclase fresh altered and other heavy minerals; hematite in grains, abundant, secondary. Clay is not amorphous but crystalline.

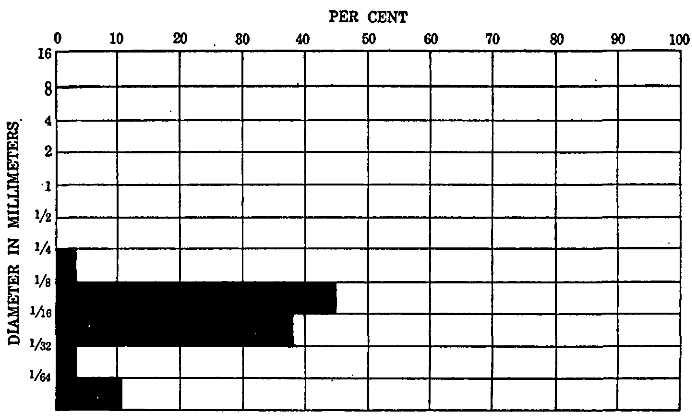

FIGURE 27.—Mechanical analysis of sample 02176

Size.—Mechanical analysis resulted as shown in Figure 27.

Shape.—All angular.

Porosity.—Slide shows "shaken down" appearance. Porosity very low, as fine material is packed between the tight-fitting grains.

Cement.—No cement except clay. Close packing of grains aids in cementation Friability not marked, although sandstone breaks easily.

Color.—Uniformly medium gray.

Analysis of sample from uppermost sandstone of Mount Selman formation on San Pedro Hill (sample 02177)

Bedding.—Apparently massive fractures in irregular chunks and breaks off in scales.

Mineralogy and lithology.—Quartz, crystals common; feldspar, mostly altered; garnet, tourmaline, zircon, heavy minerals present in smaller fragments; glauconite, 10 grains in 4 grams of heavy minerals; hematite, no clay.

Size.—Mechanical analysis resulted as shown in Figure 28.

Shape.—Angular for the most part; a few rounded grains.

Cement.—Cemented with iron. Not very firm. Friable on sharp edges but resists fracture fairly well.

Porosity.—Rather porous, but pores are very small.

Color.—Medium brown on fresh surfaces. Weathers black.

Fossils.—A very few Foraminifera, opaque, milky white, rounded as if they had been rolled.

Analysis of sample from the bed of massive sandstone on the bluff at Palafox (13, fig. 24) (sample 02201)

Size.—Mechanical analysis is given in Figure 29. The sample ranks as a fine-grained sandstone.

Shape.—Most of the grains are angular in all size grades.

Mineralogy and lithology.—Is an almost pure quartz sand without calcareous cement. Contains a small quantity of feldspar and a few ferromagnesian grains. Heavy minerals include, in order of abundance, zircon (many good crystals), staurolite, garnet, rutile, tourmaline, magnetite, olivine, and pyrite (?).

Porosity.—Compact.

Color.—Gray to pinkish.

Organic remains.—None.

Analysis of sample from a typical Mount Selman concretion 3¼ miles west of Big Wells, Dimmit County (sample 02064)

Bedding.—Shows no stratification or structure. Breaks easily into rectangular blocks.

Color.—Uniformly a light yellowish or brownish gray.

Cement.—Firmly and compactly cemented.

Mineralogy and lithology.—Soluble in HCl ($CaCO_3$), 30.0 per cent; clay and other finely divided materials, 58.4 per cent; quartz; mica unusually abundant, including muscovite and both fresh and altered biotite.

Size.—Mechanical analysis of the insoluble residues resulted as shown in Figure 30. More than 83 per cent of the insoluble residues fall in the clay grades.

It appears from the above analysis that this concretion is really not limestone but calcareous clay.

Analysis of sample from Mount Selman formation near Santo Tomas mine, Webb County (sample 02170)

Bedding.—No bedding planes visible. Fractures irregularly. Joint planes colored by limonite.

Mineralogy aud lithology.—Quartz, feldspar mostly fresh, mica abundant in coarser grades, aggregations of limonite. Finer grades clean and appear to contain volcanic ash. No heavy minerals.

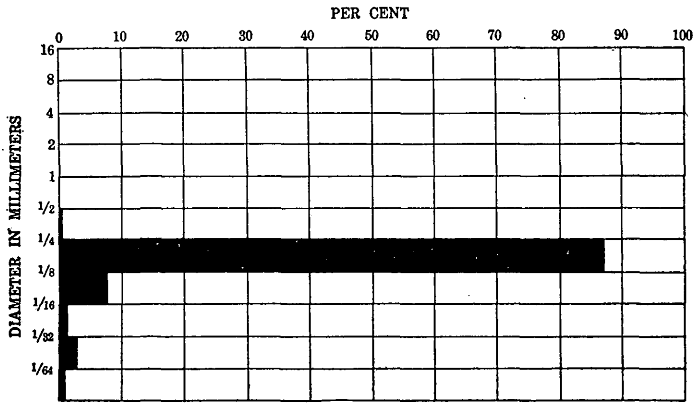

FIGURE 28.—Mechanical analysis of sample 02177

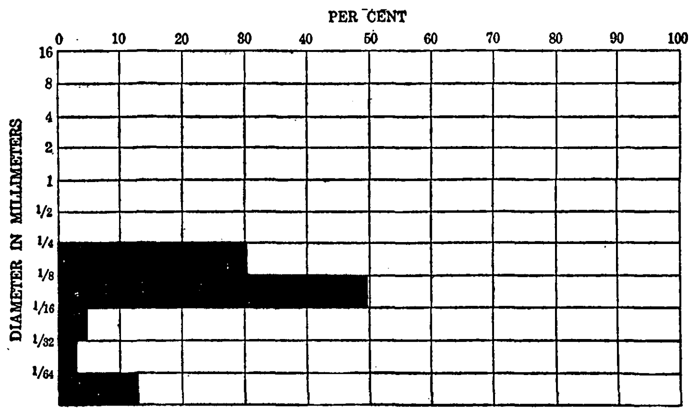

FIGURE 29.—Mechanical analysis of sample 02201

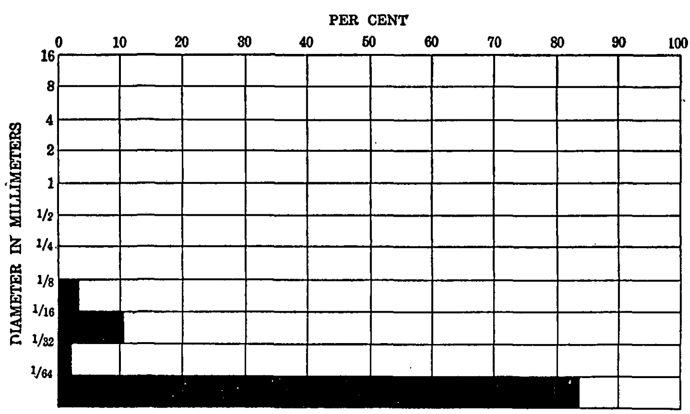

FIGURE 30.—Mechanical analysis of insoluble residue from sample 02064

Size.—After deflocculation by boiling in Na_2CO_3 mechanical analysis resulted as shown in Figure 31.

Shape.—All pieces notably angular except a few rounded quartz grains in the ⅛ to 1/16 millimeter grade and somewhat abraded pieces of volcanic ash.

Porosity.—More porous than sample 02175. Small cavities and fissures filled with limonite.

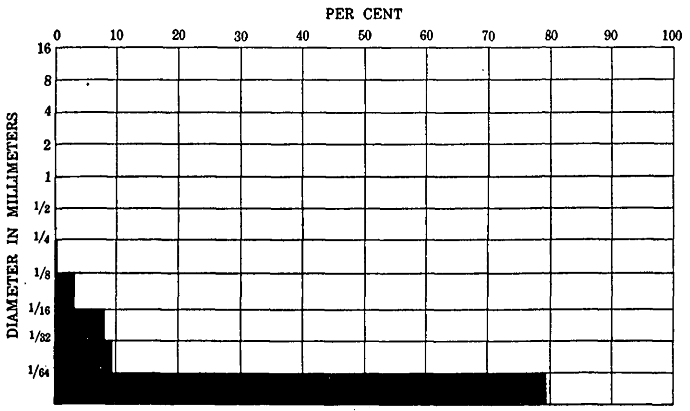

FIGURE 31.—Mechanical analysis of sample 02170

Cement.—Held together by clay and limonite. Breaks into fragments ½ to 5 millimeters.

Color.—Yellowish gray.

Organic remains.—None.

This sample bears a strong resemblance to No. 02175 (compare figs. 26 and 31) and may represent the same bed.

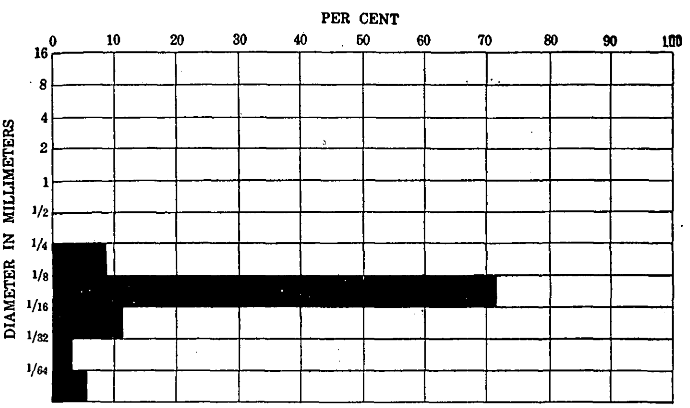

FIGURE 32.—Mechanical analysis of insoluble residue of sample 02181

Analysis of sample from calcareous sandstone of Mount Selman formation near Palafox (sample 02181)

Bedding.—Very tough, compact rock with no evidence of bedding.

Mineralogy.—Soluble in HCl, 29.1 per cent; feldspar, 16 per cent; muscovite; very few grains of glauconite. Heavy minerals very rare.

Size.—Mechanical analysis of the insoluble residues resulted as shown in Figure 32.

Feldspar makes up 5 to 20 per cent of all the Mount Selman samples examined. The samples with the higher clay content contain the larger proportion of fresh feldspar, suggesting that the weathering of the feldspars took place after deposition and was more rapid in the sandy and porous beds than in the more nearly impervious clays. This suggestion is given further weight by the fact that grains of kaolin derived directly from decomposing feldspar occur in some abundance in the coarser samples. Heavy minerals are notably scarce in all the samples.

Interpretation.—Although the Mount Selman formation has long been included in the "Marine beds" and has been universally thought to be of marine origin and although it has some characters that indicate such an origin, neither field nor laboratory evidence was obtained demonstrating conclusively that it is completely or even largely marine. On the other hand, evidence of nonmarine origin is meager. There are at least three facts that suggest marine origin. (1) The formation contains, in some of its few lenses of limestone, molluscan fragments that, although for the most part unidentifiable specifically within the lower Rio Grande region, appear to represent marine forms. (2) Some of the clay, shale, and sandstone layers of the formation have a greenish hue, glauconite is found sparingly with small amounts of other heavy minerals in the laboratory samples, and a very few Foraminifera were found in one sample from San Pedro Hill. No Foraminifera were seen in any other sample, and those found could well have been derived from some preexisting marine formation. (3) Apparent conformity with the overlying marine Cook Mountain formation suggests but does not prove marine origin for the Mount Selman. It appears that a formation of so great thickness and extent, if it were strictly and completely marine, should contain more conclusive evidence of marine origin than this. Neither the coal nor the sediments that carry land plants can be said to be typically marine; they doubtless were deposited in isolated coastal basins and lagoons and perhaps in part on tidal flats.

The conclusion is that the Mount Selman had about the same origin as the Indio and Bigford formations and that there was no notable change in physical conditions at the beginning of Claiborne time.

COOK MOUNTAIN FORMATION

Definition and correlation.—The term Cook Mountain is here used precisely as originally defined by Kennedy,[53] who named the formation after Cook Mountain, in Houston County, and included within it all the beds lying stratigraphically on the Mount Selman and under the "Yegua" (Cockfield). It is the upper and highly fossiliferous

[53] Kennedy, William, A section from Terrell, Kaufman County, to Sabine Pass, on the Gulf of Mexico: Texas Geol. Survey Third Ann. Rept., pp. 54–57, 1892.

part of what has been known as the "Marine beds" and a part of the "Timber Belt beds" of Penrose.[54] Deussen[55] reports that on faunal grounds, as suggested by Roemer[56] in 1852, the Cook Mountain and Mount Selman formations of Texas are correlated with the Talahatta formation plus the Lisbon formation of Mississippi and Alabama, and that these Texas and Alabama formations are continuous with and lithologically and faunally similar to the St. Maurice formation, of lower Claiborne age, in Louisiana.

Lithology.—The Cook Mountain formation of the lower Rio Grande region is similar to that farther north and east[57] in consisting chiefly of sand and sandstone. The sand is more or less firmly cemented. Most of the rock is medium grained, but there are beds of fine-grained and coarse-grained sandstone. The beds are green, brown, red, yellow, and gray and are commonly glauconitic, ferruginous, and micaceous. Many of them are cross-bedded and ripple marked. Interbedded with the sandstone are some white, yellowish, bluish- and greenish-gray or chocolate-colored clays and a few thin lenses of gray limestone. In some places the clay is silky or fluffy. The sandstone and at some places the clay contain large dark-gray hard-centered crystalline limestone concretions, some of which are fossiliferous. The lower two-thirds of the formation weathers characteristically into red sandy soil; the upper third at most places weathers gray. All the soils derived from the Cook Mountain formation support unusually luxuriant vegetation.

Distribution.—The outcrops of the Cook Mountain formation lie in a belt that averages 13 miles in width where the full thickness of the formation is included, extending from the northeast border of the region at and west of Encinal almost due south for about 40 miles, to a point where the base of the formation is cut off by a bend in the Rio Grande, 8 miles above Laredo. From this point for about 70 miles down the river the strike of the formation is so nearly parallel to the general course of the river that the river does not cut the top of the formation—the Cook Mountain-Cockfield boundary—except at the Zapata-Starr County line, 15 miles upstream from Roma. Thus the formation is exposed in the breaks of the Rio Grande for 75 miles. Although the belt of outcrop extends into Dimmit and Lasalle Counties at the northeast border of the area mapped, the formation crops out within this area only in Webb and Zapata Counties.

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[54] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to Rio Grande: Texas Geol. Survey First Ann. Rept., pp. 22-47, 1890.

[55] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 66, 1924.

[56] Roemer, Ferdinand, Die Kreidebildungen von Texas und ihre organischen Eienschlüsse, pp. 4–5, 1852.

[57] Deussen, Alexander, op. cit., p. 64, 1924. Dumble, E. T., The geology of east Texas: Texas Univ. Bull .1869, p. 67, 1918.

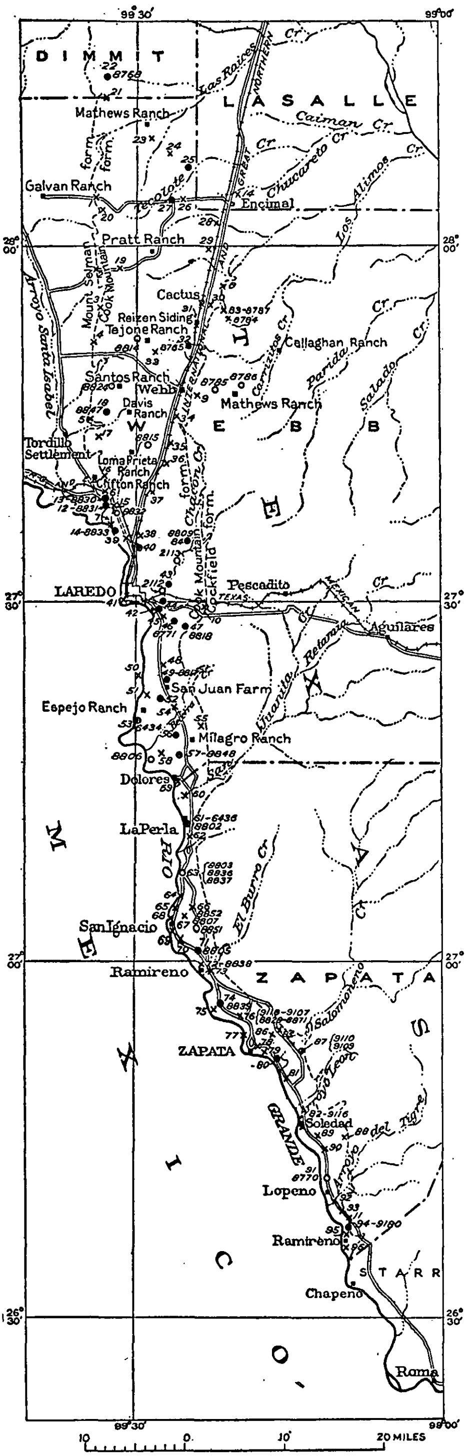


FIGURE 33.—Sketch map showing the areal distribution of the Cook Mountain formation and the location of exposures described. Four-digit figures refer to National Museum collections

(See pl. 7 and fig. 33.) The towns included within the belt of outcrop are Encinal, Laredo, San Ygnacio, Zapata, and a large number of places inhabited chiefly by Mexicans.

The lines on Plate 7 and Figure 33 marking the position of the base of the formation separate the fossiliferous sandy red-weathering glauconitic Cook Mountain with beds of white fluffy marly clay from the almost unfossiliferous clayey concretionary Mount Selman. This line of separation was located definitely in the field at a tank 4¼ miles east of the Galvan ranch (1, fig. 33), 3 miles northeast of Las Tiendas (2, fig. 33), at the H. H. Jeffries ranch, 4 miles southeast of Las Tiendas (3, fig. 33), 5 miles west of the Tajone ranch (4, fig. 33), just east of Tordillo settlement (5, fig. 33), at milepost 13 on the Rio Grande & Eagle Pass Railway (6, fig. 33), and near the mouth of Sambarieto Creek (7, fig. 33).

The line at the top of the formation separates it from the Cockfield ("Yegua"), which is chiefly clay and weathers to a dark-gray or black clay soil. The Cook Mountain contains many more species of invertebrate fossils than the Cockfield, in which *Ostrea georgiana* is the only form found in abundance, and has a characteristic fauna in its uppermost layers. The Cook Mountain soils maintain heavy mesquite vegetation, whereas the Cockfield is prairie. The Cook Mountain-Cockfield contact runs about 2 miles east of Cactus station (8, fig. 33), 1 mile east of Webb station (9, fig. 33), on the Aguilares road 5 miles east of the east edge of Laredo (10, fig. 33), and on the river road 3 miles southeast of Lopeno (11, fig. 33).

Thickness.—It is estimated by comparison of the width of outcrop across the strike with similar widths of outcrop of formations of known thickness that the Cook Mountain formation averages about 685 feet in thickness where it crops out in the lower Rio Grande region. However, where penetrated in wells in Zapata and Webb counties it is thicker than this, as follows:

Thickness of Cook Mountain formation in wells

Well	Location	Depth (feet)	Thickness (feet)
Jennings No. 1	Zapata County	2,521–3,345	824
Jennings No. 2	do	2,511–3,380	869
Feldman No. 1	Webb County	2,539–3,414	875

Fossils.—The formation almost everywhere contains abundant fossils, by which it can be distinguished from the Mount Selman below and the Cockfield above; indeed, it can thus be distinguished from all other formations in the region, for its faunas are larger and more diversified than those of any other Tertiary formation in Texas.

There are three more or less distinct Cook Mountain faunas—one at and near the base, one in the middle portion, and one at and near the top.

Sections of basal part of formation.—The only continuously exposed section that includes the base of the Cook Mountain in contact with the Mount Selman is on the Rio Grande just below the mouth of Sambarieto Creek (7, fig. 33). (See p. 91.)

On the west side of the west fork of Sambarieto Creek 100 yards below the county road (12, fig. 33) is a large calcareous concretionary area, some parts of which carry abundant fossils, chiefly gastropods and pelecypods (collection 8831). The concretion is bedded in reddish sandstone, which is underlain by 5 feet of compact light-gray shale.

Section of Cook Mountain formation on north side of county road on east side of west fork of Sambarieto Creek (13, fig. 33)

[See pl. 14, *A*]

	Ft.	in.
Concealed by gravel and sandstone float	8	
Reddish-brown sandstone in thin layers interbedded with 4 to 6 inch beds of light, fluffy shale	5	3
Thick-bedded sandstone stained reddish brown by iron	5	

	Ft.	in.
Interbedded and thin-bedded impure sandstone and shale, with more shale near base and more sandstone near top	5	3
Irregularly bedded limestone layer or lens entirely filled with fossils (collection 8830)		4
Soft thin-bedded reddish-brown sandstone	6	6
Concealed by fossiliferous float blocks	13	

This section is close to the base of the Cook Mountain formation and only a few feet stratigraphically above the concretionary zone last described. The fossils are associated with the red-weathering sandstone that distinguishes the base of the Cook Mountain from the top of the Mount Selman. The strata dip 2° due east.

Half a mile downstream in the same valley the fossiliferous layer appears between beds of sandstone with no shale in the section. The fossils are in a definite bed not more than 1 foot thick. Still farther down the valley the fossils appear again with sandstone below and white silky shale above.

Section of Cook Mountain formation in Rio Grande bluff 1½ miles below mouth of Sambarieto Creek and 7 miles above Laredo (14, fig. 33)

	Feet
Reynosa formation: Gravel	10
Cook Mountain formation: Flaggy brown to buff sandstone	15
Gray clay shale with ferruginous sandy layers	18
Massive sandstone weathering into thin flakes and large concretionary masses; contains abundant fossils at the base (collection 8838)	30
Dark-gray sandy gypsiferous shale alternating with ½-inch to ¼-inch sandy layers that weather brown	25
Massively bedded soft brown sandstone with its base concealed by a silt terrace on the Rio Grande	10

Where the Laredo-Dolores road crosses Sambarieto Creek (15, fig. 33) 12 feet of compact gray shale with one 3-inch bed of sandstone is overlain by 5 feet of reddish-brown thin-bedded sandstone. No fossils and no concretions occur here. Half a mile farther south, on the west side of the road, heavy sandstone without concretions is overlain by thin-bedded sandstone with large fossiliferous limestone concretions (collection 8832), and this in turn by thin-bedded red sandstone with marly partings and without fossils.

At the first creek crossing east of the Clifton ranch (16, fig. 33) are fairly extensive outcrops of heavy-bedded reddish-brown sandstone with a few concretions and some limy beds carrying a few poorly preserved fossils. This exposure is within a few feet stratigraphically above the base of the Cook Mountain formation.

Two miles southeast of Tordillo settlement (17, fig. 33) is a surface exposure of flaggy micaceous gray to buff sandstone, which weathers red and forms a sandy loam soil. Three miles west of the Davis ranch (18, fig. 33) a calcareous ferruginous brown sandstone that forms red sandy soil yielded the fossils in collection 8847.

White and gray shale crops out in a shallow surface drain 6.6 miles southwest of the Pratt ranch on the road to Las Tiendas (19, fig. 33). The shale contains an abundance of selenite in seams and nodules and many small black iron concretions. Some of the shale breaks up into white chunks that are highly calcareous.

Five miles southeast of the Galvan ranch and 1 mile southeast of a tank (20, fig. 33), large slabs of hard, compact crystalline white-coated unfossiliferous limestone crop out in the road.

At a gate 6¾ miles southeast of the Velenzuela ranch (21, fig. 33) a 2-foot bed of red sandstone overlies 3 feet of clay shale and marks approximately the base of the Cook Mountain formation. The section next described is 1½ miles northeast of the gate:

Section of Cook Mountain formation 7 miles southeast of Velenzuela ranch (22, fig. 33)

	Feet
Layer or lens of concretionary sandy limestone containing many unidentifiable pelecypods (collection 8768)	5
Massive red sandstone	3–5
Gray and reddish clay	20

Section of middle part of formation.—For many miles along the Rio Grande where the surface is much dissected there are numerous exposed sections in the middle portion of the formation. In the northern part of the region, where the belt of outcrop is away from the river, exposures are not so common as along the river south of Laredo. For convenience the exposures are described in order from north to south.

Northwest of Encinal, just on the northeast border of the area shown on the map, there are a few shallow exposures. Red sand with a few large concretions persists in the road for 5 miles northwest of the Mathews ranch. A heavy ledge of concretionary limestone in which large oysters are imbedded is exposed 1½ miles southeast of this ranch (23, fig. 33). Half a mile farther south on the road to Encinal is an exposure of red sandstone with numerous small round iron concretions and several large calcareous sandstone concretions containing scattered and poorly preserved oysters. Northwest of the Becker ranch and 8½ miles from Encinal (24, fig. 33), 10 feet of hard red micaceous, unevenly bedded sandstone crops out, containing a few irregular limy areas and a large number of small black iron concretions. Heavy concretionary layers of crystalline and sandy limestone crop out 6.2 miles northwest of Encinal (25, fig. 33), on the surface of which are many poorly preserved fossils. About 4 miles west of Encinal on the Galvan ranch road (26, fig. 33) reddish-brown and gray fine-grained sandstone crops out in a hillside. The rock is coated with caliche and weathers to red sandy soil. A mile farther west (27, fig. 33) calichified concretionary limestone crops out, carrying fossils.

There are a number of shallow exposures along and near the International-Great Northern Railroad and the Laredo-San Antonio automobile road south of Encinal. About 3 miles south of Encinal (28, fig. 33) a railroad cut exposes 3 feet of thin-bedded sandstone overlain by a shaly bed containing large limestone concretions, and 2¾ miles farther south (29, fig. 33) another cut shows a highly gypsiferous marly shale. About 150 yards south of Cactus station (30, fig. 33) a long, shallow cut exposes 3 feet of gray sandstone, uniformly medium grained and poorly cemented, interbedded with a soft white silky noncalcareous substance which laboratory analysis shows to be the result of hydration of anhydrite to gypsum. Half a mile south of Reizen siding (31, fig. 33) thin-bedded shaly sandstone is exposed, containing a few spheroidal clay ironstones and numerous flattened cylindrical bodies somewhat resembling branches and roots of trees in form but lacking markings of any sort. Farther south, 4 miles from Webb (32, fig. 33), 5 feet of gray compact gypsiferous clay is exposed, containing at the top of the cut a 6-inch layer of oysters in shale (collection 8765). One mile east of the Tajones ranch and 5 miles northwest of Webb (33, fig. 33) the surface material is ferruginous sandstone weathering red. This is stratigraphically lower than the sections on the railroad, which are not red. Light-gray gypsiferous clay is exposed on the railroad 3 miles south of Webb (34, fig. 33).

Section just south of Green's, on International-Great Northern Railroad (35, fig. 33)

	Ft.	in.
Reynosa formation: Cross-bedded conglomerate, cemented with calcium carbonate	6	
Cook Mountain formation:		
White silky soft clay	2	6
Fossiliferous limestone	1	
Shale and thin-bedded sandstone	5	

Gray clay 12 feet thick crops out 1½ miles south of Green's (36, fig. 33). Some of the clay is mingled with the soft white silky substance noted in other sections in this neighborhood, but some of it is compact and hard, and all of it contains much selenite. Sandstone, limestone, and shale beds are exposed half a mile northeast of Orvil (37, fig. 33). The limestone is made up almost entirely of fossil shells so broken as to be unidentifiable. Half a mile northeast of the junction of the Laredo-San Antonio and Laredo-Dolores roads (38, fig. 33) 10 feet of thin-bedded shaly sandstone is overlain by shale in which there is more of the white fluffy silky-feeling substance noted in other sections. (For laboratory analysis, see p. 126.)

Section on Laredo-Dolores road 1 mile northwest of junction with Laredo-San Antonio road (39, fig. 33)

	Ft.	in.
Surface material: Gray sandy clay and gravel	4	
Cook Mountain formation:		
Thinly laminated cross-bedded sandstone and greensand	2	
Hard gray sandstone and greensand with oyster bed	1	6
Cross-bedded greensand	1	
Interlaminated green clay and sandstone	2	
Hard greensand	1	6
Interlaminated soft sand and clay	2	
Hard, thinly laminated sandstone	4	
Dark-green shaly sandstone, weathering to green clay, with sandy concretions and laminae	3–4	
Dark thinly laminated carbonaceous sandy shale	1–2	
Hard gray sandstone	4	

Section of Cook Mountain formation at and near milepost 470 on International-Great Northern Railroad about 5 miles north of Laredo (40, fig. 33)

	Ft.	in.
Brown sandstone and clay with large concretions, some of which are fossiliferous	10	
Brown sandstone and sandy clay with concretions 2 to 3 feet thick and 4 to 6 feet across	10	
Brown shaly sandstone	8	
Brown to yellow fossiliferous sandy bed		4
Brown clay	10	
Brown concretionary fossiliferous sandstone	4	

Section at Texas end of Rio Grande highway bridge at Laredo (41, fig. 33)

	Feet
Reynosa formation:	
Sand and gravel	8
Cobble gravel including chert and quartzite	1–2
Cook Mountain formation:	
Cross-bedded yellow sand with thin clay laminae and weathered greensand	3
Yellow laminatedsand stone with gypsum in bedding planes	4
Yellow cross-bedded sandstone with some greensand	5

Section in Arroyo Chacon near Rio Grande (42, fig. 33)

	Feet
Reynosa (?) formation:	
Gray sandy clay	5–10
Quartz, quartzite, and crystalline gravel 1 to 3 inches in diameter	1–6
Cook Mountain formation:	
Massive and cross-bedded greensand with some hard concretions	10–15
Alternating hard and soft layers	3
Massive yellow greensand	4
Laminated greensand	2

Section in Arroyo Chacon in Laredo just north of street railway bridge (43, fig. 33)

	Feet
Pleistocene: Gray silt, somewhat sandy, containing shells of recent air-breathing snails and forming Laredo terrace	5–20
Cook Mountain formation:	
Hard yellow greensand, cross-bedded in some layers	10–20
Porous yellow laminated greensand coated with sinter	4
Hard gray sandstone	1

This section is stratigraphically above the section at the international bridge.

Section 1 mile east of Laredo (44, fig. 33)

	Ft.	in.
Surface loam and gravel	4	
Cook Mountain formation:		
Decomposed shaly brown sandstone	6	
Hard concretionary brown sandstone	3	
Fossiliferous gray sandstone		8
Soft shaly brown sandstone	10	
Concealed to stream bed	4	

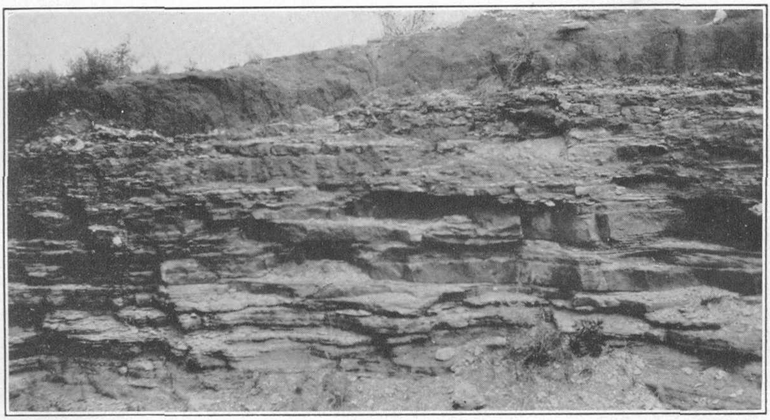
Section of Cook Mountain formation 100 yards east of section at locality 44 on east side of arroyo

	Ft.	in.
Gray shale and brown sandstone	10	
Oyster bed	2	
Blue shale with some sandstone	7	
Hard brown sandstone	2	
Brown fossiliferous sandstone	1	6
Hard concretionary brown sandstone	3	
Sandy gypsiferous shale	12	
Hard brown sandstone		4
Sandy gypsiferous laminated shale	6	

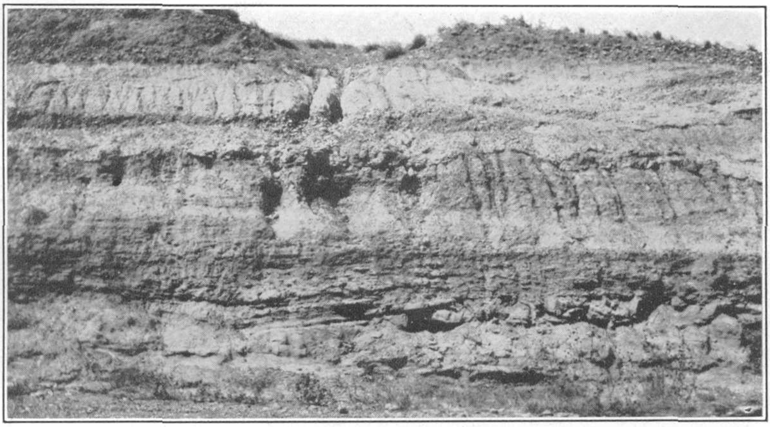
Section of Cook Mountain formation on county road just below Chacon Creek bridge, 2 miles southeast of Laredo (45, fig. 33)

	Feet
Gray fissile shale with much selenite and some thin layers of sandstone	20
Concealed	5
Gray sandy fossiliferous clay	12
Hard cross-bedded clayey gray sandstone and greensand	8
Fossil bed	4
Hard gray cross-bedded sandstone and greensand	6
Green sandy clay	2

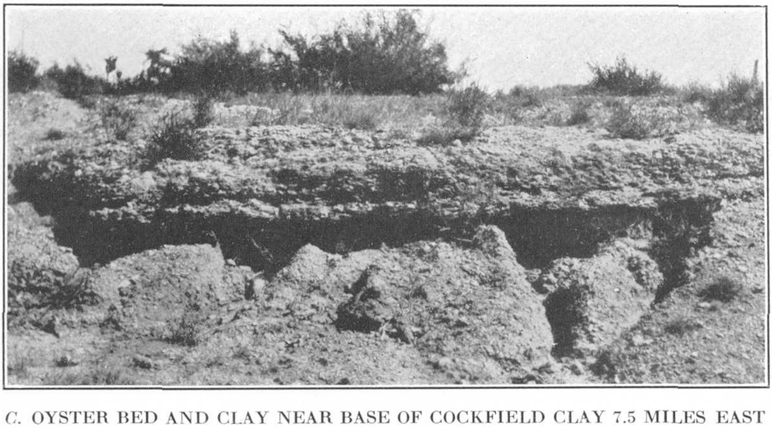
In the southeast edge of Laredo, 2.9 miles from the Laredo post office on the road to Aguilares, 12 feet of alternating green sandstone and green shale in beds 1 to 6 feet thick crop out. (See pl. 14, *B*.) Six-tenths of a mile farther east on the same road the following section is exposed:



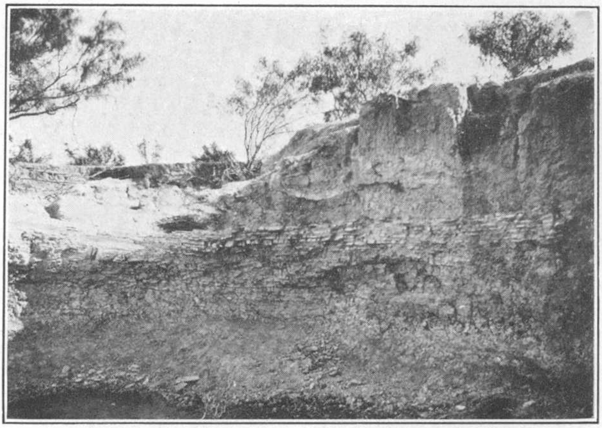
A. FOSSILIFEROUS SHALE AND SANDSTONE NEAR THE BASE OF THE COOK MOUNTAIN FORMATION ON THE LAREDO-DOLORES ROAD AT THE WEST FORK OF SAMBARIETO CREEK



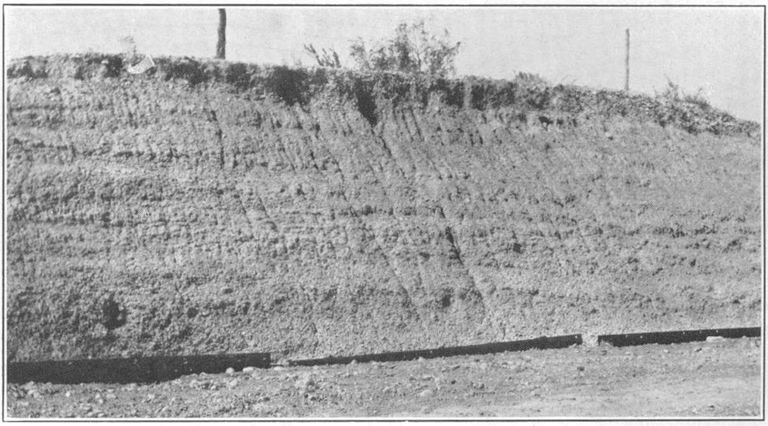
B. SANDSTONE AND SHALE 2.9 MILES SOUTHEAST OF LAREDO POST OFFICE



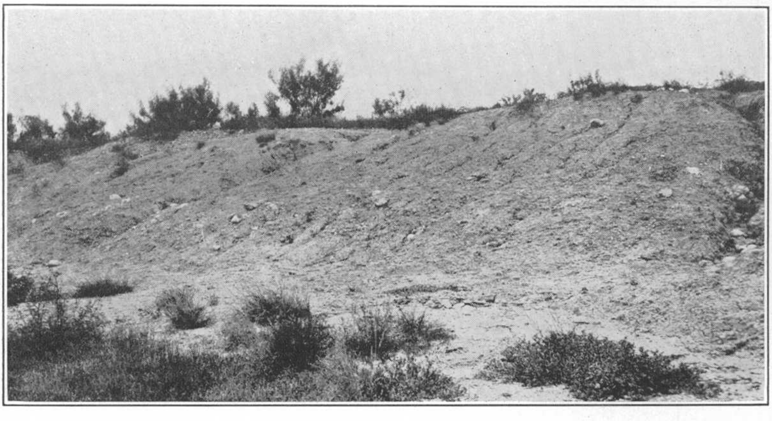
C. OYSTER BED AND CLAY NEAR BASE OF COCKFIELD CLAY 7.5 MILES EAST OF LAREDO POST OFFICE



A. FAYETTE SANDSTONE SOUTHWEST OF COMITAS



B. TYPICAL COCKFIELD CLAY 8.7 MILES EAST OF LAREDO POST OFFICE



C. CONCRETIONARY CLAY NEAR THE BASE OF THE FAYETTE SANDSTONE EXPOSED IN THE CLAY PIT AT REISER

Section 3.5 miles southeast of Laredo post office

	Ft.	in.
Greenish-gray sandstone	4	
Laminated bluish shale	3	
Sandstone		6
Laminated shale	3	
Sandstone	1	6

The sandstones are fine grained, and all beds are selenitic.

About 4 miles southeast of Laredo, on the eastern slope of a small tributary to Chacon Creek (46, fig. 33), soft brown sandstone crops out, overlain by brown and drab clay containing a diversified fauna (collection 8771). A mile farther southeast (47, fig. 33) similar sandstone, probably 100 feet higher stratigraphically, is exposed, characterized by limy concretionary masses, some of which are fossiliferous (collection 8818).

Along the main river road for 6 miles south of Laredo soft brown flaggy medium-grained sandstone containing mica and iron oxide, in layers 6 inches to 3 feet thick, overlies greenish-gray clay shale.

Section of Cook Mountain formation 6 miles south of Laredo at San Ildefonso Creek (48, fig. 33)

	Feet
Gray sandstone with thin clay laminae	5
Gray clay with thin layers of sandstone	5
Brown and greenish-yellow sandstone	10
Gray clay grading upward into thin layers of brown sandstone	30
Light-yellow sandstone	10

At the San Juan farm, 7 miles due south of the eastern part of Laredo (49, fig. 33), fossils (collection 8817) occur in limy layers within alternating beds of flaggy sandstone and sandy clay shale similar to the strata between this location and Laredo.

Section in the middle part of the Cook Mountain formation on the Mexican side of the Rio Grande opposite the San Juan farm pumping station, 7 miles south of Laredo (50, fig. 33)

	Feet
Pleistocene: Gray silt forming terrace	20
Cook Mountain formation:	
Flaggy sandstone	10
Shaly member	4
Flaggy and massive sandstone	12
Talus to river edge	15

Section of Cook Mountain formation at Santa Rosa farm pumping station, 9 miles below Laredo (51, fig. 33)

	Ft.	in.
Smooth gray shaly sandstone in massive beds with thin sandy strata	12	
Dense dark-gray sandstone		1–4
Regularly bedded glauconitic sandy shale and shaly sandstone with thin clay partings	6	
Hard green sandstone	3	
Soft green sandy shale	2	
Hard green sandstone	2	

Section of Cook Mountain formation 1 mile east of Santa Rosa farm (52, fig. 33)

	Feet
Brown sandstone blocks embedded in brown clay	1
Brown shale with thin layers of sandstone and much selenite	4
Brown shaly sandstone, fossiliferous	6

Section of truncated ridge of Cook Mountain formation on the Rio Grande one-third of a mile to 1 mile below Espejo ranch and 11 miles below Laredo (53, fig. 33)

	Feet
Medium-grained brown soft flaggy glauconitic sandstone containing large calcareous lens-shaped concretions	15
Gypsiferous sandy clay shale	6
Brown sandstone in 2 to 6 inch beds	10
Gypsiferous sandy clay shale	8
Flaggy sandstone in beds less than 1 foot thick, many of which are glauconitic	33

In an arroyo at the upper end of this bluff, a quarter of a mile from the river and 250 yards southeast of the Espejo ranch house, quartzitic sandstones are exposed 50 feet above river level, between two of which there is a 3 to 6 inch parting of carbonaceous shale. The flaggy sandstones of the main section extend up the slope eastward from the river almost to Loma Laguna.

Section of Cook Mountain formation at Loma Laguna, on river road 10½ miles south of Laredo (54, fig. 33)

	Feet
Brown sandy clay to hilltop	10
Yellow clay	15
Gray clay	5
Hard sandstone	2
Gray clay	4
Hard sandstone	2
Gray clay	10
Oyster bed	½

An oyster bed is exposed at the surface for a mile east of the Esperanza ranch house (55, fig. 33).

Section of Cook Mountain formation 1 mile west of Milagro ranch (56, fig. 33)

	Feet
Fossil bed; fossils include large oysters and gastropods	½
Interbedded green sandstone and shale	12

Section of Cook Mountain formation at Loma Santa Lucia, 1½ miles northeast of Dolores settlement (57, fig. 33)

	Feet
Shell breccia forming resistant rock (collection 8848)	20
Gray sandy clay shale	20
Flaggy sandstone (see laboratory analysis of sample 02046, p. 127)	10

The twin hills known as Lomas Altitas 3 miles northwest of Dolores settlement (58, fig. 33) consist of brown sandstone of medium grain, weathering readily into flags, and are capped by gravel and caliche. Between these hills and the river there are three fossil zones. The lowest, which is at river level, is diversified (collection 8806) and lies in sandy gypsiferous gray and purple clay, interbedded with brown soft sandstone in beds 6 inches to 3 feet thick. About 100 feet higher stratigraphically, in the base of the brown sandstone listed above, there is a bed of oysters, probably *O. georgiana*, and 75 feet still higher in the section there is another oyster bed, the species in which have not been determined.

Section on Rio Grande bluff at Dolores settlement (59, fig. 33)

	Feet
Residual sandy soil	2–4
Cook Mountain formation:	
Regularly bedded green sandstone, somewhat case hardened	8
Irregularly bedded green sandstone with cubical fracture; contains some rounded concretions	18
Soft green shale, weathering chocolate-brown, with lenses of green sandstone	13
Coarse irregular cross-bedded concretionary greensand, sandstone, and sandy shale	23
Concealed at base of bluff	15

Section on San Juanita Rettanna Creek just below Laredo-Zapata road crossing (60, fig. 33)

	Ft.	in.
Gray loam in terrace	8	
Cook Mountain formation:		
Oysters in glauconitic sandstone		6
Hard glauconitic sandstone	4	
Oysters in glauconitic sandstone		4
Hard glauconitic sandstone	4	

Driller's log of J. T. Hare well, 1.4 miles north of La Perla

[This log records mainly Cook Mountain strata]

	Feet
Yellow sand, soft	16–33
Soft blue sand	33–90
Soft gray sand; water at 130 feet	90–130
Gray shale; water at 150 feet	130–150
Blue shale	150–325
Dark shale	325–400
Gray shale	400–435
Blue shale	435–450
Sand, white, soft	450–470
Water	470–475
Dark shale	475–497
Gray sand, soft	497–535
Dark shale	535–640
Soft blue sand	640–690
Gray sand, soft; casing leaking	690–750
Soft white sand	750–760
Soft blue sand	760–775
Blue mixed shale	775–800
Soft gray sand	800–805
Mixed blue shale	805–825
Soft gray sand	825–865
Mixed brown shale.	

Section at La Perla (61, fig. 33)

	Feet
Pleistocene or Recent:	
Silt, sandy in places, with shells of fresh-water and air-breathing mollusks	15
Medium-sized gravel	5
Cook Mountain formation:	
Gray and green sandstone containing fossil imprints	2
Roughly cross-bedded green sandstone	5
Concealed	4
Hard, smooth green sandstone containing casts of fossils	½
Thinly laminated friable green sandstone	6
Concealed to river level	10

Fossils collected at this locality (collection 6436) are typical of middle Cook Mountain faunas.

Section at Laredo-Zapata road crossing of Salado Creek (62, fig. 33)

	Ft.	in.
Sandy loam with land and fresh-water shells	25	
Cook Mountain formation:		
Coarse gravel	3	
Hard fossiliferous green sandstone	1	2
Fine green sandstone	6	
Oyster bed; very large shells		4
Fine green sandstone	4	
Sandstone and green sandstone in massive beds	4	

Section 5 miles south of La Perla and 5 miles north of San Ygnacio (63, fig. 33)

	Ft.	in.
Fragmentary material and gravel at top of hill	4	
Cook Mountain formation:		
10. Yellowish, irregularly bedded, loosely cemented sandstone	8	9
9. Iron-stained sandstone with 1½-foot oyster bed	11	6
8. Irregularly cross-bedded shaly sandstone with much gypsum in the partings, containing some large concretions and lenses of fossils 16 feet above the base	46	
7. Reddish-gray clay with thin seams of sandy clay	14	
6. Thin-bedded green micaceous sandstone	1	
5. Reddish-gray sandy clay shale with much gypsum and iron on the joints	12	6
4. Laminated green sandstone forming irregular lenses	7	
3. Irregularly laminated gypsiferous strata, half clay and half sand	5	3
2. Massive green sandstone in layers 2 feet thick with interbedded 4-inch irregular layers of shaly sand	6	
1. Irregularly bedded medium to fine grained sandstone with irregular concretionary masses, some of which are fossiliferous, to river level	12	

Fossil collection 8836 was taken from No. 1 of this section. The fossils in No. 8 (collection 8837) represent one of the most diversified faunas in the formation. The fossils in No. 9 are *O. georgiana* (collection 8864).

Section of Cook Mountain formation one-eighth of a mile north of San Francisco ranch and 3 miles north of San Ygnacio (64, fig. 33)

	Ft.	in.
Thin-bedded coarse-grained gray sandstone	3	
Green sandstone	2	
Greenish-gray shale with lenses of green sandstone in upper 2 feet	6	
Gray shale with dark laminae	2	
Brown sandstone		6
Greenish-gray shale	1	2
Gray sandstone lens		2
Greenish-gray shale	1	

Section 2 miles north of San Ygnacio (65, fig. 33)

	Feet
Reynosa formation: Pebbles in calcareous matrix	5
Cook Mountain formation:	
Sandstone and clay; large sandstone concretions as much as 3 feet in diameter; sandstone fine grained, micaceous, color originally greenish	31
Thin-bedded fine-grained micaceous sandstone	1½
Thinly laminated chocolate-colored clay	8
Fine-grained micaceous yellowish-brown sandstone	1¼
Thinly laminated chocolate-colored clay, oxidizing yellowish	12

A bed of sandy concretionary fossiliferous limestone crops out in the old Laredo-Zapata road and in a ranch road leading east from a point 3⅝ miles northeast of San Ygnacio (66, fig. 33). The fossil bed is 6 to 12 inches thick and is associated with sandstone that weathers to bright-red soil. The fossil species are included in collection 8852. Hard limy sandstone containing pebbles of black flint and brown sandstone and some fossils (collection 8807) crops out 1½ miles northeast of San Ygnacio (67, fig. 33).

Section at arroyo in north edge of San Ygnacio (68, fig. 33)

	Feet
Pleistocene: Silt with some layers of gravel	15
Cook Mountain formation:	
Green clay	5
Greenish-gray sandstone	4
Gray sandstone	4
Green sandstone	2

At the watering place at San Ygnacio (69, fig. 33), a bed of unidentifiable oysters 1 to 2 feet thick is interbedded with green shaly sandstone and more massive green sandstone, forming a reef in the river.

Section of Cook Mountain formation 1 mile southeast of San Ygnacio (70, fig. 33)

	Ft.	in.
Reddish-brown sandstone and clay to tops of hills	40+	
Hard green sandstone	2	
Hard brown sandstone with oysters and black pebbles and some pebbles of red chert		4
Hard green sandstone	4	

Three miles southeast of San Ygnacio (71, fig. 33), brown ferruginous fine-grained sandstone with flakes of iron oxide is interbedded with 2 to 3 foot beds of gray sandy clay shale. The sandstone is fossiliferous (collection 8805). Similar strata are exposed 1½ miles farther south (72, fig. 33), from which collection 8838 was taken.

Section of Cook Mountain formation at Burro Creek crossing of Laredo-Zapata road, 6 miles southeast of San Ygnacio (73, fig. 33)

	Feet
Gray, brown, and red shale with concretions and selenite plates	20
Gray to brown shale with sandy concretions	15
Dark-gray shale with selenite and some flat concretions of sandstone	5
Concretionary thin-bedded sandstone	1
Gray calcareous shale	1
Gray shale with selenite	4

At the second creek crossing of the Laredo-Zapata road south of Burro Creek (74, fig. 33) massive and irregularly bedded green sandstone is underlain by soft shaly sandstone containing concretionary bodies and lenses, some of which are fossiliferous (collection 8839).

Section of Cook Mountain formation on the Rio Grande 5 miles above Zapata (75, fig. 33)

	Feet
Cross-bedded green sandstone	12
Gray concretionary sandstone with oysters	2
Greenish-brown shale	30

Section of Cook Mountain formation on Los Molletes Creek above and below crossing of Laredo-Zapata road (76, fig. 33)

	Ft.	in.
Yellow soft thin-bedded sandstone with fossils (collection 9118)	10	6
Concealed, but with fossil bed (collection 9107) in middle	20	
Green friable massive and thin-bedded sandstone containing resistant, compact sandstone concretions in upper 2 to 4 feet and fossils (collection 8828)	14	
Purple shale, much iron stained, with 2-inch layer of sandstone in the middle	6	
Fine-grained light-gray sandstone		10

	Ft.	in.
Purple and red laminated and jointed shale, highly sulphurous and selenitic, containing large clay concretions surrounded and impregnated by selenite	10	
Limy and clayey nodules in lens		6
Purple shale	2	
Massive jointed fine-grained greenish-gray and brownish-gray sandstone, containing pyrite and iron nodules	1	6
Purple shale, laminated and jointed, selenitic and sulphurous	15	
Green irregularly bedded sandstone with a 2 to 4 inch layer of calcareous conglomerate at the base and with unidentifiable fossils	5	
Gray-brown iron-stained shale	4	
Gray sandstone	1	
Iron-stained sandstone with seams of purple-gray sulphurous and selenitic shale	5–6	
Gray selenitic clay stained by iron and sulphur	3	
Massive green jointed sandstone	4	
Gray sandy clay	1	
Brown thin-bedded sandstone	2	
Purple-gray shale	3	
Greenish-gray sand with seams of iron	8	
Hard green nodular sandstone	3	

Section of Cook Mountain formation 2 miles north of Zapata (77, fig. 33)

	Ft.	in.
Gray clay with concretions, partly concealed	12	
Hard gray concretionary sandstone	6	
Gray concretionary sandstone with some gray clay	8	
Gray clay	8	
Oyster shells		4
Hard concretionary sandstone	2	
Greenish-gray clay	4	

Section on the Rio Grande 1½ miles above Zapata

	Ft.	in.
Reynosa formation:		
Loose gravel	5	6
Gravel cemented with $CaCO_3$	3	6
Cook Mountain formation:		
Loosely compacted limestone	2	6
Yellowish-gray medium-grained, loosely cemented, irregularly bedded sandstone	10	
Fine-grained massive and irregularly bedded yellowish-gray and green sandstone, with inclusions of blue clay and lime-coated concretions	27	6
Light-gray clay	4	2
Laminated, poorly cemented sandstone	1	6
Light-gray clay	5	
Medium-grained thin and irregularly bedded jointed gray and green concretionary sandstone	6	6
Yellowish massive coarse-grained sandstone	15	
Yellowish-gray clay, partly concealed	21	6
Blue and pink sandy shale	1	

Section of Cook Mountain formation half a mile northeast of Zapata courthouse (78, fig. 33)

Clay.
Soft yellowish and light-brown cross-bedded sandstone.
Interbedded clay and sandstone.
Brown and green fine-grained sandstone.
Weathered greensand marl; contains fossils including *Volutocorbis petrosa*, *Lucina alveata*, and *Venericardia planicosta*.

The upper sandstone bed has been quarried for buildings in Zapata. Within 10 miles below Zapata the middle beds of the Cook Mountain formation are cut out by the gradual eastward trend of the Rio Grande. A few exposures along the river, however, are interpreted as showing middle rather than upper beds of the Cook Mountain.

A heavy ledge of dark-gray compact crystalline limestone containing numerous rolled and broken shells and rounded quartz pebbles and overlain by fine-grained sandstone lies below high-water mark on the Rio Grande three-quarters of a mile below Zapata (79, fig. 33).

Section of Cook Mountain formation in the first bluff below Zapata on the Texas side of the Rio Grande (80, fig. 33)

	Feet
Soft yellowish sandstone.	
Interbedded clay and soft laminated sandstone	10
Soft yellowish laminated and cross-laminated sandstone	10
Gypsiferous clay, weathering purple	45
Concealed by river terrace	40
Fine-grained greenish sandstone	2

On the bluff next south the top sandstone of this section is fossiliferous, including *Lucina alveata*, *Venericardia planicosta*, *Cerithium*, *Ostrea alabamiensis*, and other forms and is overlain by 2 feet of light-yellow gypsiferous clay, 40 feet of thin-bedded sandstone, 5 feet of sandstone and clay, and at the top 10 feet of yellow gypsiferous clay containing large oysters.

Section of Cook Mountain formation in arroyo at San Rafael ranch, 4½ miles below Zapata (81, fig. 33)

	Ft.	in.
Greenish-gray massive and cross-bedded sandstone	8–9	
Massive green sandstone	16	
Greenish-gray shale	9	
Massive green sandstone with seams of selenite	7	
Thin-bedded clayey sandstone	5	
Massive brown sandstone	4	
Green laminated sandstone	4	6
Green clay	2	6
Massive green sandstone	3	
Green thin-bedded sandstone	6	
Hard gray conglomerate, consisting of black and brown pebbles and shell fragments, firmly cemented with $CaCO_3$	1	6
Green thin-bedded sandstone with seams of shale	4	
Massive green sandstone	4	
Concealed to river level	15	

Section of Cook Mountain formation between store and river at Soledad (82, fig. 33)

	Feet
Gray to brown fossiliferous sandstone (collection 9116)	3
Stratified green selenitic clayey sand, containing large numbers of hard gray calcareous concretions like cannon balls, which weather out and accumulate along the river	11
Greenish-gray sandstone	1
Concealed	16
Compact greenish-gray sandstone	2

Sections of upper part of formation.—Although the strata just below the Cook Mountain-Cockfield contact extend along the strike for a distance of 100 miles within the lower Rio Grande region, exposed sections are common only in the southern 25 miles of this course, where these strata are cut by the Rio Grande and its tributaries. (See fig. 33.) There is no sharp break between the middle and upper portions of the formation, although there are lithologic as well as faunal differences. Lithologically the upper beds are not so commonly red as the middle beds, and the formation is much more shaly in its uppermost part just below the base of the Cockfield formation. The upper beds are further characterized by their content of fossiliferous limestone concretions. The exposed sections are described below in order from north to south.

One mile east of Cactus station (83, fig. 33), in the road to the Callaghan ranch, a number of concretions occur in clay or shale. They consist of coarse-grained sandstone with black and white grains, but the cement is calcareous. Many of them are fossiliferous (collection 8787). At a point 1.3 miles farther east there is an oyster bed (*Ostrea georgiana*, collection 8784) in dark-gray shale of the Cockfield formation and therefore the exposure at locality 83 must be very close to the top of the Cook Mountain. The same oyster bed (collection 8785) in the same clay is exposed 2.1 miles due east of Webb station, but nearly a mile farther east, at the Mathues ranch, blocks of upper Cook Mountain concretions and green sandstone appear in an old building and must have been hauled eastward over the Cook Mountain-Cockfield contact. Some of these blocks contain *Natica dumblei* (collection 8786).

A large limestone concretion containing *Ostrea georgiana* (collection 8809) was noted in the road to the Ferias ranch 7½ miles northeast of Laredo (84, fig. 33). This is believed to be Cook Mountain rather than Cockfield, although typical Cockfield shales are exposed not far east.

About 3 miles northeast of Zapata (85, fig. 33) the Cook Mountain sandy clay contains numerous large concretions of hard gray limestone that carry many fossils, including large *Natica*, *Astarte*, and *Ostrea georgiana*. Some of the shells appear to have been rolled. Three-quarters of a mile closer to Zapata (86, fig. 33) the exposed surface materials are green, blue, and gray selenitic clay shale and thin-bedded and cross-bedded sandstone, together with a few lenses of indeterminate shells.

Section 4½ miles east of Zapata (87, fig. 33)

	Feet
Reynosa formation: Gravel with large oysters and fossil wood	4
Cook Mountain formation:	
Yellowish-gray clay with seams of gypsum	10–12
Loose yellow sandstone with fossils (collection 9110) in the upper 3 or 4 inches	2½– 3
Hard fossiliferous sandstone (collection 9109)	1
Soft brown and gray selenitic sanstone	10+

This section is practically at the top of the Cook Mountain formation, for gray and green clay carrying *Ostrea georgiana* only crops out from this locality eastward.

Section of Cook Mountain formation 4¼ miles southeast of Soledad and 5 miles northeast of Lopeno (88, fig. 33)

	Ft.	in.
Calcareous buff sandstone, somewhat concretionary, with thin limy seams on the bedding planes	15	9
Yellowish clay with sandstone concretions 6 inches to 3 feet in diameter, some of which contain fossils, including a small unidentifiable pelecypod, a large *Natica*, and *Ostrea georgiana*	6	
Yellowish-gray selenitic clay	13	
Oyster bed (*Ostrea georgiana*)		6
Blue and gray clay	10	
Deep-blue clay	10	6

A little more than a mile east of locality 88 a bed of *Ostrea georgiana* and beds of dark-gray clay, characteristic of the basal Cockfield, crop out.

About 2½ miles southeast of Soledad (89, fig. 33) there is a ledge of conglomerate the pebbles of which are oyster and other pelecypod shells so much abraded as to be almost unrecognizable as shells. The conglomerate is underlain by clay and overlain by gravel.

At the crossing of the Zapata-Roma road over Loma Blanca Creek (90, fig. 33) there is an exposure of greenish-gray cross-bedded concretionary medium to fine-grained firmly cemented sandstone. A fraction of a mile farther south this sandstone is overlain by green calcareous clay containing a bed of small fragile oysters and 7 feet higher a bed of large oysters, and the clay is overlain by soft friable sandstone containing poor specimens of oysters and other pelecypods 11 feet above the larger oysters.

Just north of Lopeno post office (91, fig. 33) a heavy limestone bed that crops out in the road contains a fairly large fauna (collection 8770) common to the lower part of the upper Cook Mountain strata or the uppermost part of the middle beds.

Section of Cook Mountain formation where Zapata-Roma road crosses Arroyo del Tigre (92, fig. 33)

	Feet
Sandy gypsiferous clay, originally dark colored but weathered yellow and brown, with interbedded layers of sandstone	25+
Sandy clay	6
Evenly bedded and cross-bedded soft yellowish sandstone	3
Irregularly bedded greenish-yellow coarse sandstone with large nodular masses	3

At this place a small fault strikes northeast and is downthrown on the northwest. The 6-foot bed of sandy clay exposed on the upthrown side of the fault contains *Conus sauridens*, *Venericardia planicosta*, and other fossils. The top of this section is very close to the top of the Cook Mountain formation stratigraphically.

Section 2.7 miles southeast of Lopeno on road to Roma (93, fig. 33)

	Feet
Gravel and surface débris	5
Cook Mountain formation:	
Yellowish-brown nodular sandstone	7
Yellow clay weathering reddish brown	7
Dirty-yellow sandstone	3
Loose greenish-gray iron-stained selenitic sandstone	6
Steel-gray selenitic shale	5
Yellow shale with selenite in joints	20
Gray compact cross-bedded sandstone	4
Gray, yellow, and greenish-gray shale stained with iron and sulphur	6½
Brown nodular sandstone	3

A mile up the Rio Grande from Ramireno, in a small arroyo (94, fig. 33), 30 feet of cross-bedded brown concretionary sandstone with seams of clay and of hard dark-gray limestone containing fossils (collection 9180) is overlain by 25 feet of alternating sandstone and shale.

Section of Cook Mountain formation on the Rio Grande half a mile above Ramireno (95, fig. 33)

	Feet
Compact massive sandstone and limestone with poorly preserved fossils	10
Clay, partly concealed	22
Sandstone with large, irregular limestone concretions	3
Clay, partly concealed	5
Sandstone with limestone concretions	4
River silt	26

Section of Cook Mountain formation 1⅝ miles below Ramireno and 100 yards from the Rio Grande (96, fig. 33)

	Ft.	in.
Limestone with shell fragments in uppermost 2 inches	1	6
Fine hard gray nodular sandstone with calcareous cement	2	6
Hard and soft gray and green sandstone with concretions of gray sandy limestone	28	
Green, brown, and black shale	3	

Laboratory analyses.—A number of samples from the Cook Mountain formation were taken in the field for special study in the laboratory. The analyses are reported below.

Analysis of sample from lower part of middle beds of Cook Mountain formation 1 mile east of Light, on the Asherton & Gulf Railway (sample 02178)

Bedding.—Bedding not apparent except as roughly parallel fracture planes.

Mineralogy and lithology.—Quartz, fresh and altered feldspar, muscovite, tourmaline, zircon, glauconite, iron oxide as cement and in small secondary grains.

Size.—Mechanical analysis results as shown in Figure 34.

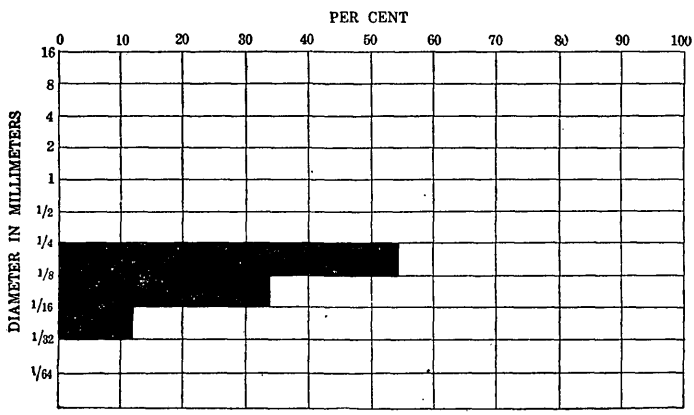


FIGURE 34.—Mechanical analysis of sample 02178

Shape.—Markedly angular except glauconite and few quartz grains ⅛ to 1/16 millimeter.

Porosity.—Was originally porous, but interstices are now filled with iron oxide, so that porosity is low.

Cement.—Iron oxide. Permeates all interstices and forms grains in some places. Breaks easily on thin edges, but larger pieces do not break easily. Fragments maintain angularity. Slightly friable to touch.

Color.—Medium brown except a few spots of lighter brown.

Fossils.—No Foraminifera were found.

Analysis of sample from Cook Mountain formation 1 mile east of Light, above bed yielding sample 02178 (sample 02179)

Bedding.—Mica flakes are roughly oriented, although rock fractures in irregular chunks across this roughly indicated bedding.

Mineralogy and lithology.—Quartz, feldspar, muscovite abundant, heavy minerals very rare, glauconite present but not abundant, very soft, probably altered.

No clay. Limonite present in specimen as concentric rings. All grains within the limonite zones are coated with limonite; all others pure white.

Size.—For mechanical analysis see Figure 35.

Shape.—Glauconite grains rounded, very soft, and most of them broken up during sieving. Rest of grains angular except a few rounded quartz grains in ⅛ to 1/16 millimeter grade. Muscovite in irregular flakes.

Porosity.—Rather porous.

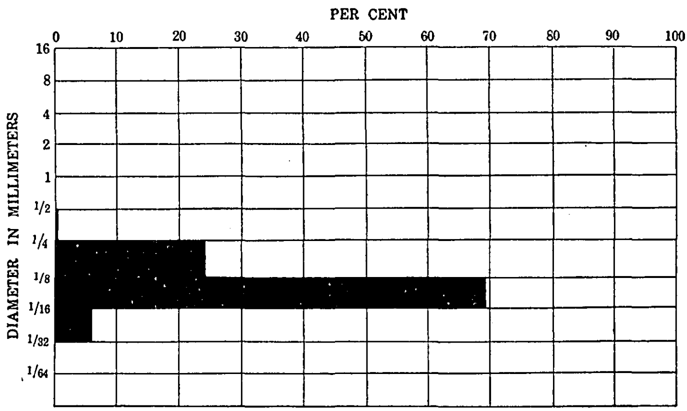


FIGURE 35.—Mechanical analysis of sample 02179

Cement.—No cement except limonite. Very friable to touch and easily broken. Does not maintain sharp edges. Parts containing limonite slightly more resistant.

Color.—Light gray with patches of various shades of brown.

Fossils.—Foraminifera present in milky-white spheres. Not abundant.

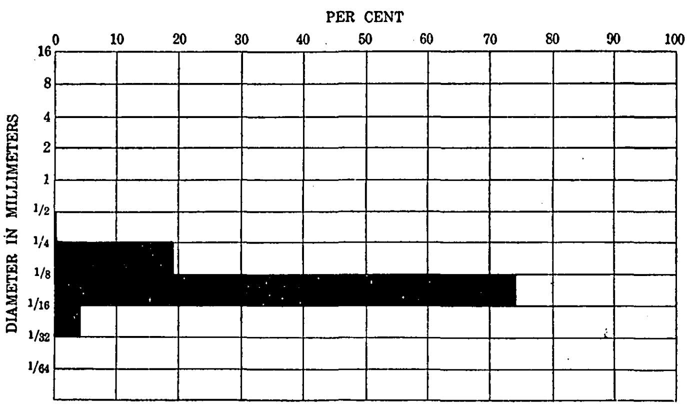


FIGURE 36.—Mechanical analysis of sample 02180

Analysis of sample from Cook Mountain formation 1 mile east of Light, above bed yielding sample 02179 (sample 02180)

Bedding.—No bedding evident on sample.

Mineralogy and lithology.—Quartz, feldspar, fresh and altered orthoclase, abundant glauconite, very few heavy minerals, muscovite rare, tourmaline.

Size.—For mechanical analysis see Figure 36.

Shape.—Quartz and feldspar very angular. Good cleavage fragments of feldspar. Glauconite occurs in rounded, spherical, or spheroidal grains. Seen in section some grains consist of several smaller ones fused together. Some have concentric structure.

Porosity and packing.—Original sandstone was very porous because of marked angularity and loose packing. Now very firm, solid, and impervious.

Cement.—Interstices filled with calcite.

Color.—Medium gray, close inspection shows it to be shot with black specks.

Fossils.—Some of glauconite grains have concentric structure and may be Foraminifera replaced by glauconite. No certain Foraminifera.

Analysis of sample of white silky material in Cook Mountain formation on San Antonio road 5½ miles north of Laredo (38, fig. 33; sample 02043)

Bedding.—Specimen is powdery and is finely divided for the most part. Some few fragments as aggregated fine material are 8 millimeters in diameter. No bedding is evident.

Mineralogy and lithology.—Gypsum and anhydrite abundant, quartz, feldspar, mica, clay, iron oxide and heavy minerals scarce.

Size and shape.—In detail as follows:

Size (millimeters)	Per cent	
2-1	0.4	Pure gypsum.
1-½	2.6	Pure gypsum and aggregates of finer grains.
½-¼	1.8	Pure gypsum and aggregates of fine grains; also rounded quartz grains. This is notable, as rounded grains are rare, and these are extremely large for Cook Mountain. Some of the aggregates are tubular and suggest root tubes.
¼-⅛	3.2	Chiefly sand, quartz, and feldspar. Aggregates of finer material.
⅛-1/16	8.6	Chiefly sand. Crystals of anhydrite abundant. Rod-shaped crystals both clear and milky. Distinguished from gypsum by form, high refractive index, and cleavage. Gypsum has inclined extinction, anhydrite parallel extinction.
1/16-1/32	13.4	Fine material, gypsum, anhydrite, quartz, and clay aggregates.
1/32-1/64	10.6	Aggregates and quartz.
Less than 1/64	59.4	

In sieving this sample no attempt was made to break up aggregates, as both gypsum and anhydrite are soft and would be crushed.

Color.—Cream-colored.

Fossils.—None were seen.

This material seems to represent a bed or lens of anhydrite changed to gypsum after original precipitation.

Analysis of sample of sandstone from the middle part of the Cook Mountain formation 2.9 miles southeast of the post office at Laredo (sample 02203)

Bedding.—Massive in sample.

Mineralogy and lithology.—Almost pure quartz sand. Not calcareous. Few if any feldspars or ferromagnesian minerals. Considerable glauconite, especially in coarsest grade. Heavy minerals listed in order of abundance are zircon, magnetite, staurolite, chalcopyrite, tourmaline, garnet, and rutile.

Size.—The mechanical analysis (see fig. 37) shows that this is a very fine grained sandstone but with considerable fine sand, coarse silt, and clay and some medium sand and fine silt.

Shape.—Grains angular in all grades.

Porosity and cement.—Only slightly compacted and friable.

Color.—Dark buff, owing to iron staining of quartz grains.

Fossils.—None.

Analysis of sample from middle part of Cook Mountain formation north of Dolores (57, fig. 26, sample 02046)

Bedding.—Bedding represented by roughly parallel fracture planes.

Mineralogy and lithology.—Quartz, glauconite, very abundant, feldspar fresh, muscovite, and tourmaline.

Size.—Mechanical analysis is given in Figure 38.

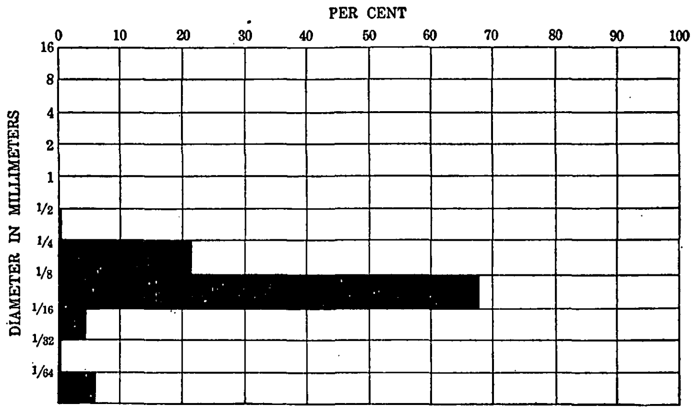


FIGURE 37.—Mechanical analysis of sample 02203

Shape.—Glauconite grains are rounded or spheroidal. All other minerals angular except a few rounded grains of quartz in ⅛ to 1/16 millimeter grade.

Porosity.—Appears to have rather high degree of porosity. Absorbs water readily.

Cement.—Apparently no cement. Breaks easily; is friable to touch and does not maintain sharp edges.

Color.—Dark olive-green; burns to brick-red.

Fossils.—No Foraminifera were seen. Probably if present they are replaced by glauconite and have been altered beyond recognition.

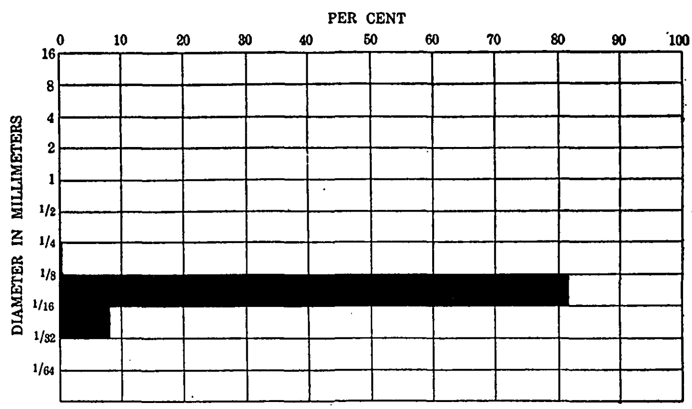


FIGURE 38.—Mechanical analysis of sample 02046

Analysis of sample from beds of clayey sand near top of Cook Mountain formation east of Laredo (sample 02202)

Bedding.—No bedding planes visible in sample.

Mineralogy and lithology.—Chiefly quartz but contains some grains of material that look like volcanic glass but are not original in this sample, some grains of ferromagnesian minerals, and a small proportion of heavy minerals—zircon, magnetite, staurolite, tourmaline (2 varieties), garnet, rutile, muscovite, fluorite, and epidote(?). Sample is not calcareous.

Packing and cement.—Compacted but not cemented to sandstone.

Size.—The mechanical analysis (fig. 39) shows that this is a fine-grained sandstone with large admixtures of fine sand and clay and smaller admixtures of

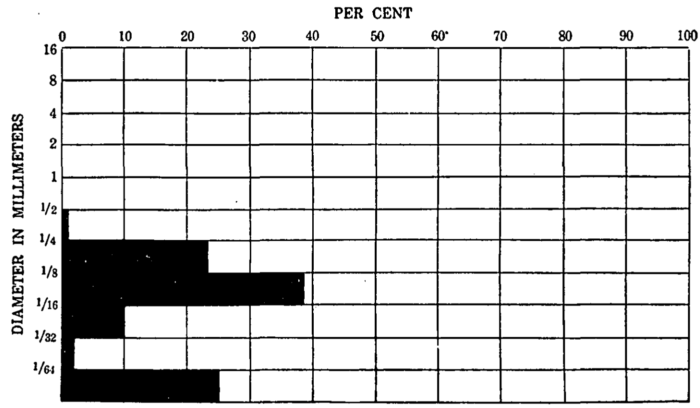


FIGURE 39.—Mechanical analysis of sample 02202

medium sand and silt. This sample is believed to represent fairly the finer sediments of the Cook Mountain formation, which contain little or no real clay or shale.

Shape.—Grains are angular and slightly shaped in the coarsest grade but predominantly angular in all other grades.

Color.—Grayish buff.

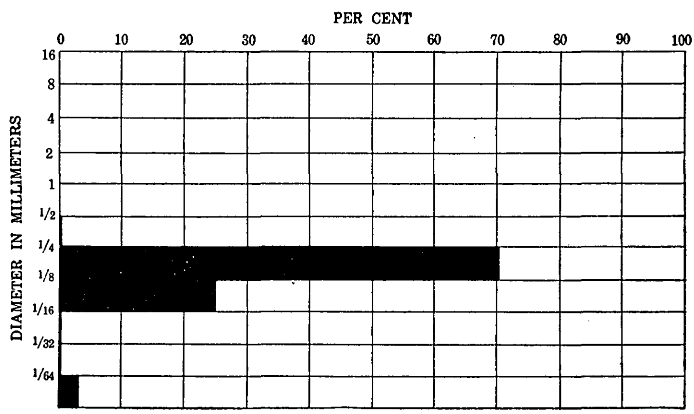


FIGURE 40.—Mechanical analysis of sample 02204

Analysis of sample of sandstone from bed near the top of the Cook Mountain formation at Loma Blanca Creek crossing of the Zapata-Roma road (90, fig. 26, sample 02204)

Bedding.—Sample massive.

Size.—The mechanical analysis (fig. 40) shows that this is a fine-grained sandstone with 25 per cent of very fine sand grains and very small amounts of materials coarser and finer.

Shape.—Grains angular in all grades.

Mineralogy and lithology.—Almost pure quartz sand with some glauconite in the coarser grades. Heavy minerals include staurolite, tourmaline, chalcopyrite, zircon, rutile, and leucoxene. Noncalcareous.

Packing.—Slightly compacted to friable sandstone.

Color.—Light buff, owing to slight iron staining.

Interpretation.—It is evident from the fossils and glauconite present throughout the formation that the Cook Mountain is almost entirely if not entirely of marine origin. The similarity of the sandstones under laboratory analysis suggests uniform conditions over wide areas and for considerable lengths of time. The presence of what appear to be original gypsum and anhydrite in at least some beds and of carbonaceous clay in a few localities suggests partial inclosure in bays and lagoons, but the formation as a whole was doubtless deposited in the open sea. At least more typically marine conditions are recorded by the Cook Mountain than by the Mount Selman.

COCKFIELD FORMATION

Name and definition.—The Cockfield, which is the youngest of the Claiborne formations in Texas but which on the Rio Grande has close relations with an overlying formation of Jackson age, lies with some indications of unconformity upon the Cook Mountain and underlies the Fayette sandstone (of Jackson age).

Strata now known as Cockfield were included in the Fayette of Penrose.[58]

The name Cockfield was first applied by Vaughan,[59] in 1895, to a series of laminated clays and sands with intercalated beds of lignite in Louisiana which lie at the top of the Claiborne group, just below the Jackson formation.

In 1892 Dumble[60] applied the name "Yegua" to a formation in Texas, composed of clay, sand, and lignite, which he thought intervened between the Cook Mountain formation below and the Fayette formation above.

Dumble's assignment of the "Yegua" (=Cockfield) to a position between the Cook Mountain and the Fayette was apparently accepted by Vaughan[61] and other investigators, for in 1912 its position was so indicated in a published correlation chart, and since that time "Yegua" has been used by most authors instead of Cockfield, for the lignitic sands and clays at the top of the Claiborne.

The lower Claiborne age of the marine faunas, both molluscan and foraminiferal, in the type sections of the "Yegua" on Elm and

[58] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Survey First Ann. Rept., pp. 47-58, 1890.

[59] Vaughan, T. W., The stratigraphy of northwestern Louisiana: Am. Geol., vol. 15, p. 220, 1895.

[60] Dumble, E. T., Report on the brown coal and lignite of Texas, pp. 148-154, Texas Geol. Survey, 1892.

[61] Vaughan, T. W., in Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 723-731, 1912.

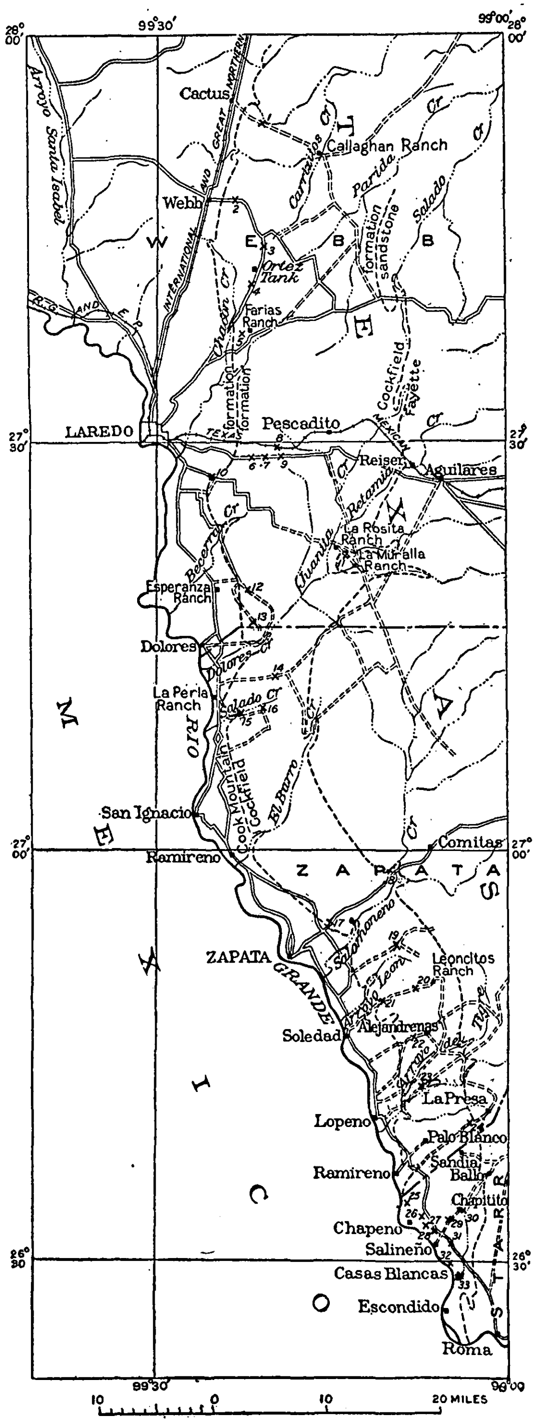


FIGURE 41.—Sketch map showing the areal extent of the Cockfield formation and the location of the exposures described.

Yegua Creeks in Lee County was recognized by Gardner[62] and Stadnichenko[63] in 1927, but the faunas were interpreted as Cook Mountain faunas persisting into latest Claiborne time. Later field work in the area by Gardner and others has shown that the field relations as well as the faunas ally the type outcrops of the "Yegua" with the earlier Claiborne. The name "Yegua" has for that reason been abandoned by the United States Geological Survey in favor of Cockfield.

Distribution.—Plate 7 and Figure 41 show the distribution of the formation at the surface in the lower Rio Grande region. The belt of outcrop ranges in width from 4½ to 17 miles, the difference being due probably to an irregular overlap of the Fayette. The outcrop within the region is confined to Webb and Zapata Counties and a small part of western Starr County.

[62] Gardner, J. A., The correlation of the marine Yegua of the type sections: Jour. Paleontology, vol. 1, No. 3, pp. 245–251, December, 1927.

[63] Stadnichenko, M. M., The Foraminifera and Ostracoda of the marine Yegua of the type sections: Jour. Paleontology, vol. 1, No. 3, pp. 221–243, December, 1927.

The line on the west side of the belt of outcrop which separates the dark-gray, predominantly clayey, only slightly glauconitic, noncon-cretionary Cockfield, which contains only one abundant molluscan species, *Ostrea georgiana*, and which occupies an open prairie, from the green, sandy, highly glauconitic, concretionary Cook Mountain, with its red soils, its dense vegetal covering, and its diversified fauna, is fairly easily recognized in the field. The Cockfield-Fayette line along the east side of the belt of outcrop is not so definite, but it lies between the clayey Cockfield on one side and the more sandy Fayette, containing opalized wood, beds of volcanic ash, and characteristic leaf impressions on the other.

Character.—Most of the formation in this area appears to consist of dark-gray, black, red, pink, purple, green, and brown selenitic carbonaceous clays. The predominant color is dark gray, and the material weathers into dark-gray clay soils. There are also many beds, lenses, and seams of soft gray and buff sand and sandstone, most of them thin. Near the base of the formation just below the Zapata-Starr County line on the Rio Grande, there is more sandstone than clay. Dark, irregular limestone concretions occur sparingly in the clay.

Thickness.—The thickness of the Cockfield strata exposed in the lower Rio Grande region, so far as it can be determined from the surface, ranges from 210 to 895 feet and averages 493 feet. It appears to average 1,533 feet, however, in the oil and gas fields of Webb and Zapata Counties. This is another illustration of the fact that the formations of this region are much thicker where drilled east of their outcrops than at their outcrops.

Fossils.—Dumble[64] reports *Tellina mooreana* Gabb, *Turritella houstonia* Harris, and *Natica recurva* Aldrich from beds in Mexico identified as "Yegua" (=Cockfield), and Deussen[65] states that the lower "Yegua" (=Cockfield) beds in southwestern Texas carry *Volutocorbis* sp., *Corbula* sp., and *Ostrea alabamiensis* Lea, but as these are all common species in the upper Cook Mountain and were not found in the Cockfield as separated from the Cook Mountain in the lower Rio Grande region, it is likely that the beds from which these species were collected would have been included in the Cook Mountain had they been present in the region covered by this report. Leaves have also been found in the formation outside the region[66] but not inside. The only common fossils seen in the Cockfield in the greater part of the region covered by this report are *Ostrea georgiana*,

[64] Dumble, E. T., Tertiary deposits of northeastern Mexico: California Acad. Sci. Proc., 4th ser. vol. 5, No. 6, p. 177, 1915.

[65] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 75, 1924.

[66] Berry, E. W., The middle and upper Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 92, p. 31, 1924.

a species abundant throughout the formation vertically and horizontally but perhaps more common near the base than elsewhere, and *Venericardia* sp., which is associated with the oysters between Roma and the Zapata-Starr County line. More than a score of the oyster beds, some of them containing also *Venericardia*, occur within the Cockfield north of Roma, but these fossiliferous beds high in the formation do not continue to the latitude of Laredo. It is reported [67] that the Cockfield is more highly fossiliferous in Mexico than in Texas, and the beds near Roma seem to represent an extension of this Mexican facies for a short distance into Texas. Mr. C. E. Jamison, in a personal communication to Miss Julia Gardner, reports that he has found a good fauna in the Roma area, in beds that seem to be of Cockfield age, but the list of species contained in this fauna is not available.

Although a good Claiborne fauna has been collected from the Cockfield of Brazos and Lee Counties and from eastern Zapata County, in a large part of the Rio Grande area the Cockfield fauna, like that of the Fayette, is reduced to *Ostrea georgiana* reefs. The correlation of these beds with the Claiborne rather than with the Jackson rests upon somewhat slender evidence.

Webb County sections.—The surface of the Cockfield belt of outcrop in Webb County is so nearly flat that exposures of underlying strata are few and generally very shallow. Indeed, the nature of the rock must be determined over most of this area from the character of the soil or from barely exposed layers of shale, sandstone, or oyster beds in roads, shallow drains, and similar situations.

About 3½ miles east of Cactus station (1, fig. 41), clay weathering to gray and black soil crops out in the road to the Callaghan ranch and contains an oyster bed from which the shells are weathered loose. The clay is dark gray where freshest and is probably black beneath, but it weathers gray. The oysters, which are all of the species *Ostrea georgiana*, are 6 to 8 inches long and 3 to 4 inches thick and lie in two or three beds only a few feet apart stratigraphically. These beds are probably within 100 feet of the base of the Cockfield.

The surface for 3 or 4 miles on both sides of the Callaghan ranch is nearly flat, and the soil is dark gray or black. West of the ranch house clay and "salt and pepper" sand alternate in the strata, the clay predominating, to judge from the surface indications. Southeast of the ranch, at least as far as the lower Callaghan ranch, the underlying material seems to be all clay.

The same clay and oysters which occur at locality 1 (fig. 41) crop out also 2.1 miles east of Webb (2, fig. 41). Gypsiferous red clay is exposed on top of a low hill 7 miles southeast of Webb (3, fig. 41), and from this point red and black clays appear at intervals for

[67] North, Lloyd, personal communication.

several miles to the southeast. A mile southwest of Ortez Tank (4, fig. 41), gray and dark-gray clay and limy septarial concretions are exposed. An oyster bed crops out 2 miles west of the Ferias ranch (5, fig. 41), and clay appears at several places within 6 or 7 miles northeast of this point.

The Cockfield formation is crossed practically at right angles to the strike by the Laredo-Mirando City road. The basal Cockfield beds are exposed about 5 miles east of the east edge of Laredo, where the following composite section was measured:

Section of basal part of Cockfield formation 5 miles east of Laredo

	Ft.	in.
Gray clay with some clayey concretions	5	
Gray sand	1	
Gray clay	2	
Gray sandstone, concretionary	1	
Gray clay, buff in places	6	
Oysters in clay		4
Gray to buff clay	2	
Oyster bed		2
Greenish-yellow clay		4
Oyster bed, like preceding	1	
Greenish clay	4	
Oyster layer, decomposed, and scattered oysters in gray clay	2	
Green gypsiferous shale	12	
Oyster bed, decomposed	2	
Clay, gray to purple	6	

Section of Cockfield formation about 5½ miles east of Laredo

	Feet
Green clay	15
Blue clay, with selenite	7
Gray fine sand, with selenite	2
Blue clay, with selenite	1+

At a point 7½ miles from the Laredo post office on the new road to Mirando City (6, fig. 41) and perhaps overlapping stratigraphically the sections just described, three oyster beds alternating with beds of compact gray clay are exposed. The oyster beds contain but one species, *Ostrea georgiana*, and are similar to those east of Cactus and Webb. An analysis of the interbedded clay is given on page 139. The middle one of the three oyster beds and the clay below it are shown in Plate 14, *C*. At 1.2 miles east of locality 6 and 8.7 miles from the Laredo post office (7, fig. 41), 10 feet of dark-gray, stiff, indistinctly bedded Cockfield clay is exposed on the north side of the road. (See pl. 15, *B*, and analysis, p. 140.)

Clay occurs on the Texas Mexican Railway 11 miles east of Laredo (8, fig. 41), green where fresh and deep red where weathered, with a few lenses of gray coarse friable sandstone. At 1.8 miles east of this locality on the south side of the road (9, fig. 41), 3 to 4 feet of white silicified clay (sample 02206, p. 140) crops out, overlain by gravel and apparently bedded with the Cockfield. Alternating gray, red, and brown clay and sand, with clay predominating, continue along the road and railroad to Reiser, where basal beds of the Fayette formation are exposed.

Driller's log of wells of Border Gas Co. at Reiser

[Well No. 2 to 860 feet; No. 1 from 972 to 1,234 feet]

	From—		To—	
	Ft.	*in.*	*Ft.*	*in.*
Rock, white lime	57		61	
Shale; show of gas	150		161	
Rock	295		307	
Shale; show of gas	371		407	
Hard sandy shale	846		860	
Brown sandy shale	972		1,013	
Blue gumbo	1,013	3	1,028	3
Red shale	1,028	3	1,031	10
Soft sand	1,031	10	1,033	
Soft red shale	1,033		1,061	
Hard gyp rock and rough white-lime rock	1,061		1,090	8
Blue shale	1,091	8	1,106	
Hard shells; no cuttings	1,106		1,106	7
Blue shale	1,106	7	1,131	3
Blue shale; streak of gyp	1,131	3	1,152	1
Soft gyp	1,152	1	1,210	
Brown shale; trace of sand	1,210		1,215	
Gumbo; streak of gyp	1,215		1,228	
Hard white rock	1,228		1,229	
Sandrock; gas	1,229		1,234	

The 40 wells drilled by the Border Gas Co. within a radius of 5 miles around Reiser, ranging in depth from 70 to 2,936 feet, show the underlying material to be chiefly clay with thin sand seams. The drill sites are not far above the top of the Cockfield. The top of the Cook Mountain is not definitely recognizable even in the deeper wells, although the materials penetrated become more sandy with increasing depth.

An oyster bed similar to those 5 miles east of Laredo is exposed for 50 yards in the road to La Rosita ranch, 7 miles southeast of Laredo (10, fig. 41). It is about 2 feet thick and is associated with sandy clay. This exposure is near the base of the Cockfield. From this locality eastward to La Rosita ranch clay and sand alternate in the road, but half a mile southeast of the ranch (11, fig. 41) strata crop out that belong in the basal part of the Fayette.

About 4 miles east by south of the Esperanza ranch and 3 miles from the south line of Webb County (12, fig. 41) there is a bed of large oysters (*O. georgiana*) in shale. This or other and lower beds of oysters crop out at intervals for 3 miles toward the west. Soft thin-bedded sandstone 1½ feet thick is exposed in a creek bank half a mile northwest of El Sauz ranch and half to three-quarters of a mile from the Webb-Zapata County line (13, fig. 41).

Zapata County sections.—Clay and sand, with clay predominating, alternate in the ranch road leading to Caballos Tank, 7½ miles southeast of Dolores settlement (14, fig. 41).

Southeast of La Perla, in the bed of Salado Creek just above the crossing of a poor trail (15, fig. 41), two ledges of sandy shale full of oysters crop out. The oysters in the upper bed are 6 to 8 inches long, but those lying 3 or 4 feet lower are smaller. At the head of Salado Creek, 3 miles farther east (16, fig. 41), soft fine-grained sandstone with gray clay is overlain by dark-purple clay.

The road from Zapata to Comitas crosses the Cockfield belt of outcrop where it is narrow. The upper Cook Mountain section described on page 121 is 3 miles from Zapata. About 4½ miles from Zapata and 0.7 mile northeast of the old Zapata-San Ygnacio road crossing (17, fig. 41) a long, straight ditch exposes a patch of Reynosa gravel overlying strata that probably represent the base of the Cockfield or possibly the top of the Cook Mountain. The base of the Reynosa varies irregularly in altitude by 15 feet within short distances, and the conglomerate rests here on clay, there on limy concretionary materials, and still elsewhere on sandstone. The concretions consist of hard, compact dark limestone and are similar to those in strata between the Cockfield and Cook Mountain elsewhere. A mile north of the road several feet of resistant calcareous sandstone overlies 8 feet of lime-checked clay. Specimens of *Ostrea georgiana* are scattered loose over the surface and occur in the surficial gravel and conglomerate, having been weathered out of Cockfield strata not now exposed at this place. Five miles farther northeast, a quarter of a mile north of the Zapata-Comitas road (18, fig. 41), 21 feet of red clay is overlain by 7½ feet of green clay, followed by 10 feet of calcareous sandstone in beds 1 foot or more thick. The clays are jointed, and the joints are filled with calcium carbonate. The clays of this section are tentatively assigned to the Cockfield and the overlying sandstone to the Fayette.

From the section 4½ miles east of Zapata described on page 122 and classified as the uppermost strata of the Cook Mountain, red and green clays with oyster beds are exposed at intervals in the road leading northeast. About 9½ miles due east of Zapata (19, fig. 41) a 1½-foot ledge of limy sandstone and a bed of oysters (*O. georgiana*) crop out on a hillside.

At a point 6½ miles northeast of Soledad (20, fig. 41) lime-coated sandstone and clay are exposed, weathering to a dark sandy loam. Between the Leoncitos and Alejandrenas ranches the surface materials are all clay. About 3½ miles northeast of Soledad (21, fig. 41) oyster shells and gray clay are exposed, and for 5 miles east of this locality the surface is almost flat, vegetation is low and sparse, there is a great deal of open prairie, the surface material is gray clay, and the soil is black loam. Locality 21 is approximately at the base of the Cockfield. A mile and a half southwest of the Alejandrenas ranch (22, fig. 41) a bed of *Ostrea georgiana* crops out in gray clay. Some of the shells are 7 inches long. This is probably at about the same horizon (basal Cockfield) as the large oysters east of Cactus, Webb, and Laredo, for a section in the top of the Cook Mountain described on page 122 is 1¼ miles west of this point.

Section of Cockfield formation 3.2 miles northeast of Lopeno, in the bed of Arroyo del Tigre Creek (23, fig. 41)

	Ft.	in.
Brown to green-gray shale	1	6
Oysters in clay		4
Buff clayey concretionary limestone		6
Greenish shale with some oysters		10
Oysters and green-brown clay	1	
Oysters with a small amount of greenish-yellow clay	3	

This section is also close to the base of the Cockfield. Some of the oysters are very large, and the beds are similar to those exposed elsewhere at this horizon.

A mile and three-quarters southwest of La Presa (24, fig. 41) a 3-foot oyster bed is associated with yellowish-gray clay. The oysters are *O. georgiana* of the large variety. About half a mile farther northeast and at a somewhat higher altitude another oyster bed overlies a calcareous brown-gray sandstone, although the oysters are in gray clay. Beneath the sandstone, which is thin, is more clay. Just over the hill on the east large oysters, gray clay, and thin layers of gray sandstone are exposed.

Starr County sections.—The higher divides west of the river road and between Chapeno and the northwest line of Starr County consist of dark-gray and green clays with oyster beds of the typical Cockfield overlying fossiliferous green sand and clay of the Mexican facies of the Cockfield at and somewhat above river level.

Section in arroyo 3 miles south of Ramireno (25, fig. 41)

	Ft.	in.
Surface materials	9–10	
Cockfield formation:		
Brown weathered sandstone	10	
Hard gray nodular sandstone	3	
Loose green sandstone	10	
Even-bedded green-brown sandstone with oysters at top	2	
Green-brown sandstone with compact gray sandstone concretions	9	
Seams of gray sandstone and fine conglomerate		2
Brown-gray sand	2	
Massive gray sandstone with some clay	5	
Loose massive green sandstone	3	
Green-gray concretionary sandstone	2	

A mile east of Chapeno (26, fig. 41) 10 feet of greenish-gray clay with 1½-inch beds of gray calcareous sandstone is exposed in a gully.

Section of Cockfield formation 1¼ miles east of Chapeno, where river road crosses Los Merteros Creek (27, fig. 41)

	Ft.	in.
Soft coarse-grained gray calcareous sandstone	12	
Shaly and sandy limestone containing *Venericardia*	1	6
Yellowish-gray limy clay	4	
Concealed by oyster fragments and bits of shale and sandstone	36	9
Irregularly bedded sandstone with seams of shale carrying oyster fragments	5	3
Hard gray sandstone containing abundant though poorly preserved fossils and limestone concretions	5	
Yellowish-gray limy and sandy clay	5	
Concealed	7	
Limy gray sandstone with *Ostrea georgiana* a foot long and a few *Venericardia*	1	6

Two miles southeast of Chapeno on the river road (28, fig. 41) is exposed an oyster bed underlain by yellow-gray clay, which is in turn underlain by green clay and another oyster bed. Between the river road and Chapitito (29, fig. 41), where an oyster bed crops out, the subsoil is gray clay weathering to black loam, with a little sand in the low places. Northeast from this place toward Ballo the Cockfield clays grade into the more sandy but still clayey and oyster-bearing Fayette, with its silicified wood and beds of volcanic ash. At locality 30 (fig. 41) there is an exposure of brown sandstone containing dark-colored limestone concretions coated and impregnated with calcium carbonate. Less than a mile south of the crossing of the Zapata-Roma and Salineno-Chapitito roads (31, fig. 41), there are clay and oysters that in their large size and the fashion of outcrop resemble strongly the oysters east of Cactus and Webb, east of Laredo, and elsewhere.

Section of Cockfield formation on the Rio Grande a quarter of a mile below Santa Margarita (32, fig. 41)

	Feet
Oyster bed	1
Selenitic clay	21
Concretionary sandstone	2
Selenitic clay	13
Bed of large oysters (*O. georgiana*)	1
Gray cross-bedded sandstone with large calcareous concretions; no fossils	20
Concealed to river level	36

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Section of Cockfield formation 8 miles below the west line of Starr County [68]

	Ft.	in.
Indurated light-brown sand	3–6	
Loose light-brown sand	10	
Gray clay	5	
Oyster bed (*O. georgiana?*)		10–12
Gray clay	1	
Oyster bed (*O. georgiana?*)	1	
Concealed to water level	4	

Some of the shells in the two oyster beds are more than a foot long.

Section of river bluff at Casas Blancas (33, fig. 41)

	Ft.	in.
Reynosa formation: Conglomerate bearing large oyster shells	20	
Cockfield formation:		
Yellowish clay	10	
Soft brown cross-bedded concretionary sandstone with seams of selenite and oyster shells	16	6
Soft yellowish sandstone with thin seams of selenite and a few limy concretions carrying oysters	11	
Irregularly bedded soft gray sandstone	8	6
Gray clay with thin seams of selenite	5	6
Bed of large oysters	2	
Gray clay	3	
Bed of large oysters	1	6
Gray clay with 2-inch oyster bed	1	
Blue clay with thin seams of carbonaceous material near the top, to river level	16	6

Section of Cockfield formation on the Mexican side of the Rio Grande 6 miles above Roma [69]

	Feet
Greenish-yellow hard clay with white calcareous concretions, gypsum, and sulphur, indurated in layers 1 to 3 inches thick	18
Oyster bed in a white calcareous rock	2
Some sand and clay as in uppermost bed	20
Brown and black lignitic clay with gypsum and sulphur	6
Siliceous sandstone, rusty and hard in seams, gray to brown and containing much sulphur as it approaches bed above	10

The Cockfield-Fayette boundary northwest of Roma (pl. 7 and fig. 41) is complicated by the Roma anticline, which is shown in detail in Plate 29.

Laboratory analyses.—Several samples were collected from the Cockfield for analysis. Two of them, which came from outside the region of this report, were sent to the writer by Lloyd North.

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[68] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Survey First Ann. Rept., p. 46, 1890.

[69] Penrose, R. A. F., jr., op. cit., p. 46.

Analysis of sample from Cockfield formation 7.3 miles east of Cotulla, La Salle County (sample 02106)

Physical properties.—Cream-yellow; conchoidal fracture; bedding planes or laminations not visible. Compact and very fine grained. No grit can be felt with teeth. Not highly absorptive, as drop of water placed on surface remains without spreading. Clay slakes rather slowly forming small flakes.

Mineral content.—On treatment with dilute hydrochloric acid 9.8 per cent of the sample dissolved, and the insoluble residues consist almost entirely of clay particles less than 1/64 millimeter in diameter, although there is also a small amount of secondary limonite.

Analysis of sample from Cockfield formation 9 miles east of Cotulla, La Salle County (sample 02105)

Physical properties.—Brick-red; grainy fracture, which forms irregular surfaces; no bedding or lamination visible. Very porous to water and slakes rapidly into grains. Very gritty.

Texture.—Mechanical analysis of insoluble residues resulted as shown in Figure 42.

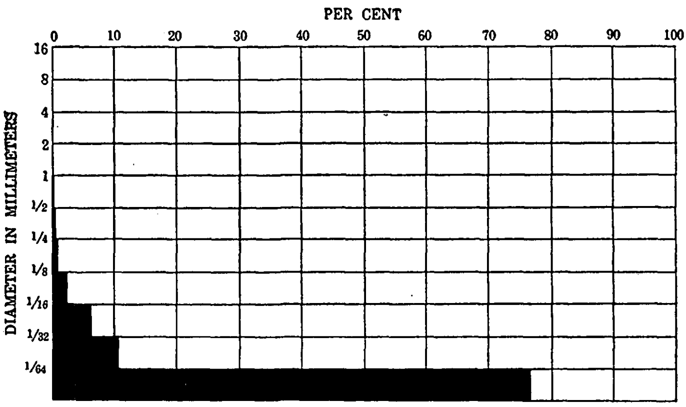

FIGURE 42.—Mechanical analysis of sample 02105

Mineral content.—Quartz, altered feldspar, and gypsum are the most common minerals in the residue. The gypsum occurs in lens-shaped grains, the largest about 1/2 millimeter in diameter, and is probably secondary. Eighteen per cent is soluble in dilute HCl.

Analysis of sample from Cockfield formation 7½ miles from Laredo post office on Mirando City road (6, fig. 41; sample 02205)

Physical properties.—A massive, gritty, crumbly clay.

Mineral content.—Soluble in HCl, 28 per cent; insoluble residue mostly clay and quartz sand and silt. Heavy minerals in small proportions but large variety, as follows: Chalcopyrite, tourmaline, limonite aggregates, magnetite, rutile, staurolite, garnet, and zircon.

Size.—A satisfactory mechanical analysis could not be made of this sample because of the presence in the several size grades of clay aggregates that could not be completely broken up. Probably 95 per cent is in the clay grade (less than 1/64 millimeter), but some grains are in the 1/4–1/8 millimeter grade.

Analysis of sample of Cockfield clay from point 8.7 miles from Laredo post office on Mirando City road (7, fig. 41; sample 02207)

Bedding.—Bedding planes discontinuous and poorly defined.

Mineralogy and lithology.—A crumbly to compact calcareous clay. About 36 per cent is soluble in HCl. The $CaCO_3$ forms calcite crystals, evidently secondary, and cement. There are also gypsum aggregates of various sizes. A few quartz grains and some flakes of mica were noted.

Size.—Because of difficulty in dissociating the clay mechanical analysis was not successful. The insoluble residues deflocculate to some degree when treated with carbonate but reaggregate on washing. More than 95 per cent of the insoluble material is probably clay. Except for gypsum and calcite and clay aggregates there are no grains above the ⅛–1/16 millimeter grade, in which there are a few quartz grains.

This sample under laboratory treatment acts much like Nos. 02205 and 02106 described above, both of which also represent Cockfield clays.

Petrographic description of sample of silicified clay from Cockfield formation 10½ miles east of the Laredo post office (9, fig. 41; sample 02206)

Hand specimen.—This material is an extremely compact, very fine grained white, claylike substance.

Thin section.—Texture very finely conglomeratic; the matrix is material of clay grade, and through it are scattered detrital fragments which are, with few exceptions, less than 1/16 millimeter in greatest dimension. These separately identifiable fragments are mostly angular and subangular. The minerals are quartz, making up most of the separately identifiable grains; plagioclase feldspars, most of the rest of the grains, both fresh and weathered; biotite, minor amount; limonitic aggregates, minor amount; zircon (?), altered. The matrix or groundmass is material of clay grade that has been silicified and hence rendered very compact by the infiltration of opaline material, presumably contemporaneous or nearly so with deposition. Some of this groundmass may be sericitic. It is difficult to estimate with much accuracy the relative proportions of the clay and opal matrix and the separately identifiable grains of silt grade, but the matrix certainly makes up the bulk of this material as a whole.

Analysis of sample from bed of sandstone near the base of the Cockfield formation 13.7 miles above Roma on the road to Laredo (27, fig. 41; sample 02208)

Bedding.—Sample appears massive.

Consolidation.—Slightly friable.

Size.—Mechanical analysis (fig. 43) shows that this is a fine sandstone with about equal parts of medium and very fine grains and only a small proportion of silt and clay.

Shape.—Grains angular and subangular in the two coarse grades, mostly angular in other grades.

Mineralogy and lithology.—A calcareous quartz sandstone (23.8 per cent soluble in HCl), containing considerable ferromagnesian minerals in some size grades. Heavy minerals include in order of abundance magnetite, staurolite, tourmaline (two varieties), rutile, garnet, chalcopyrite, zircon, and leucoxene.

Color.—Greenish gray.

Origin.—The Cockfield formation was deposited in salt and brackish water and possibly some of it in fresh water in coastal marshes and bays. Such an origin is indicated by the fine texture, the carbon content, the included plant shreds, and the oysters. The sediment was doubtless derived from low-lying land on the west.

FAYETTE SANDSTONE

Name.—The name Fayette, which is derived from Fayette County, Tex., as applied to Tertiary strata on the Gulf Coastal Plain, has had a somewhat varied and confusing history. It was first used by Penrose[70] and Dumble[71] as a name for all the Tertiary beds on the Brazos and Colorado Rivers and the Rio Grande lying stratigraphically above the "Marine beds" (now known as the Cook Mountain formation). In 1892 Dumble[72] divided the Fayette of Penrose into formations, calling the lower clayey part "Yegua" (=Cockfield) and

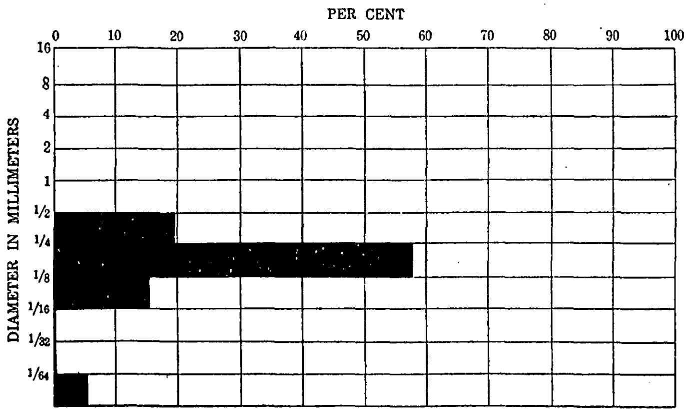

FIGURE 43.—Mechanical analysis of sample 02208

the upper sandy beds Fayette, and in 1903[73] he redefined the Fayette by taking from it the younger Oakville sandstone and the clay that directly underlies the Oakville in some places, later called by him the Frio clay, and all Tertiary formations that overlie the Oakville.

In 1923 the writer[74] used the term Fayette precisely as used by Dumble in 1903, and so did Deussen[75] in 1924 and Bailey[76] in 1926. In 1924 Dumble[77] divided the Fayette as earlier defined by him into two units, the lower of which he called "true Fayette" and assigned to the Claiborne and the upper of which he called "Whitsett beds" and assigned to the Jackson. The "Whitsett" is now correlated,

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[70] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Survey First Ann. Rept., p. 47, 1890.

[71] Dumble, E. T., op. cit., p. xxxiii.

[72] Dumble, E. T. Report on the brown coal and lignite of Texas, pp. 148–154, Texas Geol. Survey, 1892.

[73] Dumble, E. T., Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, p. 32, 1903.

[74] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 97, 1923.

[75] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 80, 1924

[76] Bailey, T. L., The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, p. 38, 1926.

[77] Dumble, E. T., A revision of the Texas Tertiary section with special reference to the oil-well geology of the coast region: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 431–434, 1924.

in part at least, with the Frio clay. It has not proved possible to separate the Fayette of the lower Rio Grande region, and this report follows the earlier work of Dumble and the work of Deussen and Bailey in including in the Fayette sandstone the sandy and clayey beds conformably overlying the Cockfield and conformably overlain by the Frio clay. The lower part of the Fayette of this report is probably the equivalent of the "true Fayette" of Dumble's report of 1924, although here it is not believed to be of Claiborne age, and the upper part is equivalent to part of the "Whitsett" of Dumble; part of Dumble's "Whitsett beds" probably falls within the Frio clay.

Character.—The materials of the Fayette are fairly characteristic, although they are lithologically like those of the Cook Mountain and the Oakville, with both of which they have been confused, but the fauna and flora are different from those of any other lithologically similar formation, and on the whole the formation is not difficult to recognize in the field. The top and bottom, however, can be located only arbitrarily, for the Fayette grades down into the Cockfield formation and up into the Frio clay, so there is more clay in the highest and lowest parts of the Fayette than in the rest of the formation.

The Fayette contains more sand and sandstone than rock of any other kind, yet it is not so sandy in the Rio Grande region as it is farther north and east. The sandstone is exceedingly variable—in color almost white, gray, greenish gray, or buff; in texture fine, medium, or coarse; in consolidation ranging from loose sand to quartzitic sandstone. The most characteristic feature of the sandstone is that it is fossiliferous. It is commonly laminated and cross laminated in intricate patterns. Interbedded with the arenaceous beds are many beds and lenses of sandy and limy greenish-gray, pink, and red shale and clay, especially in the upper and lower parts of the formation. Limestone is scarce. Beds of white volcanic ash are found in the formation at several places. Large dark crystalline limestone concretions are common. Silicified wood occurs abundantly, chiefly in the clay but also in the sandstone. Most of the silica is opal, but chalcedony is also found. The silicified wood is characteristic of the formation in this region.

Thickness.—Although the Fayette is conformable with formations below and above and is not overlapped by any younger formation, the total thickness of the strata included in it that crop out in the lower Rio Grande region ranges from about 210 to about 1,000 feet. The average thickness of the outcropping beds is about 530 feet. However, thicknesses of 1,275 or even 1,600 feet are assigned to it in the oil and gas fields of Webb and Zapata Counties.

Outcrop.—The belt of outcrop of the Fayette sandstone is shown on Plate 7 and Figure 44. It ranges in width from 5½ to 18 miles and lies in southeastern Webb County, eastern and central Zapata County, and western Starr County.

Fossils.—The formation in this region contains comparatively few invertebrate fossils—although a large variety of *Ostrea georgiana* Conrad is locally abundant and reef building. A characteristic Fayette foraminiferal fauna is recognizable in well cuttings. In the coastal dome area of eastern Texas the Jackson subsurface section is considered by the micropaleontologists the most highly fossiliferous of the stratigraphic divisions. In southwestern Texas the section is more sandy and the fauna less rich. The rich Claiborne fauna erroneously attributed to the Fayette by Dumble came in part from the Cook Mountain and the Cockfield.[78]

A number of species of fossil plants are found in the ash beds and some in the sandstone. The best

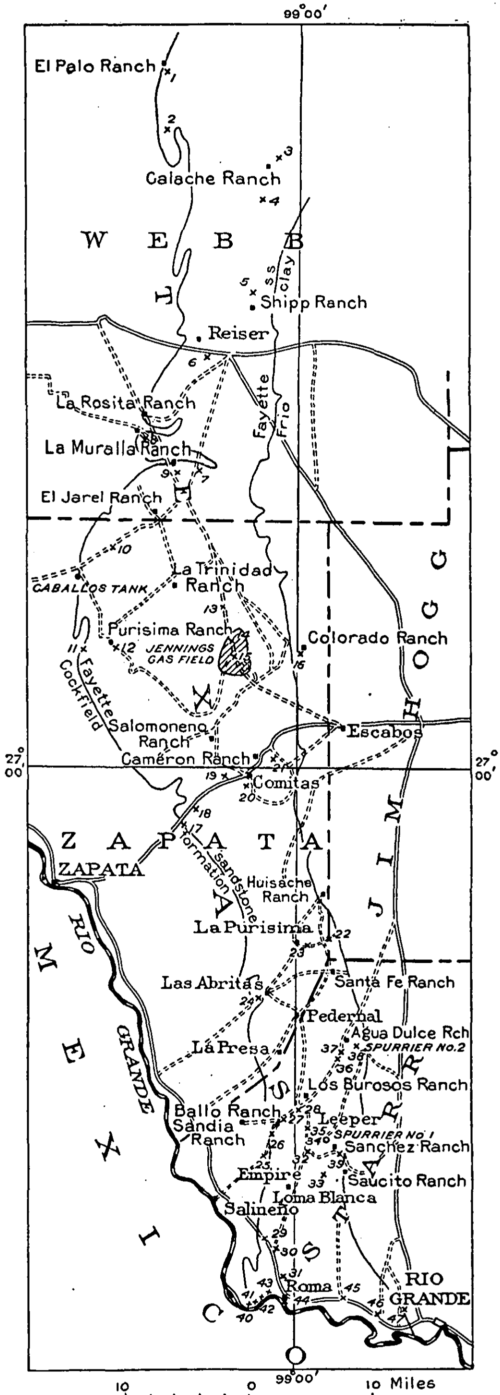

FIGURE 44.—Sketch map showing the outcrop of the Fayette sandstone and the location of the exposures described

[78] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 94, 1923.

collections were obtained at points 2½ and 4½ miles north of the Miraflores ranch, in Zapata County. Berry has indentified the following forms, which he regards as of middle or upper Jackson age.

Apocynophyllum, two n. sp.
Bombacites, n. sp.
Cinnamomum sp.
Conocarpus eocenicus Berry.
Diospyros, n. sp.
Inga, n. sp.
Mespilodaphne, n. sp.
Myristica catahoulensis Berry?
Nectandra, n. sp.
Papilionites, n. sp.
Pisonia, n. sp.
Sabalites vicksburgensis Berry.
Sapindus dentoni Lesquereux.
Sapotacites, n. sp.
Sophora claibornensis Berry?
Terminalia phaeocarpoides Berry.
Ternstroemites, n. sp.

Correlation.—The synonymy and correlation of the Fayette have been treated at length by Deussen,[79] who, together with Matson,[80] concludes that it is entirely of Jackson age, that it has its greatest development in southwestern Texas and becomes thinner in eastern Texas and Louisiana, that it is not to be correlated with the "Grand Gulf" of the Mississippi section as thought by Hilgard, Hopkins, Loughridge, and Veatch, and that it is not the exact equivalent of any single formation elsewhere.

Dumble[81] admits that the identity of the Foraminifera of the "Whitsett beds" with those of his Caddell clays of eastern Texas warrants the reference of the "Whitsett" to the Jackson, "although the molluscan forms collected along our line of section are not distinctive of that age."

Webb County sections.—In the neighborhood of the Becerra ranch, which is about 15 miles east of Cactus and 3 miles beyond the northeast border of the area whose geology is shown on Plate 7, gray, green, and pink clay, gray sandstone, and white volcanic ash alternate in the section. There is also much petrified wood, one piece of which is the silicified remnant of a tree 1½ to 2 feet in diameter. These strata are near the base of the Fayette and are more clayey than normal for the formation as a whole.

At El Palo ranch (1, fig. 44) in the extreme northwestern part of the Fayette belt of outcrop, about 15 miles east of Webb and 5 miles

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[79] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 80, 82–84, 1924.

[80] Matson, G. C.,The Catahoula sandstone: U. S. Geol. Survey Prof. Paper 98, pp. 209–226, 1916; The Pliocene Citronelle formation: Idem, pp. 167–192.

[81] Dumble, E. T., A revision of the east Texas Tertiary section with special reference to the oil-well geology of the coast region: Am. Assoc. Petroleum Geologists Bull., vol. 8, p. 434, 1924.

southeast of the lower Callaghan ranch, where the surficial conditions are characteristic of the Cockfield clay, 1 foot of hard, thinly laminated shale underlies 6 inches of gray friable sandstone, which underlies 4 feet of pink clay. The ranch house, which is now in ruins, was built of dense white volcanic ash that is reported to have been quarried from a hill 3 miles east of south of the house (2, fig. 44). Other houses in this vicinity are built of the same rock. For 10 miles south of locality 2, along the outcrop of the basal Fayette beds, gray and pink clays with abundant fragments of silicified wood are exposed at intervals.

Section of Fayette sandstone 1¼ miles northeast of Yates Calache ranch, 17 miles north of Aguilares (3, fig. 44)

	Feet
Fine-grained sandstone	5
Light-gray kaolin-like clay	6
Coarse gray irregularly bedded sand with a layer of gypsum at base	2–3
Light-gray clay	4

This section is on the border of the region mapped and close to the middle of the Fayette belt of outcrop. In addition to the clay, sand, and sandstone, there is much opalized wood of a brownish to reddish agate color, weathering to dark smoky gray on the surface. Three miles farther south (4, fig. 44) white, chalklike but noncalcareous material like the clay beds in the above section crops out. These are probably ash beds also.

On the south slope of a ridge 1½ miles north of the Shipp ranch and 6¼ miles north of Aguilares (5, fig. 44), a prominent belt of white rock, 200 yards wide, crosses the road from east to west. The bed is essentially horizontal and about 50 feet thick, It overlies drab clay that is exposed on the south, and it is overlain on the north by dark clay followed by light-gray clay with sandy lenses. At the base of the white bed there is gray clay with opalized tree trunks and several bands of siliceous material resembling sinter. The fossil wood is dark colored, and the siliceous bands contain specks and flakes of dark-colored ferruginous material. The upper 25 feet of the bed is sandy, and some layers are cross-bedded on a small scale. This material is doubtless volcanic ash or tuff bedded with clay.

The clay pit for the brick plant at Reizer is south of the Laredo-Aguilares road and connected with the plant by a narrow-gage railway (6, fig. 44). This pit, which is 6 to 12 feet deep and 200 feet square, exposes Fayette clay, probably near the bottom of the formation. The clay is stiff, compact, unstratified, selenitic, and yellow on long exposed surfaces but gray to green on fresh surfaces. (See analysis, p. 153.) Scattered irregularly through the clay are many spheroidal limestone concretions 1 inch to 1 foot in diameter, which are septarial and have dendritic markings on the joints. (See analysis, p. 154.) In an artificial ditch that drains the pit large specimens of *Ostrea georgiana* and fragments of silicified wood were seen in the clay. (See pl. 15, *C*.)

At and around Aguilares the surface materials are clay and sand with a gravel admixture from the Reynosa formation, which caps the neighboring hills. The town itself is very sandy. The alternating clay and sand, though poorly exposed, are indicated in the surface for 5 or 6 miles southwest from Aguilares. Eight miles southwest of Aguilares, near Agua Azul Creek (7, fig. 44), 15 feet of jointed gray clay is exposed.

Section of Fayette sandstone half a mile southeast of La Rosita ranch (8, fig. 44)

	Feet
Gray sandy clay	4
Light-brown to yellow flaggy soft, regularly bedded sandstone	6
Dark-drab and chocolate-colored clay	6

The sandstone member in this section supplied stone for buildings at La Rosita ranch. It crops out on the east side of the valley of Cerrito Creek as low scarps here and there and is probably a series of lenses rather than a continuous bed. There are no exposures for some miles west of this point, but these beds probably lie at or near the base of the Fayette.

Section of Fayette sandstone half a mile southeast of La Muralla ranch (9, fig. 44)

	Feet
Soft gray shale weathering pink	10
Hard gray sandstone	4
Soft coarse gray sandstone	6

In the extreme southern part of Webb County there is no exposure of the Fayette, but the surface materials consist of sand and some clay.

Zapata County sections.—From Caballos Tank to El Jaral ranch the the road is sandy, whereas west of the tank it is clayey, and the Cockfield-Fayette zone of transition crosses the road about at the tank. Three miles northeast of the tank and 4 miles southwest of El Jaral ranch (10, fig. 44) bluish clay, oyster shells, and an abundance of silicified wood at the surface record the presence of Fayette beneath. Between this ranch and the gas main that connects the Jennings gas field with Laredo and for several miles southeast on the gas main the the surface materials are alternately clayey and sandy. The road ditches made by rain water show only clay, but they are not continuous. The clay layers and lenses, being nonporous, wash out, and the porous sand absorbs the water and remains uneroded.

A mile and a half west of the Purisima ranch (11, fig. 44) the dark-gray clay of the Cockfield on the west changes eastward to green clay, gray sand, oyster shells, and silicified wood. For some distance to the east the higher parts of the surface are underlain by Fayette and the valley bottoms by Cockfield clay where the overlying Fayette has been removed. Half a mile south of the Purisima ranch (12, fig. 44) a bed of hard buff sandstone crops out in the low bank of a creek. It is coated white on bedding and joint planes. This sandstone, which resembles that at locality 8, was used in the foundation of the Purisima ranch house, where there are also two doorstep slabs 4 and 5 feet long, 18 inches wide, and 8 to 12 inches thick of the hard bluish quartzitic phase of this rock. Between the Purisima and La Trinidad ranches heavy sand and gray and green clay alternate. At La Trinidad ranch blocks of drab and brown sandstone and of silicified wood, one piece 4 inches square and 15 inches long, were used in the house foundation. A mile east of this ranch the sand changes to clay, which continues at the surface eastward to the gas main.

Five miles north of the Miraflores ranch (13, fig. 44) there is a large surface exposure of white volcanic ash, from which the fossil plants described on page 144 were obtained. In addition to the fossils collected there are many impressions of woody material and partly decayed but lithified nuts. The ash bed is apparently only about 3 feet thick and overlies and underlies clay. The beds are essentially horizontal.

Much the same rock is exposed 2.3 miles north of the Miraflores ranch in the Jennings gas field (14, fig. 44), in an arroyo below an old tank. Here it forms a bed about 2 feet thick with clay beneath, and the lens is bent so that its dip varies by several degrees within 10 feet horizontally. The white rock contains fewer plant remains than at locality 13 but many dark specks.

At the Miraflores ranch in the Jennings gas field (15, fig. 44) volcanic ash occurs again in the tank bottom and has been used in the house foundations. The rock is pure white, noncalcareous, not gritty, and may be scratched with the thumb nail, but it is indurated and tough and must be struck a severe blow with the hammer to be broken. There are large numbers of plant fragments in the rock. Gray clay crops out between the ranch and locality 14 and continues at the surface for 2 miles south of the Miraflores ranch.

About 200 yards west of the Colorado ranch (16, fig. 44) pieces of dense white rock, probably volcanic ash, are brought up in animal burrows, although the surface is gray clay. Thin gray flaggy sandstone is used in buildings at the Colorado ranch.

The soil and other surface materials around the wells of the Border Gas Co. in the Jennings gas field are sandy. The sand in the roads is deep, and the sludge from the wells is sandy, although clay also appears in the sludge. From the Jennings ranch to the Salomoneno ranch clay and sand alternate in the roads without actual exposures of either.

A fairly complete section of the Fayette from bottom to top is exposed discontinuously along the road from Zapata to Hebbronville, beginning at a point about 9 miles out from Zapata and entering the Frio about 14 miles farther northeast, just southwest of the Escobas ranch.

Section of Fayette sandstone 9 miles northeast of Zapata (17, fig. 44)

	Ft.	in.
3. Light-gray sandstone in beds more than 1 foot thick	10	
2. Green clay, nodular and jointed	7	6
1. Crimson clay, nodular, checked, jointed, and crumbly	21	

This section is in the transition zone between the Cockfield and the Fayette. Arbitrary choice of a line of contact places Nos. 1 and 2 in the Cockfield and No. 3 in the Fayette. (See p. 142.) The sandstone of No. 3 is firmly cemented with calcium carbonate and contains small shiny particles and poorly preserved fossil plants. Within it also are peculiar small bodies, with small protruding stems or cores in the center. The results of laboratory study of this sandstone are given on page 154. On the surface there are large quantities of silicified wood, one piece of which is 8 inches long and 6 inches wide.

One mile to the northeast (18, fig. 44) 2 to 4 feet of calcareous sandstone with lenses of sandy limestone is underlain by 9 feet of poorly exposed blue clay. The sandstone contains plant markings, and one palm ray was seen. Where the road crosses Salomoneno Creek only reworked saliferous clay is exposed.

Section of Fayette sandstone 1½ miles southwest of Comitas (19, fig. 44)

	Feet
Sandstone with thin clay lenses	5
Alternating sandstone and clay layers and lenses about 2 inches thick on the average	3
Fairly pure clay	5

The layers and lenses of clay in this section are greenish gray, and the sandstone is white or light gray. Lenses 4 inches thick in the middle disappear in both directions within 6 feet. The clay is limy and sandy, and the sandstone limy and clayey. All the rocks are loosely cemented. The more sandy layers and lenses are finely cross-bedded in intricate patterns and are micaceous. They also contain poorly preserved plant remains and leaf impressions. (See pl. 15, *A*.)

A gully below the tank dam at Comitas (20, fig. 44) exposes about 15 feet of interbedded clay, soft sandstone, and limy sandstone and shale. The sandstone is intricately cross-bedded and laminated and is gray and greenish gray. The clay is greenish gray, sandy, and limy and is coated with lime carbonate and salt. There is more clay than sandstone in the section. The stratification is lenticular and pockety, suggesting considerable agitation of water during deposition. Half a mile southeast of the Cameron ranch (21, fig. 44) a lens of white volcanic ash has been quarried out. The quarried blocks are massive and a foot or more in thickness. The ash is associated with greenish and bluish-gray clay checked in joints with calcium carbonate. About 3 miles east of the Cameron ranch the deep surface sand derived from the sandy layers of the Fayette gives place to the hard clay of the Frio.

A bed of oysters (*Ostrea georgiana*) crops out 3.6 miles S. 30° E. of the Huisatche ranch and 1 mile northeast of the Webb-Zapata oil field headquarters (22, fig. 44), associated with gray clay and a single layer or lens of gray sandstone cemented with calcium carbonate. This same oyster bed was seen 1.3 miles west and south of the oil field headquarters and 1 mile east of the Purisima ranch (23, fig. 44) and has been traced by John W. Priour for 2 miles south of this point and 8 miles north, through locality 22.

The surface rock in the Webb-Zapata shallow oil field is Fayette, probably within 100 feet of the top of the formation. Forty or more wells have been drilled here, which determine the nature of the materials to depths of 137 to 175 feet. Two typical logs are given below.

Log of wells in the Webb-Zapata shallow oil field

Well 16

	Feet
Yellow clay	0–18
Green shale	18–60
Blue shale	60–88
Blue sandstone	88–96
Shale and shells	96–145
Cap rock of hard limy clay containing unidentifiable fossil pelecypods	145–148
Oil sand	148–153
Hard sand	153–161

Well 15

	Feet
Yellow sandy clay	0–42
Shale	42–159
Cap rock	159–162
Dry sand	162–164
Oil sand	164–166
Dry sand	166–170

It is noted from these logs that the upper part of the Fayette formation in this vicinity is predominately clay. The oyster bed at 96 to 145 feet in well 16, which is penetrated just over the cap rock in most of the wells, is doubtless the same as that exposed at localities 22 and 23. (See fig. 44.) Fossils similar to those in the cap rock occur in exposed sections at and west of Roma.

About a mile southwest of Las Arbritas (24, fig. 44) an oyster bed is exposed overlying an 18-inch bed of coarse gray crumbly calcareous sandstone. This shallow exposure is taken to mark the base of the Fayette, although there is a predominance of clay east and southeast of it, and the sandstone may be merely a local lens or layer in the upper part of the Cockfield formation. Between the Pedernal and Santa Fe ranches gray and green clay and white and gray sand are indicated by the surface materials.

Starr County sections.—The road leading northeast from Salineno crosses from the Cockfield to the Fayette within 4 or 5 miles of the Rio Grande. Brown concretionary sandstone coated with lime carbonate crops out in the road 3¾ miles northeast of Salineno (25, fig. 44) and again 1.7 miles farther northeast (26, fig. 44). The house on the old Ballo ranch is built of white volcanic ash and light-gray sandstone which contains oyster shells. An oyster bed is exposed at the house. Seven-tenths of a mile farther northeast, where the road from the Sandia ranch comes in (27, fig. 44), a conspicuous ridge is held up by a heavy oyster bed. The shells are fragmental and consolidated to make up a dark-gray limestone with a slight parallel orientation of the shells. Within the limestone there are large and small irregular concretionary masses of chert or chalcedony. Between the Ballo ranch and this locality there is a large quantity of white and yellow soil that comes from weathered gypsiferous clay or shale. A quarter of a mile east of locality 27 a bed of *Ostrea georgiana* crops out, associated with highly selenitic clay and its weathering product, the limy and sulphurous clay soil noted above. Three-quarters of a mile west of Los Burosos ranch (28, fig. 44) there is an outcrop of gray sandy and limy concretionary clay with thin seams of gypsum and a 2-inch oyster bed. In the 7 feet of strata exposed there is a 5-inch bed of sandy and limy concretions, which are spheroidal or slightly flattened and range from half an inch to 4 inches in diameter.

On the Zapata-Roma road at La Anagua ranch (29, fig. 44) there is a bed of very large oysters covered by about 10 feet of selenitic gray clay and a sandstone concretionary bed. North of Roma at the branching of the Laredo and Hebbronville roads (30, fig. 44) there is a wide outcrop of brown concretionary sandstone with a limy coating. About 2½ miles north of Roma (31, fig. 44) gray friable calcareous sandstone and concretionary clay are interbedded.

Northeast of Roma on the road to Hebbronville there are several exposures of Fayette clay, sandstone, and oyster beds, with some silicified wood. In this section the formation is unusually clayey. From the forks in the road at locality 30 to Loma Blanca the soil, topography, and vegetation suggest that clay is the underlying material. There are no deep exposures, but the surface material is dark-gray selenitic clay with a few thin seams of brownish sandstone with calcium carbonate on the surface and in the bedding planes and joints. More than 90 per cent of the material must be clay. At the old Empire Co.'s deep oil test hole 7.4 miles northeast of locality 29 (32, fig. 44) the surface material is bluish-gray clay with fragments of oyster shells, and 2½ miles southeast of this point (33, fig. 44) a bed of large *Ostrea georgiana* appears in the dump of a shallow dug well. A bed of oysters over gray clay is exposed 1½ miles northeast of the

Empire drilling, and gray clay is exposed half a mile farther east, at the Spurrier well No. 1 (34, fig. 44). At the Leeper well No. 1 (35, fig. 44) the exposed clay is green rather than gray and contains an abundance of fossil oysters and silicified wood. An opalized pelecypod seen by the writer is reported to have come from a depth of 60 feet in a water well near the Leeper well. Half a mile north of the Leeper well two oyster beds 10 feet apart vertically are interbedded with green and brown clay, and 5 miles farther north (36, fig. 44) much the same beds crop out but with considerable associated selenite and silicified wood. At Alta Vista well No. 1 of the Valley Oil & Gas Co. (37, fig. 44) yellow and blue clay and compact white sandstone are associated. Between the Agua Dulce ranch and the Spurrier drill hole No. 2, (38, fig. 44) a silicified tree stump 3 feet high and a foot in diameter was noted. About 3 miles north of the Agua Dulce ranch the green and gray clay of the Fayette gives place to the red clay of the Frio.

An oyster bed crops out just southeast of the Sanchez ranch (39, fig. 44), but a mile north of the Saucito ranch the surface material changes to unfossiliferous gray and white clay, which continues eastward into and across the Frio belt of outcrop.

The best exposures of the Fayette formation occur on and near the Rio Grande between Roma and a point 8 miles farther east and down the river.

Section of Fayette sandstone 1¼ miles west of Roma Barracks (40, fig. 44)

	Feet
Soft gray sandstone alternating with yellowish-gray clay	43
Yellowish-gray highly selenitic sandy clay	31
Gray clay and sandstone containing a few oyster shells and some selenite	37

Section on the Rio Grande at second ranch house west of Roma (41, fig. 44)

	Ft.	in.
Surface material	10	
Fayette sandstone:		
Oyster bed	2	
Selenitic greenish gray clay	4	
Oyster bed; large shells	2	
Concealed, probably clay	8	
Soft gray sandstone, stained brown or yellow by weathering, irregularly laminated	10	6
Interbedded gray sandy clay, thin gray sandstone, and oyster beds	10	6
Oyster bed		3
Blue and green selenitic clay containing large numbers of shell fragments, including small, fragile, and unidentifiable pelecypods similar to those in the "cap rock" of the Webb-Zapata oil field and a small and unidentifiable gastropod	1	6

Section of Fayette sandstone half a mile west of Roma Barracks (42, fig. 44)

	Ft.	in.
Brownish-gray calcareous sandstone	21	
Soft gray rock bearing unidentifiable casts of small pelecypods	1	
Heavy sandstone beds with gray clay partings	11	
Alternating sandstone and clay, without fossils	15	9
Gray clay, weathering yellow	21	
Oyster bed (*Ostrea georgiana*)	1	
Clay, partly concealed	12	
River silt covering bedrock	5	
Bed of large oysters	1	
Gray clay	3	6
Calcareous sandstone with oyster shells	1	
Clay	2	
Oyster bed		8
Gray clay	4	
Bed of large oyster shells		8
Gray clay	3	
Concealed by river silt	10	6
Gray concretionary, irregularly bedded sandstone with oyster shells	13	
Bed of large oyster shells	1	

A pit 16 feet deep with rim 31 feet above low water at the Roma Barracks pump house (43, fig. 44) disclosed 8 feet of fine-grained gray sandstone 2½ feet from the surface, with blue clay or shale below it. The sandstone is finely and evenly laminated and notably hard.

Section of Fayette sandstone at the river end of the main street in Roma (44, fig. 44)

[Pl. 16, *A*]

	Feet
Soft, slightly concretionary yellowish shaly sandstone with fragments of oysters and small shells of other pelecypods in the concretions	3–4
Massive light-gray selenitic sandstone containing so many compact bluish-gray crystalline limestone concretions 50 feet long as to make almost a continuous but irregular bed of concretions at the top of the member	32
Concealed; probably clay	26
Soft shaly sandstone, irregularly bedded and somewhat concretionary	3

Although the Cockfield-Fayette contact has not been located precisely at or near Roma, it is believed that at localities 41, 42, 43, and 44, at least, the exposed strata should be placed in the Fayette rather than in the Cockfield, for the sections at these localities are sandy and contain pelecypods which are unidentifiable but apparently similar to those that occur elsewhere in the Fayette. Petrified wood is common in the north-south ridges east of Roma, one log 30 feet long having been reported but not seen by the writer. Such materials are unknown west of Roma.

Section 3.2 miles due east of Roma (45, fig. 44)

	Feet
Reynosa formation: Gravel and conglomerate containing angular fragments of petrified wood among its cobbles	10
Fayette sandstone:	
Soft, irregularly bedded fine-grained gray sandstone	15
Gray and green clay, partly concealed	42
Bed of *Ostrea georgiana* with base 34 feet above river level at normal stage	½

Penrose [82] and Dumble [83] report an exposure of sea-green clay, leaf impressions, rusty pyrites, and white calcareous concretions 5 miles below Roma, on the Tamaulipas side of the river; similar beds overlain by concretionary sandstone with worn silicified wood and oyster-shell fragments 3 miles farther down stream; and silicified tree trunks in Fayette sands 9 miles above Rio Grande City.

The top of the Fayette is not recognizable between Roma and Rio Grande City, but an oyster bed crops out on the north side of the main Roma road 6 miles upstream from Rio Grande City (46, fig. 44), and 3¼ miles north of west of Rio Grande City (47, fig. 44) several feet of nodular lime-coated greenish sandstone is overlain by lime-cemented Reynosa conglomerate containing silicified wood and oyster fragments. These exposures doubtless represent the upper part of the Fayette formation.

Laboratory analyses.—The results of laboratory study of seven samples from the Fayette sandstone are here given:

Analysis of sample of Fayette clay from Reiser clay pit (6, fig. 44, sample 02211)

Physical appearance.—Hard, compact clay with no visible bedding.

Size.—The mechanical analysis (fig. 45) shows that the insoluble residues are 97.5 per cent clay and 1.4 per cent fine silt but contain traces of coarser material up to and including medium sand.

Mineral content.—Although chiefly clay the sample is calcareous, for 12.1 per cent dissolved in HCl. The light mineral is quartz. Heavy minerals include limonite in aggregates (bulk of heavy minerals), magnetite, and zircon.

Shape.—Quartz grains are subangular to fairly well rounded.

Analysis of limestone concretion from the Fayette formation at the Reiser clay pit (6, fig. 44, sample 02209)

This sample is a hard, dense dark-gray limestone with a few small calcite crystals and manganese dendrites. It is 87.2 per cent soluble in HCl, and of the insoluble residue 86.6 per cent is in the clay grade. The material coarser than clay consists of a mixture of what is probably manganese oxides or hydroxides and a few quartz grains, none of which are as much as 1/16 millimeter in diameter.

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[82] Penrose, R. A. F., jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Survey First Ann. Rept., pp. 56–57, 1890.

[83] Dumble, E. T., Report on the brown coal and lignite of Texas: Texas Geol. Survey, pp. 153, 156–157, 1892.

Analysis of sample from lowermost bed of Fayette sandstone 10½ miles northeast of Zapata (17, fig. 44; sample 02092)

Bedding.—No bedding evident. Breaks into irregular angular chunks. Has curved parting surfaces, which seem to represent the insides of shells now dissolved.

Mineral content.—Quartz both as grains and as cement makes up about 70 per cent; feldspar both fresh and altered; volcanic glass about 15 per cent; mica, green, black, and white; clay. Slightly calcareous.

Size and shape.—The siliceous cement is insoluble, and the sample could not be disintegrated for mechanical analysis. The volcanic glass is in angular grains and plates, the largest of which are ¼ to ⅛ millimeter in diameter. Much of the sample is below 1/16 millimeter. The sand grains are both angular and rounded. The largest grains are less than ¼ millimeter in diameter and the ⅛ to 1/16 millimeter grade is predominant.

Cement.—Firmly cemented by quartz, although the interstices are not completely filled. Maintains semisharp edges and is not friable.

Porosity.—Was originally very porous, as packing is not pronounced. All sizes are mingled together and lie at all angles.

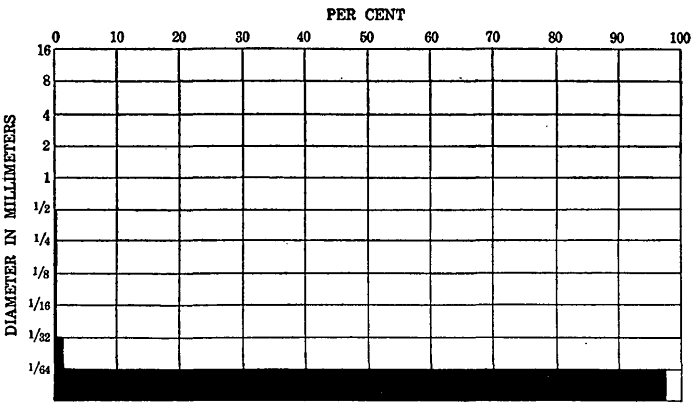

Figure 45.—Mechanical analysis of insoluble residue of sample 02211

Color.—Light gray. Some surfaces are slightly iron-stained.

Fossils.—Pelecypods of several sizes and one gastropod shell were filled with sand and later dissolved, leaving the consolidated sand fillings in the form described on page 148. The smaller coils of the gastropod were not completely filled, and a hollow was left from the center of which a spine of sandstone projects, representing the umbilicus of the gastropod.

Analysis of sample from section 1 mile southwest of Comitas (19, fig. 44) (sample 02090)

Bedding.—Laminated in curved lines suggesting ripples. Some bedding planes are flat; others are curved. Breaks tending irregularly to follow the laminae.

Mineral content.—Feldspar very abundant; quartz; volcanic glass, somewhat milky in appearance, perhaps slightly altered; clay. The proportion of these constituents vary greatly at different points on the specimen.

Size and shape.—All fragments and grains are markedly angular. The size varies greatly from point to point on the specimen, although there is a general range which is not exceeded. About 50 per cent of the material is below 1/16 millimeter in size. Sand grains have a maximum upper limit of ¼ millimeter. The ⅛ to 1/16 millimeter grade makes up about 14 per cent of the sample.

Cement.—Some infiltrated quartz. Cemented fairly well but is slightly friable owing to the thinness of the lamination and lack of cement between the partings.

Color.—Cream-colored.

Porosity.—Very porous along lamination planes. Packing varies from point to point on specimen but in general is better than in sample 02092.

Analysis of sample from Fayette sandstone in pit at Roma Barracks (43, fig. 44; sample 02142)

Bedding.—Bedding indicated by smooth, parallel bedding planes. Small "steps" 3 to 5 millimeters in height show thickness of some beds. Grains are oriented and packed; well sorted. Sand grains about 1/12 millimeter in diameter on the average; predominantly sand. Ash and clay present but not as abundantly as in sample 02092. Partly cemented by quartz. Light gray.

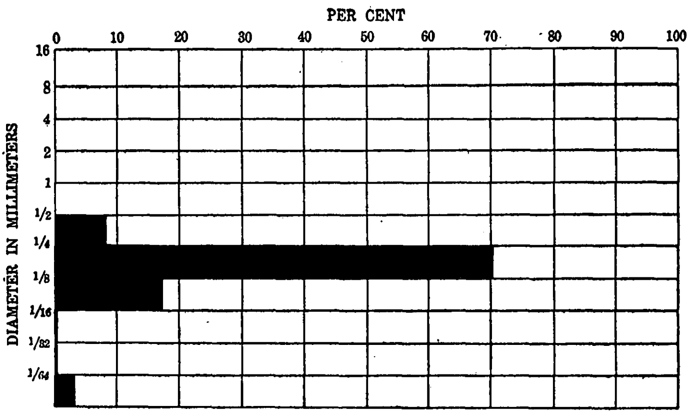

FIGURE 46.—Mechanical analysis of insoluble residue of sample 02212

Analysis of sample of Fayette sandstone from the top of the bluff at the international ferry at Roma (44, fig. 44; sample 02212)

Bedding.—Massive.

Cement.—Loosely cemented with $CaCO_3$. Friable. Soluble in HCl, 23.3 per cent.

Size.—As shown by the mechanical analysis (fig. 46) this is a fine-grained sandstone.

Shape.—Grains are mostly angular in all grades.

Mineral content.—Nearly all the grains are quartz, but there are some grains of ferromagnesian minerals and some grains of heavy minerals, including magnetite (more abundant than all the other heavy minerals combined), staurolite, garnet, rutile, zircon, and tourmaline. There is no volcanic glass in this sample.

Color.—Brownish gray.

Analysis of sample of Fayette sandstone from an outcrop on the Rio Grande-Laredo road in Roma (sample 02210)

Bedding.—Massive.

Cement.—Calcareous; 22.1 per cent soluble in HCl. Friable.

Size.—Mechanical analysis (fig. 47) shows this to be a fine-grained sandstone but it contains much more clay than sample 02212.

Shape.—Grains angular or subangular in the coarser grades; predominantly angular in the finer grades.

Mineral content.—Chiefly quartz; some grains of dark-colored flinty material; a very few grains of feldspar; in some grades some ferromagnesian minerals. Heavy minerals include in order of abundance magnetite, staurolite, rutile, tourmaline, garnet, leucoxene, zircon, and glauconite.

Color.—Gray to light buff with a greenish tinge.

Conditions of origin.—Although the Fayette sandstone is at least partly of true marine origin and partly of brackish-water origin, much of it, as the leaf impressions and silicified wood suggest, was deposited subaerially on sandy and clayey coastal plains. The character of much of the formation indicates deposition in shallow water that was

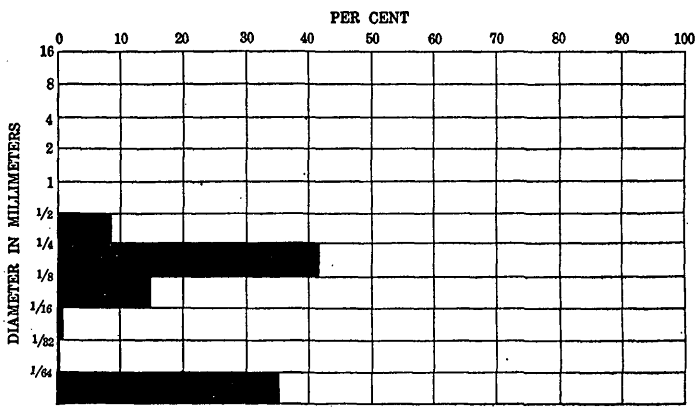

FIGURE 47.—Mechanical analysis of insoluble residue of sample 02210

subject to considerable agitation. The ash beds and ash particles mixed with some of the sand and clay were supplied by volcanoes, probably outside this region, some of the volcanic dust falling in standing water and being almost immediately deposited, some falling in forests and burying leaves and tree trunks, and some falling on other land surfaces from which it was removed by wind and streams for final deposition in adjacent water bodies.

According to Berry, the fossil leaves found on the Miraflores ranch at localities 13 and 14 (fig. 44) and listed specifically on page 144 indicate a warm, probably subtropical climate, with local or seasonal aridity, probably without general deficiency in rainfall.

OLIGOCENE (?) SERIES

FRIO CLAY

Name and correlation.—Overlying the Fayette sandstone in southern Texas is a formation consisting dominantly of nonvolcanic clay and ranging in thickness from 175 to 800 feet, to which the name Frio clay is applied. This usage of Frio is a radical restriction of the application of the name as originally proposed by Dumble,[84] whose Frio included the overlying volcanic beds to which the name Catahoula tuff (="Gueydan formation" of Bailey) is now applied, and may have included part of the underlying Fayette formation. Dumble regarded the Frio as being the highest formation referable to the Eocene in the valleys of the Nueces and Frio rivers.

In 1903 Dumble[85] defined the Frio as overlying the Fayette sands and underlying the Oakville beds. He correlated the Frio with the upper part of the Claiborne group. In this connection it is appropriate to state that all of Dumble's featured outcrops, on which he based his description of the Frio clay, fall within the volcanic beds which are now called Catahoula tuff. His general definition of the stratigraphic limits of the Frio—namely, that it lies between the Fayette below and the Oakville above—would seem of necessity to include the nonvolcanic clay within the Frio.

In his preliminary report on the lower Rio Grande region the writer[86] followed the original definition of Dumble but erroneously included within the Frio the beds of volcanic ash exposed north and east of Rio Grande City, which are now assigned to the Oakville formation.

Dumble[87] in 1924 proposed a new name, "Whitsett beds," for a formation above the Fayette sandstone and below the Frio clay, but this division was so vaguely defined that it has not been possible to determine just what beds were included in it. However, the "Whitsett" probably included parts of both the Fayette and Frio as at present understood.

Deussen's usage of Frio[88] in 1926 is essentially the same as that of Dumble in 1903—that is, it included all the beds between the Fayette sandstone below and the Oakville sandstone above.

In 1926 Bailey[89] divided the Frio, as defined by Dumble in 1903, into two parts—a lower nonvolcanic clay and an upper formation composed mainly of volcanic material. To the former he applied the name Frio formation, thereby redefining and restricting the application of that name, and to the latter he applied the name "Gueydan formation," which he had introduced in 1924.[90]

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[84] Dumble, E. T., The Cenozoic deposits of Texas: Jour. Geol., vol. 2, pp. 554-555, 1894.

[85] Dumble, E. T., Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, pp. 953-956, 1903.

[86] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, pp. 97, 98, pl. 28, 1923.

[87] Dumble, E. T., A revision of the Texas Tertiary section with special reference to the oil-well geology of the Coast region: Am. Assoc. Petroleum Geologists Bull., vol. 8, p. 433, 1924.

[88] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 92, 1926.

[89] Bailey, T. L., The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, pp. 42-52, 1926.

[90] Bailey, T. L., Extensive volcanic activity in the middle Tertiary of the south Texas Coastal Plain: Science, new ser., vol. 59, pp. 299, 300, 1924.

In April, 1931, Gardner and Trowbridge[91] proposed the name "Yeager" clay to replace the name Frio as used by Bailey, because, in their opinion, the use of Frio for the nonvolcanic clay was a greater modification of its original usage than is desirable. Although the United States Geological Survey at the time acquiesced in the proposal and approved the adoption of the name "Yeager," the Survey has subsequently yielded to the insistent demand of many Texas geologists that "Yeager" be discarded in favor of Frio, because Frio in this restricted sense has come into general use by geologists actively at work in the region.

Bailey's was the first really detailed field and laboratory work ever done on the coastal plain of southwestern Texas. The "Gueydan formation" of Bailey consisted of thick and widely distributed beds of pyroclastic rocks, divided into the Fant tuff (mud flow) member at the base, the Soledad volcanic conglomerate, sandstone, and tuff member in the middle, and the Chusa argillaceous tuff and tuffaceous clay member at the top.

Bailey[92] extended the Fant and Soledad members of the "Gueydan formation" as far south as the north line of Zapata County, thus placing in the "Gueydan" strata that had previously been mapped in the region of this report as the upper part of the Frio clay. Within the boundaries of the lower Rio Grande region, however, he described no detailed surface sections, reported no analyses, and described no subsurface samples that he separated with certainty from the Frio below or the Oakville above and thus determined positively as being "Gueydan." Except at and near the Rio Grande, where Bailey found no "Gueydan," the surface is almost flat and exposures are few and shallow, so that the problem is especially difficult, but neither the additional field work of 1927 nor the laboratory analyses of surface or subsurface samples from these beds disclosed any considerable thickness of pyroclastic rocks between those of the Fayette described on pages 145–148, which are of Jackson age, and those of the Oakville described on pages 171–181, which are of Miocene age. The clay that Bailey classed as tuff, bentonitic tuff, bentonitic clay, or tuffaceous clay and mapped as "Gueydan" near the Rio Grande is indistinguishable in the field from the underlying clay which he mapped as Frio and the samples of which on analysis yield little or no volcanic material in the coarser grades and no evidence that the clay matrix is largely volcanic.

It is believed, therefore, that the "Gueydan tuffs" of Bailey do not crop out in the lower Rio Grande region, either because they have thinned out with distance from their volcanic source or because

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[91] Gardner, Julia, and Trowbridge, A. C., Yeager clay, south Texas: Am. Assoc. Petroleum Geologists Bull., vol. 15, No. 4, p. 470, April, 1931.

[92] Bailey, T. L., op. cit., pl. 1.

they are overlapped by the younger Oakville and Reynosa formations, or for both reasons.

In the lower Rio Grande region the Frio clay, as defined in the present report, overlies the Fayette sandstone with apparent conformity and is overlain unconformably by the Oakville sandstone, although in many places the Oakville is overlapped by the Reynosa so that the Frio is directly and unconformably overlain by the Reynosa.

The Frio (as now restricted) is not known outside of southwestern Texas and can not be certainly correlated with formations elsewhere.

The Fayette sandstone becomes increasingly argillaceous toward the top, and the absence of any evidence of unconformity between the Fayette and the Frio may be due not to continuous deposition but to the slight resistance offered to erosion both by the Frio and by the upper Fayette. Silicification is locally characteristic of the upper beds of both formations. In the Frio it has produced chalcedony concretions; in the Fayette in Karnes County siliceous and very brittle shales. It is possible that these may be due to the leaching of the silica from the ash beds in the Oakville, Catahoula, and Fayette formations and its redeposition in the Frio and Fayette in the forms just indicated. The line of contact between the Fayette and Frio, though not sharp and generally arbitrary, is indicated by differences in topography, vegetation, and coloring of the soil too vague and inconstant to be incorporated in a formational description but sufficiently definite to be detected in the field.

No fossils have been found in either the Frio clay or the overlying Catahoula tuff. The field relations suggest that the latter is of the same age as the Catahoula formation of central Texas, Louisiana, and Mississippi. This correlation is further suggested by the results of the work of Baker and Lonsdale,[93] who have found that all the larger deposits of fuller's earth in Texas are in either the Catahoula tuff or the typical Catahoula. There is some reason to believe that the Catahoula is of lower Miocene age.[94] However, until this relationship has been established the age of both the Frio and the Catahoula must remain uncertain. If the lower Miocene age of the Catahoula is granted, the time interval between the Fayette and Catahoula is wide and the Oligocene may be represented in the intervening Frio clay. But in view of the lack of present positive evidence it is not known whether the Frio is of Eocene, Oligocene, or lower Miocene age.

Areal extent.—The Frio clay crops out in a belt of unequal width along the west side of the Bordas scarp in southeastern Webb County,

[93] Baker, C. L., and Lonsdale, J. T., oral communication.

[94] Stephenson, L. W., Major features in the geology of the Atlantic and Gulf Coastal Plain: Washington Acad. Sci. Jour., vol. 16, No. 17, p. 469, 1926; personal communication, January 14, 1928. Gardner, Julia personal communication, January 16, 1928.

eastern Zapata County, western Jim Hogg County, and west-central Starr County. (See pl. 7 and fig. 48.) From Webb County the formation has been traced in a north-northeast direction through McMullen, Live Oak, and Atascosa Counties, almost to the Karnes County line, where it abruptly disappears.

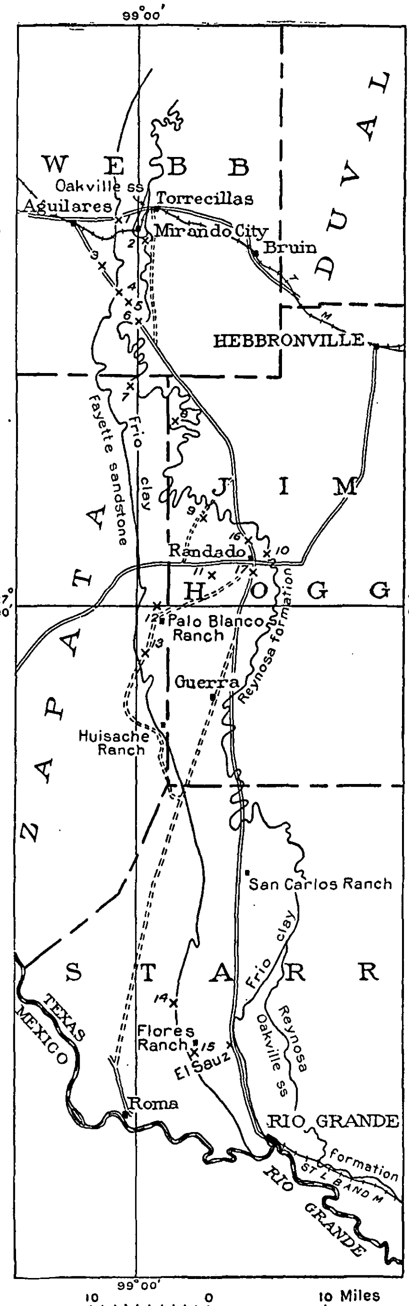

FIGURE 48.—Sketch map showing the areal extent of the Frio clay and Oakville sandstone and the location of the exposures described

Lithology.—The formation consists of massive or obscurely bedded clays in pastel shades of green, gray, yellow, or pink, the latter predominating. The clays are remarkably pure, especially in the upper part of the section; the lower beds usually carry a small percentage of very fine clear angular quartz intimately mingled with the clay. Gypsum is more commonly present in the upper beds than in the lower; calcareous nodules are prevalent, but the cone-in-cone concretions that abound in the upper Fayette have not been observed. Nearly everywhere the clay is checked by joints in which secondary calcium carbonate occurs in thin plates. The clays offer slight resistance to erosion and crop out in few places except where they are protected by harder formations. Fossil wood is associated with them, but no other organic remains, either macroscopic or microscopic, have been recovered from surface exposures or from well cores.

Thickness.—The Frio strata exposed in the lower Rio Grande region range in thickness from about 175 to about 800 feet, the variation being due to an irregular gradation into the

Fayette below and to an irregular overlapping of the Oakville and Reynosa above. Thicknesses of 250 to 500 feet (average about 300 feet) are assigned to the Frio clay in the oil and gas fields of Webb and Zapata Counties.

Webb County sections.—The surface on the Frio clay in Webb County is so nearly flat that there are no deep bedrock exposures. About 4 miles east of Aguilares (1, fig. 48) bluish-gray clay is exposed and continues eastward for 2½ miles, almost to the foot of the Bordas scarp, but it is obscured locally by patches of reworked Reynosa limestone. Yellow clay 9 feet thick covered by 6 feet of conglomerate was exposed in 1920 at the foot of the Bordas scarp, in the spudded pit of the Hughes Petroleum Co. (2, fig. 48), southeast of Mirando City. The scarp itself is so covered with caliche that the bedrock does not show.

The road leading southeast from Aguilares to the south end of the Aviators field crosses the belt of outcrop of the Frio obliquely. At a point 4½ miles southeast of Aguilares (3, fig. 48) clay beds that appear to alternate with sand beds change from gray to pink, but evidence of sand beds continues southeastward to a point 7 miles from Aguilares (4, fig. 48), where stiff pink clay without sandstone begins, and this point is chosen as the base of the Frio. About 8 miles southeast of Aguilares and an eighth of a mile northeast of the road (5, fig. 48), where material has been taken out to harden the road in wet weather, some sediment that appears on analysis to be silicified clay and silt is exposed. About 10½ miles southeast of Aguilares (6, fig. 48) clay extends from the plain on the west up the slope of the Bordas scarp within 25 feet of the top, where it passes beneath the Reynosa. An analysis of the clay is given on page 163. There is no Oakville between the Frio and the Reynosa at this place.

In the Mirando Valley oil field (7, fig. 48) a bed of clay exposed at the base of the salient of the Bordas scarp and apparently continuing westward under the Aguilares Plain is assigned to the Frio. (See p. 164 for analysis.) It is overlain here by Oakville sandstone, above which at the top of the escarpment is Reynosa limestone and conglomerate.

At the north end of the southward extension of the original Henne, Winch & Fariss oil and gas field (8, fig. 48) compact, stiff gray Frio clay crops out at the foot of the Bordas scarp, which consists here of Oakville sandstone overlain by Reynosa limestone and conglomerate. A mile west of this point a small outlier of Reynosa overlies Frio clay directly, the Oakville here having been overlapped by the Reynosa. An analysis of the Frio clay of this section is given on page 164.

Sections in Zapata and Jim Hogg Counties.—About 5½ miles northwest of Randado and 1 mile north of the Felipe Cuellar ranch

(9, fig. 48), in a low place between the Bordas scarp and an outlier of the Reynosa, gray Frio clay is exposed in shallow drains.

There is clearly a clay subsoil at the foot of the Bordas scarp half a mile east of Randado (10, fig. 48), although no clay is exposed. Four miles west of Randado on the road to the Escobas ranch (11, fig. 48) 2 feet of gray and blue jointed clay underlies 2 feet of lime-cemented gravel, and clay shows through sand, gravel, and caliche at several points between this locality and Randado and also between this locality and the Escobas ranch.

South along the west side of the Bordas scarp from Randado for 13 or 14 miles toward Guerra the underlying strata are covered by sand washed down from the Reynosa of the Bordas.

Three feet of Frio clay is exposed about a mile north of the Palo Blanco ranch (12, fig. 48) in a drain tributary to San Juan Creek. The material is compact, almost pure bluish-gray clay, weathering slightly yellowish. The bed contains no sand layers or lenses, concretions, or fossils. Opening of joints in the clay when dry has let down calcium carbonate and even small pebbles from the overlying limestone conglomerate of the Reynosa formation, so that the white calcareous seams give the darker clay a mottled or checked appearance. Such clay forms the subsoil between locality 12 (fig. 48) and a point 3 miles southwest of the Palo Blanco ranch (13, fig. 48), where a roadside gully exposes gray, bluish-gray, and yellowish-gray clay in which there are small irregular soft white crumbly masses of calcium carbonate, which appear to be weathered limestone concretions. In the ditch and probably derived from the covering gravel of the Reynosa there are small and fairly large pieces of silicified wood. The replacing material is chalcedony rather than opal, but the pieces are coated and impregnated with calcium carbonate, and one of the large pieces inclosed crystals of calcite. The silicified wood was probably derived originally from the Frio or Fayette by the same erosion agent that shaped and deposited the pebbles of the Reynosa.

Starr County sections.—Red, gray, and green clay is exposed at the surface at a number of places along the Hebbronville-Roma road in the northwest corner of Starr County and between the San Carlos ranch and El Sauz on the road between Hebbronville and Rio Grande City. The oyster-bearing green clay of the Fayette changes eastward to gray and white clay without fossils about halfway between the Sanchez and Saucito ranches about 6 miles northwest of El Sauz (14, fig. 48). The Frio clay is blue half a mile southwest of Las Flores ranch (15, fig. 48), and gray, brown, and red clay is exposed at and south of El Sauz. At the south bridge there is a reddish-brown clay with much selenite and calcium carbonate, and at the north bridge there is 2 feet of resistant material made up of sand and clay and impregnated with calcium carbonate, which is underlain downstream by brownish clay incrusted with salt.

Variously colored clay crops out in the low places and is capped on the hills by Reynosa gravel west of the Hebbronville road and 3 to 6 miles northwest of Rio Grande City. These exposures are in the Frio not far from its line of contact with the Oakville. The sample mentioned by Bailey[94a] as having been obtained from the Frio 4 miles west of Rio Grande City and containing *Ostrea georgiana* would be placed in the Fayette of this report.

Laboratory analyses.—Samples of material from the Frio clay were subjected to laboratory study with results as follows:

Analysis of sample from Frio clay in lower slope of Bordas scarp 10½ miles southeast of Aguilares (6, fig. 48; sample 02213)

Bedding.—Massive.

Size.—Mechanical analysis of the insoluble residue (fig. 49) shows them to be

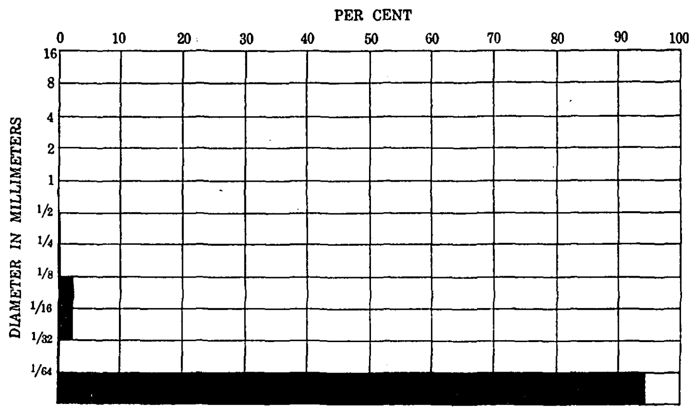

FIGURE 49.—Mechanical analysis of insoluble residue of sample 02213

94.2 per cent clay with small admixtures of silt and very fine sand and traces of fine and medium sand.

Shape.—Grains of quartz angular and subangular in coarser grades.

Mineral content.—Sample is 22.4 per cent soluble in HCl, indicating presence of secondary calcite in this proportion. Light residues consist of quartz grains with a few grains of ferromagnesian minerals. There is no glass or other volcanic material. Heavy minerals include magnetite, zircon, and staurolite. The mineral content of the clay grades was not certainly determined, but it appears to be kaolinitic and not glassy.

Porosity.—Compact; breaks into hard irregular chunks.

Color.—Light gray to pinkish.

This sample appears to be an ordinary calcareous, slightly silty and sandy sedimentary clay of the kind that characterizes the Frio clay of this report rather than a volcanic, tuffaceous clay such as those described by Bailey from the Fant tuff member of his Gueydan formation (=Catahoula tuff of this report) farther north.

[94a] Bailey, T. L., The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, p. 47, 1926.

Analysis of sample of Frio clay from the Mirando Valley oil field (7, fig. 48; sample 02215)

Bedding and porosity.—Massive; compact.

Color.—Greenish gray.

Cement.—Calcareous; 17.5 per cent soluble in HCl; probably secondary.

Size.—As shown by mechanical analysis (fig. 50) the sample is clay with traces

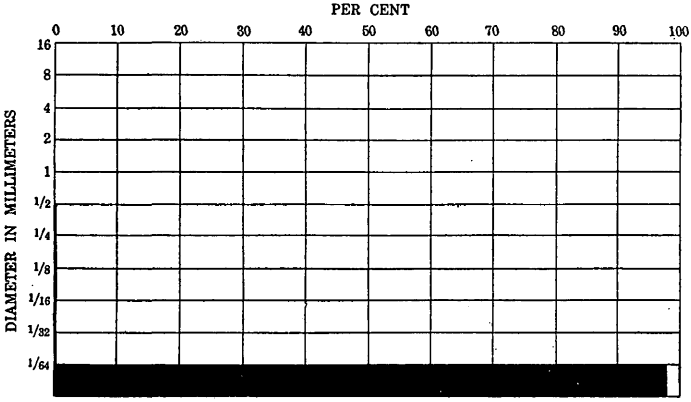

Figure 50.—Mechanical analysis of insoluble residue of sample 02215

of silt and with sand up to medium-sized grains.

Shape.—Mostly angular.

Mineral content.—Coarser grades consist almost entirely of quartz grains. Heavy minerals include limonitic aggregates, zircon, and magnetite. Like No. 02213, this sample showed no glass in the coarser grades and no indication of the presence of glass in the clay matrix.

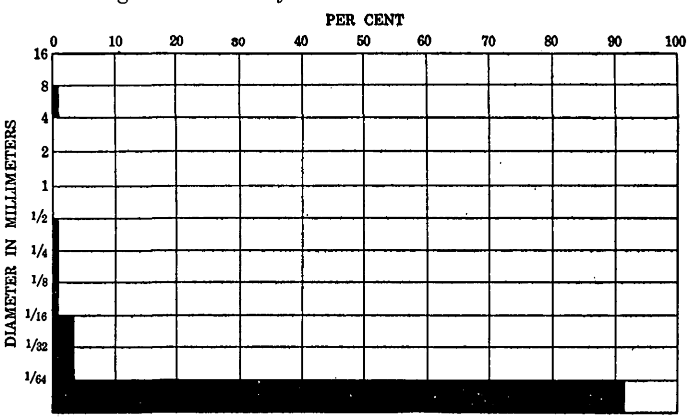

FIGURE 51.—Mechanical analysis of insoluble residue of sample 02220

Analysis of sample of Frio clay from a point 1 mile west of the Henne, Winch & Fariss oil and gas field (8, fig. 48; sample 02220)

Lithology.—Compact clay.

Color.—Light gray.

Size.—Figure 51 shows the mechanical analysis of the insoluble residue. It is largely clay but contains considerable admixtures of silt and traces of fine and medium sand. The trace in the 8 to 4 millimeter grade is a single pebble of chert that may have come down from the overlying Reynosa limestone conglomerate.

Mineral content.—The sample is 6.8 per cent soluble in HCl, indicating the presence of $CaCO_3$ in this proportion, either as cement or as secondary crystals of calcite. The sand and silt consist chiefly of quartz grains, but there are also a few grains (less than 2 per cent) of volcanic glass and a small proportion of heavy minerals, including magnetite, zircon, rutile, garnet, and limonitic aggregates. The clay may possibly be tuffaceous, but there is nothing to indicate this, and the fact that volcanic materials are so small a constituent of the coarser grades suggests that it is in the main an ordinary sedimentary clay.

Shape.—The quartz grains are fairly well rounded, but the glass particles have sharp, jagged edges, fluted structure, and conchoidal fracture.

Origin.—Although the Frio clay was not observed to contain marine fossils in the lower Rio Grande region, it was doubtless deposited in lagoons along a late Eocene, Oligocene, or early Miocene shore line. The uniformity of the clay and its general lack of lamination indicate uniformity of conditions or rapidity of deposition. During normal bay or lagoon deposition small quantities of volcanic ash, probably derived from eruptions outside this particular region, settled out of the air and mingled with the other deposits.

MIOCENE SERIES

OAKVILLE SANDSTONE

Name and classification.—The Oakville sandstone was named in 1894 by Dumble,[95] who applied the name to gritstone, sandstone, and interbedded and included clay lying unconformably over the Frio clay and under strata of Pliocene age on the Nueces River in Live Oak County. Dumble recognized the Miocene age of these deposits from the contained vertebrate remains.

In his preliminary work the writer[96] failed to find certain evidence of the cropping out of Oakville sandstone in the lower Rio Grande region, thought that it had been overlapped by the Reynosa formation, and called attention to thick Miocene strata recognized in drill holes on the east, but in 1924 North[97] reported several patches of Oakville along the Bordas scarp and along the wall of the Rio Grande Valley east of Rio Grande City, and in 1927 these exposures and others were visited by the writer.

The type section is in the region mapped in 1924 by Deussen,[98] who described and correlated the formation fully, without changing in any important particulars the original classification of Dumble.

In 1926 Bailey[99] included within the "Gueydan" some of the beds that Deussen had placed in the lower part of the Oakville, thus drawing an Oligocene-Miocene line of contact within the Oakville of Deussen. He also called attention to the fact that the Oakville crops out in places in the lower Rio Grande region and tentatively

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[95] Dumble, E. T., The Cenozoic deposits of Texas: Jour. Geology, vol. 2, pp. 556–559, 1894.

[96] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 98 and pl. 28, 1923.

[97] North, Lloyd, personal communication.

[98] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 97–99, 1924.

[99] Bailey, T. L., The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, 1926.

assigned certain conglomerates near Mirando to the Soledad member of the "Gueydan formation." In addition he stated that the thick beds of volcanic ash east of Rio Grande City, assigned by the writer in his preliminary report[1] to the Frio, are in reality in the Oakville, a fact verified by the writer in 1927.

The writer is, however, unable to separate Bailey's "Gueydan" from the Oakville near Mirando and in this report uses the term Oakville precisely as it is used by Dumble and Deussen.

Distribution.—Doubtless owing entirely to an overlap of the Reynosa, the Oakville crops out in the lower Rio Grande region at only a few points, and nowhere is anything like the full thickness of the formation exposed. The only exposed strata that are certainly to be placed in the Oakville are along the west face of the Bordas scarp at and near Mirando, in the Mirando Valley oil field, in the Henne, Winch & Fariss oil field, at points a few miles northwest of Randado, and for a distance of several miles north of Rio Grande City and continuously along the north valley wall of the Rio Grande for about 17 miles southeast of Rio Grande City. Some of these outcrops are so small that they are not shown on Plate 7, but they are located in Figures 48, 52, and 53.

Lithology.—The Oakville exposed in this region consists of conglomerate, gritstone, sandstone, clay, and volcanic ash. The finer sediments inclose fragments and rounded pellets of Frio clay in some places.

Included also within the formation are beds, irregular masses, and cylindrical bodies resembling tree trunks, composed of quartzite, chalcedony, and other siliceous materials.

Fossils.—No fossils were found in the Oakville of the lower Rio Grande region, although remains of Miocene vertebrates have been reported from it elsewhere.

Sections at and near Mirando.—A number of exposures at and within a mile of Mirando are assigned to the Oakville. About three-quarters of a mile northeast of the town, in the low ridge near the foot of the Bordas scarp, there are some shallow pits in which are exposed silicified gravel, silicified sandstone (see p. 173 for petrographic description), some clay, and white calcareous fine-grained sandstone. (See p. 179 for analysis.) On the Magnolia tank farm, half a mile northeast of the town, there is a series of low hills a quarter of a mile west of the main Bordas scarp and in the extension of the ridge mentioned above, made up of conglomeratic quartzite. There is a low hill of quartzite and conglomerate just north of the railroad and just west of the main road at Mirando. The matrix is light-gray fine-grained quartzite, and the pebbles are quartz and chert, some as large as an inch in diameter and most of them well rounded. This is clearly an ordinary conglomerate and not an agglomerate or a tuff.

[1] Trowbridge, A. C., op. cit., pp. 97, 98, pl. 28.

Another hill of the same kind of material occurs just south of the Mirando City Hotel. (See p. 180.) These are the conglomerates that Bailey[2] tentatively assigns to the Soledad member of the "Gueydan formation."

It is reported that a patch of chalcedony was removed from the main street of Mirando. Three-quarters of a mile south of the town

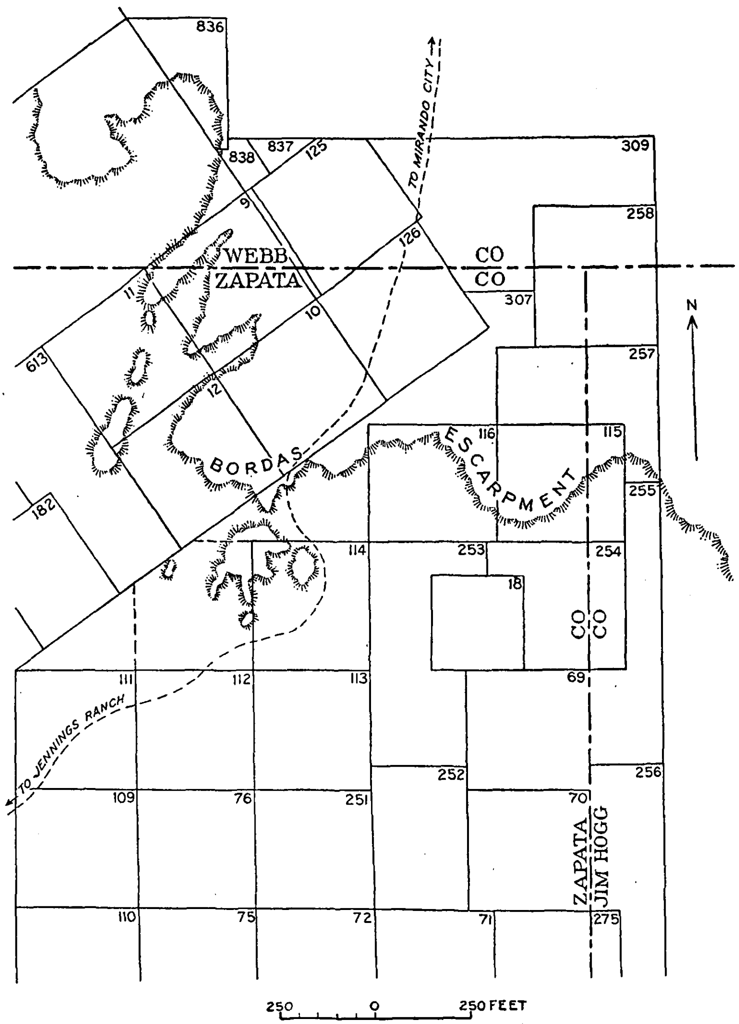


FIGURE 52.—Map of the Mirando Valley oil field, showing the Bordas scarp, in which the Oakville sandstone is exposed

and just north of the Kanokah lease there is a large irregular mass of quartzite. (See p. 180.)

Sections in the Mirando Valley oil field.—Strata belonging to the Oakville sandstone are exposed in the Mirando Valley oil field, in northeastern Zapata County. (See fig. 52.) The outcrops are on

[2] Bailey, T. L., The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, fig. 1, 1926.

vertical faces of the Bordas scarp and therefore are not areally mappable. The formation as exposed consists of beds of sand and clay, which range from 6 to 25 feet in thickness. A typical section in this field including Oakville strata is as follows:

Section on Bordas scarp in Mirando Valley oil field

	Feet
Reynosa formation:	
Limestone and conglomerate	12–15
Gray compact clayey limestone to clay	20
Oakville sandstone: Light gray, somewhat layered compact, hard limy sandstone (sample 02219, p. 174) with some layers of silty clay and sandy shale (sample 02225, p. 174)	24
Frio clay: Stiff compact gray or pink clay (sample 02215, p. 164)	8–12

Section in the Henne, Winch & Fariss oil field.—The following section is exposed between the original Henne, Winch & Fariss field and the south extension of this field:

Section on Bordas scarp in Henne, Winch & Fariss oil field

	Feet
Reynosa formation: Limestone conglomerate	15
Oakville sandstone:	
Sand containing siliceous "pipes" in upright position (pl. 16, *B*)	6
White, very fine-grained sandstone, partly silicified (samples 02224, p. 175, and 02242, p. 176)	7
Medium-grained sandstone (sample 02222) (pl. 16, *C*)	10
Frio clay: Compact calcareous clay	2

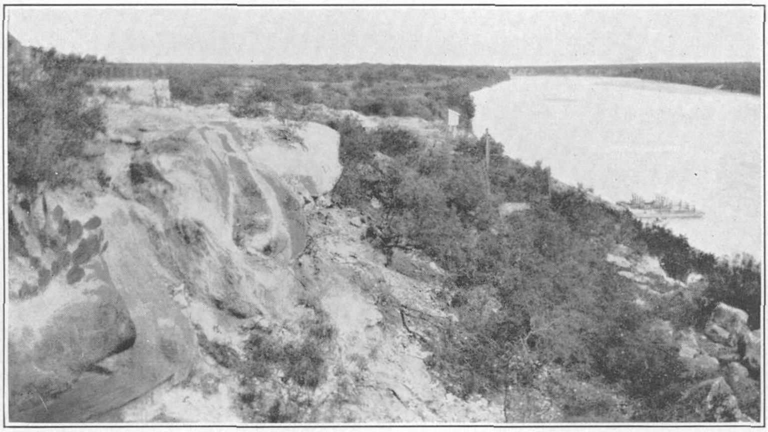
Sections near Randado.—At a point 8,000 feet N. 48° W. from Randado (16, fig. 48) there is about 20 feet of Oakville sandstone, mostly quartzitic (sample 02243, p. 181), overlain by Reynosa limestone; and 6,000 feet S. 20° W. from Randado (17, fig. 48) there are blocks of Oakville sandstone under a thin bed of Reynosa.

Sections near Rio Grande City.—Figure 53 shows the localities near Rio Grande City at which the Oakville sandstone is exposed.

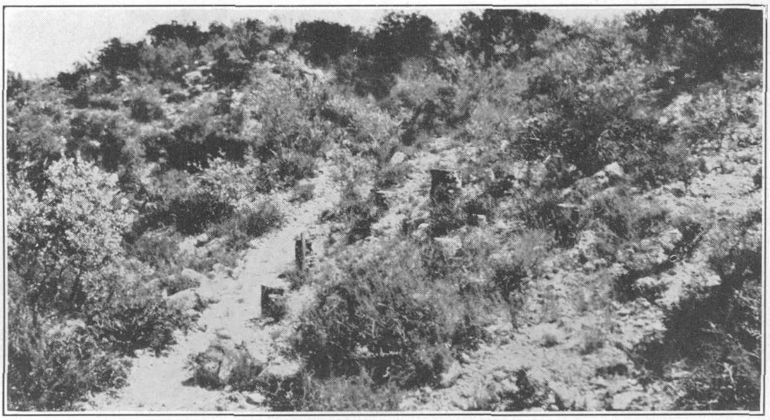
According to Bell[3] there are four low mounds of chalcedony about 10 miles north of Rio Grande City on porción 80 on the Del Monte ranch (1, fig. 53). Although not visited by the writer, these are known to occur in the area of outcrop of the Oakville and as described are similar to the siliceous masses of the Oakville at Mirando.

Oakville sandstone that was used in bridge abutments and the road grade on Los Olmos Creek at El Sauz is reported to have come from the bed of the creek 3 or 4 miles downstream from the bridge. The sandstone is hard and gray.

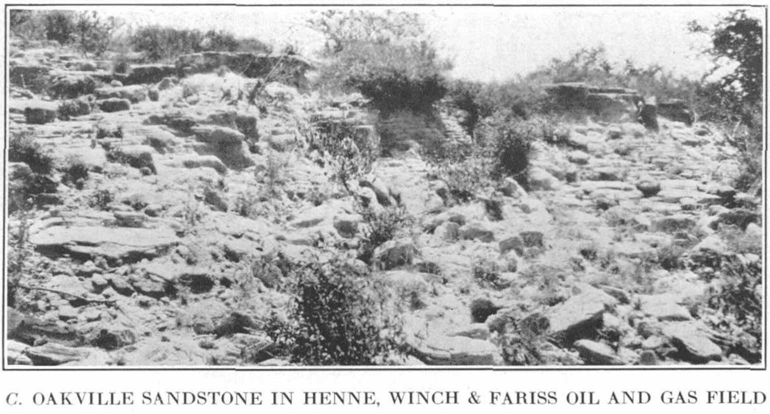
[3] Bell, O. G., oral communication.



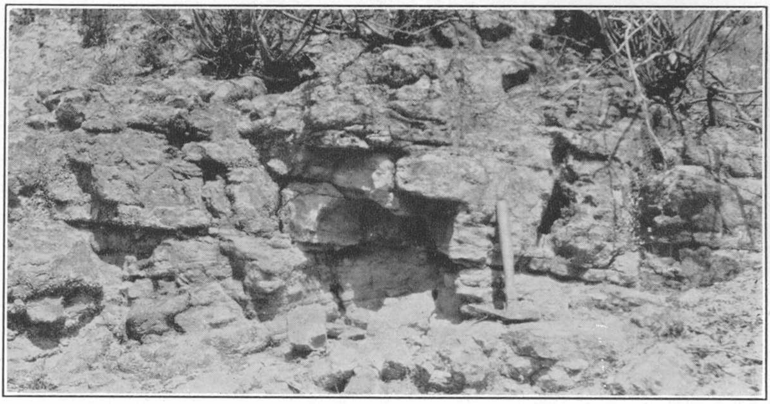
A. FAYETTE SANDSTONE AT ROMA FERRY



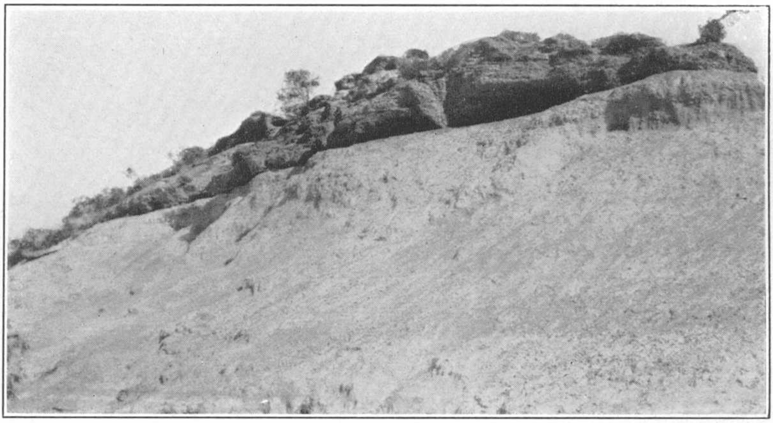
B. SILICEOUS PIPES IN OAKVILLE FORMATION IN HENNE, WINCH & FARISS OIL AND GAS FIELD



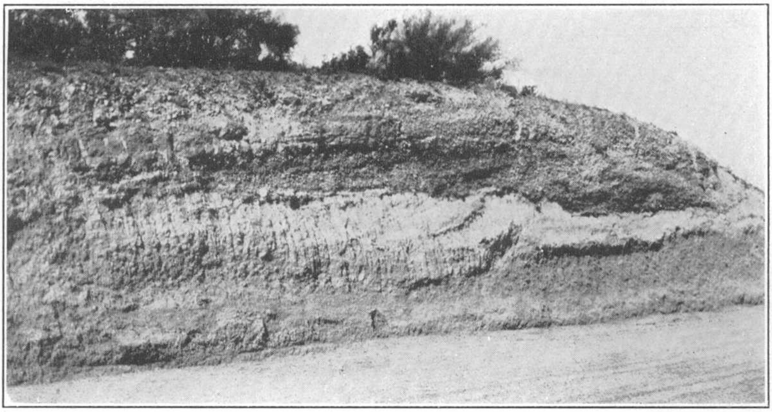
C. OAKVILLE SANDSTONE IN HENNE, WINCH & FARISS OIL AND GAS FIELD



A. OAKVILLE SANDSTONE 5½ MILES NORTH OF RIO GRANDE CITY



B. VOLCANIC ASH IN THE OAKVILLE FORMATION OVERLAIN BY LISSIE (?) GRAVEL AT LA LOMA DE LA CRUZ, 3 MILES EAST OF RIO GRANDE CITY



C. LAGARTO CLAY OVERLAIN BY REYNOSA GRAVEL 11.7 MILES WEST OF SAMFORDYCE

Section 1 mile south of Puenlicmos ranch (2, fig. 53)

	Feet
Soil	0–1
Brownish, yellowish and greenish-gray, and black clay	6
Light greenish-gray sandstone of differing hardness, thin-bedded and cross-bedded, with clay and calcium carbonate on the partings	12

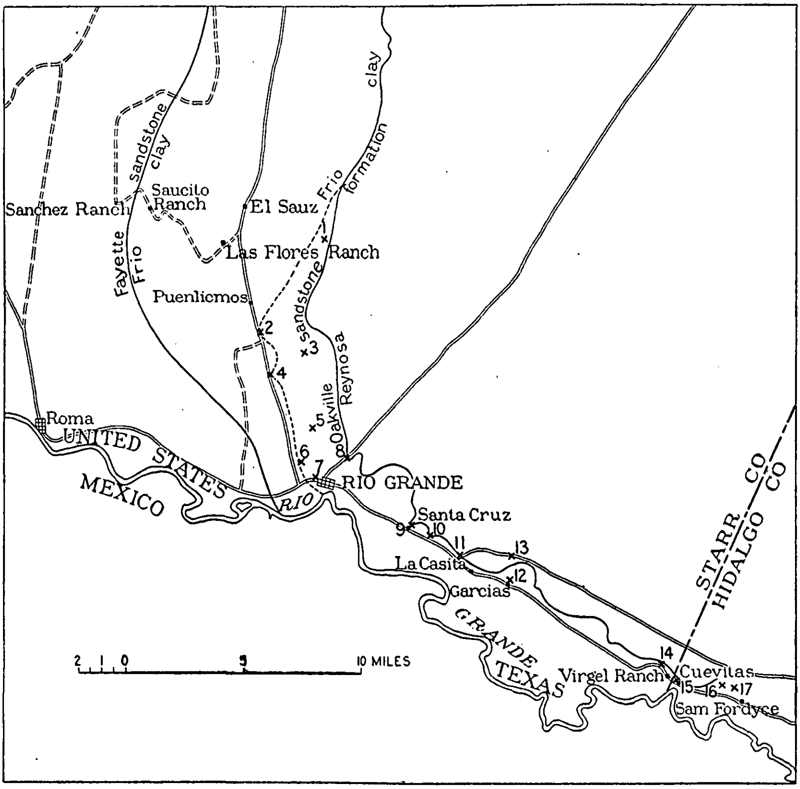


FIGURE 53.—Sketch map showing the location of exposures of Oakville sandstone and Lagarto clay near Rio Grande City and Samfordyce

This section is probably Oakville rather than Frio, no such sandstone as that of the section being known in the Frio elsewhere. On the other hand, clay is a fairly common constituent of the Oakville.

About 5½ to 6 miles north of Rio Grande City (3, fig. 53) there are several exposures of greenish-gray porous friable medium-grained calcareous sandstone now assigned to the Oakville. (See p. 176 for analysis and pl. 17, *A*, for photograph.)

Gray fine and coarse grained gritty clayey sand and soft sandstone containing small clay-ball inclusions in some parts and fine iron pellets in others unconformably overlie red lime-checked gypsiferous clay at a point 5.6 miles north of Rio Grande City on the Hebbronville road (4, fig. 53). The mixed materials above are Oakville, and the clay below is Frio. The Oakville exposed is not more than 10 feet thick.

In a small area 2½ to 3 miles north of Rio Grande City (5, fig. 53) about 20 feet of clay with sandstone fragments belonging in the Oakville crops out.

Section at gravel pits 1 mile northwest of Rio Grande City (6, fig. 53)

	Feet
Reynosa formation:	
Gravel on surface.	
Limestone containing gravel	5–6
Oakville sandstone: White material, probably volcanic ash and clay	7

In some places in this vicinity materials represented by the Oakville sandstone of this section are 35 feet thick.

Section one-eighth of a mile northwest of the courthouse in Rio Grande City (7, fig. 53)

	Feet
Reynosa formation:	
Loose gravel	1
Limestone containing pebbles	1
Oakville sandstone:	
Gray clay weathering pink	10
Concealed	4
Pinkish-gray dense silt with rounded conchoidal fracture and without distinct bedding, which crumbles to fine white powder (volcanic ash)	3

Dumble[4] described the section at Rio Grande City as follows:

The town of Rio Grande City (Ringgold Barracks) is situated on a bluff of hard white clay, rising some 50 feet above the river, of chalky consistency but only slightly calcareous; probably represents the light-green clays of the Fayette beds and has become indurated by exposure to heat in a dry climate. Effect of same agencies would account for its white appearance, as the characteristic pale-green color of the clays is doubtless due to their dehydration. Highly conchoidal fracture; contains iron pyrites and is much jointed. Joint cracks are frequently filled by veins of smoky quartz one-eighth inch to 1 inch thick, often showing a globular surface. The bluff extends along the river for half a mile below the town and 200 yards above it. Beyond these limits it disappears under the gray river silt.

Except for the facts that the white material is largely volcanic ash instead of the result of dehydration of the green clay and that since 1892 the Fayette beds have been divided and the Oakville has been recognized the above is an accurate description and interpretation of this section.

A mile and a half northeast of Rio Grande City on the road to Hebbronville (8, fig. 53) white fluffy noncalcareous volcanic ash that

[4] Dumble, E. T., Report on the brown coal and lignite of Texas, p. 157, Texas Geol. Survey, 1892.

blows about when disturbed comes in under the Reynosa. (See p. 177.) Owing to the infiltration of calcium carbonate from the overlying calcareous Reynosa formation the white material appears to grade upward into the Reynosa.

Section on south face of La Loma de la Cruz (9, fig. 53)

[See pl. 17, *B*]

	Ft.	in.
Lissie (?) gravel:		
Light-gray conglomerate with limestone matrix and pebbles concentrated in pockets	13	6
Stratified conglomerate with calcareous cement and lenses of calcareous sandstone	24	6
Oakville sandstone: Fine white material, massive in lower part but seamed with $CaCO_3$ above parallel with the surface (volcanic ash; see p. 177)	60	

Section just north of La Loma de la Cruz (9, fig. 53)

	Ft.	in.
Lissie (?) gravel:		
Gravel and red sand	1	
Conglomerate with limestone matrix	13	
Coarse varicolored, highly calcareous sandstone with conglomerate in top and bottom	3	6
Fine conglomerate in limestone	5	6
Oakville sandstone: Fine white gritless volcanic ash	60	

In the ash bed of this section joints or partings are parallel to the slope of the hill and contain calcium carbonate from the overlying gravel.

Section of southeast face of hill next east of Santa Cruz ranch (10, fig. 53)

	Ft.	in.
Loose gravel		6
Limestone conglomerate	4	
Pink hard, compact nodular clay, partly concealed by débris from above	34	
Light-brown crumbly sandstone, lenticular, pockety, and cross-bedded	11	
Gray highly calcareous sandstone, lower part silicified and used as building stone, less firm above (sample 02241, p. 181)	16	6

Section of northwest face of hill next east of Santa Cruz ranch (10, fig. 53)

	Ft.	in.
Limestone conglomerate	15	
Pink clay	23	6
Hard nodular clay forming protruding ledge	1	
Pink clay	2	6
Gray massive and irregularly bedded sandstone	11	
Pink clay	3	
Hard blocky sandstone	4–5	

The sandstone and clay of the two preceding sections are believed to represent the Oakville formation, and the overlying limestone conglomerate to belong in the Reynosa or Lissie.

Section a quarter of a mile southeast of locality 10 (fig. 53)

	Feet
Reynosa or Lissie formation:	
Conglomerate consisting of pebbles in a limestone matrix, sandy in lower part	19
White limestone	11
Oakville sandstone:	
Pink and red clay	35
Brown and white blocky volcanic ash (sample 02216, p. 178)	11
Sandstone, including pellets of clay which, being softer than the sandstone, wear out, leaving cavities	3
Pinkish clay	5

The clay pellets included in this section are probably the result of erosion of the Frio clay and incorporation of its fragments within the basal Oakville, thus indicating unconformable relations between the Oakville and the Frio. Such clay inclusions are rather common in the Oakville in this part of the region.

Section 1 mile west of La Casita (11, fig. 53)

	Ft.	in.
Reynosa or Lissie formation:		
Loose gravel		4
Resistant conglomerate with limestone cement	5	6
Limestone conglomerate not so resistant as adjacent beds	16	
Resistant brown and red limestone-cemented conglomerate with a 2-foot lens of gray sandstone; contains opalized wood, one piece 8 inches long	8	
Oakville sandstone: White volcanic ash similar to that at La Loma de la Cruz	54	6

On the east side of Arroyo Chapote at the Garcia ranch (12, fig. 53) is a shallow exposure of greenish-gray calcareous clay intermediate between the typical pink clay and the white material of preceding sections. Several exposures of clay that underlies the Reynosa within 4 miles west of Samfordyce are now assigned to the Lagarto rather than to the Oakville.

Laboratory analyses.—Several samples were taken from the Oakville sandstone for special study in the laboratory. The sandstone, siltstone, and clay were treated in the usual way, the ash required special treatment, and the silicified sediments, quartzite, and conglomerate were studied in thin section under the petrographic microscope.

For comparison a sample from the sandstone at its type locality was analyzed, with results as follows:

Analysis of sample of Oakville sandstone at Oakville, Tex. (sample 02226)

Bedding.—Visible but indistinct and poorly defined.

Cement.—Calcareous (37.7 per cent soluble in HCl); friable and porous.

Size.—The mechanical analysis (fig. 54) shows that this is a medium-grained sandstone with finer admixtures including 5.5 per cent of clay.

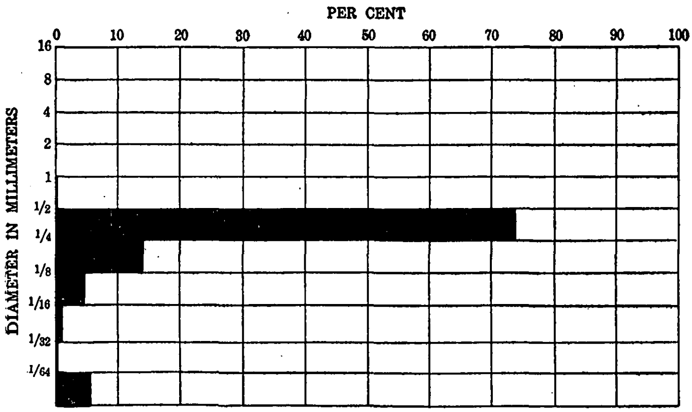


FIGURE 54.—Mechanical analysis of insoluble residue of sample 02226

Shape.—Grains range from rounded to angular and are subrounded and subangular in the maximum grade.

Mineral content.—Grains are mostly quartz but include some pieces of dark-colored chert and ferromagnesian minerals. Heavy minerals include limonitic aggregates, staurolite, garnet, rutile, tourmaline, and magnetite.

Color.—Gray.

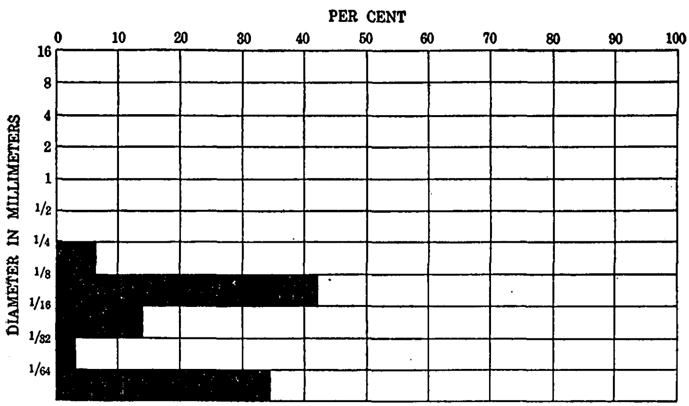


FIGURE 55.—Mechanical analysis of insoluble residue of sample 02223

Analysis of sample of sandstone three-quarters of a mile northeast of Mirando (sample 02223)

Bedding.—None visible.

Cement.—Calcareous (29.8 per cent soluble in HCl).

Size.—Mechanical analysis (fig. 55) shows this to be a very fine-grained sandstone with small fine sand and silt and large clay admixtures.

Composition of grains.—Light separate consists chiefly of quartz grains but with some volcanic glass and a little biotite. Heavy separate included garnet, obsidian, magnetite, staurolite, rutile, zircon, and leucoxene.

Shape.—Grains of quartz and volcanic glass angular.

Color.—Light gray.

Analysis of Oakville sandstone in Mirando Valley oil field (sample 02219)

Bedding.—None visible.

Cement.—Much calcareous cement (44.1 per cent soluble in HCl); porous; friable.

Size.—Insoluble residue consists of medium sand with considerable fine sand and clay and smaller proportions of very fine sand and silt. (See fig. 56.)

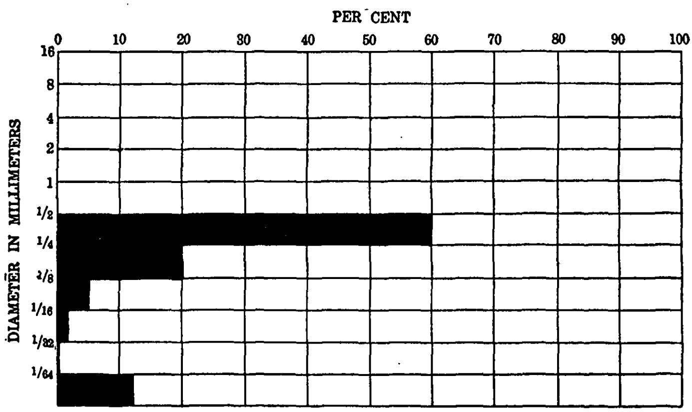


FIGURE 56.—Mechanical analysis of insoluble residue of sample 02219

Composition.—Chiefly quartz with some dark-colored aggregates of volcanic glass and heavy grains, including obsidian, actinolite, garnet, magnetite, rutile, olivine, and tourmaline.

Shape.—Subrounded to angular, mostly subangular.

Color.—Greenish gray.

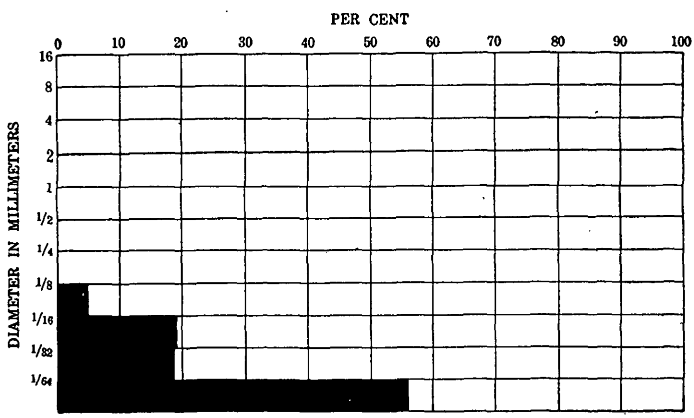


FIGURE 57.—Mechanical analysis of insoluble residue of sample 02225

Analysis of clay from Oakville sandstone in Mirando Valley oil field (sample 02225)

Cement and packing.—Contains 47.6 per cent of soluble matter as cement and crystals of calcite; extremely compact.

Size.—Silty clay with some very fine sand. (See fig. 57.)

Composition.—Light fractions chiefly quartz; much gypsum, some of which is in crystals, perhaps secondary; some biotite; a little volcanic glass. Heavy fraction consists of hematitic pseudomorphs after cubical pyrite crystals.

Analysis of Oakville sandstone in Henne, Winch & Fariss oil field (sample 02222)

Bedding.—Fairly regular but poorly defined.

Cement.—Calcareous (29.3 per cent soluble in HCl); porous; friable.

Size.—Medium sand with fine sand and silt admixtures and 25.3 per cent of clay. (See fig. 58.)

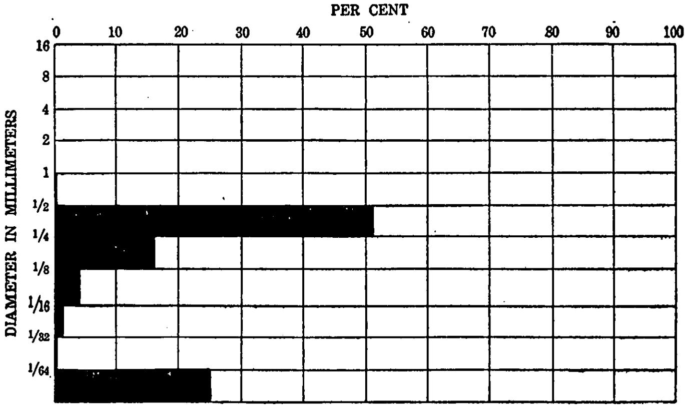


FIGURE 58.—Mechanical analysis of insoluble residue of sample 02222

Shape.—Mostly angular.

Composition.—Light materials, chiefly quartz, some chert, volcanic glass as aggregates in coarse grades and fragments in finer grades, a few plates of biotite. Heavy materials, obsidian, magnetite, garnet, actinolite, limonitic aggregates, rutile, leucoxene, olivine, and tourmaline.

Color.—Gray.

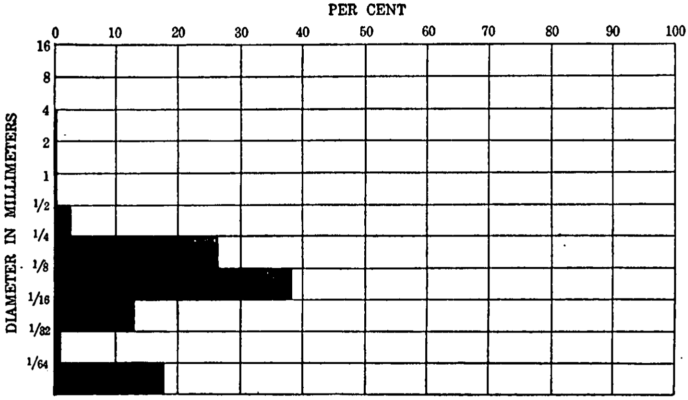


FIGURE 59.—Mechanical analysis of sample 02224

Analysis of white material in the Oakville sandstone above sandstone of sample 02222 and below the siliceous pipes in the Henne, Winch & Fariss oil field (sample 02224)

Cement.—Only slightly if at all soluble in HCl, but prolonged soaking loosened material so as to permit dissociation mechanically.

Size.—Slightly conglomeratic, fine-grained sandstone with considerable admixtures of silt and clay. (See fig. 59.)

Shape.—Subrounded to angular, chiefly subangular.

Composition.—Pebbles consist of angular chert fragments; sand and silt chiefly quartz with considerable feldspar. Heavy fraction, magnetite, garnet, tourmaline, obsidian, rutile, staurolite, zircon, anatase, and hematitic aggregates.

Color.—Grayish.

Petrographic description of sample of white sandstone in Henne, Winch & Fariss oil field (sample 02242)

Hand specimen.—This material is very compact, grayish, medium sandstone, with no visible bedding.

Thin section.—Texture granular; chief size grade is probably the ¼ to ⅛ millimeter; only a very few grains more than half a millimeter in greatest dimension, and apparently not much material of clay grade. Grains are mostly subangular and angular. Minerals include quartz, about 35 per cent; plagioclase feldspars, about 35 per cent; calcite, about 25 per cent; limonitic aggregates, minor amount; chert, magnetite, and biotite, traces.

This material is a medium-grained arkosic sandstone, cemented by calcite and to a minor degree by limonitic material. Most of the limonitic material, however, along with the magnetite, appears to be of detrital origin, but some of the limo-

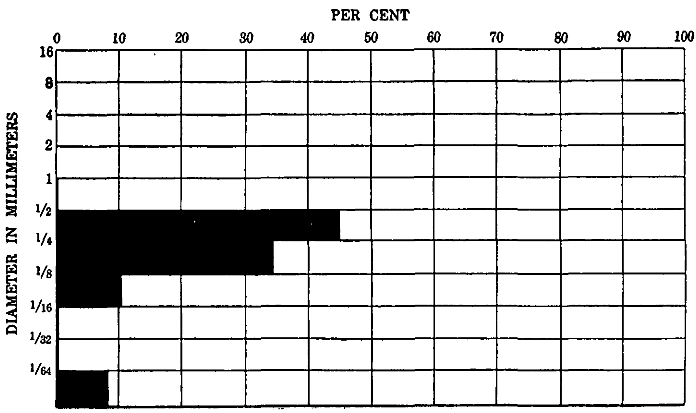


FIGURE 60.—Mechanical analysis of insoluble residue of sample 02218

nite may be secondary in so far as it has resulted from the alteration of the detrital grains of magnetite. The chert is present as a very minor amount of the detrital grains. The feldspars are present both as perfectly fresh fragments and as material showing all degrees of alteration; there are more weathered grains than fresh ones, but there are many grains that show no evidence of alteration whatever.

Analysis of Oakville sandstone 5½ miles north of Rio Grande City (3, fig. 53; sample 02218)

Bedding.—Massive.

Cement.—Calcareous (28.4 per cent soluble in HCl); porous, friable.

Size.—Medium sand with large admixtures of fine sand and smaller quantity of fine sand and clay. (See fig. 60.)

Composition.—Chiefly quartz but some dark-colored aggregates of volcanic glass. Heavy minerals, limonitic aggregates, magnetite, staurolite, tourmaline, garnet, rutile, and zircon.

Shape.—Angular to subangular.

As the analyses show, the sandstones of the Oakville are notably uniform from the town of Oakville to the Rio Grande.

Samples from the beds of volcanic ash east of Rio Grande City were studied in the laboratory with results as follows:

Analysis of sample of volcanic ash from Oakville sandstone 1 to 1½ miles east of Rio Grande City (sample 02131)

Bedding.—No bedding apparent. Fractures into chalklike but noncalcareous lumps.

Mineralogy and lithology.—Chiefly clay, which is white and very soft. The $CaCO_3$ content is less than 1 per cent by weight. Burned sample indicates small amount of gypsum; must be very finely divided. Volcanic glass abundant in finer grades. Quartz and other minerals very rare except in very fine grains; no sand.

Size.—Mechanical analysis resulted as shown in Figure 61.

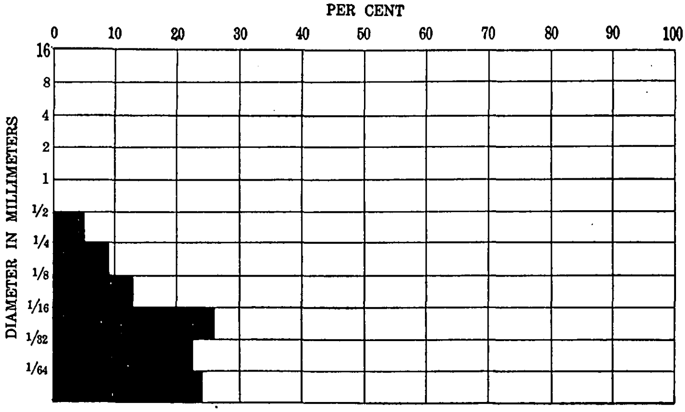


FIGURE 61.—Mechanical analysis of sample 02131

Shape.—Volcanic glass is angular with sharp edges, concave surfaces, fluted plates, and pumice-like grains. Much of the material below 1/32 millimeter may be glass but is not easily distinguished in the mass.

Cement.—Although $CaCO_3$ is present it does not constitute cement, as after dissolving the surface is as firm as before. The clay particles are held firmly together, suggesting a high degree of flocculation. Breaks easily but is only slightly friable to the touch.

Porosity.—Very porous for such fine-grained material. Absorbs water easily.

Color.—Cream-colored when dry and buff when wet.

Analysis of sample of volcanic ash 1½ miles northeast of Rio Grande City (8, fig. 53; sample 02144)

Bedding.—Same as sample 02131.

Size, mineralogy, and lithology.—In detail as follows:

Size (millimeter)	Per cent	
½–¼	0.8	Aggregates of volcanic ash.
¼–⅛	6.2	Do.
⅛–1/16	12.2	Aggregates of volcanic ash, quartz, and feldspar. Fully half of this grade is sand.
1/16–1/32	25.6	Aggregates of volcanic ash and silt.
1/32–1/64	24.6	Predominantly clay and silt; little ash.
Less than 1/64	30.6	

This sample contains more ash than sample 02131, and the particles are much larger. The sample is slightly calcareous.

Shape.—Ash very sharp and angular and does not appear to have been transported.

Porosity.—Similar to sample 02131.

Cement.—Similar to sample 02131 except more friable to touch, owing to coarser texture.

Color.—Same as sample 02131.

Analysis of sample of clay from Oakville sandstone at La Loma de la Cruz (9, fig. 53; sample 02143)

Bedding.—Similar to samples 02131 and 02144.

Mineralogy and lithology.—Entirely clay, without coarse ash or sand. More calcareous than preceding samples.

Size.—No mechanical analysis made. Under high power of microscope no grain was seen larger than 1/12 millimeter, and grains of that size were scarce. Predominantly fine clay with high degree of flocculation.

Color.—Same as other samples.

Cement.—Same as other samples except that small fragments are more friable to touch. Appears very chalky and subdivided but aggregates strongly in water.

Porosity.—Absorbs water readily.

Analysis of sample of volcanic ash from Oakville sandstone 1½ miles east of La Loma de la Cruz (10, fig. 53; sample 02216)

Bedding.—Massive.

Packing.—Fairly compact.

Size.—Impossible to dissociate for mechanical analysis. About 75 per cent in 1/8–1/64 millimeter grades, but grains as large as ½ millimeter in diameter were noted.

Composition.—Chiefly volcanic glass in aggregates and separate particles, but some quartz grains and a very few grains of garnet and zircon.

Shape.—Glass fragments jagged and angular; quartz grains angular and subangular.

Color.—Light pinkish gray, almost white.

From some of the samples from the Oakville sandstone that could not be broken down for regular sedimentary analysis thin sections were cut and were studied microscopically, with results as follows:

A sample was taken from one of the Oakville "chalcedony knobs" known as Seven Sisters, on the McMullen-Duval County line outside the region of this report, and studied microscopically in thin section for comparison with the siliceous Oakville materials of this region.

Petrographic description of sample of "chalcedony knob" of Seven Sisters, on the McMullen-Duval County line (sample 02244)

Hand specimen.—The particular piece from which thin sections were cut is in part extremely hard grayish to brownish very fine grained material resembling chert and in part siliceous clay.

Thin section.—Separately identifiable detrital grains scattered through material of clay grade. A very few of the grains are as much as ¼ millimeter in greatest dimension, but nearly all are less than 1/8 millimeter; on the basis of the dominant size of the detrital grains, this material is siltstone. The material of clay grade probably forms about as much of the whole as the detrital fragments. Nearly all the grains are angular. Minerals, quartz, all the separately identifiable detrital grains; clay, a large proportion of the rock as a whole; calcite, cementing material, and segregations, perhaps 20 per cent of the rock as a whole; limonitic aggregates and streaks, minor amount; chalcedony, in veins and segregations, minor amount.

This material is silicified silty clay, in which the angular, detrital fragments of quartz are scattered through silicified brownish and reddish-brown clay. It appears that the material in one part of this section was originally cemented with calcite, and that in another part with silica. Most of it is now cemented with silica. Silica in the form of chalcedony has replaced some of the calcite, even in the small part originally cemented with calcite and in veins or stringers originally filled with calcite. Larger veins are now entirely filled with chalcedony, which is probably the original vein material in them. However, J. T. Lonsdale[5] suggests that these may be replacements of the original vents from which volcanic material was ejected. There are also many chalcedony segregations in the mass of the clay. The color of the clay is probably due to the limonitic masses, all of which are probably secondary.

Petrographic description of Oakville sandstone three-quarters of a mile southeast of Mirando (sample 02236)

Hand specimen.—This material seems to be a rather fine grained, very compact light gray massive sandstone.

Thin section.—Texture granular, with a large proportion of material of clay grade as cement. Grains are about ⅓ millimeter in greatest dimension; chief size grade, aside from the clay cement, is probably the ¼ to ⅛ millimeter; grains mostly angular and subangular. Minerals, quartz about 35 per cent; plagioclase feldspars, about 30 per cent, ferruginous, siliceous clay, about 30 per cent; biotite, calcite, magnetite, amphiboles and zircon, minor amounts; garnet (?) and olivine (?).

This material is a fine-grained arkosic sandstone composed almost entirely of quartz, feldspar, and a brownish-pink ferruginous siliceous clay. There is only a very small amount of the usual heavy minerals found in sandstone. The feldspars exhibit all degrees of alteration, but although fresh grains are present, much of the feldspar is highly weathered, giving rise to intimate mixtures of feldspar and various alteration products such as kaolin and sericite. Most of the amphiboles and some of the biotite are weathered. The calcite occurs as indefinite segregations and in a disseminated form; it is probably mostly secondary.

Petrographic description of sample of Oakville sandstone half a mile northeast of Mirando (sample 02238)

Hand specimen.—This material appears to be a light gray very compact medium-grained massive sandstone.

Thin section.—Texture granular, with the material rather well sorted. Grains are ⅔ millimeter in greatest dimension; chief size grade is probably ½ to ¼ millimeter; grains angular to subrounded, mostly subangular and subrounded. Minerals, quartz, about 60 per cent; chalcedony (cement), about 15 per cent; quartzite (detrital grains from a preexisting rock), about 10 per cent; chert (detrital grains), about 10 per cent; plagioclase feldspars and limonitic aggregates, minor amounts.

This sandstone owes its extreme compactness to the chalcedony cement, which forms a band or ring around many of the sand grains and fills all the

[5] Oral communication to Miss Gardner.

interstitial spaces. In these spaces the chalcedony has at most places a distinctly banded structure, like agate, and these bands tend to curve around and approximately follow the borders of the sand grains, like the encircling rings mentioned above. At some points in the interstitial spaces the curving bands are interrupted by what appear to be segregations of chert. There are also detrital grains of chert, as stated in the list of minerals above. All the feldspar grains are weathered, and some of them show considerable sericitization. In so far as this section indicates, this sandstone shows a notable dearth of heavy minerals.

Petrographic description of sample of conglomerate from Oakville sandstone back of the hotel at Mirando (p. 167) (sample 02239)

Hand specimen.—This material is a very compact light-colored conglomerate, with subangular and subrounded pebbles of chert and quartzite, the largest 5 or 6 millimeters in diameter, set in a sandy matrix.

Thin section.—Texture conglomeratic; pebbles from about 1¼ to 5¾ millimeters in greatest dimension, subrounded. Matrix of sand, not very well sorted; most of it between ½ and ⅛ millimeter. Grains mostly subangular. Pebbles are chert and quartzite. Sand grains are nearly all quartz, a minor amount of them chert. The cement in the matrix is dominantly calcareous, but there are also a few patches of chalcedonic material, which is of the nature of an infiltrated cementing material and is not of detrital origin.

This particular thin section, chosen especially to include pebbles, is taken from a conglomerate whose cementing material is dominantly calcareous. In a thin section of the specimen as a whole the cementing material is dominantly siliceous, instead of containing mere patches of siliceous cement. There seems to be some tendency for pieces containing many pebbles to be more calcareous with respect to the cement than pieces of this general material not so pronouncedly conglomeratic. Some of the large pebbles in the thin section are broken across, and in these fractures there is material exactly like that of the matrix in general—that is, subangular sand with calcareous cement—indicating that the breaking took place while the matrix was still unconsolidated.

Petrographic description of sample of quartzite from the Oakville sandstone three-quarters of a mile south of Mirando (p. 167) (sample 02240)

Hand specimen.—This material appears to be a very compact light-gray medium-grained quartzite.

Thin section.—Texture granular; grains are ½ millimeter in greatest dimension, and the chief size grade is probably the ¼ to ⅛ millimeter. Grains are mostly subangular and angular. Minerals, quartz, about 75 per cent; chert (detrital grains), about 10 per cent; quartzite (very fine grained material, as detrital grains from a preexisting rock), about 5 per cent; siliceous cementing material, about 5 per cent; limonitic aggregates, minor amount; biotite and zircon, traces; plagioclase feldspars (?), greatly weathered; rutile (?).

This is a medium-grained sandstone cemented chiefly with silica, a considerable part of which came in and crystallized in optical continuity with the detrital quartz grains. Limonitic material also acts as a cement, and there are some limonitic aggregates, probably secondary. In some parts of this slide there is evidence of three generations of cementing action, there being around some quartz grains a film of the limonitic material, then silica crystallized in optical continuity with the detrital quartz, and then another film or band of the limonitic material. Most of the limonitic material was introduced later than the siliceous cementing material, however.

Petrographic description of sample of Oakville sandstone 1½ miles east of La Loma de la Cruz (10, fig. 53; sample 02241)

Hand specimen.—This is a fairly compact light-buff medium-grained indistinctly bedded sandstone.

Thin section.—Texture granular; few if any grains more than ½ millimeter in greatest dimension; chief size grade is probably the ¼ to ⅛ millimeter, but the material is not very well sorted on the whole. Grains range from angular to subrounded and are mostly subangular and angular. Minerals, quartz, about 65 per cent; plagioclase feldspars, about 15 per cent; calcite, about 15 per cent; chert, limonitic aggregates, biotite, and various ferromagnesian minerals, all considerably weathered, minor amounts.

This is a medium-grained sandstone, cemented largely by calcite. There seems to be some calcite present as detrital grains also. The feldspars are both fresh and weathered in approximately equal proportions. The chert is present as detrital grains. Some of the quartz grains contain great numbers of inclusions. There does not appear to be much material of clay grade in this sample.

Petrographic description of sample of quartzitic sandstone from point northwest of Randado (16, fig. 48; sample 02243)

Hand specimen.—This is a fairly compact light-buff medium-grained indistinctly bedded sandstone.

Thin section.—Texture granular; chief size grade is probably the ¼ to ⅛ millimeter, but the material is not very well sorted on the whole; largest grains are slightly less than ½ millimeter in greatest dimension. Grains are mostly angular and subangular. Minerals, quartz, about 40 per cent; plagioclase feldspars, about 30 per cent; calcite (cementing material, apparently no detrital grains), about 25 per cent; limonitic and hematitic aggregates; biotite, minor amounts; magnetite, chalcedony (minor cementing material), and epidote, traces.

This is a medium-grained sandstone, cemented chiefly by calcite, but with a minor amount of chalcedonic cement. There is a notably high proportion of feldspars, and the sandstone might perhaps be considered arkosic; the feldspars are both fresh and weathered, the latter being probably the more abundant. In so far as this thin section indicates, this sandstone is finer grained than typical Oakville sandstone.

Origin.—The sandstone, siltstone, and clay of the Oakville sandstone exposed in the lower Rio Grande region appear to be of fresh-water origin and to represent fluviatile materials deposited in broad, shallow valleys previously developed in the surface of the Frio clay. The deposits doubtless came to fill the valleys and spread over the low divides to form a continuous sheet of varying thickness. The interbedded volcanic ash around Rio Grande City records volcanic eruptions outside this region and the settling of a finer glassy ejecta on the surfaces of deposition. The conglomerate, quartzite, chalcedony, and silicified sandstone, siltstone, and clay were made from the original sediments by the infiltration of and replacement by silica that was probably derived from the ash beds. It is not believed necessary to account for these silicified sediments by the presence of faults along which the siliceous solutions might have risen from great depths.

OTHER MIOCENE STRATA

That there are thick Miocene sediments overlapped by younger formations in this region is indicated by the discovery of Miocene fossils at depths between 4,325 and 4,500 feet in the Niels Esperson oil test well, 15 miles east of Brownsville. The species, as identified by Julia Gardner are given below.

Fossils from Niels Esperson oil test well, 15 miles east of Brownsville, Tex.

Depth (feet)	4,325	4,360	4,375	4,390	4,410	4,415	4,420	4,445	4,465	4,475	4,480	4,485	4,500
Textularia? sp				×									
Cristellaria americana Cushman	×	×	×	×	×	×	×	×	×	×	×		×
Nucula sp. indet	×										×		
Leda sp. cf. L. proteracuta Gardner	×				×								
Leda sp. indet								×		×			
Pecten aff. P. eboreus Conrad	×	×	×	×	×	×	×	×	×	×	×	×	
Pecten? sp				×									
Cardium (Cerastoderma) sp. indet	×	×	×		×	×	×	×	×	×	×	×	×
Chione (Lirophora), sp. indet	×	×	×	×	×	×	×	×	×	×	×		×
Tellina sp. indet											×		
Corbula (Caryocorbula) cf. C. (C.) nasuta Dall		×			×		×	×				×	×
Corbula sp. indet	×					×							×
Dentalium sp. indet						×							
Cadulus? sp											×		
Cadulus sp. indet	×					×							
Adeorbis	×												
Architectonica? sp												×	
Natica (Cryptonatica) cf. N. (C.) pusilla Say								×					
Natica (Cryptonatica), n. sp	×												
Natica? sp								×					
Polynices (Euspira)												×	×
Turritella cf. T. terebriformis Dall							×	×	×	×			
Alectrion? sp											×		
Oliva cf. O. literata Say			×										
Cancellaria n. sp	×			×					×				
Cancellaria? sp												×	×
Drillia n. sp											×		
Balanus sp										×			
Crab claw									×				

Miss Gardner has interpreted this fauna as follows:

The fauna is uniform in character from 4,325 to 4,500 feet and points consistently to Miocene age. The exact position in the Miocene can not be determined, but there is a prominent Chipola factor indicating a lower or lower middle Miocene age.

According to Miss Ellisor[6] a well at Kingsville, 5,203 feet deep, did not penetrate to the base of the Miocene.

PLIOCENE SERIES

LAGARTO CLAY

In 1923[7] it was thought that the Pliocene Lagarto formation, described by Dumble,[8] by Udden, Baker, and Bose,[9] and by Deussen[10]

[6] Ellisor, Alva, oral communication.

[7] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 98, 1923.

[8] Dumble, E. T. Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, pp. 963-975, 1903.

[9] Udden, J. A., Baker, C. L., and Bose, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, p. 90, 1916.

[10] Deussen, Alexander, op. cit. (Prof. Paper 126), pp. 100-102.

did not crop out in the lower Rio Grande region, but in 1927 it was concluded that, as pointed out by Bailey,[11] the clays that crop out under the Reynosa in the Rio Grande bluff west of Samfordyce are better referable to the Lagarto formation than to the Frio or to the Oakville.

Lithology.—The Lagarto formation in the region of this report consists of stiff compact gray clay and some thin lenses or layers of gray laminated sand.

Sections west of Samfordyce.—On the new upland road 11.7 miles west of Samfordyce (13, fig. 53) 8 feet of Lagarto clay (sample 02214, p. 184) underlies 6 feet of Reynosa gravel in a road cut. (See pl. 17, *C.*) Light-brown jointed clay 15 feet thick, similar to the Lagarto clay of the last section, is exposed under the Reynosa at the Virgel ranch (14, fig. 53).

Section in gravel pit at Cuevitas (15, fig. 53)

	Feet
Reynosa or Lissie formation: Conglomerate with sandy and limy matrix and lenses of gray sandstone, stratified and cross-bedded	27
Lagarto clay:	
Pink clay	3
Gray stratified sand	3

Section including Lagarto clay in gravel pit 1 mile west of Samfordyce (16, fig. 53)

	Ft.	in.
Gray unbedded limestone containing scattered pebbles	8	
Layered conglomerate cemented by sand and limestone	7	
Concealed by débris from above	16	6
Gray clay irregularly jointed	10	6

It is possible that the gray clay of this section is Oakville rather than Lagarto, but as it resembles the Lagarto more than the Oakville it is tentatively assigned to the Lagarto. The limestone and conglomerate are Reynosa.

Half a mile west of Samfordyce (17, fig. 53) an 18-foot section is exposed in a gravel pit. The base is at the level of a terrace 12 feet above the river at an average low stage. The lower 6 feet of the section is light-gray clay, impregnated on joints with calcium carbonate from the Reynosa above and containing 1 to 8 inch lenses of soft sandstone. Small blocks of apparently pure kaolin can be broken out of the clay, although there are sandy areas in it as well. Roughly spheroidal clay balls also appear in the clay. This is taken to be Lagarto clay, over which is 12 feet of typical Reynosa conglomerate.

Laboratory analyses.—Only one sample of Lagarto clay was available for analysis.

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[11] Bailey, T. L., The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, p. 50, 1926.

Analysis of Lagarto clay at Virgel ranch, west of Samfordyce (14, fig. 53; sample 02214)

Lithology.—A hard, stiff, massive, sandy and silty calcareous clay; 12.9 per cent soluble in HCl.

Size.—The finer grains reaggregate after washing in HCl and in water, so that mechanical analysis is difficult, suggesting the presence of colloidal matter in the clay. In this the sample resembles those from the Cockfield and Frio clays. As indicated in Figure 62, most of the grains are of clay size, but there are considerable admixtures of silt and fine sand.

Mineral content.—Light minerals, practically all quartz. Heavy minerals, staurolite, magnetite, tourmaline, zircon, and garnet.

Shape.—Most of the grains are angular or subangular. On the whole this clay bears strong resemblance to those of the Oakville sandstone and Frio clay and is analytically indistinguishable from them.

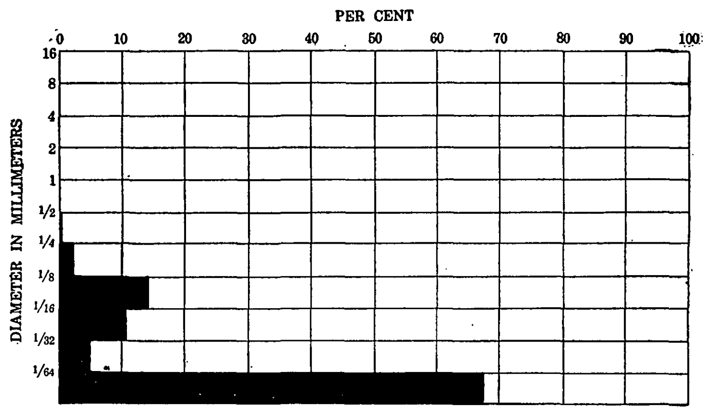

FIGURE 62.—Mechanical analysis of insoluble residue of sample 02214

Origin.—The Lagarto clay seems to be an ordinary fine-grained sediment. There is no evidence of marine origin.

PLIOCENE (?) SERIES

REYNOSA FORMATION

Name.—The following is quoted from the preliminary report on the lower Rio Grande region:[12]

In 1890 Penrose[13] described a deposit of limestone containing many pebbles and cobbles under the name "Reynosa limestone," from the town of Reynosa, Tamaulipas, Mexico. This limestone overlies what was then called the Fayette sand at Reynosa, directly across the Rio Grande from Hidalgo, Tex. Penrose found Recent shells embedded in the surface of exposures of this formation and, thinking it was Recent, included it in his "post-Tertiary formations." In 1891 Hill[14] described remnants of a formation that consisted of coarse and fine gravel cemented by a calcareous matrix and that occupied terraces 400 to 1,000 feet above the Rio Grande to the north of this region. This he called the Uvalde formation. Dumble[15] applied the name Reynosa division to the series of

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[12] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 98, 1923.

[13] Penrose, R. A. F., jr., Report of geology for eastern Texas: Texas Geol. Survey First Ann. Rept., pp. 57, 58, 63, 1890.

[14] Hill, R. T., Notes on the geology of the Southwest: Am. Geologist, vol. 7, pp. 366–370, 1891.

[15] Dumble, E. T., The Cenozoic deposits of Texas: Jour. Geology, vol. 2, p. 560, 1894.

deposits forming the plateau between Nueces and Rio Grande, which he called the Reynosa plateau. He stated that the "Reynosa limestone" of Penrose formed the top member of his Reynosa division, which rested on the Lagarto formation. These downstream deposits to which Dumble applied the name Reynosa are now known to be the same as the upstream remnants to which Hill applied the name Uvalde, and the necessity for discarding one of the names has become apparent. In view of the fact that Reynosa as applied to a part of this formation has priority over Uvalde and that the downstream deposits perhaps afford a better type locality, the name Reynosa has been adopted by the United States Geological Survey, and "Uvalde" formation has been abandoned.

In 1924 Deussen[16] tentatively questioned Dumble's correlation of the main mass of limestone and conglomerate in Texas with the limestone at Reynosa, on the ground that there is a difference in altitude of 732 feet between the limestone at Reynosa and that at Torrecillas, and suggested that perhaps the material at Reynosa, being at a much lower topographic level than the rest, represented a younger and perhaps a Pleistocene formation. The limestone is continuous along the Bordas scarp from Torrecillas to Rio Grande City, from which it dips eastward toward Reynosa. At Torrecillas the limestone is at an altitude of about 800 feet and at Rio Grande City at an altitude of about 250 feet, and all the way it lies on the beveled edges of the Frio and Oakville formations. Evidently the surface on which the sediments were deposited sloped gently toward the Rio Grande, which may have been then as now the main line of drainage. If the dip of 15 to 20 feet to the mile usually assigned to the Reynosa is projected eastward from Rio Grande City, the base of the formation would be 300 or 400 feet below sea level at Reynosa, 36 miles to the east. A slope of the base of the limestone amounting to about 7 feet to the mile in a direction oblique to the dip would be required to tie up the exposures at Torrecillas and Reynosa at the same stratigraphic horizon. It is believed, therefore, that Dumble was right in correlating the main sediments here called Reynosa with the sediments at Reynosa, Mexico, and that the name is in consequence properly used.

A brief description and interpretation of the Reynosa formation by the present writer[17] was published in 1926.

Distribution.—Plate 7 shows the distribution of the Reynosa in the lower Rio Grande region. Its resistant layers and those of the Oakville hold up the Frio clay, and its base thus forms the Bordas scarp, from which it dips at a very low angle eastward, cropping out as a continuous formation in a north-south belt 35 to 45 miles wide. It occupies southeastern Webb County, all of Jim Hogg and

[16] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 102, 1924.

[17] Trowbridge, A. C., Reynosa formation in lower Rio Grande region, Texas: Geol. Soc. America Bull. vol. 37, pp. 455–462, 1926.

Starr Counties except their western portions, and the western part of Brooks and Hidalgo Counties. In much of this area, however, its outcrops are obscured by the wind-blown sands of the sand belt.

West of the Bordas scarp patches of gravel, some of them cemented by or embedded in limestone, which are erosional remnants or outliers of the Reynosa, occupy many of the highest elevations in Starr, Jim Hogg, Zapata, Webb, Dimmit, Zavala, Maverick, and Uvalde Counties and extend northward and westward beyond the boundaries of this region to the Balcones fault and up into the larger valleys in the edge of the Edwards Plateau. This is the "Uvalde" formation of Hill, which has now been correlated with the Reynosa and hence is called Reynosa in this report. By no means all the gravel in these counties is in its original position, however, for that on the lower topographic levels has been reworked and as it lies is of more recent age than the Reynosa. Only the larger and more certainly undisturbed areas are shown on the map.

Stratigraphic relations.—The Reynosa overlies the Frio clay and the Oakville sandstone unconformably along the Bordas scarp. In the main belt of outcrop east of the scarp and on the Gulfward side of this belt, it probably overlies the Lagarto clay, which is not exposed in this region except in a few localities west of Samfordyce. At the east border of this belt it dips under the Lissie gravel, which overlies it unconformably. West of the Bordas scarp the Reynosa outliers lie unconformably on all older Tertiary formations and overlap the Upper Cretaceous. Thus the Reynosa, which dips more gently than the older formations and lies on a surface that is almost flat, bevels the older formations.

Lithology.—The Reynosa formation is an intricate mixture of gravel cemented by calcium carbonate, uncemented gravel, limestone in which are embedded pebbles and cobbles, limestone almost free from gravel, sand, sandstone, gravelly sand, and a relatively small quantity of clay. The pebbles and cobbles consist of chert, limestone, vein quartz, and igneous rocks of various sorts. Where the gravel or conglomerate overlies the Fayette and Oakville formations it includes petrified wood. Most of the pebbles and cobbles are well shaped by abrasion, many of them are highly polished, and some show markings made by hard impact during transportation. The gravel deposits are roughly sorted into lenses and pockets of different textural grades.

The limestone is gray and sandy and weathers into rough, irregular surfaces due to irregular concretions and impurities. In places it has surficially a tufaceous appearance. Its basins, rims, terraces, channels, and concentric banding suggest deposition by springs. Patches south of the Espejo ranch, in north-central Webb County, and at Carrizo Springs are clearly spring deposits, but these are not typical, for they contain little or no gravel.

The sand and sandstone are gray, brown, or red and almost everywhere weather into a dark-red sand. The grains are quartz, coated with red iron oxide, but in places where this red coating has been worn off by the wind the sand is gray or even white.

The few beds of clay are generally sandy, but some are almost free from grit. Below Rio Grande City the Reynosa formation includes mud balls of Oakville and Lagarto clay.

The surficial material derived from the Reynosa is typically deep-red, pink, or gray sand, through which white or gray limestone projects at many places.

Thickness.—The thickness of the formation can not be determined with accuracy. The patchy deposits west of the Bordas scarp are not more than 30 feet thick except at a very few places. Even in the main belt of outcrop the Reynosa overlaps older formations and is probably not as thick as the width of outcrop would indicate. The average dip is probably less than 10 feet to the mile, and even this is probably due to the fact that the sediments were laid down on a surface that had this much slope.

Fossils, age and correlation.—No fossils indigenous to the Reynosa have been found in the lower Rio Grande region. Just as Recent snails were found by Penrose embedded in the surface of the limestone at the town of Reynosa, the remains of land snails, crayfish, jackrabbits, and birds occur in some places embedded in the surface as the limestone has been dissolved and reprecipitated. Some of the pebbles and cobbles of which the gravel and conglomerate of the formation are composed contain fossils originally left in the formations from which the Reynosa was derived. Marshall[18] reports the collection of three new indigenous genera and four new species of mollusks, named by him *Pliconaias popenoei, Eonaias reynosenica, Antediplodon dewittensis,* and *Polygyra myersi,* from the Reynosa of DeWitt County, Tex. Marshall thinks that these fossils are of Pliocene age. In the same collection were some fossil teeth that were determined by J. W. Gidley to have belonged to extinct horses and rhinoceroses of Pliocene age. This locality is in the valley of the Guadalupe River about 110 miles north by east of the type locality of the Reynosa formation.

The stratigraphic position of the formation between the Miocene Oakville and the Pleistocene Lissie, with an unconformity below and another above, indicates late Tertiary, probably Pliocene age, a tentative conclusion confirmed by the discovery of the Pliocene mollusks and mammals. The Reynosa is probably to be correlated with the Citronelle of eastern Texas, Louisiana, Mississippi, Alabama,

[18] Marshall, W. B., New fossil land and fresh-water mollusks from the Reynosa formation of Texas: U. S. Nat. Mus. Proc. No. 2798, 1929.

and Florida, which has a similar stratigraphic position, is similar lithologically, appears to be a continuation of the Reynosa, and contains Pliocene fossils.[19]

The formation was included by McGee in the "Lafayette" formation.

In 1926 Bailey[20] stated that the Pleistocene ("probably lower Pleistocene") age of the Reynosa had been established by the discovery in 1923 by Wortman of a specimen of *Equus* cf. *E. fraternus* 2 feet above the base of the gravel at La Loma de la Cruz, 3 miles east of Rio Grande City. The writer can not agree with this conclusion. The age of a thick and widely distributed formation can hardly be established by the discovery at one spot of a single fossil not specifically determined. Fossil horses have long characterized the "*Equus* beds" of Dumble—the Lissie gravel of Deussen, which lies unconformab y on the Reynosa and is of early Pleistocene age. (See pp. 203–207.) The gravel cap of La Loma de la Cruz is isolated from the main mass of the Reynosa formation, occupies a terrace in the valley of the Rio Grande, bears stronger lithologic resemblances to the Lissie than to the Reynosa, and according to Wortman contains a fossil genus that is common in the Lissie and unknown in the Reynosa. It would be more logical, therefore, to correlate this small patch of gravel with the Lissie than to assign a Pleistocene age to the whole Reynosa formation.

Exposures in the main belt of outcrop.—Most of the best exposures of the Reynosa, which occur along the Bordas scarp from Torrecillas to Rio Grande City and along the river bluffs from Rio Grande City to Samfordyce, have been described on pages 161–181. Three-quarters of a mile north of Oilton the westward-facing Bordas scarp consists of 20 to 30 feet of gray fine-grained sandy and clayey rock containing quartz grains and chert pebbles. Calcareous nodular masses are common. There are also pockets of red sand, and over much of the surface caliche has been formed.

On the Garcia ranch, 10½ miles southeast of Aguilares, sandy and clayey materials with nodular limestone and gravel hold up the Frio clay. The materials appear to be sand and gravel almost covered by Recent deposits of caliche and sinter. There are nodular concretions 1 to 6 feet in diameter, which are calcareous in their outer portions and siliceous within. Many of them resemble tufa cones with open craterlets, some of which have siliceous cores and some are hollow. Some of the hollow spaces contain fine gravel or sand. Gravel in which cobbles 3 to 6 inches in diameter are more numerous than smaller pebbles occurs in great abundance on the surface and at the

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[19] Matson, G. C., and Berry, E. W., The Pliocene Citronelle formation of the Gulf Coastal Plain and its flora: U. S. Geol. Survey Prof. Paper 98, pp. 167–204, 1916.

[20] Bailey, T. L., The Gueydan, a new middle Tertiary formation from the southwestern Coastal Plain of Texas: Texas Univ. Bull. 2645, pp. 59, 60, 1926.

base of the scarp. Some of it has been recemented in a calcareous and siliceous matrix.

In the Mirando Valley oil field limestone and caliche of varying thickness form the upper slope of the escarpment. Besides the limestone there are included pockets of gravel and hardened red sand. The gravel occupies rounded depressions 6 inches to 2 feet across and is also scattered loose over the top of the scarp.

Patches of gray and white limestone interspersed with red and gray sand and beds and lenses of gravel crop out in roads and in the walls and bottoms of shallow drains at innumerable places in western Hidalgo County north of Samfordyce, in Starr County northeast of Rio Grande City, in Jim Hogg County east of Cuevitas, Guerra, and Randado and between Hebbronville and the Mirando Valley oil field, and in Webb County southeast of Oilton. The surface in this whole area is so nearly flat that only surficial exposures are available, but these are characteristic of the main Reynosa formation.

About 7 miles southwest of Hebbronville is a pit from which material was taken in 1920 for hardening the road to Randado. The rock exposed is unusually white and pure limestone, containing a small amount of flint and limestone gravel and large, hard, irregular calcareous masses with concentric structure. The thickness of rock exposed is 6 feet.

Four miles southwest of Hebbronville 10 feet of limestone interbedded with clayey sand is exposed in the wall of a shallow drain. On the surface of the limestone are basins, rims, channels and concentrically arranged materials suggesting deposition by springs.

About 2½ miles south of Hebbronville a considerable area of Reynosa limestone appears in a north-south road. On the surface are smooth, rounded depressions or craterlets that resemble the basins of spring pools. They range in diameter from 1 to 2½ feet and are irregularly oval to round. The rims of these basins are wavily laminated and thus suggest building up by precipitation from water.

In the bottom of a shallow arroyo 3½ miles southeast of Hebbronville is an outcrop of limestone that was utilized long ago for building what appears to have been an old firing wall and possibly a rude fort. Beside the wall is an open well, square in section and 60 feet deep, which exposes in its sides limestone similar to that in the wall. The limestone in the arroyo underlies the general sandy plain at a depth of 8 to 15 feet and has an irregular surface.

About 2¼ miles southeast of Sejita are two pits used for silage, each 20 feet in diameter and 32 feet deep. One is cemented artificially from top to bottom, and the other is cemented for 17 feet from the top, but the remaining 15 feet is in natural limestone. The limestone underlies the surface sand in this vicinity and projects through it locally.

A pit 3 miles south and west of Falfurrias exposes 6 feet of limestone overlain by 4 feet of sandy clay. The contact between limestone and clay is not regular; knobs of limestone project into the clay, and portions of the clay project down into the limestone. The limestone is white and the clay gray or buff.

Between Cuevitas and San Roman compact red sand and sandstone stand in miniature cliffs, and gray limestone crops out in many places. The surface of the limestone is pitted by bowl-like depressions, which are smooth and symmetrical. One basin 3 feet in diameter and 18 to 20 inches deep was observed. The limestone is unbedded and nodular. Chert pebbles are associated with the sand and limestone. At Cuevitas an arroyo 50 feet deep exposes limestone on both walls from top to bottom.

At Rancho Nuevo a borrow pit exposes 8 feet of red sandstone standing in vertical faces.

On the Webb-Jim Hogg County line 14 miles southeast of Oilton the usual Reynosa limestone and red sand are exposed. The limestone is pitted and banded and contains lenses of gravel consisting of greenstone, chert, and limestone pebbles 7 inches in maximum diameter.

In addition to the section 11.7 miles west of Samfordyce (p. 183 and pl. 17, *C*) in which Reynosa beds lie unconformably on the Lagarto clay, there are a number of other exposures of Reynosa sediments west of Samfordyce on the new road from Rio Grande City to Mission. At a point 7.1 miles west of Samfordyce there is an exposure of gravel, sand (sample 02234, p. 198), and limestone intricately interlensed, and similar materials are exposed 5.4 miles west of Samfordyce (sample 02231, p. 198).

At La Lomita, 6½ miles south of Mission, on the Rio Grande, sandstone (sample 02228, p. 200) crops out at two or three places. It is impossible to determine certainly, even after analysis of the sandstone, whether this hill represents a doming or plugging up of Oakville sandstone or an ordinary erosion remnant in the Reynosa, but because the sandstone sample is more calcareous than most of the Oakville sandstones and because there is no other evidence of doming, this exposure is tentatively assigned to the Reynosa.

Subsurface sections.—Many of the wells on the Lasater ranches penetrate the Reynosa, and their logs give some idea of the formation.

Driller's log of Tres Encinos well, Lasater ranch

	Feet		Feet
Soft rock and sand	0–20	White sand and boulders	456–477
Blue clay and rock	20–120	Sand and rock	477–500
Red clay and rock	120–260	Red clay	500–540
White sand	260–270	Loose boulders	540–560
Red clay and loose boulders	270–420	Red clay	560–585
Rock	420–434	Water sand	585–615
Hard rock	434–456		

Exposures of remnants west of the Bordas scarp.—Most of the Reynosa outliers west of the main belt of outcrop, only the larger of which are shown on the map, consist of rounded and polished pebble and cobble gravel, either loose on the surface, in beds a few inches to a few feet thick, or loosely cemented by calcium carbonate. The pebbles and cobbles are mostly chert but include limestone and igneous rocks.

In Uvalde and Zavala Counties large flat, high interstream areas are covered with gravel, much of which is coarse. These gravel-covered flats are so large and so nearly accordant in level as to constitute the "Uvalde terrace" on the "Uvalde plain," from which the "Uvalde" formation was named. The gravel overlies and obscures strata of the Indio and Carrizo formations and overlaps the Cretaceous.

In eastern Maverick County, especially between the old Indio ranch and the Rio Grande (see pl. 7), the hills and higher divides are covered with several feet of cobble and pebble gravel, most of which is deeply iron stained. Here the gravel covers the Indio and Midway formations and hides the Cretaceous-Eocene contact.

The high tabular stream divides at and around Carrizo Springs, in Dimmit County, are covered with several feet of limestone in which are embedded crystalline pebbles and cobbles. In the town the hill slopes are coated with gray nodular laminated limestone. The nodular rock occurs in patches at the surface and embedded in the laminated rock as pockets and lenses. Matson [21] describes a section here as follows:

> In the north edge of town is an instructive cut of gray sand containing lenses 15 to 30 inches long and 3 to 4 inches thick of gray lime. This partial section is about 3 feet above thin layers of sandy lime 1 to 1½ feet thick and locally coating 2 feet of botryoidal lime. In the town the laminated layer has a range in altitude of about 25 feet and the nodular material is not limited to any particular horizon.

Some of the cuts made in grading streets show 4 to 10 feet of calcareous tufa evidently deposited from springs. All the limy beds here contain sand grains.

Webb County contains upland patches of Reynosa gravel, tufaceous limestone, and conglomerate, too numerous for all to be especially mentioned.

Between the Espejo and Chupadero ranches and north of the Bigford ranch the higher hills are capped by 1 to 10 feet of gravel, in some places cemented by gray limestone. Many of the pebbles are less than an inch in diameter, but some reach 8 inches.

The Twin Peaks or Los dos Hermanos, 3½ miles south of the Espejo ranch, and a hill 2 miles farther south (pl. 7) consist almost entirely

[21] Matson, G. C., field notes.

of calcium carbonate. The south hill of the pair is 52 feet high, 1,500 feet long, and 600 feet wide and is elongate in a northeasterly direction. (See pl. 18, *A*.) Fragments of fine white calcareous tufa cover its slopes to a level within 6 feet of the top, but a more resistant layer of porous calcium carbonate caps the hill. The north hill of the pair has a flat top, reaches practically the same height as its twin, and has the same composition and structure. The hill 2 miles south of the Twin Peaks and a mile north of Loma Blanca Tank stands 15 to 25 feet above the general plain and is conspicuous from all sides. It is 1,000 feet long from north to south and 200 feet wide and is nearly flat on top. The capping material is resistant porous calcium carbonate, in which there are irregular and roundish areas with small pits resembling spring vents in the middle. Below this is several feet of whiter and more porous calcareous material, which weathers into small white bits. All three of these hills are spring cones and terraces. The springs that formed them issued through the Mount Selman formation on which they stand. Hill and Vaughan [22] report a few pebbles in the otherwise pure limestone of these hills.

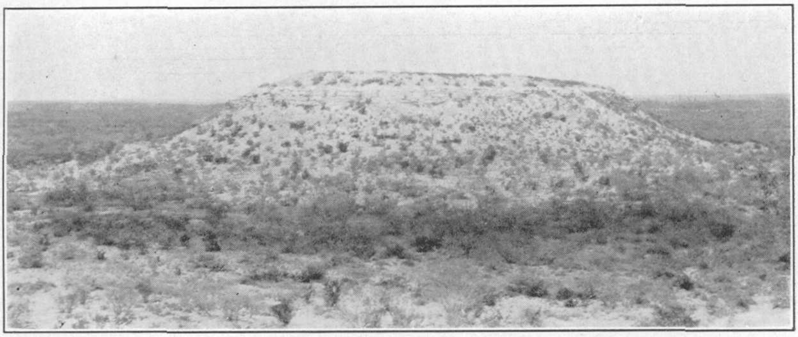
At and for several miles around the Pilotes ranch flat-topped mesa-like hills are capped with coarse gravel. In this vicinity there are numerous pieces of petrified wood among the chert cobbles. Five miles northwest of the ranch house 4 feet of pebble conglomerate with white calcareous cement is overlain by 1 foot of loose gravel.

There is a great deal of gravel on the divide between Artillero and Llave creeks north of Santo Tomas. In some places it is loose, and in others it is cemented with calcium carbonate. It veneers the rock hills for the most part but also forms low mounds composed entirely of gravel. The pebbles include andesite with a predominance of chert and some white quartz, and the largest are 4 inches in diameter.

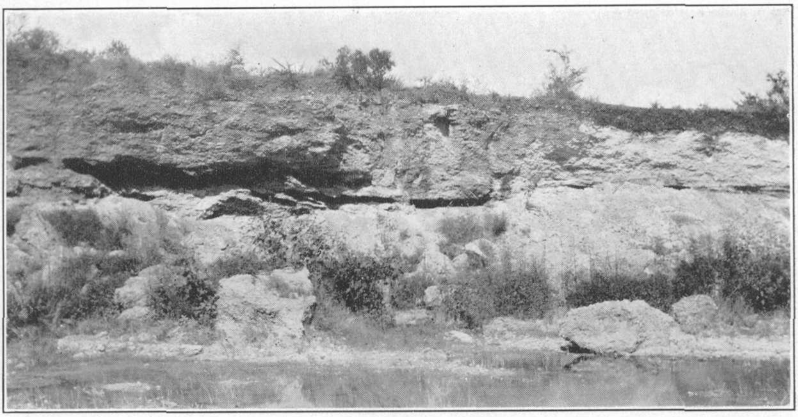
Hills near Cannel are capped with as much as 10 feet of gravel, cemented locally with calcium carbonate and including crystalline pebbles as large as 4 inches in diameter.

The best exposure of Reynosa gravel seen outside the main belt of outcrop is in the International-Great Northern Railroad pits a quarter of a mile south of Green's, where a steam shovel was working in 1919 and 1920. Most of the pebbles are less than an inch in diameter, but there are also 3-inch and even 5-inch cobbles. There are some lenses of sand. The material is fairly well sorted and is irregularly bedded, chiefly in lenses. Cross-bedding is conspicuous. Both gravel and sand are cemented with calcium carbonate, many of the lenses being firm conglomerate. The total deposit is 15 feet thick, of which the upper 1 to 5 feet is loose and oxidized, and lies on the Cook Mountain formation. (See pl. 18, *B*, *C*.)

[22] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 246, 1898.



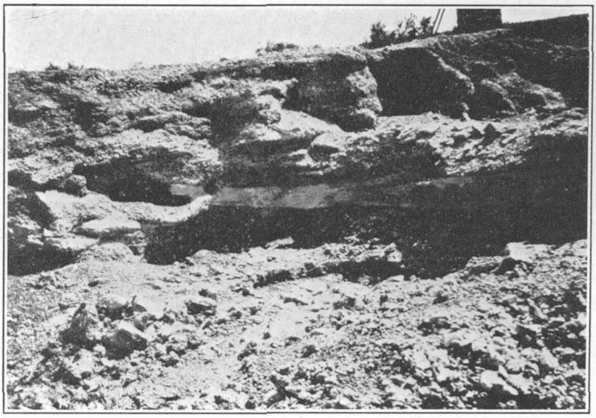
A. SOUTH HILL OF TWIN PEAKS, SOUTH OF ESPEJO RANCH



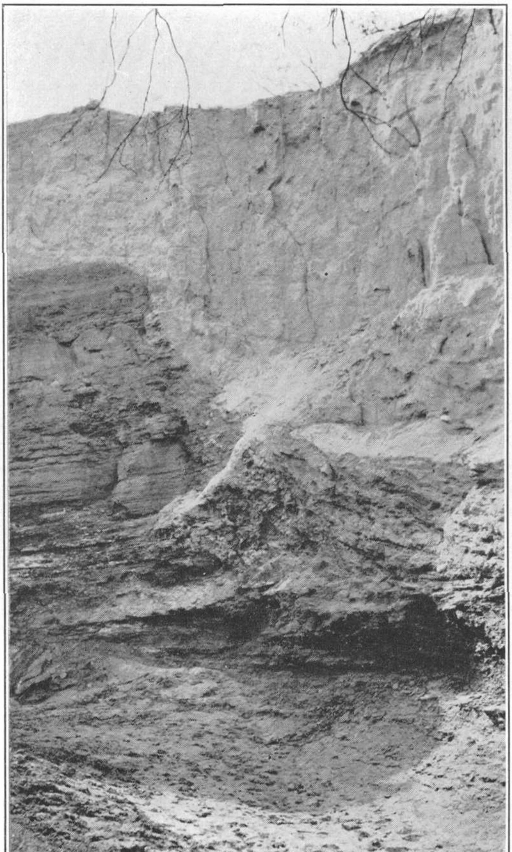
B

C

B, *C*. GRAVEL OF REYNOSA FORMATION AT GREEN'S, ON THE INTERNATIONAL-GREAT NORTHERN RAILROAD



A. LISSIE GRAVEL IN A PIT EAST OF SAMFORDYCE



B. SILT IN THE RIO GRANDE TERRACE UNCONFORMABLY OVERLYING WILCOX STRATA IN THE SOUTHEAST CORNER OF MAVERICK COUNTY

At Benevides switch, on the Rio Grande & Eagle Pass Railway about 12 miles north of Laredo, limestone-cemented gravel 3 by 5 feet thick is exposed in a cut, and material of the same sort caps hills to the north.

A hill on which a Coast and Geodetic Survey triangulation station is located, on the Rio Grande 7 miles above Laredo, is capped with 10 feet of gravel ranging in diameter from a small fraction of an inch to 5 inches.

Unconsolidated gravel occurs east and south of Laredo, both as a thin veneer over the Cook Mountain formation and as low detached hillocks on the uplands. It is possible, however, that much of the gravel here has been reworked since its original deposition so as to lie now below the level of the Reynosa plain. Gravel with some calcareous cement caps the hill on the Rio Grande 16 miles below Laredo used as a triangulation station by the Coast and Geodetic Survey.

Gravel with cobbles as much as 6 inches in diameter occurs on the slopes and top of a hill 5 miles north of Zapata and at many other high points in Zapata County. The hills and ridges southeast of Soledad are covered with gravel to a thickness of 20 feet or more. The pebbles average 1½ inches in diameter. About 3½ miles north of Ramireno well-shaped and polished pebbles and cobbles averaging 3 inches in diameter cap the Rio Grande bluffs. At one point the gravel is 15 feet thick, is cemented to conglomerate by calcium carbonate, and includes cobbles 8 inches long.

There is a large patch of Reynosa gravel, limestone, and conglomerate west and northwest of Randado, in Jim Hogg County. (See pl. 7.)

Much gravel occurs on the hills north and east of Santa Margarita, in Starr County. Three miles due east of Roma there is 10 feet of firm conglomerate with calcareous cement. The pebbles, which are well shaped and polished, average 2½ to 3 inches in diameter.

Los Olmos Creek has cut through the Reynosa north and east of Rio Grande City, separating a considerable area of it from the main outcrop on the east. The outlier consists of gravel and conglomerate in all respects similar to exposures farther east in the main outcrop, described on pages 188–190.

Laboratory analyses.—Analyses were made in the laboratory of several samples taken from the Reynosa, with the results given below:

Analysis of sample of limestone from Reynosa formation at Reynosa, Mexico (sample 02146)

Bedding.—Structure is roughly radial and concretionary and is expressed by concentric shading and by distribution of manganite. The slide shows that the laminae of $CaCO_3$ govern the position of the sand, and the laminae curve, and in places a radial structure is seen. Fracture has no relation to this structure and is subconchoidal.

Mineral content.—$CaCO_3$, 79 per cent; sand, 6.4 per cent, quartzose, but contains feldspar; clay, 17.6 per cent, fluffy, buff.

Size and shape.—Analysis of the insoluble residue after removal of 79 per cent of the sample by solution in HCl results as follows:

Size (millimeter)	Per cent	
1/4-1/8		Few grains of quartz, partly rounded.
1/8-1/16	0.8	Sand partly rounded.
1/16-1/32	5.6	Sand and clay aggregate.
1/32-1/64	2.6	
Less than 1/64	12.0	

Color.—Gray, with shading of light and dark.

Analysis of sample from Reynosa formation on Bordas scarp 10½ miles southeast of Aguilares (sample 02050)

Bedding.—Horizontal bedding expressed as color shades by fracture along bedding planes. Has minutely irregular fractures but breaks into roughly cubical blocks. The sand grains are oriented, and the $CaCO_3$ is evenly distributed.

Mineral content.—$CaCO_3$, 76 per cent, includes also a small amount of manganite; sand, 20.4 per cent, contains quartz, some of which is iron-stained and fresh, plagioclase, and orthoclase, with very few heavy minerals; clay, 2.0 per cent, in white flaky grains.

Size.—The insoluble residues were mechanically analyzed, with results as shown in Figure 63.

Shape.—Large proportion of rounded grains in all grades above one-sixteenth millimeter, some grains being very well rounded and frosted. Looks like a sand that has been eolian.

Cement.—Well cemented by $CaCO_3$. Maintains angular points but not sharp edges. Slightly friable.

Color.—Cream-colored, with chalky appearance.

Analysis of sample from Reynosa formation on Bordas scarp 10½ miles southeast of Aguilares (sample 02051)

Bedding.—Laminated similar to sample 02146.

Mineral content.—$CaCO_3$, 70 per cent, includes manganite also; sand, 13.2 per cent, quartz and feldspar; clay, 16.8 per cent, fluffy, buff.

Size.—The mechanical analysis of the insoluble residue is shown in Figure 64.

Color.—Tan with irregular black spots of manganite.

Cement.—Well cemented with $CaCO_3$. Maintains sharp edges and is not friable.

Analysis of sample from Reynosa formation on Bordas scarp 10½ miles southeast of Aguilares (sample 02052)

This sample is similar to 02050 and 02051, except that 90 per cent of it is soluble in dilute HCl.

Size.—The mechanical analysis of the 10 per cent of insoluble residue is shown in Figure 65.

Shape.—Sand grains are rounded in the finer grades, suggesting eolian abrasion.

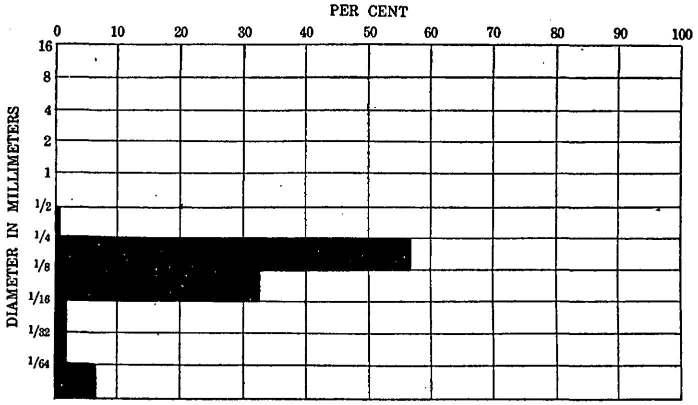


FIGURE 63.—Mechanical analysis of insoluble residue of sample 02050

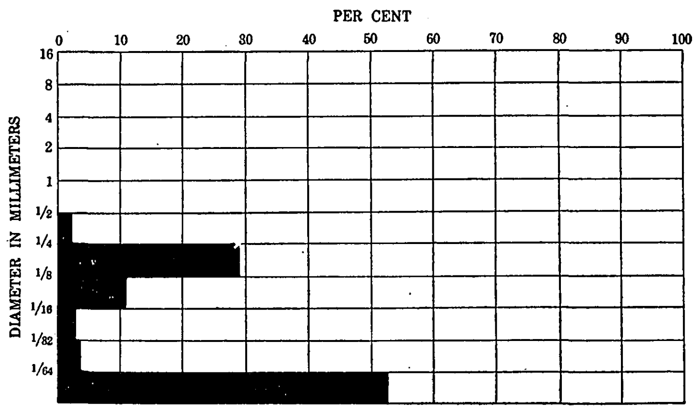


FIGURE 64.—Mechanical analysis of insoluble residue of sample 02051

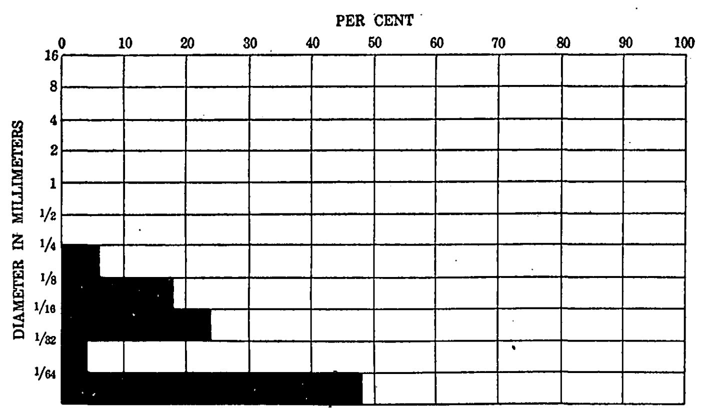


FIGURE 65.—Mechanical analysis of insoluble residue of sample 02052

Analysis of sample of limestone from Reynosa formation on Bordas scarp 10½ miles southeast of Aguilares (sample 02230)

Lithology.—An impure limestone (81.9 per cent soluble in HCl).
Size.—Mechanical analysis of insoluble residue is shown in Figure 66.
Mineral content.—The light grains consist of quartz and chert. Heavy minerals, magnetite, garnet, obsidian, staurolite, tourmaline, anatase, rutile, zircon, hematitic aggregates, and actinolite.
Shape.—Grains angular to subrounded, mostly subangular.
Color.—Pinkish.

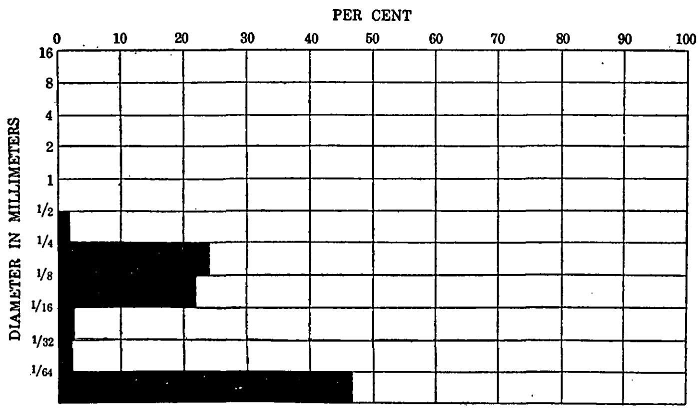


FIGURE 66.—Mechanical analysis of insoluble residue of sample 02230

Analysis of sample of limestone conglomerate from Reynosa formation in the Mirando Valley oil field (sample 02229)

Lithology.—A pinkish-gray impure earthy limestone (75.8 per cent soluble in HCl) with embedded pebbles.
Size.—As shown in Figure 67 the insoluble material ranges in size from clay particles to pebbles 16 millimeters in diameter.
Mineral content.—Pebbles are chert of various colors. Sand and silt grains are practically all quartz but include a few grains of gypsum, dark-colored volcanic glass, and heavy materials as follows: Obsidian, garnet, magnetite, rutile, staurolite, zircon, anatase, chalcopyrite (?), hematitic aggregates, actinolite, and tourmaline.
Shape.—Grains angular and subangular.
Color.—Matrix is light pink or pinkish gray.

Analysis of sample of Reynosa limestone from point 1 mile west of Henne, Winch & Fariss oil field (sample 02221)

Sample is similar to 02229 except that there are more impurities in the limestone (72.3 per cent soluble in HCl), there are no pebbles in the insoluble residue (fig. 68), and the proportion of heavy minerals is higher. Fragments of volcanic glass occur in very minor proportions in all the size grades.

Analysis of sample of Reynosa limestone on Randado-Rio Grande City road 44 miles from Rio Grande City (sample 02235)

Structure.—Slight indications of thin, even lamination.
General composition.—Impure limestone, 84.3 per cent soluble in HCl.
Porosity.—Very compact.
Color.—Light pinkish.

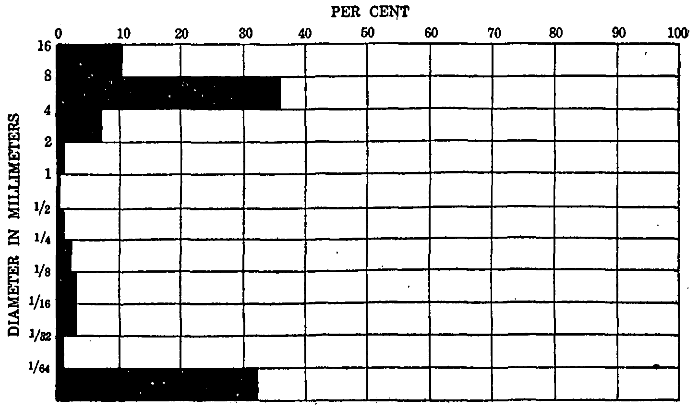


FIGURE 67.—Mechanical analysis of insoluble residue of sample 02229

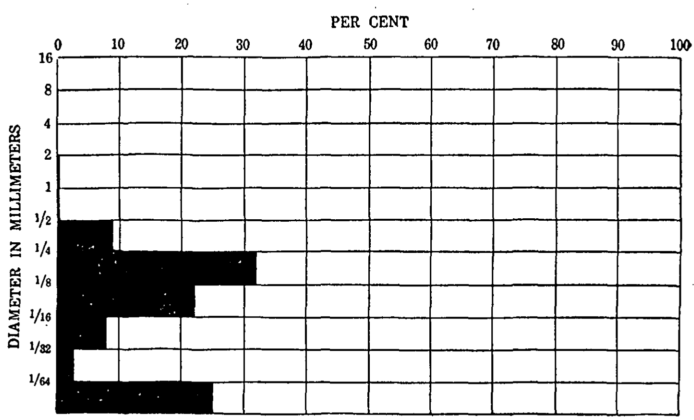


FIGURE 68.—Mechanical analysis of insoluble residue of sample 02221

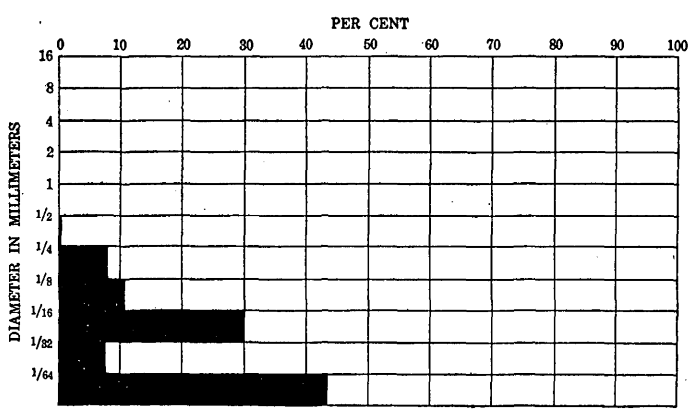


FIGURE 69.—Mechanical analysis of insoluble residue of sample 02235

Size.—Mechanical analysis (fig. 69) shows that the chief impurity in the limestone is of clay grade but that there is also considerable silt and fine sand.

Minerals.—Clastic impurities consist of quartz sand and silt, some grains of chert and feldspar, and grains of magnetite, garnet, tourmaline, hematite aggregates, staurolite, and rutile.

Shape.—Grains angular and subangular.

Analyses of samples of Reynosa limestone and limestone conglomerate on the Laredo-Hebbronville road north of Mirando (samples 02227 and 02233), where isolated patches of Reynosa, possibly somewhat reworked, overlie the Frio clay, are so nearly identical with the analyses given above that description would be pure repetition. In fact, all the limestone or limestone conglomerate samples analyzed are notably similar.

The nature of the beds and lenses of sandstone within the Reynosa formation is given in the three following analyses:

Analysis of sample of sand from Reynosa formation east of Rio Grande City (sample 02232)

Bedding.—Visible but poorly defined.

Cement.—Calcareous (40.2 per cent soluble in HCl); compact.

Size.—Mechanical analysis (fig. 70) shows that this is a fine-grained sand with small medium sand, silt, and clay admixtures.

Mineral content.—Light minerals, mostly quartz with minor amounts of feldspar and biotite. Heavy minerals, magnetite, obsidian, actinolite, hematitic aggregates, anatase, garnet, tourmaline, rutile, staurolite, zircon, and olivine (?).

Shape.—All grains angular or subangular.

Color.—Brownish gray.

Analysis of sample of sandstone from Reynosa formation 5.4 miles west of Samfordyce on the new road to Rio Grande City (sample 02231)

Bedding.—Indistinctly laminated.

Cement.—Calcareous (34.5 per cent soluble in HCl); friable.

Size.—A well-sorted fine-grained sandstone. (See fig. 71.)

Mineralogy.—Light fraction, quartz, some chert, subordinate number of aggregates of dark volcanic glass. Heavy fraction, magnetite, obsidian, garnet, actinolite, rutile, staurolite, anatase, hematitic aggregates, and zircon. The proportion of heavy grains is higher than in most of the other samples analyzed.

Shape.—Quartz grains angular, subangular and subrounded.

Color.—Light gray.

Analysis of sample of sandstone from Reynosa formation 7 miles west of Samfordyce on the new road to Rio Grande City (sample 02234)

Bedding.—Massive.

Cement.—Calcareous (38.1 per cent soluble in HCl); compact.

Size.—A conglomeratic sandstone, in which medium and fine grains make up nearly 88 per cent of the whole and occur in almost equal proportions and in which there is a small amount of clay and a few pebbles as much as 3.4 inches in diameter. (See fig. 72.)

Shape.—Pebbles subrounded to subangular; smaller grains mostly angular to subangular.

Composition.—Pebbles mostly of chert but some of fine-grained igneous rock. Sand grains chiefly quartz but with some chert, feldspar, and heavy minerals,

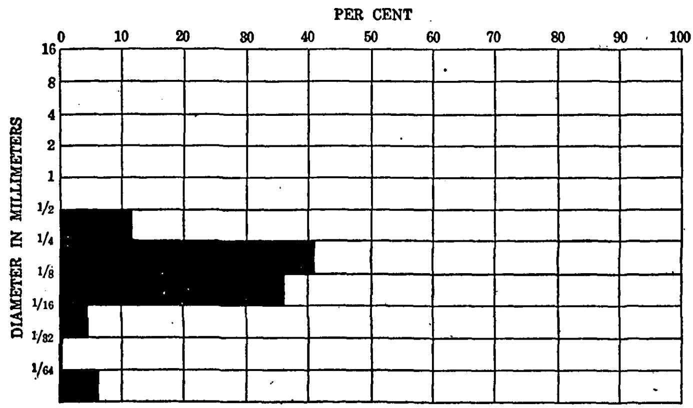


FIGURE 70.—Mechanical analysis of insoluble residue of sample 02232

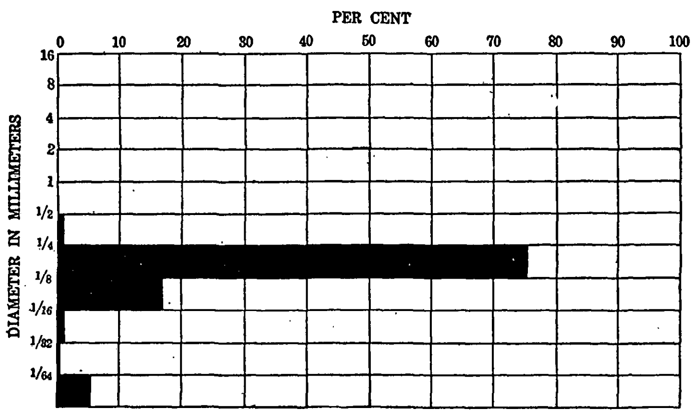


FIGURE 71.—Mechanical analysis of insoluble residue of sample 02231

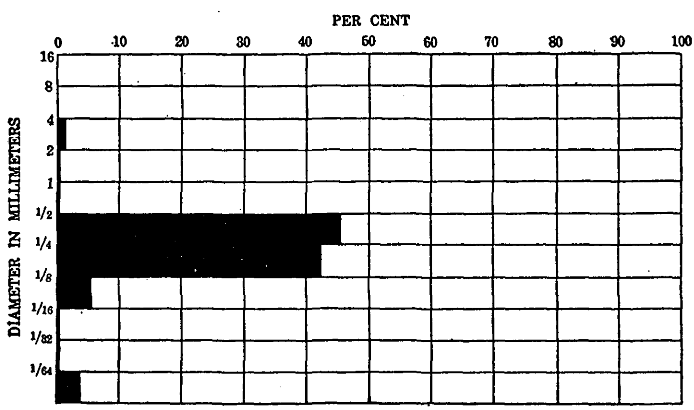


FIGURE 72.—Mechanical analysis of insoluble residue of sample 02234

including magnetite, garnet, actinolite, limonitic aggregates, hematitic aggregates, staurolite, rutile, tourmaline, zircon, biotite, anatase, and diopside.

Color.—Light gray.

Analysis of sample of sandstone at La Lomita (sample 02228)

Bedding.—Indistinctly laminated.

Cement.—Calcareous (44.4 per cent soluble in HCl); fairly compact.

Size.—A poorly sorted medium-grained sandstone with grains ranging in size from less than 1/64 millimeter (clay) to 2 millimeters (very coarse sand). (See fig. 73.)

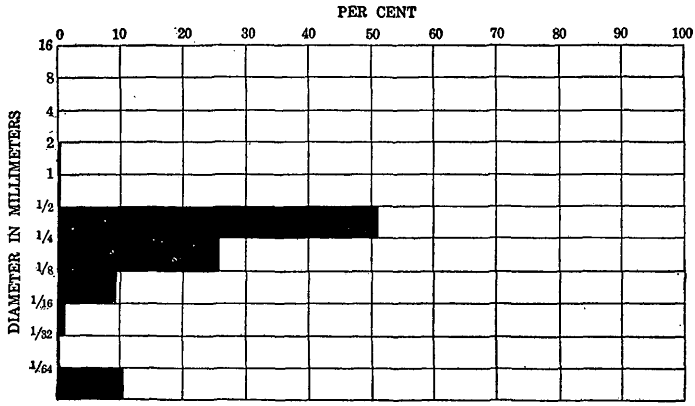


FIGURE 73.—Mechanical analysis of insoluble residue of sample 02228

Shape.—Grains range from rounded to angular, but most of them are angular or subangular.

Minerals.—Chiefly quartz but with some aggregates of dark volcanic glass, pieces of chert, and heavy grains including obsidian, garnet, magnetite, actinolite, rutile, staurolite, zircon, and tourmaline.

Color.—Grayish.

These analyses show that the Reynosa sands, like the limestones, are all similar. There is also, however, a notable similarity between the Reynosa sands and the Oakville sands. In general, the Reynosa sands are more calcareous and finer grained than the Oakville sands, but these differences are not necessarily true for any single sample.

Petrographic description of sample of silicified sandstone from Reynosa limestone a mile northeast of Mirando (sample 02245)

Hand specimen.—Extremely hard, compact light-grayish material, with somewhat the appearance of silicified clay.

Thin section.—Texture granular, but with considerable material of clay grade. Detrital grains are poorly sorted as to size; the largest are more than 1/2 millimeter in greatest dimension, but the chief size grade is probably the 1/8 to 1/16 or the 1/16 to 1/32 millimeter. The grains are mostly angular and subangular, but a few are rounded. Minerals, quartz, about 95 per cent of the detrital grains; clay, forming a considerable part of this material as a whole; quartzite (detrital grains), chalcedony (veins and segregations), chert (detrital grains), and limonitic aggregates, minor amounts; rutile, zircon, biotite, and diopside, traces.

This material was originally a very fine-grained sandstone or a siltstone that contained considerable clay. It is now completely silicified, the clay "matrix" being partly crystalline and partly amorphous silica, and in addition there are numerous veins and segregations of chalcedony. The silicification of the material of clay grade probably went on at approximately the same time as deposition, but the introduction of the chalcedony came later. The chalcedony forms nearly complete bands around some of the quartz grains, and some of the chalcedony veins or stringers pass between the two halves of split quartz grains. The limonitic material is probably secondary.

History.—After the Oakville sandstone was deposited and probably after the formation of the Lagarto clay, the coastal plain of southwestern Texas appears to have been slightly elevated, tilted, and eroded so that a peneplain was formed, beveling all formations and doubtless extending northward and westward across the Edwards Plateau toward and perhaps to the Cordilleran mountains of western Texas and New Mexico. On this low-lying surface the products of weathering accumulated. The cherty Cretaceous limestones of the Edwards Plateau gave rise to calcareous, argillaceous, and arenaceous residual soils and to fragments of chert which could not be dissolved and were left at the surface. The higher surfaces west of the Edwards Plateau were probably subdued and likewise covered by residual materials, such as clay, sand, and fragments of vein quartz.

The Tertiary sediments of the coastal plain were similarly weathered and formed surficial residual soils consisting of clay, sand, silicified wood, etc. On this old surface such residual materials probably accumulated to a considerable thickness.

At some time late in the Tertiary period, probably in the Pliocene, this condition was changed by a diastrophic disturbance in which the Balcones fault was formed, the Edwards Plateau and perhaps the plateaus and mountains farther west were elevated, and the coastal plain was depressed and left as a low and relatively featureless plain extending from the foot of the Balcones scarp to the Gulf coast.

The elevation of the surfaces west of the escarpment, by increasing the declivity and perhaps by interference with winds, giving rise to increased precipitation, caused the rejuvenation of streams, which were thus enabled to remove large quantities of the accumulated residuum, even including the fragments of chert and other insoluble residues. Some of the streams in time penetrated the surficial materials and eroded their valleys into the unweathered rocks below. This elevation also increased the ground-water circulation and gave rise to gulfward-moving water beneath the surface, carrying large quantities of calcium bicarbonate and other salts in solution.

The materials thus removed from the elevated surface on the west were deposited on the relatively depressed plain south and east of the Balcones scarp. The shallow valleys were soon filled, and the streams anastomosed over the general surface, spreading a more or less continuous sheet of sediment. In general the finer materials were carried on to the Gulf and the coarser materials were left on the surface to make up the gravel of the Reynosa. Thus a sort of piedmont plain was formed topographically and a sort of compound fan lithologically.

The larger and more vigorous streams, such as the Rio Grande, carried and deposited the coarser gravel. Most of the pebbles and cobbles of the gravel and conglomerate came from the Edwards Plateau, but the Rio Grande brought vein quartz and igneous rocks from the western mountains across the plateau and laid them down with the rest on the Coastal Plain.

The limestone of the Reynosa was contributed mainly by ground water and perhaps to some extent by the streams. The ground water, rich in dissolved calcium carbonate, coming from the elevated western area with invigorated circulation, stood high in the pores of the rocks and close to the low surface of the eastern plain. Although precipitation was at least fairly abundant in the high plateau on the west, the Coastal Plain was arid or semiarid then as now, and evaporation caused the precipitation of the calcium carbonate to form the limestone. Some of the precipitation took place in the interstices of the gravel near the surface as the surface was built up by the deposition of the gravel. Some of the limestone, such as that near Hebbronville and elsewhere in the main belt of outcrop and that at Carrizo Springs and at Los dos Hermanos, in Webb County, was precipitated at the surface from springs, forming both cones and terraces where the springs issued and deposits of bolson and alkali-flat types in shallow basins into which the spring water flowed and there evaporated. Perhaps also some of the stream water flowed into sloughs, bayous, resacas, and lagoons and into shallow flats, where it was evaporated and deposited its dissolved salts. The agitation of the water of the streams at the swifter places along their courses may have permitted the escape of carbon dioxide and so aerated the water that calcium carbonate was precipitated direct in pools and pockets. The laboratory analyses, which show rounded and frosted sand grains embedded in the limestone of some of the samples, demonstrate that sand and dust were shifted about by the wind and blown into these surface waters to be inclosed in the tufaceous deposits.

The faulting that caused and conditioned the deposition of the Reynosa was doubtless renewed from time to time as deposition on the Coastal Plain progressed, and that portion of the plain near the Balcones fault line or zone was probably dragged up somewhat periodically, resulting in partial or complete removal, or at least a thinning, of the surficial sediment there and a thickening of the formation toward the coast. Thus the Reynosa came to be thicker near the coast than at and near the foot of the Balcones scarp.

After the Reynosa had been deposited its landward margin where the sediments were thin was eroded until only remnants remained on the higher parts of the surface of deposition, and the thicker and originally continuous deposit nearer the coast remained as a continuous formation, dipping below the Pleistone and Recent coastal clays. Somewhere east of its present outcrop the formation doubtless grades into marine deposits of the same age.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

LISSIE GRAVEL

Name and correlation.—In 1894 Dumble[23] described under the name "*Equus* beds" some gravel and sand containing fossil bones of horses and other vertebrates, all of early Pleistocene age, lying with great unconformity on what he termed the Reynosa division. He stated that these deposits occur in detached valleys and depressions resulting from erosion of the Reynosa prior to the deposition of the "*Equus* beds" and that they consist of materials derived from the Reynosa. These deposits, which have their typical development near San Diego, in Duval County, Tex., were included in the Port Hudson formation of Hilgard, and, as described by Kennedy[24] in 1903 under the name Columbia sands, they form the lower part of McGee's so-called Columbia formation[25] of this area.

In 1914 Deussen[26] substituted the name Lissie gravel, from Lissie, Wharton County, Tex., for Dumble's name "*Equus* beds," in order to comply with the modern system of nomenclature, and this name has been in use since that time.

Deussen found that the gravel was a continuous formation, and in 1924[27] he mapped a belt of Lissie gravel from 10 to 20 miles wide from Falfurrias, in Brooks County, to the Brazos River and stated that it continued eastward into eastern Texas and Louisiana.

As now defined, therefore, the Lissie gravel includes deposits that lie unconformably on the Reynosa and have been derived largely from the Reynosa and that underlie the Beaumont clay.

Distribution.—Owing to a scarcity of exposures and close lithologic similarity to the Reynosa, the Lissie gravel was not recognized in the preliminary report[28] as cropping out in the lower Rio Grande region.

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[23] Dumble, E. T., The Cenozoic deposits of Texas: Jour. Geology, vol. 2, pp. 563–564, 1894.

[24] Hayes, C. W., and Kennedy, William, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 212, pp. 26–66, 1903.

[25] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 384-408, 1891.

[26] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 78–80, 1914.

[27] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 108–110, pl. 8, 1924.

[28] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 100, 1923.

Since 1923, however, it has been discovered that sections exposed in the low Rio Grande bluffs between Samfordyce and Closner represent the Lissie rather than the Reynosa and that a narrow belt of Lissie extends from this locality northward to the sand belt between the Reynosa on the west and the Beaumont on the east. Aside from Deussen's Lissie, which extends to the north border of this region in a belt including Falfurrias, in Brooks County, the whole area of outcrop is in Hidalgo County.

The Lissie-Reynosa line of contact north of the sand belt and just outside the region shown on Plate 4 appears to cut the Falfurrias-Hebbronville road 4 miles west of Copita, for typical Reynosa limestone appears abundantly in the road west of this point, but there are no exposures of it farther east. If not covered in northern Hidalgo County and eastern Brooks County by drifting sand the outcrops north and south of the sand belt would be connected.

Details of distribution are shown on Plate 7 and Figure 74.

Lithology.—The Lissie gravel is closely similar to the Reynosa in many respects but differs from it in consisting chiefly of gravel rather than of limestone and in being for the most part unconsolidated. In addition to the gravel the formation includes beds and lenses of sand, irregular masses and balls of clay, and thin and mostly surficial beds of limestone or caliche. Where it underlies flat surfaces it gives rise to dark-gray or black loamy soils with only a few exposures of limestone or caliche.

Thickness.—The formation is so poorly exposed in this region and is so doubtfully distinguishable from the Reynosa in well logs that its thickness can not be determined. It is probably not so thick, however, as farther north, where Deussen [29] reports thicknesses ranging from 493 to 1,020 feet.

Paleontology.—No fossils were found in the Lissie of this region; but elsewhere Pleistocene vertebrates occur in it, including *Bison latifrons*, *Elephas imperator*, *Equus complicatus*, *Equus francisci*, *Glyptodon*, and *Trucifelis fatalis*. To these should now be added *Equus* cf. *E. fraternus*, reported by Bailey as found in the gravel at La Loma de la Cruz. (See p. 188.)

Rio Grande sections.—The Lissie gravel is best exposed between Rio Grande City and Closner, where the bluffs decrease eastward in height above the main Rio Grande terrace.

The section at La Loma de la Cruz, now interpreted as being Lissie gravel over Oakville ash, is described on page 171 and shown photographically in Plate 17, *B*.

In a gravel pit and several test pits 1.2 miles east of Samfordyce (1, fig. 74), where the river terrace ends abruptly against a steep

[29] Deussen, Alexander, op. cit., p. 108.

bluff of gravel 15 to 20 feet high, a section 40 feet in total thickness is exposed. The materials consist of bedded gravel, with thin seams and lenses of sandstone and a little limestone. (See pl. 19, *A*.)

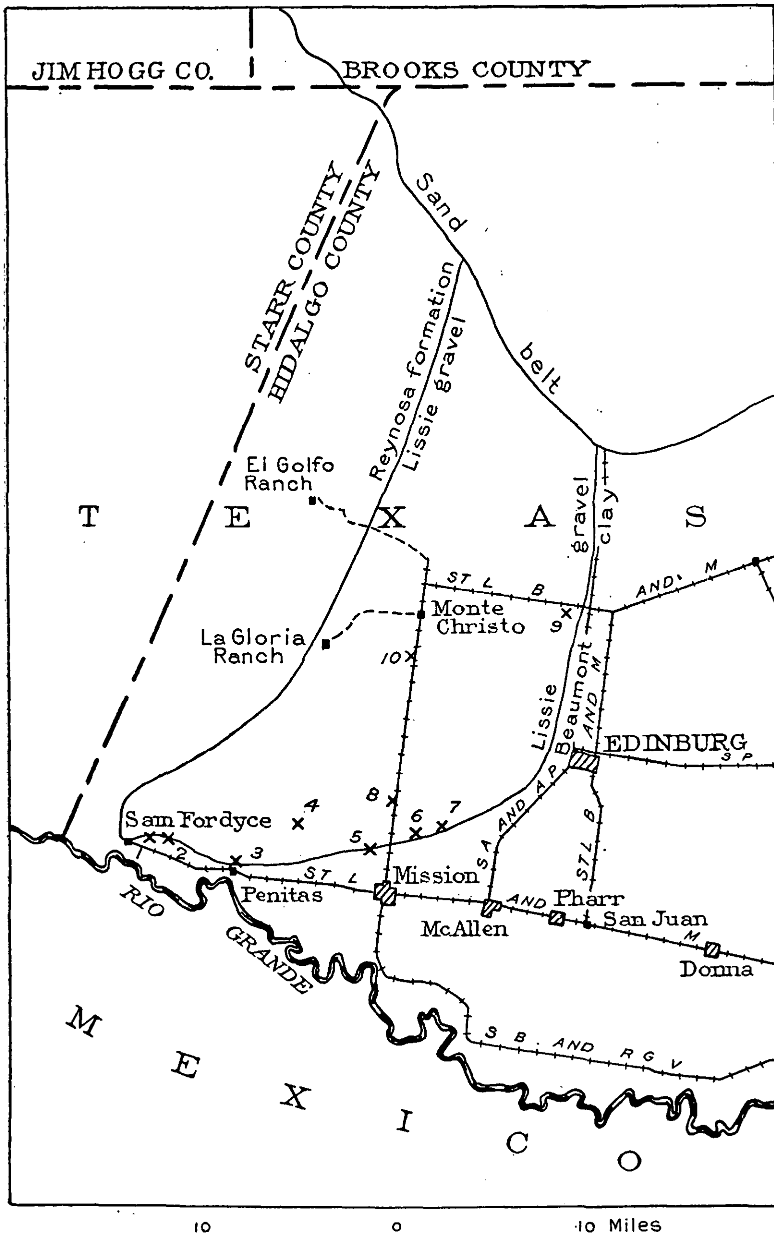

FIGURE 74.—Sketch map showing the areal extent of the Lissie gravel and the location of exposures described

Two miles east of Samfordyce (2, fig. 74), 200 yards north of the main road, there are large pits exposing 30 to 35 feet of gravel interbedded with a subordinate quantity of sandstone, clay, and limestone.

The four kinds of material grade into one another vertically and horizontally. The gravel is loosely cemented and roughly stratified, and the pebbles average less than an inch in diameter, although there are lenses and pockets containing cobbles as large as 7 inches in longest diameter. In places white clay balls 10 to 12 inches in diameter occur within the gravel. The sandstone is gray, soft, friable, laminated, and cross-bedded, takes the form of lenses, and has pebbles scattered through it. The clay is fine and gritless but contains lenses and pockets of sand and gravel and even an occasional cobble. The limestone is soft and white, contains pebbles, and is here at the top of the exposure.

A quarter of a mile east of locality 2 is another pit, which exposes loosely cemented gravel and sandstone occurring in lenses.

In another pit of considerable size at Penitas (3, fig. 74), the gravel is fairly clean, with little sand, clay, or limestone. One 4-foot bed is cemented with calcium carbonate, but otherwise the gravel is unconsolidated. According to the manager of the pit, the sorter shows that about 1 per cent of the gravel is of a grade coarser than 4 inches in diameter, the grade between 1½ and 4 inches runs 25 to 50 per cent of the whole and averages close to one-third, the grade between ⅝ and 1½ inches varies but averages about one-third of the whole, and the grade less than ⅝ inch varies proportionally but averages almost one-third. Of this finest grade about 15 to 35 per cent is dirt and fine waste. Pebble counts in each of the three main grades resulted as given below.

Pebble counts in gravel from pit at Penitas, in percentage

	1½ to 4 inches	⅝ to 1½ inches	Less than ⅝ inch		1½ to 4 inches	⅝ to 1½ inches	Less than ⅝ inch
Chert	54	67	60	Vein quartz	12	----------	10
Limestone	8	11	8	Basalt	4	1	2
Porphyry	8	5	----------	Felsite	10	15	20
Rhyolite	4	----------	----------	Conglomerate	--------	1	----------

East of Penitas the bluff is so low and indefinite that it is not traceable and no more pits occur.

Other exposures.—About 9 miles east of Samfordyce and 5½ miles northwest of Mission (4, fig. 74) a patch of white limestone with red sandy clay is exposed. Between this point and the Rio Grande terrace 2½ miles to the south the surface material is reddish brown and dark gray and only slightly sandy.

White limestone is exposed 2 miles north and half a mile west from Mission (5, fig. 74) and 3 miles north and 1 mile east from Mission (6, fig. 74).

At Sharyland, 4½ miles northeast of Mission (7, fig. 74), there is a pit 4 feet deep and an acre in area, from which white limestone has been taken for paving drives and building a swimming pool, and similar material is taken from a cistern half a mile northeast of this point.

White limestone and red sand are exposed 4½ miles north of Mission on the road to Monte Cristo (8, fig. 74).

In an area of several square miles from 3 to 7 miles southeast of Monte Cristo there is no limestone at the surface and no red soil but only black loam with a thin veneer of gray sand.

From 5 to 13 miles north of McAllen the surface is directly underlain by black loamy soil, without limestone, sandstone, or gravel in sight. About 7 miles east of Monte Cristo (9, fig. 74) white limestone is exposed, and for several miles north and east of this point red sand and limestone are the prevailing surface materials. For 2½ miles east of Monte Cristo the road to Edinburg leads over white limestone and red sandy surface material.

White limestone has been taken from a pit 2½ miles south of Monte Christo (10, fig. 74). The limestone underlies dark-gray sandy loam, which continues at the surface northward to Monte Cristo and thence westward to La Gloria. Between Monte Cristo and the El Golfo ranch, 7½ miles to the northwest, the surface material is red and gray sandy loam with two or three exposures of white limestone.

In the southern part of the sand belt and extending northward through the sand to Falfurrias there are occasional patches of limestone or caliche. It crops out extensively at the El Tule ranch house, although dark-gray soil with small calcareous pellets prevails for several miles eastward.

Subsurface sections.—According to Tom Gill, rancher and former well driller, artesian wells at and around Mission penetrate 700 to 800 feet of gravel, sand, and limestone without order or arrangement, no two logs showing the same sequence, and at depths around 700 feet blue clay containing shells is commonly entered. The upper material of complex structure is probably Lissie and Reynosa, and the underlying clay may be the Lagarto clay.

Wells in eastern Hidalgo and Brooks Counties and in Willacy and Cameron Counties penetrate to depths of 3,000 feet or more without striking materials similar to the exposed Lissie or Reynosa. As the Niels Esperson well (p. 182) entered Miocene beds at least as high as 3,225 (?) feet below sea level, the nonmarine Lissie and Reynosa probably grade into marine sediments of equivalent age not far east of their outcrops.

Origin.—The Lissie gravel probably represents a time of stream deposition following the erosion of the surface of the Reynosa, from which its materials were derived.

BEAUMONT CLAY

Name and correlation.—Throughout the West Gulf Coastal Plain there is a coastal belt of clay that has been named and classified in various ways. Hilgard[30] first described such deposits in Louisiana in 1869 under the name Port Hudson, and in 1884 Loughridge[31] applied the same name to coastal clays in Texas. In 1894 Dumble[32] named these sediments in Texas the "Coast clays." In 1903 Hayes and Kennedy[33] applied the name Beaumont clay to the coastal clays of Texas and Lousiana, lying on what they termed the Columbia sands and underlying what they termed the Recent or Port Hudson clays. Thus the original Beaumont clay included clay and sand of Pleistocene age between the earlier Pleistocene gravel now known as Lissie gravel and the coastal, fluvial, and eolian sediments still in process of deposition, and this is the sense in which the name is used in this report. However, as pointed out by Deussen,[34] Hayes and Kennedy were probably mistaken in classifying the Beaumont clay as older than Hilgard's Port Hudson. These two formations may not be exact equivalents, but their approximate equivalency is more likely than that one is Pleistocene and the other Recent.

The Beaumont clay is correlated in time with the Columbia group of the Atlantic coast.

Areal extent.—The Beaumont formation is covered by Recent wind-blown sand for about 50 miles southward from the north border of this region, and still farther south by the younger clay and sand that form the present delta of the Rio Grande, but it is exposed at some places in the narrow strip north of the sand belt in northern Hidalgo County, where at places it has been uncovered by the migration of dunes, and south of the sand belt in Hidalgo County above high-water mark in the Rio Grande. Its areal distribution, with as much accuracy as it can be distinguished from the Lissie below and the Recent sediments above, is shown on Plate 7.

Character.—The Beaumont formation consists of blue and red calcareous clay, weathering yellow, a few thin lenses of sand, and a few scattered calcareous concretions. It includes also, as shown by well logs, a few beds of gravel that are not exposed at the surface. The formation is coarser near the Rio Grande than elsewhere. The surficial material of the formation in its belt of outcrop is chiefly dark-gray clay loam overlain by a thin sheet of drifting sand.

[30] Hilgard, E. W., Summary of results of a late geological reconnaissance of Louisiana: Am. Jour. Sci., 2d ser., vol. 48, pp. 332–333, 1869.

[31] Loughridge, R. H., Physico-geographical and agricultural features of the State of Texas: Tenth Census, vol. 5, pt. 1, p. 22, 1884.

[32] Dumble, E. T., The Cenozoic deposits of Texas: Jour. Geology, vol. 2, pp. 564–566, 1894.

[33] Hayes, C. W., and Kennedy, William, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 212, pp. 20, 27–29, 1903.

[34] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 111, 1924.

Fossils.—No fossils were found in the Beaumont of this region, but marine or brackish-water forms including *Rangia cuneata* Gray and *Ostrea virginica* Gmelin and probably reworked vertebrates including *Elephas* and *Equus* are reported from the formation farther north.[35] Remains of trees are also reported in well borings.

Thickness.—In this region no well logs are available in which the Beaumont can be distinguished from the overlying sediments or even with certainty from the underlying Lissie, which, as explained on page 207, does not consist of nonmarine gravel far east of its outcrop, and therefore the thicknesses of the Beaumont can not be determined. Farther north thicknesses ranging from 300 to 900 feet are assigned.[35]

Exposures.—Beginning about 2 miles east of Falfurrias and extending for 10 miles eastward toward Sarita, shallow drains, some of them ending in standing water, suggest that the underlying material is clay rather than the porous Lissie gravel, which prevails at and west of Falfurrias. On the south side of the Sarita road 12.3 miles east of Falfurrias the dump of an excavation for a tank consists of yellowish-gray compact clay. For about 5 miles southwest of Sarita there are many fresh-water lagoons surrounded by sand, which doubtless have nonporous clay bottoms. About 3 miles east of Sarita there is a shallow pit from which clay has been taken to harden the otherwise sandy road. The sandy clay is 2 feet thick and covers 1 foot of pure stiff yellowish clay. In the sand belt on the Kennedy ranch between La Para and the Carnestolendas ranch there are shallow depressions among the dunes, some of which are dry and have clay bottoms and some of which contain fresh water.

Just west of La Pita ranch, 9 miles northwest of Armstrong, there is a shallow laguna with a clay bottom, and several similar lagunas occur between this ranch and Armstrong. Gray sandy clay underlies a thin sand layer at Armstrong, and blue gummy clay crops out along the railway south of Armstrong. Dark sandy soil 4 feet thick overlies caliche 1½ miles south of Armstrong.

About 1 mile northeast of the San Jose ranch and 13 miles northeast of Norias there is an outcropping ledge 150 feet long of light-gray sandstone coated dark by vegetation. The rock is soft and friable but is consolidated. The east bank of a salt lake 6½ miles west of Yturria exposes 7 feet of red clay overlain by 2 feet of surficial gray clay with lime nodules. There is a clay subsoil for several miles northeast and east of Raymondville, and on the old Clark ranch, 3 miles east and 2 miles north from Raymondville, 7 feet of reddish-brown compact, stiff structureless clay is exposed in an abandoned cistern. About 7 miles east of Raymondville a patch of light-gray sandstone containing pellets of white limestone appears in the clay.

[35] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 111, 1924.

About 5 miles southwest of Raymondville blue gummy clay crops out in the road.

East 1½ miles and north a quarter of a mile from Edinburg an irrigation ditch exposed 6 feet of brownish coarse clayey sand with limestone pellets the size of a pea and smaller, and in an Edinburg street a patch of limestone or caliche crops out.

Mission Ridge, between Closner, where the Rio Grande bluff ends, and a point about 3 miles west of Mercedes, where the river breaks through to the north in time of flood, is above high-water mark and is therefore mapped as Beaumont, although there are no exposures. The surface materials are dark clayey and sandy loams, with scattered patches containing calcareous pellets.

Wells penetrating Beaumont clay.—A well at the Lemon & Odell property 10 miles west of Lyford is reported to have penetrated about 60 feet of clean gravel with pebbles 3 inches in diameter, beginning at a depth of about 150 feet.

Driller's log of well at Panchita School 7½ miles west of Sebastian

[H. C. McGavach, driller]

	Feet
Blue and yellow clay	6
Fine nearly white dry sand	8
Light-yellow clay	2
Tough pink clay	10
Sand and clay with salt water in sand	7
Tough blue clay	10
Sand and salt water	8
Soft red and pink clay	15
Sand and clay	434
Reddish clay	100
Clay and sand	55

The following descriptions of samples from the Mercedes well, 3 miles southeast of Mercedes, Hidalgo County, by the Bureau of Economic Geology of the University of Texas, were submitted by D. D. Christner:

	Feet
Worn gravel mostly 4 millimeters in diameter, consisting of about 50 per cent of limestone, 40 per cent of chert and quartzite, and 10 per cent of clear quartz	130–202
Grayish-brown sand with many broken pebbles of brown and black chert and limestone. Most of the sand grains are more than ⅛ millimeter in diameter and are rounded. *Textularia* and a minute fragment of lignite. Pyrite	852
Reddish-brown calcareous silt and sand. The sand grains are worn and mostly ¼ and ⅛ millimeter in diameter. *Globigerina*	1, 053
Gray calcareous sandy silt. Most of the sand grains are between ¼ and ⅛ millimeter in diameter and are well rounded. Several small fossils resembling *Textularia*	1, 430
Light-gray sandy silt. No fossils	1, 770
Gray coarse sand and gravel with silt and a few fragments of dark shale. Gypsum. Fossils resembling *Textularia* and *Globigerina*	1, 970

	Feet
Worn quartz sand with some calcareous and argillaceous matter. Fossils were a few specimens of a slightly curved shell showing horizontal tubular structure. Much pyrite. Sample is badly discolored by iron	2, 167
Gray calcareous silty sand. Fossils resembling an echinoid spine (?), *Textularia*, and *Globigerina?* Many fragments of shells. Some crystalline calcite and some pyrite	2, 208–2, 225
Bluish gray calcareous silt and sand with a few fragments of reddish-brown silt. Many fossils resembling small *Textularia*, *Globigerina*, *Cristellaria*, one *Clavulina*, *Biloculina* of modern aspect, and fragments of large bivalve shells. Pyrite	2, 308
Calcareous silty sand, containing many fragments of flat (pelecypod) shells and many Foraminifera. An echinoid spine and some small pyritized fossil fragments. The Foraminifera resemble *Textularia*, *Globigerina*, and *Cristellaria*, of modern aspect	2, 429–2, 444

According to Doctor Udden all these samples are probably Pleistocene.

The following descriptions of samples from the South Texas Trust Co.'s Brown No. 1 well, 15 miles east of Brownsville, Cameron County, by the Bureau of Economic Geology of the University of Texas, were submitted by Lon C. Hill, jr., of Brownsville.

	Feet
Light-gray loose calcareous sand containing many fragments of shells of pelecypods and small gastropods. The sand grains are worn and etched and are from ½ to ¹⁄₁₆ millimeter in diameter. *Textularia* and *Globigerina* in the fine material. In closed tube a faint peaty odor	683–755
Light brownish-gray sand like that at 683–755 feet	786–816
Light salmon-red and light bluish-gray marly clay containing much sand like that at 683–755 feet	816–867
Light-gray silty sand, giving faint peaty, bituminous odor	871–954
Loosely cemented light-gray calcareous sand containing some argillaceous material. The sand upon being washed is seen to be like that at 683–755 feet. Faint peaty, bituminous odor	996–1, 059
Light-gray sand like that at 683–755 feet. A larger part of this sand is below ⅛ millimeter in diameter. Faint peaty odor	1, 100–1, 118
Bluish-gray slightly indurated marl containing some fine quartz silt. A small amount of pyrite and a few flakes of mica. In washed material several minute tests of *Globigerina* and *Textularia*. In closed tube faint peaty fumes and faint fumes of ammonia and sulphur	1, 118–1, 164
Light-gray marl containing shell fragments and worn sand. Some lumps of granular material, calcite. Fragments of larger shells. Ostracode valves, *Textularia* (several species), *Anomalina*, and a few *Globigerina*. In closed tube a very faint peaty bituminous odor	1, 164–1, 206
Light-gray and pinkish-gray marl containing considerable sand. This sand is made up of much igneous material, such as red chert, granite, and magnetite, in fragments less than 1 millimeter in diameter as they occur in the sample, and quartz grains. From the fresh fractures and sharp angles of most of the pieces, it would seem probable that larger pebbles had been	

	Feet
broken by the drill. Fragments of *Ostrea*, also *Textularia* and other Foraminifera. In closed tube a very faint bituminous odor	1,478–1,570
Light-gray marl of fine texture containing many fragments of shells of very recent aspect. Considerable fine granular sand. Several specimens of *Anomalina*. In closed tube very faint bituminous fumes	1,640–1,751
Dirty pinkish-gray and greenish-gray marl. Some pyrite and considerable clear quartz sand with many black grains. Tests of *Cristellaria, Anomalina, Globigerina*, and *Textularia*. Fragments of larger mollusks and carbonized wood. In closed tube a faint peaty bituminous odor	1,751–1,856
Light-gray marl containing some fine sand and shell fragments. Fragments of a claw of a crustacean; also usual Foraminifera. In closed tube only very faint peaty, bituminous odor and faint ammonia fumes	1,800–1,920
Light-gray marl containing some very fine sand. *Globigerina Textularia*, and several *Anomalina*. In closed tube a faint peaty odor	1,961–2,023
Gray marl containing considerable fine angular sand. Shell fragments and Foraminifera resembling *Cristellaria, Anomalina, Globigerina*, and *Textularia*. Some pyrite, apparently primary. In closed tube strong ammonia fumes	2,037–2,108
Gray loose sandy marl containing some fragments of large shell and aggregates of fine sand grains held together by a calcareous cement. Considerable sand, containing grains of red chert and quartz stained by iron rust. *Textularia, Anomalina*, and black fragments of fish teeth(?). Pyrite	2,208–2,250
Gray marl containing some fine, slightly worn sand. No fossils. Minute calcareous concretions. In closed tube weak fumes of ammonia and sulphur	2,251–2,276
Greenish-gray marl containing some fragments of large shell. Quartz sand containing some round grains of pink chert and a small amount of pyrite. *Textularia, Globigerina*, and *Anomalina*. In closed tube strong sulphur fumes and faint fumes of ammonia	2,276–2,300
Light greenish-gray marl containing considerable worn quartz sand and worn grains of black chert. Some pyrite. A worn *Textularia* and a fragment of an *Anomalina*. In closed tube, strong ammonia fumes	2,326–2,339
Light greenish-gray marl containing some worn sand. A small amount of pyrite. A worn *Globigerina* and a *Textularia*. In closed tube a faint odor of sulphur and faint ammonia fumes	2,354–2,370
Gray silty marl containing ostracodes, *Textularia?, Globigerina, Anomalina, Cristellaria*, ammonoids, a small *Pecten* valve, and many fragments of small oysters and other pelecypods	3,359–3,403
Gray sandy marl containing fragments of large shells and entire ostracodes, *Globigerina, Textularia*, and *Anomalina?*. Sulphur and ammonia fumes in closed tube	3,403–3,450
Gray marl containing much sand. Several *Textularia* and a small spirally coiled test, possibly *Anomalina*	3,425
Bluish-gray sandy marl. The sand grains are below ¼ millimeter in diameter. Pyrite. *Globigerina, Cristellaria, Anomalina?*, and several imperfect specimens of *Textularia*. In closed tube ammonia fumes	3,654

Although no characteristic fossils were found in the samples described above, J. A. Udden states that the sediments at the bottom of the drilling are in the Pleistocene or late Pliocene. Some of the samples from shallow depths may be Recent, and some of those taken near the bottom of the drilling may represent the marine equivalent of the Lissie or even perhaps of the Reynosa; otherwise they doubtless record the littoral phase of the Beaumont. A driller's log of the same well, furnished by Doctor Udden, is given below:

Driller's log of Brown No. 1 well of South Texas Trust Co., 15 miles east of Brownsville

	Feet		Feet
Red clay	0–10	Gumbo and boulders	2, 074–2, 087
White water sand	10–40	Shale	2, 087–2, 099
Water sand	40–115	Gumbo	2, 099–2, 108
Red clay	115–135	Gumbo and boulders	2, 108–2, 158
Water sand	135–153	Shale	2, 158–2, 185
Gumbo and boulders	153–256	Gumbo and boulders	2, 185–2, 213
Hard sand	256–300	Hard sand	2, 213–2, 276
Gumbo	300–320	Broken sand	2, 276–2, 300
Pack sand	320–346	Gumbo and boulders	2, 300–2, 310
Gumbo	346–433	Hard sand	2, 310–2, 339
Water sand	433–529	Gumbo and boulders	2, 339–2, 354
Gumbo	529–547	Sandrock	2, 354–2, 365
Water sand	547–632	Sandrock (containing lime)	2, 365–2, 378
Blue gumbo	632–683	Sandrock; showing of gas at 2,416 feet	2, 378–2, 444
Sand	683–755	Gumbo	2, 444–2, 448
Gumbo	755–765	Sandrock	2, 448–2, 452
Blue gumbo	765–786	Rock	2, 452–2, 455
Water sand	786–816	Sand and boulders	2, 455–2, 460
Red gumbo	816–867	Gumbo	2, 460–2, 464
Sand	867–871	Sandrock	2, 464–2, 498
Fossil sand	871–954	Boulders	2, 498–2, 501
Gumbo	954–996	Sandrock	2, 501–2, 506
Water sand	996–1, 059	Gumbo	2, 506–2, 516
Gumbo	1, 059–1, 101	Sand	2, 516–2, 524
Hard sand	1, 101–1, 116	Shale	2, 524–2, 533
Gumbo	1, 116–1, 164	Hard sand	2, 533–2, 535
Shale	1, 164–1, 206	Shale and boulders	2, 535–2, 560
Gypsum	1, 206–1, 227	Sandrock	2, 560–2, 566
Gumbo	1, 227–1, 311	Hard sand	2, 566–2, 568
Gumbo and boulders	1, 311–1, 470	Gumbo	2, 568–2, 569
Gumbo	1, 470–1, 800	Shale and boulders	2, 569–2, 680
Gumbo and boulders	1, 800–1, 820	Sandy shale	2, 680–2, 722
Gypsum	1, 820–1, 856	Shale, gumbo, and boulders	2, 722–2, 743
Gumbo and boulders	1, 856–2, 003	Shale and boulders	2, 743–2, 775
Broken sand	2, 003–2, 023	Hard sand	2, 775–2, 812
Hard sand	2, 023–2, 029	Gumbo	2, 812–2, 827
Sandrock	2, 029–2, 037		
Gumbo and boulders	2, 037–2, 052		
Hard sand	2, 052–2, 074		

The "boulders" reported in the above log are probably merely layers of superior resistance.

Samples from the Brownsville Oil Co.'s well No. 1, 7 miles north of Brownsville, 200 feet east of the railroad track, furnished by G. W. Hindman, are described as follows by the Bureau of Economic Geology of the University of Texas:

	Feet
Quartz, chert, and limestone. Sand grains are about ⅛ to 1/16 inch in diameter and smaller. Samples have probably been washed. (No. 2)	200
Quartz, chert, and a few scattered limestone pebbles, well rounded and from ⅛ to ¼ inch in diameter. (No. 5)	390
Limestone and a few chert pebbles (rounded). (No. 6)	400–405
Gray marl containing white limestone pebbles and brown cherty pebbles, well rounded and about ⅛ to ¼ inch in diameter. Under microscope seen to contain quartz grains. (No. 7)	460–505
Marly sand. About half the sand consists of clear quartz grains and the other half of brown and gray chert and quartz grains. Contains many pebbles of chert and limestone. Some black magnetic material in small grains. (No. 8)	505–512
Gray marl containing quartz sand grains. Gives off much water when heated, also sulphur fumes. Small grains of magnetic material. (No. 9)	512–520
Gray and pinkish marl containing scattered limestone and chert pebbles. Under the microscope much quartz sand was seen. Magnetic particles. (No. 10)	540–550
Limestone and chert pebbles, marl and quartz grains. Small crystals of black magnetic material. (No. 11)	661–665
Gray marl containing rounded pebbles of chert and limestone, also fine grains of quartz and black magnetic material. (No. 12)	695–705
Gray marl containing much quartz sand. Sand is composed of clear white grains of quartz. Some are yellow, brown, reddish, and smoky. Many particles of magnetic material. (No. 13)	705–735
Marly sand containing rounded chert and limestone pebbles. Sand is composed mostly of clear quartz; some yellow, brownish, red, and smoky grains. Many particles of black magnetic material. (No. 00)	721–735
Gray marl containing larger grains of chert and limestone, fine quartz sand. Sand contains mostly clear crystals of quartz; some are yellow, brown, and greenish. Small grains of black magnetic material. (No. 14)	735–740
Quartz sand containing calcareous material. Effervesces in hydrochloric acid. Much magnetic material in fine grains. (No. 15)	740–780
Marly sand. Effervesces with hydrochloric acid. Sand composed of mostly clear white grains; some brownish, yellow, and smoky. Many particles of black magnetic material. *Textularia globulosa*, *Globigerina cretacea*. (No. 16)	780–800
Gray marl containing much sand and well-rounded chert and limestone pebbles. Sand composed mostly of clear quartz grains, also yellow, brown, red, and green grains. Scattered black grains of magnetic crystalline material. *Textularia globulosa*, *Globigerina*. (No. 17)	830–850
Brownish-gray marl. Under the lenses seen to contain grains of quartz sand. *Textularia globulosa*. (No. 18)	850–860

	Feet
Marl. Under microscope seen to contain very fine grains of quartz. (No. 19)	860–870
Gray marl containing quartz sand, composed mostly of clear white quartz; some brown and smoky colored. Some black magnetic particles. (No. 20)	870–885
Gray marl containing much quartz sand Most of the quartz is in clear white grains containing small black magnetic particles, which appear to be crystalline. *Textularia globulosa.* (No. 21)	885–900
Gray marl. Under microscope seen to contain very fine grains of quartz. Scattered particles of black magnetic material. (No. 22)	900–917
Gray marl containing some quartz sand. (No. 23)	917–971
Sandy marl. Sand is mostly clear quartz grains; some yellow, brownish, and green. Scattered grains of black magnetic material. (No. 24)	1, 015–1, 050
Gray marl. Under microscope, seen to contain fine grains of quartz. *Textularia globulosa.* Bituminous fumes in closed tube. (No. 25)	1, 107–1, 142
Marly sand composed mostly of clear quartz; some greenish and brown grains. Black grains of crystalline magnetic material. (No. 27)	1, 216–1, 220
Gray marl. Under microscope seen to contain fine grains of clear quartz. *Textularia globulosa.* Faint fumes of bitumen and sulphur when heated in closed tube. (No. 26)	1, 142–1, 216

The following logs of wells in Willacy and Kenedy Counties were furnished by Mr. W. F. Cummins.

Log of well at Sauz ranch

	Feet
Pale-reddish clay with sand	0–15
Sand and water	15–30
Very pale reddish clay with half sand; some rocks	30–50
Principally sand and water with boulders about every 15 or 20 feet	50–250
Principally sand with a little bluish clay, very soft	250–315
Sand and bluish clay, with rocks; salt water	315–500
Hard rock; probably sandstone	500–512
Yellow sand; plenty of salt water	512–517
Hard rock	517–525
Sand; salt water	525–529
Very hard bluish clay, hard as rock	529–699
Principally rock	699–729
Clay and rock, part reddish and part blue; at top 3 feet of dark-blue sand that carried a great deal of water, which rose to the surface	729–899
Bluish-clay with a few spots of red	899–989
Reddish and greenish clay, very gummy	989–1, 099
Sand, very fine; water flows small stream at surface	1, 099–1, 105

Log of Loma Prieta well, 22 miles northeast of Sauz ranch

	Feet
Reddish clay	62–98
Boulder rock	98–103
Reddish clay	103–158
Reddish clay and boulder rock	158–432

	Feet
Sand; salt water	432–442
Blue clay, sand, boulders, and gypsum	442–596
Pinkish clay with boulders	596–645
Fine sand and boulders	645–650

Log of Gigantia well, 12 miles west of Loma Prieta well and 6 miles from Raymondville

	Feet
Reddish clay	0–196
Blue clay with shells, soft	196–216
Reddish clay with boulders	216–341
Sand; water came in at bottom, 80 gallons a minute	341–380

Log of Andrea well, 5 miles south of Gigantia well

	Feet
Reddish clay	0–120
Hard rock	120–122
Red clay with rock	122–196
Red and white clay	196–220
Reddish clay with boulders	220–336
Rock and white clay	336–465
Red clay	465–490
Coarse red sand	490–500
Red clay with boulders; water sand which flows 80 gallons a minute	500–530

Log of La Fravasada well, 20 miles southwest af La Parra ranch

	Feet
Soil	0–1½
Fine white salty sand	1½–10
Sand; fresh water scarce	10–45
Blue clay and boulders	45–50
Sand and boulders	50–80
Cemented shells	80–82
Sand	82–90
Sand and boulders	90–100
Cemented shells	100–103
Clay and boulders	103–110
Blue and brown clay	110–140
Brown and buff clay	140–265
Cemented shells, dark-blue scallops	265–320
Brown and buff clay	320–330
Soft sandrock	330–335
Hard sandrock	335–360
Tough clay	360–380
Hard crystallized rock	380–380½
Clay	380½–400
Crystallized rock	400–400½
Clay	400½–420
Rock	420–422
Clay	422–440
Rock	440–440½
Blue fine-grained rock	440½–460
Stiff brownish-blue clay	460–500

	Feet
Light-brown clay and sand mixed, harder at bottom	500–615
Gumbo, very hard and tough	615–640
Gumbo, reddish	640–694
Rock	694–696
Clay	696–700
Water-bearing sand, coarse; big flow	700–720
Red clay	720 765
Oil; drops coming on surface of water from fine gray sand	765–766
Red clay, hard	766–780
Sand; salt-water flow	780–800
Clay	800–920
Sand	920–955
Coarse sand; strong flow of water, so strong that it choked up everything and threw sand all over the derrick and floor. Could go no deeper on account of sand	955–975

The term "boulders" used by the drillers in the logs above does not mean siliceous pebbles, cobbles, or boulders but merely hard streaks in sandstone, according to Cummins.[36]

Log of deep well at La Parra ranch headquarters, Kenedy County

	Feet
Clay soil	0–20
Yellow soil	20–70
Sand and shell rock	70–140
Brown gumbo	140–270
Yellow sand	270–285
Brown gumbo	285–335
Gray sand	335–395
Brown gumbo	395–467
Yellow sand	467–562
Soft red sandrock	562–622
Yellow sand and shell rock; salt water	622–702
Gumbo	702–742
Blue shale	742–781
Gumbo	781–793
Blue shale	793–823
Gumbo	823–863
Rock	863–866
Sand; salt water	866–938
Rock	938–939
Blue shale and shell rock	939–1, 013
Gumbo	1, 013–1, 069
Blue shale and shell rock	1, 069–1, 189
Gumbo and shell rock	1, 189–1, 248
Rock	1, 248–1, 250
Gumbo and shell rock	1, 250–1, 287
Gumbo	1, 287–1, 354
Shale and shell rock	1, 354–1, 411
Rock	1, 411–1, 415
Shale and gumbo	1, 415–1, 466

[36] Cummins, W. F., personal communication.

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	Feet
Soft rock	1,466-1,473
Shale	1,473-1,493
Gumbo	1,493-1,510
Shale	1,510-1,570
Gumbo	1,570-1,580
Rock	1,580-1,586
Gumbo	1,586-1,648
Hard blue sand	1,648-1,688
Gumbo	1,688-1,775
Shale and gumbo	1,775-1,825
Hard blue sand	1,825-1,875
Soft rock	1,875-1,880
Hard sand shale and sandrock	1,880-1,981
Soft rock	1,981-1,986
Gumbo	1,986-1,991
Hard sandy shale and sandrock	1,991-2,027
Shale	2,027-2,047
Hard sandy shale	2,047-2,107
Rock	2,107-2,110
Hard shale	2,110-2,130
Hard sandy shale with streaks of gumbo	2,130-2,211
Hard sandy shale	2,211-2,266
Gumbo	2,266-2,272
Hard shale	2,272-2,277
Gumbo	2,277-2,312
Hard sandy shale; oil	2,312-2,373
Rock	2,373-2,375
Sand; gas and salt water	2,375-2,390
Gumbo	2,390-2,515
Blue shale	2,515-2,570
Rock	2,570-2,573
Blue shale	2,573-2,595
Gumbo	2,595-2,600
Blue shale	2,600-2,700
Shale; 6-inch casing set at 2,700 feet	2,700-2,705
Rock	2,705-2,710
Shale and rock shells	2,710-2,742
Blue shale	2,742-2,757
Blue sand; gas and hot water, artesian flow	2,757-2,797
Hard shale	2,797-2,820
Very hard blue shale	2,820-2,830
Hard shale	2,830-2,865
Gumbo	2,865-2,870
Slate	2,870-2,880
Sandy slate	2,880-2,900
Gumbo	2,900-3,000

Origin.—The outcropping Beaumont clays were deposited in estuaries and coastal marshes, and that part of the formation recorded in wells is marine, the shore line standing 25 to 40 miles farther landward during Beaumont time than it does to-day. The formation records a submergence that resulted in a ponding of the streams flowing into the Gulf and a partial filling of their valleys.

TERRACE DEPOSITS

Distribution.—In the immediate valley of the Rio Grande and in the valleys of some of its large tributaries there are a number of terraces, all at levels between the Reynosa upland plain and the present flood plains of the streams. Their occurrence is shown on Plate 7.

Character.—The deposits on these terraces are composed mainly of light-gray and buff silt but include some sand and fine gravel. The terraces are flat topped, except where dissected by erosion, and have steeply sloping riverward edges. At most places there are two or three terraces instead of a single one. These converge downstream until they merge into a single terrace.

Fossils.—The deposits on these terraces have yielded several fresh-water and air-breathing mollusks. The specific list includes

Bulimulus dealbatus Schiedeanus.
Helicina tropica Pfeiffer.
Lampsilis purpuratus Lamarck?
Planorbis tricarinatus Say.
Polygyra texasiana Mori.
Unio tetralasmus var. camptodon Say.
Unio tetralasmus var. manubius Gould.

These forms are Pleistocene or Recent. Heavy dentition on the Unios as compared with those now living in the Rio Grande and its tributaries suggests Pleistocene age rather than Recent.

Pleistocene and Recent vertebrates occur in similar terrace deposits at a number of places on the Brazos River and the Colorado River,[37] but none were found in the terrace deposits on the Rio Grande.

Classification.—The precise classification of these terrace deposits is impossible, for they differ in number from place to place, are not much different in altitude, and all have the same fossils and about the same composition. There being more than one terrace, materials and topographic features of slightly different ages are included.

In surface configuration, topographic position, composition, and fossil content these terraces are so closely similar to the Leona formation of Hill and Vaughan [38] that they were tentatively placed in that formation in the preliminary report.[39]

In 1924 Deussen [40] described terrace deposits in the valleys of the Brazos, Colorado, Little, Guadalupe, and Nueces Rivers, which not only closely resemble the Leona but were included in that formation by Hill and Vaughan, but Deussen did not employ the term Leona.

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[37] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 114, 116, 1924.

[38] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 253-254, 275-276, 1898.

[39] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U. S. Geol. Survey Prof. Paper 131, p. 101, 1923.

[40] Deussen, Alexander, op. cit., pp. 114-119.

As there is still some doubt whether the deposits on the main Leona terrace in the Nueces Basin are to be correlated with the Lissie along the coast, as seems correct to Deussen, or with the Beaumont, and as the recognition of the Lissie on the Rio Grande in the present paper leaves the correlation of the Rio Grande terrace deposits with the Beaumont in some doubt, it seems best at present to describe these terrace deposits without attempting precise classification. It is believed, however, that the Rio Grande terrace deposits represent the landward fluvial equivalents of the Beaumont or the Lissie or perhaps of both, that the main terrace is not far different in age from the main Leona terrace, and that at least the higher terraces are of Pleistocene age.

Details of occurrence.—Silt forming a terrace overlies unconformably strata of Midway and Wilcox age at the bend of the Rio Grande 3 miles north of the Maverick-Webb County line. (See pl. 19, *B*.)

Terraces extend from a point 1 mile above Bluff Crossing, in extreme southern Maverick County, for 7 miles southeastward to the mouth of San Ambrosio Creek, in Webb County. Near the upstream end of this patch of terrace, at a level 60 to 70 feet above the river, were found specimens of *Lampsilis purpuratus* Lamarck, with heavy dentition. About 5 miles from the Chupadero ranch, the lowest terrace is 200 yards wide and 15 to 20 feet above the Rio Grande, and there is another one 40 feet higher and 2 miles wide with sandy and silty gray loam on its surface.

Just above the mouth of San Lorenzo Creek *Lampsilis purpuratus* Lamarck with heavy hinge line and dentition occurs in light-gray silt that forms a terrace 50 feet above river level at a high-water stage. This same terrace, which is flat on top and marshy in places, extends for 3 miles upstream from the Bigford ranch, for 2 miles downstream, almost to the mouth of Concillos Creek, and northward for 2 or 3 miles away from the river. At the ranch house there is a single terrace 51 feet above river level, consisting of 23 feet of silt with *Unio* shells overlying 28 feet of strata in the Bigford formation. Two miles upstream from the house it is 45 feet above river level and consists of 10 feet of gray silt over 35 feet of Bigford strata. Its surface has been built up by wash from the uplands on the north, so that in places away from the river it is 75 feet above river level. East of the ranch house there is a bench subject to the higher floods, 20 to 25 feet above river level in July, 1919, and 100 to 300 yards wide, and a higher terrace with its edge 50 feet above the river. In some places the silt continues to and below river level, and in others, as at and above the ranch house, it lies on bedrock benches. The Unios collected here are of the same species and variety as those found near the mouth of San Lorenzo Creek and at Presidio Crossing on the Nueces River above Crystal City.

The Apache ranch, 8 miles above Palafox, is situated on a terrace that stands 43 feet above the river at a stage higher than normal and extends nearly 5 miles along the river and 2 miles away from the river. In 1919 there was a vertical cliff of silt between the edge of the terrace and the river. This terrace is the main one on the Rio Grande and the highest silt terrace in the region. It is the same as the 45 to 75 foot terrace at the Bigford ranch.

Palafox is on a terrace of considerable extent, which is irrigated by water pumped from the Rio Grande. The main terrace is 63 feet above river level at a fairly high stage and is flat topped and fertile. It is bordered on the side away from the river by precipitous bluffs of the Mount Selman formation, which rise above it for more than 100 feet to the gravel-covered general upland. It is separated from the river by a sandy terrace 31 feet lower and 350 feet wide; another sandy, flat-topped terrace 11 feet still lower and 250 feet wide; and a flood plain 11 feet still lower and 10 feet above the river and 150 feet wide. The ranger camp 1½ miles upstream from the Palafox store is on one of the lower terraces, and San Pedro is on the 63-foot terrace. At the Palafox cemetery 15 feet of light-gray silt and a few thin lenses of sand and grit gravel are exposed in a ditch just below the top of the main terrace, which has a sandy soil and a small amount of fine surficial gravel.

In the bend of the Rio Grande west of Minera is a single flat-topped terrace half a mile wide and 55 feet above the river, the deposit on which consists of light-gray silt that contains shells of *Bulimulus* and *Unio*.

As described by Ashley [41] there are several terraces at Dolores aside from the main and highest one, on which the town is situated and which is 75 feet above the Rio Grande at a mean low stage. The deposit on this terrace consists of silt but is underlain by 16 feet of clean sand and gravel free of clay. It is bordered on the side away from the river by gravel-covered hills of Mount Selman clay and extends for several miles down the river, where it is cultivated by irrigation.

Arroyo Santa Isabella has a terrace of mappable width for 20 miles up from its mouth. (See pl. 7.) Its surface is more nearly level than the present stream bed, so that it grades upstream into the flood plain and downstream into the main terrace about 50 feet above mean low water in the Rio Grande. Between the Cannel road and Webb road crossings the terrace material consists of silt with some fine gravel and is exposed in low cliffs along the stream channel. Near the mouth of the arroyo, in the vicinity of Islitas and San

[41] Ashley, G. H., The Santo Tomas cannel coal, Webb County, Tex.: U. S. Geol. Survey Bull. 691, p. 252, pl. 30, *A*, 1919.

Isabel, high terraces are 1 to 2 miles wide and practically all under cultivation by irrigation.

Laredo stands on a terrace which extends for several miles both upstream and downstream from the city. The surface of this terrace is almost flat, except where cut into by Chacon Creek and other tributaries to the Rio Grande, and is about 60 feet above average water level in the river. The deposit that forms it lies on the irregular surface of the Cook Mountain formation, in some places below river level and in some above river level. Its materials, which are exposed along the Rio Grande from the mouth of Chacon Creek upstream to Nye and in the walls of Chacon Creek in the city, consist of light-gray sandy silt with a few lenses of sand and very fine gravel. There are shells of *Bulimulus* and *Unio* in several exposures 50 or 60 feet above present drainage level. The main Laredo terrace is bordered on the east by a gradual ascent to more or less indefinite benches, which may constitute a terrace about 40 feet higher. The surface of this level is underlain by somewhat coarser materials—sand and fine gravel—than the main terrace. The Reynosa gravel plain is about 150 feet above the main terrace here. In the north edge of Laredo these higher terraces are fairly definite topographically and are exposed to show the gravel of the Reynosa level, silt, sand, and fine gravel under the intermediate bench, and silt and clay in the main Laredo terrace. Still farther upstream, near Nye, there are several subterraces between the main 60-foot terrace and mean river level.

About 3 miles south of Laredo there is a terrace one-eighth of a mile wide 20 feet above the river, another corresponding to the main Laredo terrace 150 yards wide and 45 feet above the river at low stage, and a third 600 yards wide and 85 feet above the river.

At the San Juan farm, 7 miles south of Laredo, 20 feet of silt overlies 41 feet of Cook Mountain strata on the Mexican side of the Rio Grande, and on the Texas side silt is continuous from river level to the top of the main terrace, 60 feet above.

At Dolores settlement there is a silt terrace half a mile wide, and at the mouth of Dolores Creek this same terrace appears, 50 yards wide on each side, and another and higher terrace comes in which is about 50 feet above the river and extends back from the creek a quarter of a mile on each side. The silt on the higher terrace is exposed in an area of many steep-sided gullies just south of the creek where the Laredo-Zapata road crosses. As shown on Plate 7, this terrace extends up the valley of Dolores Creek to the Texas Mexican Railway west of Reiser.

At the Corallitos ranch, 5 miles north of San Ygnacio, the silt terrace is 50 feet above the river, and at the San Francisco ranch, 2½ miles farther south, it contains some fine gray gravel.

The surface on which the town of San Ygnacio stands is 61 feet above ordinary river level and 56 feet above average high-water stages. The silt of which this terrace is composed is shown in vertical cliffs 50 feet high at the river edge. This is probably the same as the main terrace at Laredo.

Three miles north of Zapata a main terrace a quarter of a mile wide is bordered on the river side by a terrace 25 feet lower and on the opposite side by eroded remnants which appear to represent a terrace 30 feet higher. This higher surface is covered with gravel, and 60 feet above it are the gravel-capped hills of the Reynosa surface.

Zapata stands on a silt terrace, which extends half a mile east of the courthouse and widens to more than a mile about 1 mile north of the town. The terrace here is about 50 feet above the Rio Grande, but according to Judge Spohn, of Zapata, it was flooded by the river in 1866. Judge Spohn also reports the finding of charred wood and smoked rocks from old camp fires at depths of 17 to 20 feet below the surface of the terrace.

At the Beleno ranch, 4 miles below Zapata, this same terrace is a quarter of a mile wide, and it is continuous for 7 miles along the river from a point 5¾ miles below Zapata to Chineno and extends for 5 miles up Arroyo Leon and the valley of Clareno Creek.

About 2 miles above Pena there is a terrace 200 yards wide and 60 feet above the Rio Grande.

At Fordyce there is a steep bank from the river 23 feet up to a terrace, which is flat-topped except for low dunes, is 500 feet wide, and is cultivated by Mexicans. At 17 feet higher there is a second terrace, 2,100 feet wide, flat, and covered by large mesquite trees except where cultivated. The third and highest terrace, on the edge of which the Fordyce house stands, is 21 feet above the second terrace, or 61 feet above the river, and 51 feet below the Reynosa gravel-covered hills on the north. This main silt terrace is a quarter of a mile wide, but arroyos that cross it expose sandstone and clay of the Cook Mountain formation beneath the silt. On its surface and embedded in the silt are shells of Pleistocene or Recent fresh-water clams. At Ramireno, three-quarters of a mile southeast of Fordyce, other specimens of these same clams were found.

At Modio Creek, just below Ramireno, there are two terraces, one 28 feet above river level and 225 feet wide and the other 61 feet above river level and 1,200 feet wide. The lower terrace pinches out downstream.

Chapeno stands on a silt terrace 42 feet above the river and from half a mile to 1 mile wide. At Salineno the first terrace is 325 feet wide and 20 feet above the river, the second is 6 feet higher and 375 feet wide, and the third and main terrace, on which the village stands, is 52 feet above the river and half a mile wide. At Santa

Margarita there is a terrace 600 yards wide and 26 feet above the river and a narrower one 52 feet above the river representing the main terrace. At Escondido, 5 miles northwest of Roma, the lower terrace is 26 feet above the river at a low-water stage and is flooded during the high-water stages. At El Fronton, 4½ miles west of Roma, the river flood plain on the Texas side is 0.3 mile wide and is covered with river silt and sand, in some places 20 feet thick. Above this is a terrace 13 feet high and 0.3 mile wide; above this another terrace 23 feet high and 0.2 mile wide; and above this the main terrace, 6 feet high and three-quarters of a mile wide.

A wide silt terrace, believed to be the equivalent of the main terrace at Laredo, which has been traced downstream, is continuous from a point just below Roma to Rio Grande City. Three miles east of Roma there is a steep ascent of 17 feet from the river to a flat-topped dusty mesquite-covered terrace almost half a mile wide. From this there is another clifflike rise to the main terrace, which is half a mile wide and 34 feet above the river. Above this the Rio Grande bluff rises 57 feet to the base of the Reynosa and 67 feet to the rim of the valley.

About 4¾ miles west of Rio Grande City the main terrace is 30 feet above the river and 2.1 miles wide from the low bluffs in the north valley wall to a sharp descent to the river flood plain with its abandoned channels and low sand dunes. Material has been washed out from the bluff on to the surface of the terrace and has given it a slight riverward slope. About 3½ miles west of Rio Grande City this same terrace stands 36 feet above the irregular surface of the flood plain.

The main terrace continues eastward from Rio Grande City, but it is lower and the flood plain widens, thus narrowing the terrace. Half a mile east of Rio Grande City the main terrace keeps the same level from the foot of the bluff north of the main road to a point just back of the Garza ranch house, where the surface drops 10 feet to a lower terrace that slopes gently riverward to its outer edge, which is 18 feet above the river.

At the Refugio ranch, 6 miles southeast of Rio Grande City, the rim of the first terrace is 13 feet above the river. This terrace slopes up for a vertical distance of 5 or 6 feet, and above this slope is a 10-foot ascent to the main upper terrace, on which the ranch stands and which extends northward to the foot of the Rio Grande bluffs.

At Cuevitas the upper main terrace is 8 or 9 feet above the flood plain, which is 13 or 14 feet above the river at a low stage.

At Los Ebanos, 2 miles southwest of Samfordyce, the river bank rises 15 feet to land that is subject to flood only in high river stages and that extends 200 yards from the river. There is another rise to a terrace 100 yards in width that stands 20 feet above the river, and above that, at a level 30 feet above the river at low stage, is the main terrace, which rises 10 to 15 feet as it approaches the bluff and is a mile wide.

From Samfordyce to Closner the main terrace, the deposit on which is composed of silt, laps up on and intersects the low and indefinite Rio Grande bluffs, which are here composed of Lissie gravel; and at Closner the terrace material grades into and is continuous with the Beaumont clay of the coastal region. From its relations here it seems certain that the main Rio Grande terrace is younger than the Lissie gravel and of the same age as the Beaumont clay.

The railroad station at Samfordyce is on a second bottom, 12 feet above river level, which is subject to the higher floods. About a mile east of the town the railroad cuts through a mound of terrace silt 10½ feet above the track, which may represent the main terrace. At Penitas the flat surface of the terrace extends from the base of the Rio Grande bluff, composed of Lissie gravel, which is here so low as to be almost indistinguishable, to the edge of the river, where there is an abrupt drop of 18 feet to the water's edge. The highest floods cover this terrace and extend to the railroad track.

From Chihuahua east a low scarp extends between the slightly undulating surface of the general plain underlain by Beaumont clay and the Rio Grande flood plain with its resacas. This scarp is traceable along the south side of Mission Ridge, passing 1 mile south of Mission, 1 mile south of McAllen, 1.7 miles south of Pharr, 2.6 miles south of San Juan, and almost 2 miles south of Donna. West of Mercedes it is broken where flood water breaks through and around the end of the ridge toward Lake Tio Cano.

RECENT SERIES

FLUVIATILE DEPOSITS

Distribution.—That part of the surface near the mouth of the Rio Grande that is subject to flood from the river is mapped on Plate 7 as recent fluviatile deposits. The Rio Grande flood plain above Closner is too narrow to be mapped separately from the terraces and from the Pleistocene and Tertiary formations where the terraces are absent.

Existing conditions.—Delta deposits are still being formed at the mouth of the Rio Grande. Below Closner, where the normal flood plain merges into the delta, large areas are still subject to flood. What is known as the Mission Ridge, utilized for the railroad, the main automobile road, the "valley" towns—Mission, McAllen, Pharr, San Juan, and Donna—stands above flood water and is included within the Beaumont formation, but even here the land slopes away from and toward the river from the axis of the ridge. Other towns in the "valley," including Llano Grande, Mercedes, Harlingen, Raymondville, Lyford, Sebastian, and Brownsville, are liable to be flooded in years of high water, such as 1909, 1919, and 1922. These towns are on higher land, however, and are now largely protected by great irrigation canals and their borrow pits. Breaks occur in the river banks as far upstream as a point above Mission, and old river channels or resacas are found on the widening flood plain. These resacas extend down the valley as far as Donna, where they unite to form the definite channel of the Rio Colorado, which thus becomes a distributary of the Rio Grande. The channel of the Rio Colorado is as much as 40 feet deep at the deepest point, near Harlingen, and 200 feet wide. It carries safely the flood waters of the Rio Grande except at times of the highest floods, when the water breaks through on both sides of Mercedes and flows into the basin of Lake Tio Cano and thence northward toward Raymondville, eastward toward the Gulf (crossing the St. Louis, Brownsville & Mexico Railway south of Lyford), and back again southeastward to the Rio Colorado near Harlingen. Much of this water never reaches the Gulf, for the surface is so flat and grassy and the Gulfward slope is so low that the water stands in shallow deprssions and behind irrigation canals and there evaporates or seeps into the porous silt and sand.

Composition.—Only the surficial part of this deposit is nonmarine, as the area was reclaimed from the Gulf by the deposition of sediments brought down by the Rio Grande. The lower beds are marine, and marine Foraminifera are found in them where they are penetrated by wells. The material seen in surface exposures is a mixture of highly calcareous and somewhat selenitic gray, blue, red, and brown clay, checked by joints filled with calcium carbonate, gray micaceous sand, gray silt, and some pebbly sand, the whole impregnated with small white pellets of calcium carbonate. The clay greatly predominates.

Clay buttes.—On the surface of the delta, particularly along the coast from Raymondville to Brownsville, there are numerous mounds, 5 to 30 feet in height, made of clay and known as "clay buttes." Though several diverse suggestions as to the origin of these mounds have been offered, the one made by Coffey that they are "clay dunes" seems most reasonable. Most of them lie on the leeward side of shallow depressions, which are doubtless the source of the material of which they were formed. Many of these depressions contain salt lagunas.

Organic remains.—Fresh-water and land shells, bones, logs, leaves, and other organic matter, all of recent age, are found in the fluviatile deposits in considerable abundance.

Details of occurrence.—A mile south of Mission, at Card's sand pit, 11 feet of loose, clean gray fine-grained arkosic sand is overlain by 4 feet of stiff jointed gritless red clay, which is overlain in turn by 4 feet of surficial silty clay containing large numbers of *Bulimulus*. By use of a sand pump at the pit, the sand has been penetrated for 25 feet.

Section in pit 1½ miles south of McAllen

	Ft.	in.
Soil	4	
Reddish clay containing limy pellets	4	
Fine gray micaceous sand, seams and pockets of gravel, a few scattered pebbles and clay balls as large as 6 inches in diameter	22	
Blue clay		6
Gray micaceous sand	3	

The sections at Mission and McAllen may represent the Beaumont projecting through and above the recent fluviatile deposits, but as both are or have recently been subject to flood, they are tentatively placed in these recent deposits.

At a point 4½ miles southeast of Mercedes the Rio Colorado Valley is 39 feet deep and exposes 20 feet of reddish-gray clay with calcium carbonate on joint planes, overlain by 5 feet of stiff black gummy clay in which there are fragments of shells of gastropods similar to those living on the surface to-day.

About 8 miles southwest of Harlingen and 7½ miles southeast of Mercedes 36 feet of lenses of sand, clay, and some gravel is exposed in the banks of the Rio Colorado. Some of the sand lenses are micaceous, and some of the clay is fat. The lenses are 1 to 3 feet thick except one 6-foot lens of calcareous clay. Calcium carbonate is segregated into numerous small, irregular nodules. Snail shells of more than one species, river clams, and badly decayed fragments of bone occur here in large numbers.

Section on the Rio Colorado 1 mile south of Harlingen

	Feet
Loose gray and black sandy silt loam	1–3½
Stiff black clay, breaking into starchlike pieces	1–4
Pink and greenish clay checked with calcium carbonate and containing bone fragments	36

Wells at Harlingen are reported to penetrate clay in beds 1 to 3 feet thick and sand in beds 8 to 10 feet thick within 30 to 60 feet of the surface. Bits of bone and shell are commonly brought up from the wells.

Section at Rancho Colorado, 6¾ miles northeast of Harlingen

	Feet
Brown silty and sandy loam	3
Black compact clay breaking with a starchy fracture	6½
Brown checked clay with calcareous pellets	19

At Rio Hondo the channel of the Rio Colorado is 23 feet deep and exposes reddish-gray and yellowish-gray sandy clay.

At Paso Real, where the channel of the Rio Colorado is 13 feet deep, gray sand containing small snails and other shells is exposed. Five miles northeast of Paso Real shells similar to those found on

Gulf beaches to-day occur in the 7½-foot banks of the Rio Colorado, and still farther east, near the Laguna Madre, a 12-foot bank of gray clay is exposed.

Section at Santa Clara club house, about 15 miles north of Point Isabel

	Feet
Black silt	3
Gray clay	4
Red clay to level of Laguna Madre	12

North of Brownsville light-colored sandy silt is exposed in the banks of resacas from 3 to 15 feet deep.

Section of east end of Loma Alta, a "clay butte," 7 miles northeast of Brownsville

	Feet
Soil	1
Black sandy and salty clay with limy seams	5–6
Brown to pink compact clay seamed with calcium carbonate	2

There are numerous similar "clay buttes," from 5 to 38 feet high, between Loma Alta and the Gulf.

Section in bank of a resaca 4 miles southeast of Brownsville

	Ft.	in.
Brown to gray alluvium	5	2
Black lime-checked compact clay	9	6

Brown to pink compact selenitic and salty clay is exposed at several places on low sea cliffs near Point Isabel.

WIND-BLOWN SAND

Distribution.—As shown on Plate 7 the area in which shifting sand is so nearly continuous and so deep as to obscure the underlying formations extends along the shore of Laguna Madre southward from Baffin Bay to a point east of Raymondville and westward for 75 miles in a belt that is 25 to 50 miles wide from north to south. This area includes practically all of Kenedy, Willacy, and Brooks Counties, the northern part of Hidalgo County and the eastern part of Jim Hogg County. Padre Island also consists chiefly of sand dunes blown up from the beach on the Gulf side of the island.

Surface conditions.—The topography in the sand belt is described on pages 24–25. This is an area of migrating and stationary dunes or "medanos," of sand-covered plains, and of the shallow irregular depressions that are common in all dune areas. Near the coast, where the Beaumont clay underlies the sand, the depressions contain shallow lagunas, some salt and some fresh. There are considerable stretches of sandy prairie, and at many places where there is no surficial sand the Reynosa, Lissie, and Beaumont formations are exposed.

The dunes are sparsely covered with live-oak trees, and the prairies are dotted with patches of live-oak brush. There are also large areas of wild grasses and sacahuista.

Nature of the sand.—Most of the sand is gray or white, but some of it, especially where it overlies the Reynosa formation, is red or pink. The following analyses show its character:

Analysis of material typical of the migrating dunes of the sand belt (sample 02158)

Size, shape, and composition.—In detail as follows:

Size (millimeter)	Per cent	
½-¼	0.6	Quartz present in both well-rounded and angular grains. More are angular. Feldspar and chert and a few heavy minerals are present.
¼-⅛	87.2	Quartz both angular and rounded. Not many heavy minerals.
⅛-1/16	10.4	More markedly angular and rounded. Some rounded grains.
Less than 1/16	1.8	All crystalline. No clay.

Color.—Light gray.

Analysis of material typical of the sandy prairie of the sand belt (sample 02157)

Size, shape, and composition.—In detail as follows:

Size (millimeters)	Per cent	
2-1	----------	Vegetable matter, fresh.
1-1½	2.0	Plant stems, leaf fragments, roots, chitin from insect tests.
½-¼	1.1	Predominantly well-rounded but not frosted quartz. Feldspar rare. Chert grains. Vegetable matter.
¼-⅛	79.9	Well rounded but not frosted, mostly quartz. Other minerals rare.
⅛-1/16	18.6	Angular grains more abundant but many grains well rounded.
Less than 1/16	0.2	Fine material from organic matter, iron oxide, quartz, etc.

Cement.—Sand is loose and unconsolidated.

Color.—Yellow ocher. The color is caused by iron stain on many of the grains. Black specks of organic matter are visible.

The degree of rounding of the larger grains is greater and a larger proportion of the finer grades are rounded in these two sands than in any other of the sands analyzed, indicating that eolian action in the sand belt in recent time has been more intensive than at any other place or time.

Source of the sand.—It has been thought that all this sand was blown inland from the coast, and perhaps much of it was, although there is no greater source of sand here than elsewhere along the coast, but some of it was derived from the Reynosa and Lissie formations, on which the sand in the western part of the belt lies. Here "blowholes" expose the reddish-brown sand of the underlying formations, and the dunes consist of this sand. Even the gray sand may be locally derived, the colored iron coating having been abraded from the grains during eolian transportation.

COASTAL DEPOSITS

Padre Island is a long dune-covered barrier island, which is nowhere more than a mile wide. It encloses Laguna Madre, which is 4 to 10 miles wide. On the Gulf side of the island there are the usual littoral deposits. The beach is sandy and is strewn with innumerable sea shells. The water of the laguna is at most places so shallow that it can be easily waded; indeed at some times and places it is only a mud flat incrusted with precipitated salts. At Point Isabel, however, gasoline launches ply between the mainland and the island, but long piers are necessary, and the boats drag the bottom for considerable distances out from each shore. In the laguna, mud, silt, sand, shells, and salt are all being laid down to form the usual lagoon deposit.

STRUCTURE

REGIONAL DIPS

The scarcity of interpretable drill logs and of surface exposures, the lack of reliable topographic maps, and the reconnaissance nature of the field work made it impossible to determine with accuracy either the direction or the amount of regional dip. Most of the observable dips are abnormal both in direction and in amount, and averages based on these readings are of little value.[42] According to the most reliable figures now obtainable Midway and Wilcox strata west of Carrizo Springs in Dimmit and Maverick Counties dip S. 86° E. at the rate of 61 feet to the mile; the Cook Mountain formation north and east of Laredo in Webb County dips S. 71°-80° E. at 40 to 54 feet to the mile, between Laredo and San Ignacio in Webb and Zapata Counties N. 85° E. at 56 feet to the mile, and farther south in Zapata and Starr Counties N. 73°-77° E. at 112 to 126 feet to the mile; and the oil and gas sands in southeastern Webb County and northeastern Zapata County dip on the average N. 73° E. at 14 feet to the mile.

According to Miss Ellisor[43] an identifiable layer dips east from Laredo 2,600 feet in 18.9 miles (130.7 feet to the mile), then flattens out into a terrace and reverses slightly at the oil and gas fields of Webb County, and this same layer is penetrated in wells as follows:

Depths to "rhyolite sand" at top of the Fayette sandstone

[By Alva Ellisor]

	Feet
Leaseholders field	2,100
Carolina-Texas field	2,100
Sims pool	1,750
Cole-Bruni field	1,900
Schott field (Garcia well)	1,550
Aviators field (No. 2 Ping)	1,680
Henne, Winch & Fariss field (No. 1 Martinez)	1,450
Jonas Will well	1,300
Tom East Ranch	1,900

[42] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande U. S. Geol. Survey Prof. Paper 131, p. 103, 1923.

[43] Ellisor, Alva, oral communication, Sept. 2, 1927.

There is a change in the dip from south of east north of Laredo to north of east south of Laredo, and the amount of regional dip in Zapata and Starr Counties is more than twice that farther north.

OBSERVABLE DIPS

Dips that are steep enough to have been read direct from exposures are shown on Plate 7. With some exceptions these dips are in harmony with the regional dip in so far as direction is concerned, but in amount they range from 1° to 10°.

ANTICLINES AND SYNCLINES

Local reversals of the regional dip constituting anticlines and synclines were noted in a few places.

As shown on Plate 7 and as described by Deussen [44] there are anticlinal and synclinal folds on the Nueces River at and upstream from Pulliam in southern Uvalde County and downstream from Pulliam.

As shown on Plates 3 and 7 and Figure 10 the pronounced westward bend of the outcrops of the Indio, Carrizo, and Bigford formations west of La Pryor and Crystal City indicates the presence of a broad synclinal fold in Zavala and Maverick Counties, and an equally pronounced eastward loop of the same formations and the Midway farther south indicates the presence of an anticlinal fold in Dimmit and Maverick Counties, with its axis plunging east about through Carrizo Springs. No detailed map of these folds is available, but several horizons have been traced for many miles by Getzendaner.[45] One of these, the "Mills bed," is in the Bigford formation about 50 feet above its base. That these folds persist toward the east is shown by the fact that the Cook Mountain-Mount Selman line of contact crosses the railroad 3 or 4 miles east of Big Wells and bends north around Loma Vista about as shown in Figure 74.

Udden [46] described an anticline about 15 miles southeast of Eagle Pass.

Northeasterly dips at Santo Tomas, in Webb County, are not in harmony with the general dip, which is south of east in this part of the region.

Deussen [47] has described an uplift of about 200 feet centering around Torrecillas (now Oilton) and Los Ojuelos, in southeastern Webb County, and has named it the Torrecillas uplift.

There are a general flattening of the dip, some slight anticlinal reversals of dip, and several notable anticlines in the several oil and

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[44] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 40, 41, 55, 127, 128, 1924.

[45] Getzendaner, F. M., personal communication, Jan. 19, 1928.

[46] Udden, J. A., Report on a geological survey of the lands belonging to the New York & Texas Land Co.: Augustana Library Pub. 6, pp. 88-90, 1907.

[47] Deussen, Alexander, op. cit., pp. 124-126.

gas fields of Webb, Zapata, and Jim Hogg Counties. The Carolina-Texas field, just outside the region of this report, is situated on a pronounced anticline that has a closure of 140 feet. (See pl. 26.) As shown in Figure 77, the structure at the Cole-Bruni gas and oil field of Webb and Duval Counties is more complex than elsewhere in this region. In general the field is a terrace, but there are also five anticlines of considerable magnitude and one or two small synclines. In the old Reiser gas field there is a terrace. The Schott-Aviators field is on a terrace that has minor anticlines and noses along it. (See pl. 24.) The Mirando Valley field is on a terrace and a low anticline. (See pl. 23.) The Henne, Winch & Fariss field is also on a terrace that has a few short, low noses. (See pl. 25.) Subsurface data at the Jennings gas field, in Zapata County, indicate the presence of an anticline that has a closure of 120 feet. (See pl. 21.) A water well 17½ miles southwest of Hebbronville on the Allen ranch, Jim Hogg County, is reported [48] to have penetrated a "high" in the Oakville sandstone, which probably indicates the presence here of an anticline but may represent merely a topographic rise in the pre-Reynosa erosional surface. At the Randado field there is an almost flat terrace with irregular noses and one or two low anticlines. (See pl. 27.) There is also a low anticline at the Alworth field. (See fig. 76.)

The structure at the Charco Redondo shallow oil field, in southeastern Zapata County, is not well known, but the strike is nearly north, and the dip on the east side of the field appears to be almost 200 feet to the mile in a direction a few degrees south of east. This notably exceeds the regional dip but does not depart from its general direction. In the field itself there may be a terrace.

Anomalous dips in the vicinity of Roma indicate the presence of an anticline, the details of which are shown in Plate 29.

The relations of these minor folds to the general dip, to one another, and to certain folds in Mexico are shown in Figure 75. The line extended along the strike from the Guerrero dome at the Tamaulipas-Nuevo Leon line in Mexico passes east of the almost parallel axis of the Salada arch of Jones,[49] which is roughly parallel with the Cretaceous-Eocene line of contact. The lines connecting the anticlines at Perez, Mexico, and Roma, Tex.; the Jennings anticline and the Reiser terrace; the Charco Redondo field, the Mirando Valley terrace and anticline, and the Schott-Aviators terrace and anticline; the Alworth anticline, the Henne, Winch & Fariss terrace, and the recently discovered Killam pool; the Randado terrace and anticlines and the new Cole gas pool; and the Cole-Bruni

[48] North, Lloyd, oral communication.

[49] Jones, R. A., A reconnaissance study of the Salada arch, Nuevo Leon and Tamaulipas, Mexico: Am. Assoc. Petroleum Geologists Bull. vol. 9, pp. 123-133, 1925.

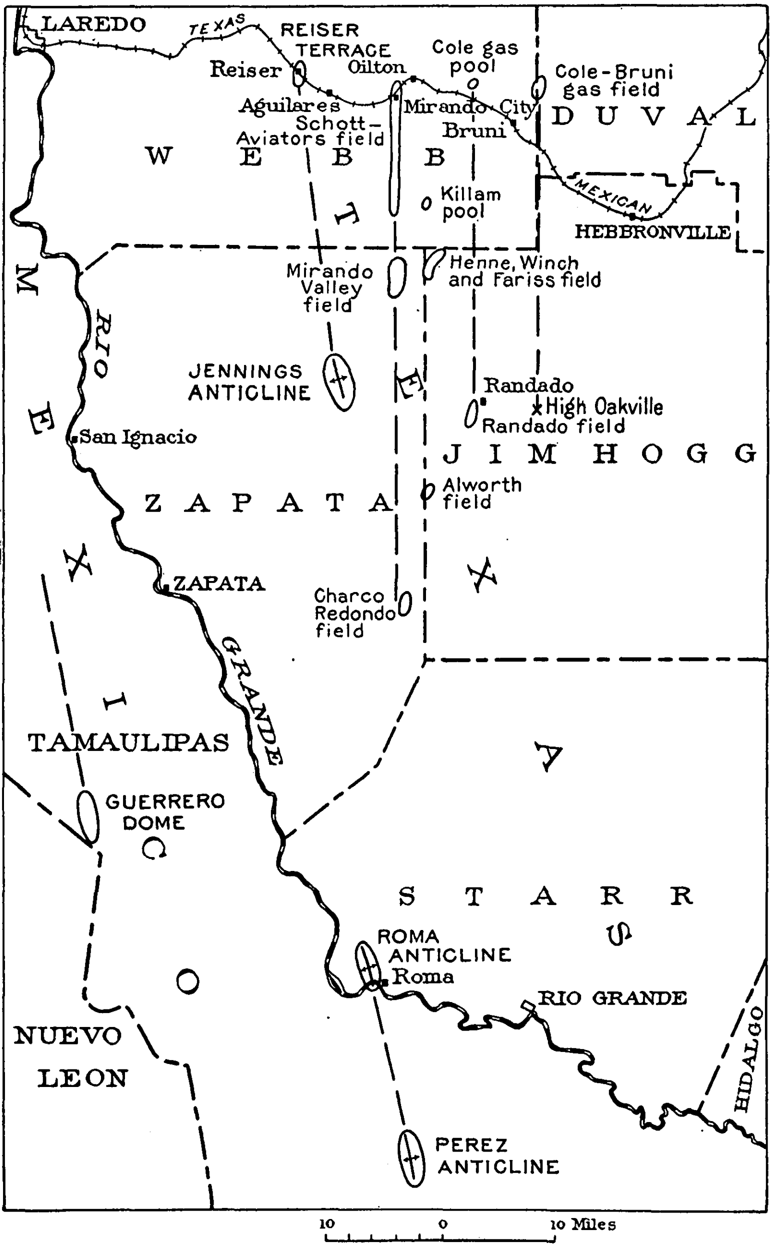

FIGURE 75.—Sketch map showing that the terraces and anticlines of the lower Rio Grande region and adjacent areas in Mexico are arranged in lines parallel with the general strike

terrace and anticlines and the Oakville "high" southwest of Hebbronville are all practically parallel with the strike, which in the western part of the region trends northwest but in the eastern part changes to north.

FAULTS

No major faults were found in the lower Rio Grande region, but a few of small throw were noted.

The Cretaceous-Eocene line of contact is somewhat obscured at Pulliam, on the Nueces River at the Uvalde-Zavala County line, by a small fault.[50] The Indio formation is cut by a fault at the exposure in the big bend of the Nueces 2 miles above the Uvalde-La Pryor road crossing. (See p. 42 and pl. 9, *B*.) The fault plane dips 57°, and adjacent beds have a drag dip of 39°, decreasing to 5° 200 feet from the fault plane. This appears to be a faulted anticline. Perhaps there is under the surface an igneous plug, and this structure may be really of the nature of a bysmalith.

On Chaparrosa Creek about 10 miles west of La Pryor and 1½ miles upstream from the La Pryor-Eagle Pass road there is a fault which strikes N. 60° E. and dips 50° SE. The fault plane is easily traceable by its breccia and slickensides for several hundred feet across and along gullies. The same phase of the Carrizo sandstone crops out on both sides of the fault plane, and the throw is not great.

A fault striking N. 22° W. cuts Bigford strata in Zavala County 8 miles northwest of Crystal City and three-quarters of a mile east of the old Jones ranch house. The strata have been dragged up to parallel the fault plane, which is practically vertical.

In the mines at Dolores the coal beds are cut by faults that strike N. 10°–15° E., dip south of east at high angles, and have throws of 3 to 5 feet.[51]

North of the lower Rio Grande region considerable importance has been attributed to faulting not only in connection with problems of topography, stratigraphy, and structure but also as related to the origin and accumulation of oil and gas.[52]

Pratt and Lahee[53] map a "Webb-Zapata County fault line" that extends far into the region of this report from the north, and Jones[54] concludes that the Bordas scarp in this region and the accumulation of oil and gas are due chiefly to faulting.

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[50] Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, p. 40, 1924.

[51] Ashley, G. H., The Santo Tomas cannel coal, Webb County, Tex.: U. S. Geol. Survey Bull. 691, p. 269, 1919.

[52] Pratt, W. E., and Lahee, F. H., Faulting and petroleum accumulation at Mexia, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 7, pp. 226–236, 1923. Lahee, F. H., The Wortham and Lake Richland faults: Idem, vol. 9, pp. 172–175, 1925. Foley, L. L., Mechanics of the Balcones and Mexico faulting: Idem, vol. 10, pp. 1261–1269, 1926.

[53] Pratt, W. E., and Lahee, F. H., op. cit., p. 232, pl. 2.

[54] Jones, R. A., The relation of the Reynosa escarpment to the oil and gas fields of Webb and Zapata Counties, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 7, pp. 532–545, 1923.

Although the presence of several minor faults in the oil and gas fields of this region is indicated by subsurface data, there is no evidence of major faulting that dominates the structure and controls either the topography or the accumulation of oil and gas. There is no indication of even minor faulting in the Carolina-Texas field (pl. 26), the Mirando Valley field (pl. 23), the Jennings field (pl. 21), the Randado field (pl. 27), the Alworth field (fig. 76), or the Cole-Bruni field (pl. 28). Three faults, all of small displacement, are shown on the structure map of the Schott-Aviators field (pl. 24), and one, also small, in the Henne, Winch & Farris field (pl. 25).

As shown on Plate 29, there are many overthrust faults on the axis of the Roma anticline. In one of these the horizontal overthrust is 10 feet and the vertical displacement is 6 feet.[55]

The date or dates of minor faulting are not certainly known. There is evidence, however, for the belief that the minor faulting is related in time with the main Balcones faulting (see pp. 201–203) and that this main faulting took place just prior to and during the deposition of the Reynosa formation.

SALT DOMES

There is but one known salt dome in the lower Rio Grande region.

FALFURRIAS DOME

Five miles southeast of Falfurrias there are both topographic and lithologic evidences of a salt dome. In this locality there is a conspicuous hill almost entirely surrounded by a salt laguna. The hill is irregular in shape and higher in some places than in others. Its sides are abrupt and cliff-like but irregular, so that there are projections of the laguna into the dome and of the dome into the laguna. One spur of the dome near the west end of its north side rises 45 feet above the laguna, the slope on one side is 450 feet long, the nearly flat top is 285 feet wide, and the opposite slope is 510 feet long.

On the south side of the dome and halfway between its east and west sides platy gypsum crops out from bottom to top of the slope of the dome, and at least 40 feet was exposed in 1920 in a cave developed by solution of the gypsum on a fissure. By 1927, however, the gypsum around the cave had been removed for marketing and the cave was thus obliterated. Drillings show that gypsum occurs close to the surface all over the dome and extends to 600 or 700 feet below the surface. Seismographic work also is reported to have demonstrated the existence of a salt dome here.

The laguna around the dome is salty at all times and deposits 6 to 8 inches of salt when the water evaporates during dry seasons.

[55] North, Lloyd, personal communication.

There is no other salt water so far from the Gulf, and the salt of this laguna is probably derived from the salt core of the dome.

The materials exposed in the low cliffs on the sides of the dome are purely surficial; they consist mainly of calcareous clay and caliche and contain abundant recent snail shells, fragments of crayfish, and decomposed bones. However, there are also some roughly bedded, slightly dolomitic limestones, more compact than the caliche.

None of the recognized Tertiary or Quaternary formations have been identified on the surface or within the dome, although the Lissie-Beaumont contact is traceable from the north to a point within a short distance of it. The surficial materials may include Beaumont or Lissie, but all those exposed have been reworked since their original deposition and may be secondary and associated genetically with the dome itself.

LA SAL VIEJA

There are some indications of a salt dome 42 miles south and a little west of Sarita, about 50 miles northwest of Brownsville, 7 miles west of Yturria, and 8 miles northwest of Raymondville, in the northwest corner of Willacy County. The topographic map of the Saltillo quadrangle published by the United States Geological Survey suggests domal conditions in this locality. Around the elevation is a salt lake, brine from which has been used in a small way for making salt, and small masses of gypsum occur in the clay that is exposed in a low bank around the lake. It is now thought, however, that the hill is not a salt dome, and that the lake is merely a depression scoured out by the wind, which piled up the sand, silt, and clay to make the hill. The salt in the water probably came from surf spray of the Gulf blown onto the surface and was washed into the depression by rain water.

SAL DEL REY

Sal del Rey is a salt lagoon similar to La Sal Vieja, 23 miles north of Donna. It is believed, however, that the salt, like that at La Sal Vieja, has been blown inland from the Gulf and does not indicate the presence here of a salt dome.

LA LOMITA

A roughly circular hill 200 to 300 yards in diameter, known as La Lomita and occupied by the Oblate Fathers' Catholic Mission, projects to a height of 25 feet above its alluvial surroundings on the bank of the Rio Grande 6½ miles south of Mission, in Hidalgo County. Brown-gray sandstone with limy partings, which may be Oakville but is believed to be Reynosa (see p. 190), crops out on two sides, but the dips are not determinable. The top of the hill was drilled in 1920 by the La Lomita Oil Syndicate, of San Antonio, and the drill was reported to have penetrated sandstone for 300 feet below the surface and below that alternating layers of clay and sand and a layer of gypsum or anhydrite 6 inches to 1 foot thick. This is probably merely an erosion remnant of Reynosa sandstone.

INTERPRETATION OF STRUCTURE

The nature of the work on which this report is based does not permit a complete interpretation of the tectonic forces that produced the structural features of the region. North of this region, where faults are prominent, the general strike and the faults are roughly parallel with the Balcones fault zone and seem to be related to this zone genetically. These northeast lines of strike are continued into Uvalde and Zavala Counties. From Dimmit County south, however, where faults are rare and of small extent, the general strike and the trends of the minor folds are in parallel lines that are at least roughly parallel with the large fold that is expressed in the mountains of Tamaulipas, and this large fold and these minor folds are probably related genetically. The anticlines near the Mexican mountains are larger than those farther away, and the folds seem to be smaller and smaller with greater and greater distances from these mountains.

The minor folds and faults in Zavala County may be due to volcanism. Igneous material is reported to have been discovered in a well of the Sun Co. on the line between the Pryor and Mills ranches, and minerals locally derived from igneous rocks are common in well cuttings from a wide area around La Pryor. These anticlines, some of which are faulted, may therefore represent laccolithic and bysmalithic structure. The igneous rocks near the Balcones fault, including those exposed in Uvalde County and those discovered by drilling in Zavala County, are fully described by Lonsdale.[56]

It appears that there are two structural provinces which meet and blend in the northern part of the lower Rio Grande region. The province on the north, dominated by the Balcones fault, connects with the one on the south, dominated by the Mexican anticlinal mountains, in Zavala, Dimmit, and Maverick Counties, where the strike turns from northeast to north and where the La Pryor syncline and the Carrizo Springs anticline are situated.

ECONOMIC RESOURCES

OIL AND GAS

Prior to 1923 more than 45 separate projects were instituted for the development of oil and gas in the lower Rio Grande region.[57] Of these and many new projects that have been started since 1923, several have produced oil or gas or both in commercial quantities.

[56] Lonsdale, J. T., Igneous rocks of the Balcones fault region of Texas: Texas Univ. Bull. 2744, 1927.

[57] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande. U. S. Geol. Survey Prof. Paper 131, pp. 104-105, pl. 28, 1923.

REISER GAS FIELD

Beginning in 1910, the Border Gas Co., a subsidiary of the Texas Co., drilled 40 wells within a radius of 5 miles around Reiser, a station on the Texas Mexican Railway, in Webb County 9 miles west of Oilton. The wells range from 70 to 2,936 feet in depth. The surface rock is in the lower part of the Fayette sandstone, and most of that penetrated by the drill is in the Cockfield formation. (See p. 134.) The strata dip east 30 feet to the mile.

Gas is obtained from the Cockfield and possibly from the Cook Mountain formation at depths ranging from 150 to 1,650 feet. For some years the producing wells in this field supplied natural gas to Laredo and to a large brick plant at Reiser, but after the opening of the Jennings field, farther south, in 1915, the Reiser field was abandoned.

JENNINGS GAS FIELD

In 1914 the Border Gas Co. brought in gas wells on the Jennings ranch, in northern Zapata County, 23 miles due south of Aguilares and 25 miles southwest by south of Mirando, and in 1915 a new main was built to connect with the older Reiser-Laredo main. Laredo began to receive gas from the Jennings field, and the Reiser field was abandoned. The Border Gas Co. drilled 11 wells in the field—8 on the Jennings lease, 2 on the Cuellar lease, and 1 on the Martinez lease. Prior to 1927 the Texas Co. had drilled seven additional wells on the Jennings lease. The producing area is blocked out, and as late as the summer of 1927 new wells were being drilled within the area of production. On August 14, 1927, Jennings No. 7 was brought in with an estimated production of 50,000,000 cubic feet and a shut-in pressure of 760 pounds. Earlier in the year Jennings No. 4 was gaged at 40,000,000 cubic feet. The gas produced in 1927 came from Jennings No. 5 and Cuellar No. 1, and all of it went to Laredo. Gas from the two new large wells, Jennings Nos. 4 and 7, had not yet been marketed, but with pipe-line connections completed to San Antonio, Houston, and the towns in the lower Rio Grande Valley, as well as to Laredo, chances for larger production from this field in the near future were very good.

The surface rock in the Jennings field is Fayette. Jennings Nos. 4 and 7 wells produce from a sand at a depth of 1,900 feet, but all the other wells produce from depths of 1,200 to 1,300 feet. The two deeper wells penetrated gas sands at depths of about 850 and about 1,300 feet in addition to reaching the main producing sand at 1,900 feet. As the surface has an average altitude of 644 feet, the two producing sands are about 600 and 1,250 feet respectively below sea level. Both the shallower and deeper sands are probably lenses or layers in Cockfield clay.

Recent drilling has confirmed the belief of the geologists of the Texas Co. that there is an anticline here. (See pl. 21.)

Log of Jennings well No. 6, Zapata County

	Ft.	in.
Set surface casing, 10-inch with collar	42	10
Shale	120	
Shale; set 6-inch casing; bailed; showed gas and oil	230	
Sand	302	
Green shale	340	
Shale and sand	360	
Sandrock	370	
Soft coal	378	
Soft shale	520	
Gray shale	580	
Blue shale	600	
Do	658	
Rock	660	
Blue shale	700	
Gray shale	710	
Red shale	718	
Shale	730	
Do	732	10
Broken rock; show of gas	740	
Reset 6-inch casing; bailed; casing "O. K."	740	6
Shale	805	
Rock	810	
Shale	840	
Rock	846	
Shale	937	
Rock	940	
Do	960	
Gray shale	969	
Set 4½-inch casing; bailed after drilling to 973 feet; show of gas	970	
Sand; bailed again; trace of gas only	1, 003	
Gray shale	1, 020	
Shale	1, 110	
Rock	1, 113	
Shale	1, 140	
Rock	1, 142	
Shale	1, 180	
Gumbo	1, 202	
Red gumbo	1, 220	
Gray shale; rock set and bailed here; trace of gas only	1, 229	
Sand and white shale	1, 245	
Hard rock and 4 feet of coarse gas sand	1, 250	

Bailed dry at 1,237 feet and at 1,244 feet 5 inches; bailed last time at 1,249 feet 6 inches. Well shows 3,000,000 cubic feet.

CHARCO REDONDO OIL FIELD

In 1920 the Webb-Zapata Co. had drilled 45 wells in the southeast corner of Zapata County to an average depth of 160 feet and found some oil and a very little gas in the Fayette sandstone. The dip here is normal in direction, a few degrees south of east, and is 198 feet to the mile, or somewhat more than the general dip in the neighborhood. As there are no reversed dips, the oil probably occurs in a lens of sand, which pinches out toward the west and is sealed up, for the cap rock crops out 1¾ miles west of the west border of the producing area. Eight of the wells were pumping in 1920, with a gasoline engine on each, and the oil was stored in tanks. The average yield was between 3 and 4 barrels a day from each well.

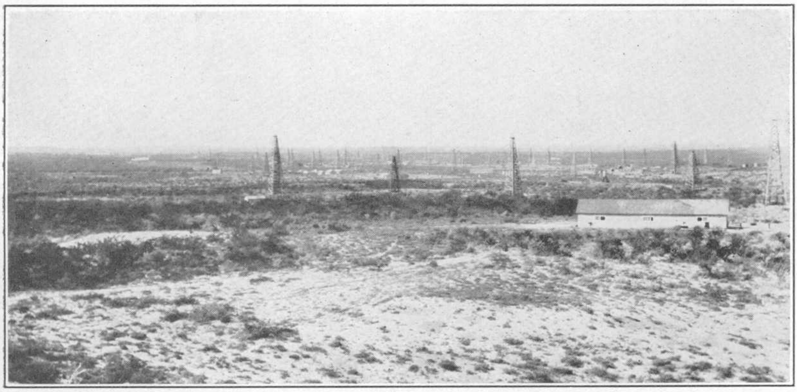
Little if any oil was marketed from this field until December, 1926, when a pipe line was extended to it from newer and larger fields in the district. The first month 4,546 barrels were produced, but for the next three months there was no production. In April, 1927, production started again with 2,395 barrels from 61 shallow wells, and from that time to the end of the year monthly production ranged from 314 barrels in May and 705 barrels in September from 81 wells to 1,368 barrels in July and 1,396 barrels in June from 66 wells, and the total production to the end of 1927 was 14,849 barrels. (See pl. 22.) On the average the wells produced little more than half a barrel a day.

MIRANDO VALLEY OIL FIELD

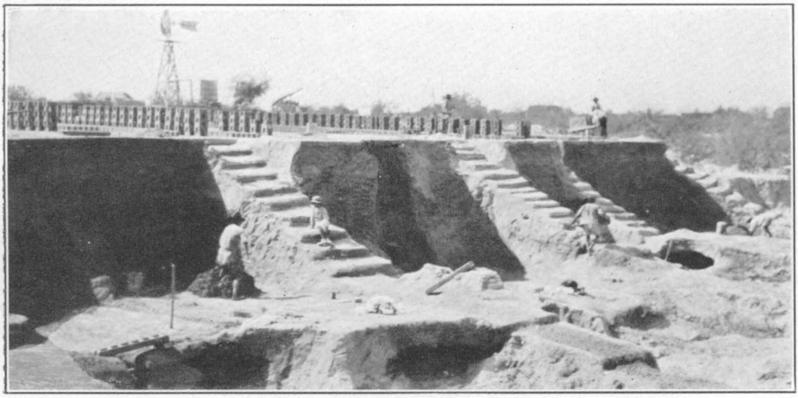
On April 17, 1921, oil was discovered in the northeast corner of Zapata County 10 miles northeast of the Jennings gas field and 15 miles from Mirando, in what is reported to have been a 20 to 100 barrel well. Since that time the producing area, which is about a square mile in extent, has been entirely surrounded by dry holes. Late in 1922, 38 wells had been drilled within the field, of which 18 produced oil, 1 produced gas, and 19 were dry; and the individual wells produced from 8 to 100 barrels a day and averaged about 38 barrels.

Production of oil from this field from the beginning of January, 1922, to the end of 1927 is shown in Plate 22. The maximum production, amounting to 711 barrels a day from 7 wells, was reached in May, 1922; after that date the yield fluctuated within narrow limits but in general declined to an average production of only about 68 barrels a day from 14 wells. To the end of 1927 the field had produced a total of 490,812 barrels. (See pl. 22.) The production per acre varied in different leases from 1,064 to 5,669 barrels and averaged 2,263 barrels.

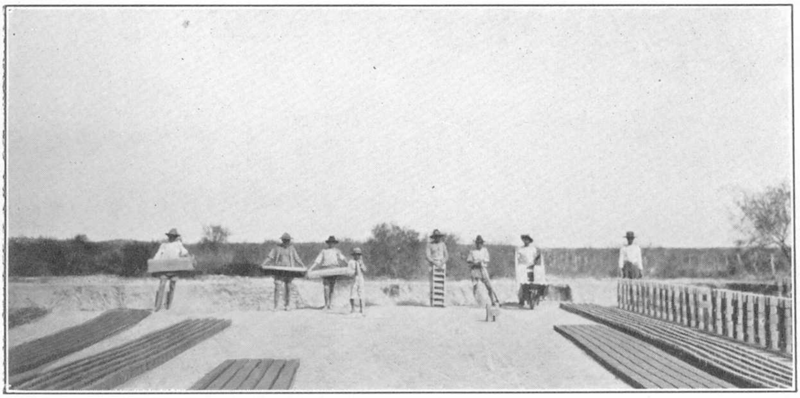
The Mirando Valley field is in a reentrant of the Bordas scarp and at its foot. The surface rock is Frio clay on the plain and Oakville in



A. NORTHERN PORTION OF THE SCHOTT-AVIATORS OIL AND GAS FIELD, NEAR MIRANDO CITY



B. TYPICAL BRICK PIT
Photograph by G. C. Matson.



C. BRICK "RICKS" AT RIM OF PIT
Photograph by G. C. Matson.

OIL-PRODUCTION CURVES FOR THE FIELDS OF THE LOWER RIO GRANDE REGION

Compiled from statistics furnished by Olin G. Bell, of the Humble Oil & Refining Co., and Lloyd North. Figures in parentheses indicate the number of wells from which monthly production was derived.

93804—32 (Face p. 240.)

the escarpment, which is capped by Reynosa. The producing sands are 1,420 to 1,470 feet below the surface and appear to lie in the Fayette sandstone.

As pointed out by Sellards [58] and Wrather [59] the producing sands in the Mirando Valley field are at about the same stratigraphic positions as the shallower sands of the Jennings field, but Sellards tentatively assigned these sands in both fields to the "Yegua" (=Cockfield), and Wrather assigned them to the Cook Mountain. The depth below sea level of the principal bed is about 685 feet.

Log of Mirando Oil Co.'s well No. 1

	Feet		Feet
Clay	35	Packed sand	706–712
Red clay	35–45	Gumbo	712–800
Chalk rock	45–53	Sandy shale	800–808
Packed sand	53–61	Rock	808–812
Blue shale	61–115	Shale	812–826
Chalk rock	115–120	Rock	826–828
Shale	120–125	Shale	828–840
Rock	125–132	Gumbo	840–870
Blue shale	132–150	Shale	870–900
Red shale	150–185	Gumbo	900–955
Gray shale	185–212	Rock	955–965
Gumbo	212–216	Hard sandy shale	965–1, 000
Rock	216–221	Rock	1, 000–1, 010
Shale	221–232	Shale	1, 010–1, 020
Rock	232–233	Gumbo and shale; gas and oil showing; tested	1, 020–1, 040
Sand	233–250	Hard shale	1, 040–1, 070
Rock; oil	250–254	Rock	1, 070–1, 075
Shale	254–293	Shale	1, 075–1, 090
Rock	293–298	Gumbo	1, 090–1, 155
Shale	298–356	Rock	1, 155–1, 160
Rock	356–359	Gumbo and shale	1, 160–1, 225
Sandy shale	359–365	Rock	1, 225–1, 230
Hard rock	365–367	Gumbo and shale	1, 230–1, 320
Packed sand	367–380	Rock	1, 320–1, 325
Shale	380–414	Sand	1, 325–1, 328
Gumbo	414–420	Shale	1, 328–1, 380
Sandy shale	420–495	Sandy shale, oil bearing	1, 380–1, 400
Gumbo, very tough	495–550	Gumbo; still going	1, 400–1, 460
Sandy shale	550–625		
Gumbo, red shale	625–700		
Rock; oil showing	700–706		

[58] Sellards, E. H., Notes on the oil and gas fields of Webb and Zapata Counties: Texas Univ. Bull. 2230, p. 10, 1922.

[59] Wrather, W. E., The Mirando Oil Co. well, Zapata County, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 5, pp. 625–626, 1921.

Log of Mirando Oil Co's Hinnant well No. 2

	Feet		Feet
Soil and clay	80	Blue gumbo; little shale	764
Green shale and lime	233	Hard green shale	852
Red gumbo	261	Tough blue gumbo	888
Hard green shale	278	Green gumbo	1, 140
Mixed sand and shale	365	Green shale	1, 151
Limerock	368	Blue gumbo	1, 199
Gumbo and pyrite	425	Green sandy shale	1, 218
Limerock	432	Blue gumbo	1, 242
Hard sandy shale	453	Green shale and lignite	1, 267
Hard shale and pyrite	457	Broken shale and gumbo	1, 324
Limerock	459	Sandrock; gas showing	1, 328
Pink gumbo	546	Green shale	1, 335
Sandy shale	578	Blue gumbo and shale	1, 447
Streaked shelly shale	581	Packed sand; oil and gas showing	1, 452
Green shale	629	Tough blue gumbo and shale	1, 508
Blue tough gumbo	710		

This well was spudded in November 5, 1920, by R. T. Ryan. On November 15, R. O. Middlebrook was placed in charge of the drilling. Driller estimated that sand at 1, 447 feet would make 40 barrels of oil a day. The well was cemented in and abandoned March 3, 1921, because of inability to shut the water off.

The structure in the Mirando Valley field is shown in Plate 23. The data are meager and uncertain in some particulars, but terracing is distinctly shown, and there is a probable anticlinal closure of about 15 feet.

As reported by Bostick [60] the oil from this field has a gravity of 22.2° Baumé, contains no light oils, and shows no lubricating stock.

SCHOTT-AVIATORS OIL AND GAS FIELD

All the producing territory, either of oil or gas, from Mirando south to the south end of the Aviators pool is here included within the Schott-Aviators field, although certain local areas of production, such as Mirando, Wolcott, and Mid-Ojuelos, are considered by some to be separate pools. Stratigraphic and structural conditions are essentially the same, however, for this whole area. The entire field including the intervals between the local pools is now drilled, and all production is obtained from the same sands.

The area of production is 11 miles long from north to south and averages about three-fourths of a mile wide. Although the trend of production is generally parallel with the Bordas scarp and at its foot, it follows the strike of the strata rather than the erosional ramifications of the scarp, so that some of the wells are on the Aguilares Plain, at the west foot of the scarp, and some on the Hebbronville Plain, east of the rim of the scarp. (See pl. 20, *A*, and fig. 75.)

[60] Bostick, J. W., Analysis of Mirando Valley oil: Am. Assoc. Petroleum Geologists Bull., vol. 5, p. 626, 1921.

The first well, which gave its name to the northern part of the field, was brought in sometime in December, 1921, and the discovery well in the Aviators pool blew in as a 40,000,000-cubic-foot gasser in June, 1922.

The history of oil production is shown in Plate 22. Starting with about 13 barrels a day from 3 wells, in January, 1922, oil production from this field increased slowly but steadily to 5,316 barrels a day from 145 wells, in June, 1923, when it yielded 95 per cent of the total production from the lower Rio Grande region. After some fluctuation a high point of 7,193 barrels a day from 190 wells was reached in August, 1924, but the production declined rapidly to 2,871 barrels a day from 89 wells in January, 1926.

Early in 1926 production began to rise again, and in July and August, 1926, the field produced an average of 8,021 barrels a day, the greatest daily production for any single field in the history of the region. Later in 1926, however, production again declined, and in December, 1927, the average was only 3,388 barrels a day from 370 wells, but even this output exceeded that of any other field in the region. The production per acre in this field has ranged from 27 barrels in the Niles-Edgington, Puig block 65, in the southern part of the field, to 17,800 barrels in the Garcia, survey 54, near Mirando, and has averaged 3,320 barrels. The average well in the field has produced about 27 barrels a day. The total production from the Schott-Aviators field to the end of 1927 was 9,111,872 barrels. (See pl. 22.)

This field also is at or near the Bordas scarp, and the conditions of oil and gas accumulation are doubtless similar to those of the Mirando Valley field.

Plate 24 shows that the strike of the beds is practically north, that there is a general flattening of the eastward dip so that in some places it is as low as 17 feet to the mile, that in a few places reversed dips make low anticlines, and that there are some irregular "noses" and several small strike or oblique faults.

The producing sands are 1,525 to 1,550 feet below the surface, about 760 feet below sea level, and about 75 feet lower than the producing sands in the Mirando Valley field. The surface rocks here are Frio clay, Oakville sandstone, and Reynosa formation, and the producing sands, like those in the Mirando Valley field, are probably in the Fayette formation.

HENNE, WINCH & FARISS OIL AND GAS FIELD

The Henne, Winch & Fariss field is situated in the extreme northwest corner of Jim Hogg County. It is about 2½ miles east of the Mirando Valley field and in a deep reentrant of the Bordas scarp. The discovery well, No. 1 Martinez, block 3, survey 256, was completed by the Big Bend Oil & Gas Co., June 3, 1924. Some of the wells are on the slope of the scarp, some are on the Aguilares Plain west of the scarp, and some are on the Hebbronville Plain east of it. The producing area is elongated in a line that is curved and departs notably from parallelism with the trend of the scarp, which is here very irregular. The structure is represented in Plate 25, which shows only a slight flattening of the eastward dips, some "nosing," and an oblique fault of slight displacement.

The Henne, Winch & Fariss field started production in November, 1924, with an average of 985 barrels a day. For seven months, from July, 1925, to January, 1926, it produced an average of 3,790 barrels a day from an average of 51 wells, which is larger than the production from the Schott-Aviators field for the same period. Later in 1926 production in the Schott-Aviators field rose to a new maximum and that in the Henne, Winch & Fariss field declined, placing it again in a subordinate position. This decline continued into and through 1927, when its production was about 750 barrels a day from 113 wells and was exceeded not only by the Schott-Aviators field but by the younger Randado field.

To the end of 1927 the total production amounted to 2,789,632 barrels, ranging from 126 to 7,977 barrels to the acre and averaging 3,918 barrels. (See pl. 22).

The producing sand in the Henne, Winch & Fariss field lies on an average more than 1,300 feet below sea level and is probably at a somewhat lower stratigraphic horizon than the Mirando Valley field, on the west, but this sand also is in the Fayette formation.

CAROLINA-TEXAS GAS AND OIL FIELD

Gas and oil have been obtained in considerable quantities from several wells in a small area centering 7 miles east of north of Oilton, just at the boundary of the lower Rio Grande region as mapped.

Log of Carolina-Texas well No. 3

	Feet		Feet
Surface soil	1–10	Shale and boulders	346–400
Clay and boulders	10–30	Gumbo	400–408
Conglomerate rock	30–53	Pink shale	408–438
Clay	53–67	Shale and sand	438–516
Rock	67–76	Blue shale	516–655
Sandy shale	76–122	Pink shale	655–697
Blue shale	122–181	Hard shale	697–750
Water sand	181–192	Water sand	750–778
Sandy shale	192–248	Packed sand	778–805
Gumbo	248–257	Soft shale	805–920
Shale	257–300	Gumbo	920–931
Gumbo	300–308	Water sand	931–946
Shale	308–316	Shale and boulders	946–1, 012
Rock	316–321	Green shale	1, 012–1, 130
Packed sand	321–346	Water sand	1, 130–1, 138

	Feet		Feet
Hard shale	1, 138–1, 160	Pink shale	1, 582–1, 635
Gummy shale	1, 160–1, 200	Blue shale	1, 635–1, 654
Gypsum gumbo	1, 200–1, 210	Shale and boulders	1, 654–1, 700
Gummy shale	1, 210–1, 235	Packed sand	1, 700–1, 712
Soft limerock	1, 235–1, 243	Soft shale; set 6-inch casing	1, 712–1, 800
Hard shale	1, 243–1, 295	Sandy shale	1, 800–1, 850
Rock and gumbo	1, 295–1, 329	Blue shale	1, 850–1, 900
Shale	1, 329–1, 372	Gumbo	1, 900–1, 912
Shale and boulders	1, 372–1, 409	Blue shale	1, 912–1, 974
Packed sand	1, 409–1, 429	Gypsum gumbo	1, 974–1, 979
Gumbo	1, 429–1, 435	Sandrock	1, 979–1, 981
Soft shale	1, 435–1, 445	Sand; gas	1, 981–1, 995
Water sand	1, 445–1, 449	Sandrock	1, 995–1, 997
Hard shale	1, 449–1, 500	Shale	1, 997–2, 005
Pink shale	1, 500–1, 571	Gas sand at 2,005–2,047 feet.	
Gumbo	1, 571–1, 582		

Log of Carolina-Texas well No. 4

	Feet		Feet
Surface rock	0–1	Green shale	990–1, 100
Limerock	1–35	Gumbo	1, 100–1, 123
Sand	35–50	Packed sand	1, 123–1, 130
Sand clay	50–115	Rock	1, 130–1, 134
Limerock	115–152	Gummy shale	1, 134–1, 200
Water sand	152–162	Rock	1, 200–1, 202
Rock	162–170	Shale	1, 202–1, 282
Sandy shale	170–211	Rock	1, 282–1, 286
Rock	211–215	Soft shale	1, 286–1, 420
Shale	215–290	Gumbo	1, 420–1, 438
Gumbo	290–312	Limerock	1, 438–1, 440
Shale	312–365	Sand	1, 440–1, 444
Rock	365–368	Not reported	1, 444–1, 580
Gumbo	368–378	Hard shale and boulders	1, 580–1, 700
Packed sand	378–392	Gumbo	1, 700–1, 722
Rock	392–415	Gypsum shale	1, 722–1, 744
Packed sand	415–430	Hard shale	1, 744–1, 850
Rock	430–439	Gummy shale and boulders	1, 850–1, 925
Gumbo	439–454	Shale and gumbo, green	1, 925–1, 995
Shell sand	454–540	Not reported	1, 995–2, 044
Packed shale	540–564	Gypsum and lignite streaks; set casing	2, 044–2, 050
Shale	564–670	Hard sand	2, 050–2, 061
Hard shale	670–692	Blue sand; lignite	2, 061–2, 068
Pink shale	692–780	Hard sand	2, 068–2, 071
Water sand	780–798	Rock	2, 071–2, 072
Packed sand	798–840	Sand gas	2, 072–2, 100
Shale	840–960	Rock	2, 100–2, 103
Gumbo	960–971		
Water sand	971–990		

The structure in the Carolina-Texas field is shown in Plate 26. The closure on the anticline is unusually great, amounting to at least 140 feet, and resembles that of the Jennings anticline. The anticline is north of the place where the general strike turns from northeast to north, and its axis is very nearly parallel with the general strike in the locality.

Although primarily a gas producer the Carolina-Texas field has also produced some oil. Beginning in July, 1926, with a maximum daily average of 226 barrels, it produced discontinuously to the end of 1927 with a fluctuating decline from this maximum to a total of 107 barrels a month from 3 wells in November, 1927, an average of about a barrel a day for each well. To the end of 1927 the field produced a total of 25,903 barrels. However, the area tested is so small that production per acre to the end of 1927 averaged 2,317 barrels, with a variation from 413 to 4,221 barrels.

The producing sands in the Carolina-Texas field are 1,100 to 1,200 feet below sea level and may occupy a lower stratigraphic position than the sands of the other fields in this part of the region, but like all those except the deep Jennings sands and the Reiser sands they are believed to be in the Fayette formation.

RANDADO OIL FIELD

As shown in Figure 75, the Randado field is half a mile west of the village of Randado, in west-central Jim Hogg County. It is west of the main Bordas scarp, and the axis of elongation of the producing area is not parallel with the scarp, although parallel with the subsurface strike. Structurally (see pl. 27) the field is a terrace with several irregular "noses" and two low anticlines showing some closure.

The discovery well was drilled by Pippen and others in survey 291. Production started at Randado in May, 1926, with an average of 582 barrels a day and with some fluctuation increased to an average of 5,731 barrels a day from 112 wells in November, 1926; since then it has slowly declined to an average of about 2,000 barrels a day from 146 wells. (See pl. 22.) The total production to the end of 1927 was 1,951,597 barrels. The production per acre to the end of 1927 ranged from 120 to 6,933 barrels and averaged 2,363 barrels.

COLE-BRUNI GAS AND OIL FIELD

The discovery well in the Cole-Bruni field, which is about 13 miles northwest of Hebbronville on the Webb-Duval County line and just outside the region of this report (fig. 75), was the Cole Petroleum Co.'s No. 4 Benevides well, completed July 20, 1924. Production began in April, 1926, with an average of 448 barrels a day, and the maximum of 683 barrels a day was reached in July, 1926. Later in 1926 there was a steady decline, and production has been intermittent and very small since January, 1927. The total production to the end of 1927 was 143,225 barrels. (See pl. 22.) The production per acre has ranged from 291 to 780 barrels and has averaged 710 barrels. No more than 6 wells have produced in this field at any one time.

The field is situated on the Hebbronville Plain about 10 miles east of the Bordas scarp and in the area of outcrop of the Reynosa formation. As shown in Plate 28, the surface is about 760 feet above sea level, and depths to the producing sand are on the average about 1,735 feet, so that the sand lies about 975 feet below sea level. This may be a younger sand than those which produce in the fields along the Bordas scarp on the west, but it also is probably in the Fayette formation. The structure here is more complex than in any other field of the region.

ALWORTH FIELD

The Alworth field is 8 miles southwest of Randado and about the same distance northeast of the Charco Redondo field, on the Zapata-Jim Hogg County line. (See fig. 75.) It is 8 miles west of the Bordas scarp, on the Aguilares Plain.

This field was discovered on December 4, 1926, when Alworth Bros. No. 2 Garza well, block 4, survey 39, was completed. There is no record of production, and presumably no pipe line had been extended to this field before the end of 1927.

As shown in Figure 76 the field comprises a terrace and a low anticline. The Frio clay crops out in the field. The producing sand is struck in the wells a little more than 500 feet below sea level and is probably in the Fayette.

COLE GAS POOL

In 1927 gas was discovered in a small area on the Hebbronville Plain 4 miles west of the Cole-Bruni field and 5½ miles east of Oilton, but there has been no great development, and the subsurface conditions are not known to the writer.

KILLAM POOL

It is reported that oil has been struck about 3 miles east of the south end of the Schott-Aviators field, on the Hebbronville Plain, where the surface rock is Reynosa, but here also conditions are not yet on record.

ROMA ANTICLINE

The probable existence at Roma of an anticline of potentially commercial importance was pointed out by the writer in 1923.[61] Detailed work was done here later by Lloyd North and others, and a structure map of the anticline was drawn (pl. 29), which shows that most of the uplift is in Texas rather than in Mexico, as at first believed, that the anticlinal axis runs northwest, and that there is a closure of at least 140 feet.

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[61] Trowbridge, A. C., A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U .S. Geol. Survey Prof. Paper 131, p. 104, 1923.

The leases and mineral rights in this anticline are owned jointly by the Texas Co. and R. E. Brooks, jr.

CARRIZO SPRINGS ANTICLINE

The anticline west of Carrizo Springs (fig. 75), in Dimmit County, was drilled in 1919 and 1920 by L. E. Hanchett and was tested in

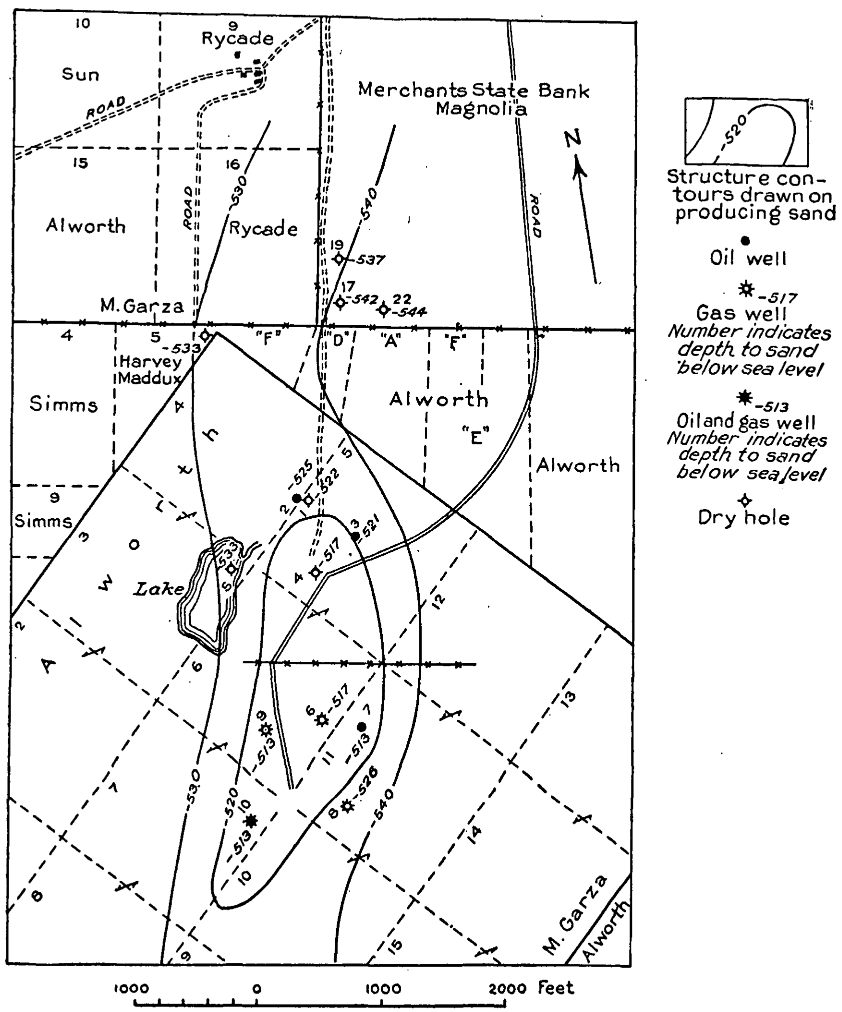

FIGURE 76.—Subsurface map of the Alworth field. By Lloyd North, Jan. 18, 1928. Contours based on producing sand; contour interval 10 feet

1927 by the Humble Oil & Refining Co. The surface rocks are Midway, Indio, and Carrizo, and producing strata were looked for in the Cretaceous.

FALFURRIAS DOME

The Producers Oil Co. drilled two wells in the Falfurrias salt dome in 1911, 1912, and 1913, the logs of which are as follows:

Log of Producers Oil Co.'s Falfurrias No. 1 well

[1,816 feet north and 1,070 feet east from southwest corner of survey 331]

	Feet		Feet
Sand or soil	1–8	Cavity	359–378
Boulders or loose rock	8–11	Rock	378–450
Rock	11–62	Sand, blue	450–451
Blue gumbo	62–64	Rock	451–592
Rock	64–75	Sand, blue	592–595
Sand and loose rock	75–80	Rock	595–607
Rock	80–256	Sand, blue	607–611
Cavity	256–263	Rock	611–622
Rock	263–359		

Log of well No. 5, Falfurrias No. 2

[1, 570 feet north and 600 feet east from the southwest corner of survey 331. Begun Apr. 29, 1912; completed Jan. 25. 1913. Total depth 1,050 feet. 118 feet of 10-inch casing and 20 feet of 4-inch casing left in hole]

	Feet		Feet
Sand or soil	1–35	Crevice	108–109
Rock	35–38	Rock	109–121
Cavity	38–42	Crevice	121–122
Rock	42–75	Rock	122–1, 034
Cavity	75–77	Sand, coarse white	1, 034–1, 040
Rock	77–108	Rock	1, 040–1, 050

In 1927 this dome was being tested further by the Texas Co., which had drilled one well to a depth of 4,878 feet.

Log of Texas Co.'s well No. 3, on the Falfurrias salt dome

[2, 380 feet south and 400 feet east from northwest corner of survey 329. Began rigging up July 10, 1927; began drilling July 16, 1927; finished drilling Dec. 2, 1927]

	Feet		Feet
Surface sand	0–40	Sand	711–831
Gypsum	40–115	Gumbo	831–841
Caliche	115–130	Sand	841–853
Sand caliche	130–170	Hard sand	853–855
Salt and pepper sand	170–190	Gumbo and boulders	855–916
Sticky caliche	190–254	Sand and boulders	916–944
Gypsum	254–299	Hard sand	944–1, 054
Shale	299–349	Sand	1, 054–1, 094
Sand	349–399	Gumbo	1, 094–1, 098
Gypsum	399–429	Sand	1, 098–1, 106
Gumbo	429–470	Gumbo	1, 106–1, 112
Sand	470–493	Sand	1, 112–1, 135
Caliche	493–504	Gumbo	1, 135–1, 170
Gumbo	504–540	Hard sand	1, 170–1, 197
Sand	540–565	Sandy gumbo	1, 197–1, 334
Sticky caliche	565–596	Gumbo, streaks of sand	1, 334–1, 364
Gumbo	596–616	Sandy gumbo	1, 364–1, 396
Sand	616–628	Gumbo and lime	1, 396–1, 533
Gumbo	628–711	Sand and boulders	1, 533–1, 575

Log of Texas Co.'s well No. 3, on the Falfurrias salt dome—Continued

	Feet		Feet
Gumbo	1, 575–1, 615	Shale and lime	3, 358–3, 442
Sand	1, 615–1, 650	Sand, shale, and lime	3, 442–3, 492
Gumbo	1, 650–1, 700	Sandy shale	3, 492–3, 494
Sand	1, 700–1, 741	Hard sand	3, 494–3, 533
Sticky shale	1, 741–1, 797	Sand and shale	3, 533–3, 551
Sand	1, 797–1, 819	Shale	3, 551–3, 626
Hard sand	1, 819–1, 834	Sand and shale	3, 626–3, 657
Gumbo	1, 834–1, 860	Shale	3, 657–3, 703
Sand	1, 860–1, 870	Sandy shale	3, 703–3, 770
Gumbo	1, 870–1, 895	Shale	3, 770–3, 778
Sandy shale	1, 895–1, 912	Sandy shale	3, 778–3, 791
Sand and lime	1, 912–1, 996	Shale	3, 791–3, 816
Gumbo	1, 996–2, 006	Sandy shale	3, 816–3, 848
Sand	2, 006–2, 042	Shale	3, 848–3, 884
Gumbo	2, 042–2, 096	Sandy shale	3, 884–3, 888
Sand and lime	2, 096–2, 112	Shale and lime	3, 888–3, 899
Gumbo	2, 112–2, 148	Sandy shale	3, 899–3, 935
Sand	2, 148–2, 158	Sand, shale, and lime	3, 935–3, 962
Gumbo	2, 158–2, 220	Sand and shale	3, 962–3, 974
Sand	2, 220–2, 231	Sand and shale	3, 974–4, 060
Gumbo and lime	2, 231–2, 247	Shale	4, 060–4, 062
Sand and lime	2, 247–2, 265	Shale and lime	4, 062–4, 071
Gumbo	2, 265–2, 308	Shale	4, 071–4, 077
Sandy shale	2, 308–2, 315	Sand and shale	4, 077–4, 083
Sand and lime	2, 315–2, 345	Shale and lime	4, 083–4, 085
Gumbo and lime	2, 345–2, 432	Shale	4, 085–4, 100
Sand, shale, and lime	2, 432–2, 440	Shale and sand	4, 100–4, 108
Sand and lime	2, 440–2, 477	Hard sand	4, 108–4, 121
Gumbo	2, 477–2, 525	Shale	4, 121–4, 145
Sand, shale, and lime	2, 525–2, 542	Sandy shale	4, 145–4, 146
Sand and lime	2, 542–2, 578	Sand	4, 146–4, 177
Gumbo	2, 578–2, 598	Shale	4, 177–4, 218
Sand and lime	2, 598–2, 629	Sand, hard	4, 218–4, 248
Sand	2, 629–2, 725	Sand and shale	4, 248–4, 252
Gumbo	2, 725–2, 790	Hard sand	4, 252–4, 286
Sand	2, 790–2, 878	Sand and shale	4, 286–4, 291
Sand and lime	2, 878–2, 915	Hard sand	4, 291–4, 304
Gumbo	2, 915–2, 933	Shale	4, 304–4, 331
Sand, shale, and lime	2, 933–2, 936	Hard sand	4, 331–4, 332
Sandy shale	2, 936–2, 949	Hard shale and quartz	4, 332–4, 339
Sand and shale	2, 949–2, 995	Hard shale	4, 339–4, 344
Sandy shale	2, 995–3, 030	Shale and sand	4, 344–4, 351
Hard sand	3, 030–3, 055	Shale and lime	4, 351–4, 361
Shale and pyrites	3, 055–3, 061	Sand and shale	4, 361–4, 365
Sand, shale, and lime	3, 061–3, 108	Sand	4, 365–4, 442
Sandy shale	3, 108–3, 209	Hard shale	4, 442–4, 456
Shale	3, 209–3, 238	Sandy shale	4, 456–4, 461
Sandy shale	3, 238–3, 303	Hard sand	4, 461–4, 475
Gumbo	3, 303–3, 305	Shale	4, 475–4, 499
Gummy shale and sand	3, 305–3, 346	Shale and lime	4, 499–4, 510
Sand and shale	3, 346–3, 358	Hard sand	4, 510–4, 595

Log of Texas Co.'s well No. 3, on the Falfurrias salt dome—Continued

	Feet
Sandy shale	4, 595–4, 599
Shale	4, 599–4, 607
Sandy shale	4, 607–4, 612
Sand, shale, and lime	4, 612–4, 631
Shale and lime	4, 631–4, 635
Sand, shale, and lime	4, 635–4, 638
Hard sand	4, 638–4, 642
Sandy shale	4, 642–4, 644
Hard shale	4, 644–4, 724
Hard sand	4, 724–4, 731
Sandy shale	4, 731–4, 739
Sticky shale and lime	4, 739–4, 783
Hard sand	4, 783–4, 812
Shale and lime	4, 812–4, 817
Hard sand	4, 817–4, 878

SUMMARY

It seems probable that the shallow gas of the Jennings field and the oil and gas of the Charco Redondo, Mirando Valley, Schott-Aviators, Carolina-Texas, Henne, Winch & Fariss, Randado, Cole-Bruni, and Alworth fields come from sands occupying somewhat similar though not identical stratigraphic positions in the Fayette formation, and that the deeper gas of the Jennings and Reiser fields comes from sands interbedded with the Cockfield clay.

It is not known whether the oil and gas were indigenous in the beds where they are found by the drill or whether they were indigenous in the marine Cook Mountain or in the black Cockfield clay and migrated upward in the usual manner and were concentrated in the sand lenses and layers of the Cockfield and Fayette under the terraces, noses, and closed areas. Contrary to the argument of Jones,[62] it is held that faulting has been relatively subordinate in causing either the migration or the accumulation of the oil and gas.

The porosity and the irregular thickening and thinning of the sands are important factors in accumulation and recovery. The progressive thickening of all the formations Gulfward gives the effect of pinching out the beds up the dip toward the west, constituting another factor favorable for accumulation.

The fields do not rank as large producers, either singly or taken together. The total production of oil to the end of 1927 was 14,527,890 barrels, and as there have been 1,700 or more wells drilled in and around the several fields, there have been as yet no huge profits for companies operating in the region.

The general decline in oil production since August, 1926, probably does not mean that these fields are becoming exhausted or that other fields will not be discovered in this region, for with declining prices of crude oil late in 1926 and early in 1927 fewer and fewer new wells were drilled in producing fields and less and less wildcatting was done, production being thus cut down. Should prices improve, the renewal of active drilling might well lead to new peaks of production.

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[62] Jones, R. A., The relation of the Reynosa escarpment to the oil and gas fields of Webb and Zapata Counties, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 7, pp. 532–545, 1923.

COAL

According to Ashley,[63] the coal that has been extensively mined at Minera, Dolores, Cannel, and Santo Tomas, in Webb County, which occurs in the Mount Selman formation, is probably the largest body of cannel coal of bituminous rank in the United States, if not in the world. During 1919 to 1921 the mines at Minera and Santo Tomas were idle, the underground workings at Santo Tomas having burned in 1918. In 1919 Johnson & Coleman took out enough of this coal at their mine 4 miles east of Palafox to run their pumping plants on the river. Coal from the same formation and probably of about the same quality is found on Espada Creek in Webb County, near the base of the Mount Selman formation. A 14-inch bed of coal is reported to crop out near the top of the Mount Selman formation on the Rio Grande at low water at and near the mouth of Arroyo Santa Isabella.

Beds of coal, probably of poorer quality, may be found in the Indio and Bigford formations at many places where these formations crop out. Lignite is found at the surface and at shallow depths at places east and southeast of Dentonio and at the Mangum and Rutledge ranches, west and south of La Pryor. It is also penetrated in wells at La Pryor. National well No. 1, near the Nueces River crossing of the Uvalde-La Pryor road, penetrated a bed of lignite at a depth of 245 feet, and National well No. 2, three-quarters of a mile southeast of No. 1, penetrated what may be the same bed at a depth of 485 feet. Lignite in beds as much as 3 feet thick is exposed at several places along the Nueces River between these wells and Pulliam. An 18 to 20 inch bed of hard, brittle bright coal crops out 1½ miles above the mouth of San Lorenzo Creek, in Webb County, in the Bigford formation. There is also an exposure of coal at the mouth of the first creek south of the Apache ranch house.

At the Pilotes ranch, about 10 miles north of Palafox, as many as 11 seams of coal and bone were struck in a test drilling at depths ranging from 74 to 236 feet. The surface formation here is the Mount Selman, but the carbonaceous beds are in the Bigford formation. Coal in this same formation crops out on Concillos Creek near its mouth and on the Nueces River 2¾ miles east of the Asherton-Big Wells road, a few miles outside the lower Rio Grande region.

Coal is reported by Judge A. F. Spohn, of Zapata, to occur just north of Zapata and in the valley of Dolores Creek near the Webb-Zapata County line. This locality is in the outcrop of the Cook Mountain formation. No coal was seen, however, in the many sections of the Cook Mountain formation examined.

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[63] Ashley, G. H., The Santo Tomas cannel coal: U. S. Geol. Survey Bull. 691, pp. 251-270, 1919.

BRICKMAKING MATERIAL

The clays of the lower Rio Grande region have not been systematically tested with reference to their suitability for making brick. At an abandoned brick plant at Reiser the pit is in the lower part of the Fayette formation, and the clay is fairly pure. Face brick of good grade was made here. The plant was abandoned when the Border Gas Co. shut down its gas wells at Reiser, thus shutting off the gas used as fuel. At no other place in the region has face brick been manufactured.

Along the lower Rio Grande and its main delta distributaries are many pits from which material is taken by Mexicans for making crude adobe brick. The largest and most efficient plant of this kind is at Los Ebanos, about 2 miles southwest of Samfordyce. Beaumont terrace silt or Recent fluvial silt is mixed with water in the pit and worked into plastic masses having the consistency of dough. This material is thrown into trays containing six brick-sized compartments, which are sprinkled with dry sand to prevent it from sticking. The clay-filled tray is then carried by hand to a sunny flat near the pit and inverted, the wet bricks being left for a time to dry. When they have dried out sufficiently they are stacked or "ricked" in open piles for further drying by sun and wind. Finally they are placed in rough kilns made of adobe bricks and baked, branches of mesquite being used as fuel. One of these pits and the crude method of brickmaking are illustrated in Plate 20, *B*, *C*. The brick is poor, but it stands fairly well the pressure of the common Mexican 1-story house.

GRAVEL

The gravel supplies of the region are plentiful, widely distributed, and of good quality. The Reynosa formation furnishes gravel of high grade for road ballast and concrete work practically wherever it is exposed, whether in the main outcrop of the formation or west of the Bordas scarp, where only patches of Reynosa are found. The Lissie gravel is cleaner and better than that of the Reynosa but is not so widely distributed. As only 1 per cent of the Lissie gravel is more than 4 inches in diameter, as three-fourths of the pebbles and cobbles are composed of chert or other siliceous material, as the pieces are well rounded and smooth, and as the material is practically nowhere so firmly cemented as to require blasting in its excavation, this deposit makes excellent commercial gravel. There are half a dozen or more pits along the river between Samfordyce and Penitas. (See pp. 204–206). In some pits the loosely cemented or unconsolidated gravel is taken out with steam shovels; in others it is shoveled out by hand. At some plants it is sorted by power-driven screens, and at others by hand screening. Most of the gravel is used in the valley, but some is shipped as far as Houston. At Green's, in Webb County, on the International-Great Northern Railroad, where there is an outlier of Reynosa, a large pit has long been under excavation. (See p. 192.) Most of the gravel is loaded by steam shovels into cars and used as ballast on the railroad. Some of it was used to surface a section of the San Antonio-Laredo vehicle road between Green's and Webb.

SAND

Good sand is not so abundantly produced in this region as gravel, although there is plenty of it. The sand lenses in the Reynosa and Lissie would furnish some, but only where the sand is mixed with the finest grades of gravel. The sand sorted out of the Reynosa by the wind and piled into dunes in the main sand belt and elsewhere is generally pure, fine-grained quartz sand, but it is not used commercially. An abundance of sand lies on the coastal beaches and banks of lagoons in the sand belt also, but neither is this utilized. The only sand used commercially in 1920 was that in the fluviatile deposits at Mission and McAllen (see pp. 226–227), where 25-foot lenses of almost pure-white sand underlie clay and silt. At that time the sand obtained at Mission sold for $2.25 a cubic yard at the pit. In 1931, sand from the Carrizo sandstone of Bexar County was being used in the glass factory at Three Rivers, Live Oak County.

GYPSUM

The sediments of the region inclose a large amount of gypsum in thin beds, seams, plates, crystal aggregates, and larger bodies, but it is nowhere utilized. The massive gypsum at the surface of the Falfurrias salt dome (p. 235) was being excavated and pulverized in 1927 by the Tidewater Gypsum Co.

ROAD MATERIAL

The quartzite, sandstone, limestone, concretions, and conglomerat of this region would make good material for building roads, but as few roads have been built they have not yet been so utilized. Argillaceous and calcareous materials from the surfaces of the Reynosa and Lissie formations were used to harden the road through the sand belt from Falfurrias to Edinburg, permitting automobile traffic into the valley from coastal points farther north. Shallow pits were opened along the road every mile or two, and the material is laid on a graded surface of sand. The same material was used in the same way on the sandy road to Rio Grande City from Hebbronville.

CEMENT

It is possible that a proper combination of limestone, clay or shale, and gypsum for the manufacture of Portland cement might be found in this region, coal, oil, or gas being used for fuel, but no commercial concern has yet found this combination.

WATER RESOURCES

In this region water is a valuable resource if the supply is satisfactory in quality and reasonably permanent. On the stock ranches, which cover so large a part of the region, water supplies are essential to successful operation. In the greater part of the region irrigation is necessary in most years to insure a crop. Under irrigation a wide variety of agricultural products can be raised and it is possible to obtain two or more crops annually. In recent years the efforts of the irrigators have been devoted chiefly to the production of vegetables and fruits for the winter market. In some winters these products have been profitable, and as a result there has been an increase in the amount of land under irrigation and a corresponding increase in population. In the winters of 1929–30 and 1930–31, however, prices have been low and irrigation farming has not been very profitable.

SURFACE WATER

A large part of the water used for irrigation in this region is pumped from the Rio Grande. Available records (p. 13) indicate that the average annual discharge of the river amounted to 3,800,000 acre-feet during 1902 to 1915 and 1924 to 1928 at Eagle Pass and to 4,500,000 acre-feet during 1923 to 1926 at Brownsville. A large part of the discharge, however, occurs during floods, and there are occasional brief periods when the discharge at Brownsville is only a few hundred acre-feet a day.

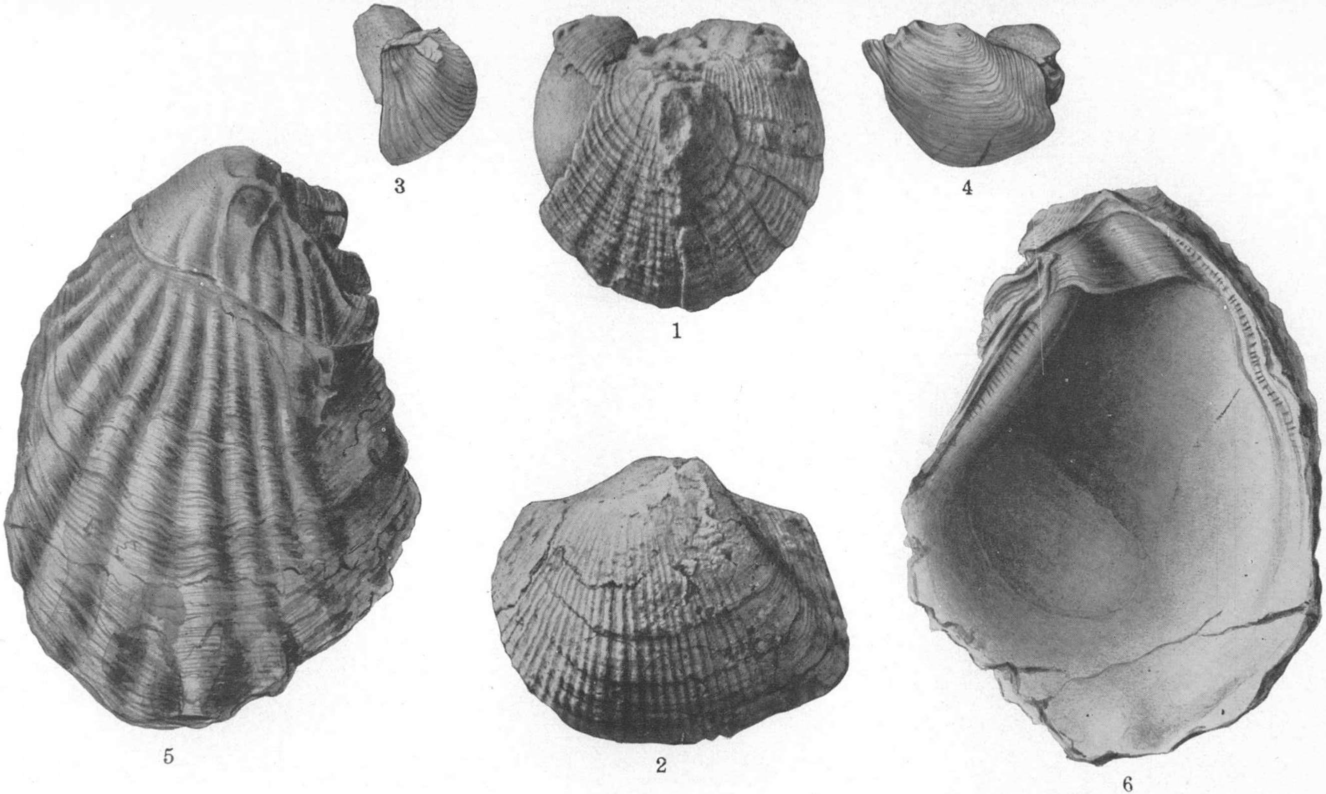
Between Eagle Pass and Dolores there are scattered pumping plants along the river by which water is raised for the irrigation of near-by terraces. Between Dolores and Laredo and for 10 or 12 miles below Laredo practically all the land near the river is under irrigation from pumps. Between Mission and Brownsville there are many large community projects for which water is raised from the Rio Grande in a series of lifts and conducted long distances through open ditches. Some of the irrigated tracts are 15 miles or more from the river and 60 feet or more above the river level. Several storage projects have been contemplated to regulate the flood discharge of the lower Rio Grande and to provide water for irrigation during periods of low natural flow. One such project is under construction by which water will be diverted near Mercedes and stored in a reservoir in Willacy County, 30 miles from the river.

The Nueces River also is an important source of irrigation supply. According to an inventory in 1929–30 by the United States Geological Survey in cooperation with the State board of water engineers about 6,100 acres was under irrigation from the river in Zavala and Dimmit Counties, and in addition 7,000 acres in these counties was irrigated partly from the river and partly from wells. Some of the river water is diverted by gravity, but most of it is pumped, and at the time of the investigation 50 river pumps were in operation. Some of the water is pumped from natural pools, but most of it is pumped from two reservoirs on the river, one in the southern part of Zavala County and the other in the northern part of Dimmit County.

The small streams of this region have little or no value for irrigation, but many of them are used for watering stock, it being a common practice throughout the region to build dams across small watercourses to impound storm water. Some of the dams are carefully constructed and kept in good repair, and the reservoirs above them supply hundreds of cattle during periods of drought. In the region there are thousands of such reservoirs, or tanks, as they are commonly called. Some of them provide water for domestic use, especially in areas where potable water is not available from wells or other sources.

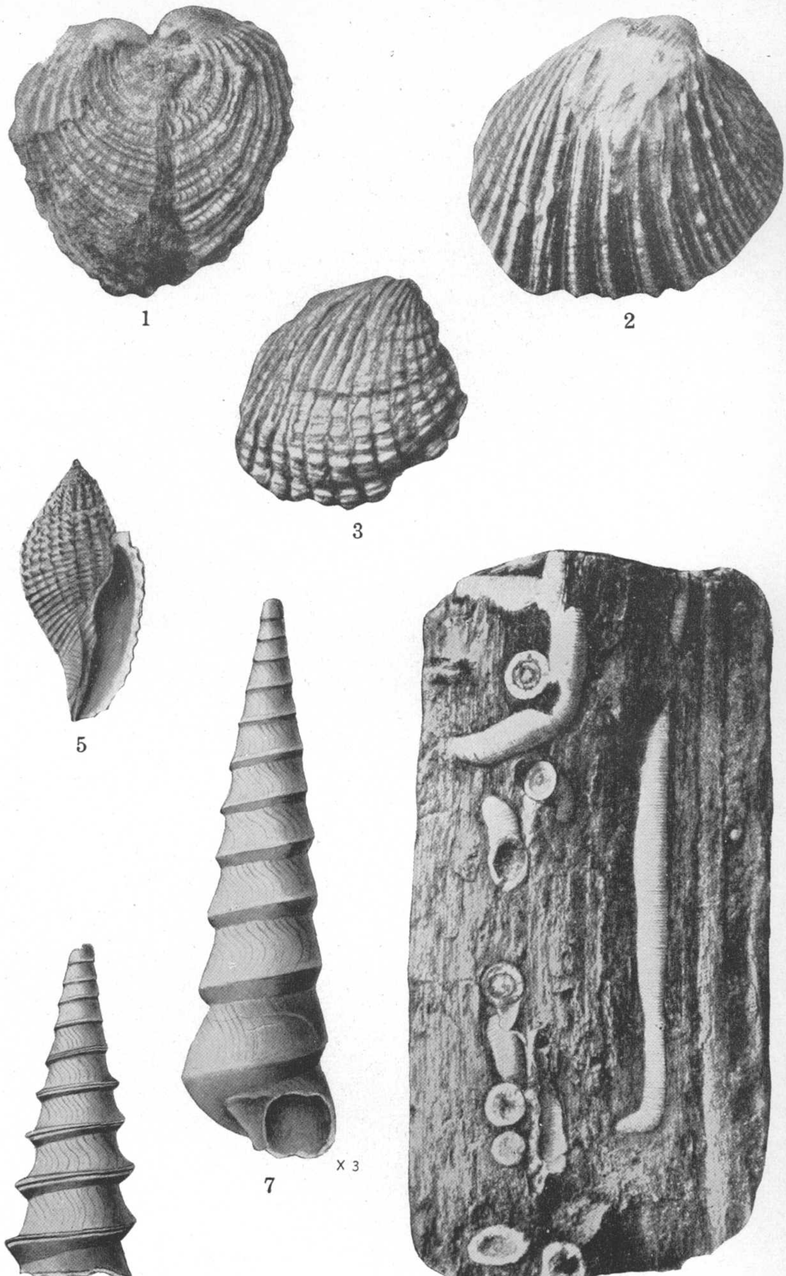
GROUND WATER

Water is obtainable in wells at moderate depths in most parts of the region, but the water varies widely in quality. An investigation of the ground water resources of Texas was undertaken by the United States Geological Survey, in cooperation with the State board of water engineers, in September, 1929, and is now in progress. The areas already covered by this investigation include Zavala, Dimmit, and Duval Counties and parts of Maverick and Webb Counties, and it is expected that the investigation will eventually be extended to the rest of the region. A preliminary report on the ground waters of Dimmit and Zavala Counties and a part of Maverick County is given in a memorandum to the press released by the United States Geological Survey February 16, 1931. One of the outstanding facts presented in the report is that in Zavala and Dimmit Counties about 27,000 acres is irrigated from wells. Reports on the ground waters of Duval and Webb Counties are in course of preparation.



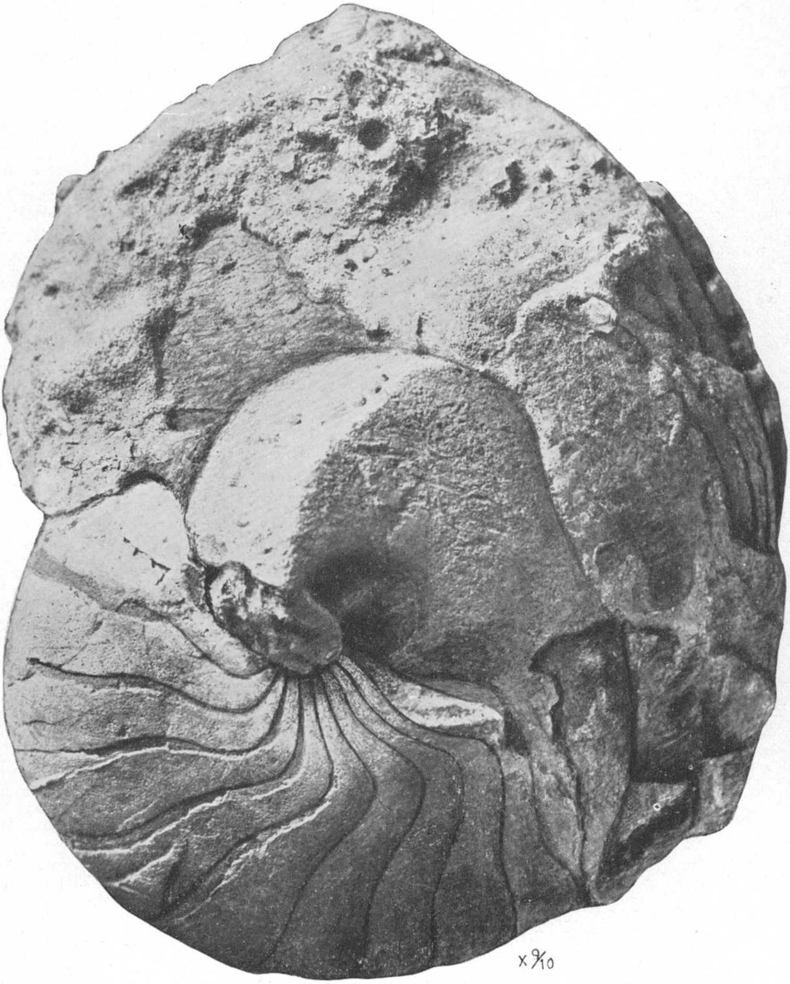
PELECYPODS OF THE MIDWAY FORMATION

1, 2. *Cucullaea texana* Gardner, type (U. S. Nat. Mus. No. 352267). 1, Front view of double valves; 2, exterior of left valve.
3, 4. *Ostrea pulaskensis* Harris, left valve (U. S. Nat. Mus. No. 371782). 3, Exterior; 4, profile.
5, 6. *Ostrea crenulimarginata* Gabb, left valve (after Aldrich, 1894). 5, Exterior; 6, interior.



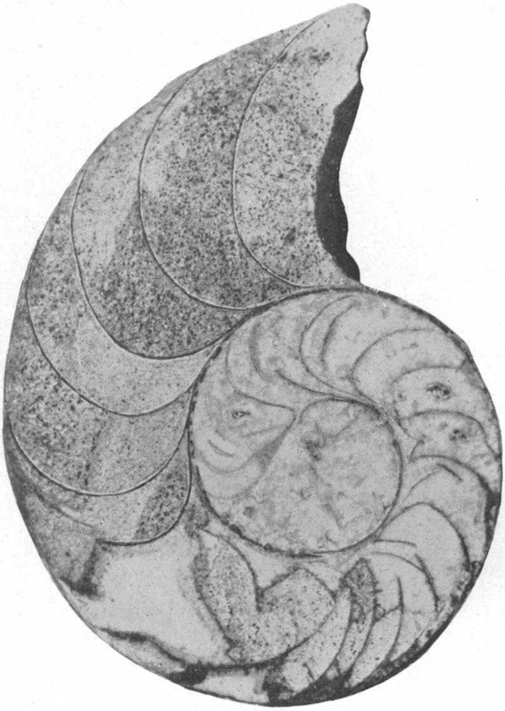
MOLLUSCA OF THE MIDWAY FORMATION

1, 2. *Venericardia hesperia* Gardner, type (U. S. Nat. Mus. No. 352268). 1, Front view of double valves; 2, exterior of right valve.
3. *Venericardia whitei* Gardner, type (U. S. Nat. Mus. No. 352269). Exterior of right valve.
4. *Teredo maverickensis* Gardner, type (U. S. Nat. Mus. No. 352274). Longitudinal views and natural cross sections of tubes in fossil wood.
5. *Volutocorbis limopsis* (Conrad). Apertural view (after Harris, 1896).
6, 7. *Turritella humerosa* Conrad (U. S. Nat. Mus. No. 11754). 6, Broken spire with sculpture detail; 7, later whorls showing outline and sculpture.



CEPHALOPOD OF THE MIDWAY FORMATION

Enclimatoceras vaughani Gardner (U. S. Nat. Mus. No. 352261). Lateral view of cotype.



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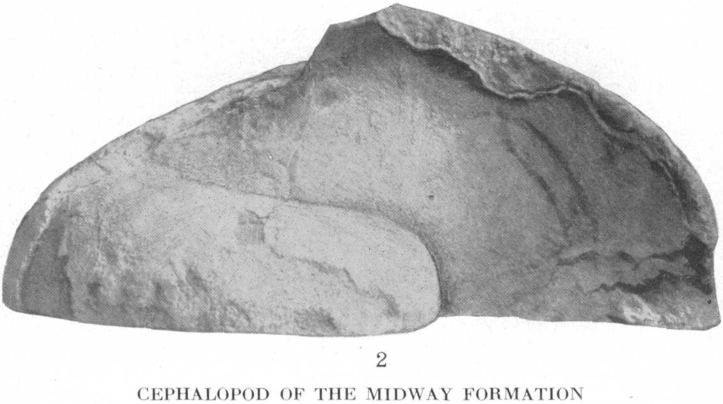
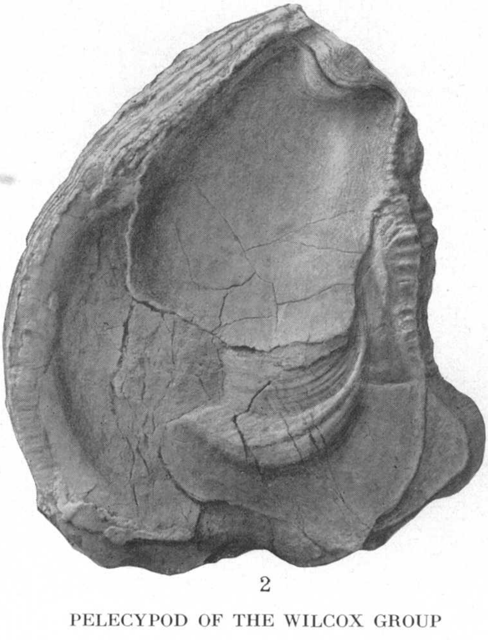


2

CEPHALOPOD OF THE MIDWAY FORMATION

Enclimatoceras vaughani Gardner, adolescent individual (U. S. Nat. Mus. No. 352262).
1, Cross section; 2 apertural view.

1



2

PELECYPOD OF THE WILCOX GROUP

Ostrea multilirata Conrad, right valve (U. S. Nat. Mus. No. 352265). 1, Exterior; 2, interior.

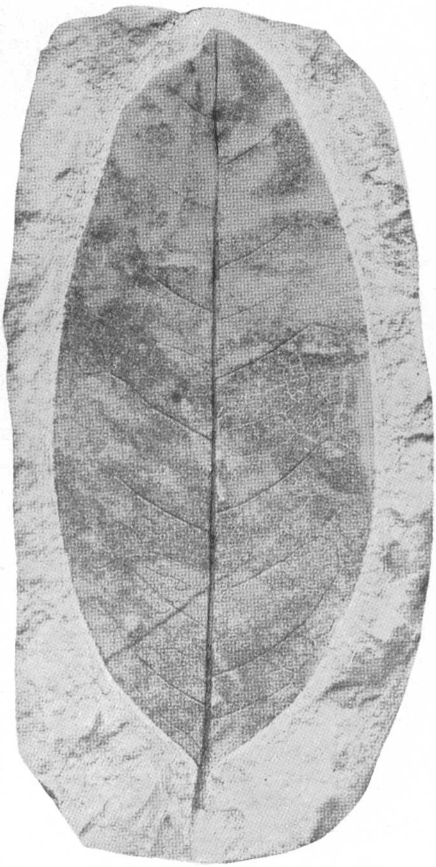
1

2

PELECYPOD OF THE WILCOX GROUP

Ostrea multilirata Conrad, left valve (U. S. Nat. Mus. No. 352265). 1, Exterior; 2, interior.

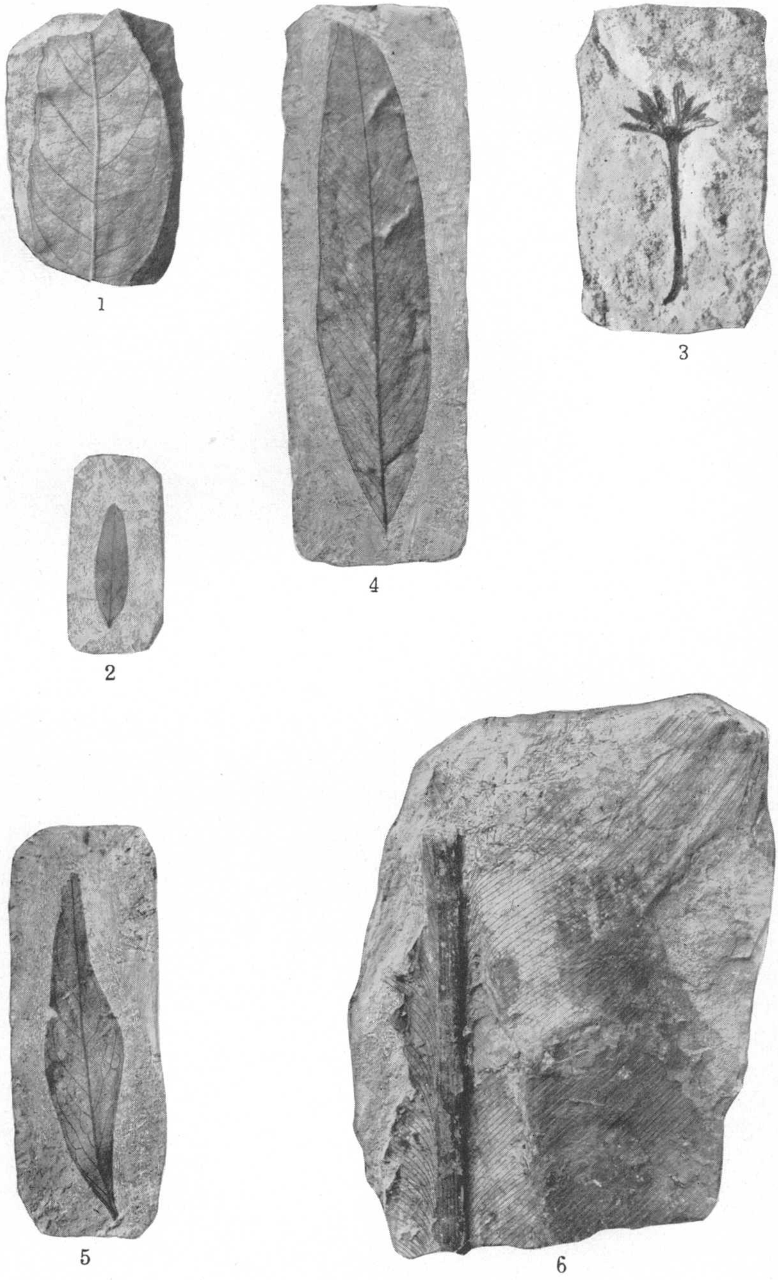
1



2

FOSSIL PLANTS OF THE INDIO AND CARRIZO FORMATIONS OF THE WILCOX GROUP

1. *Nectandra pseudocoriacea* Berry, a perfect leaf from the eastern Gulf region, illustrating a common species of the Carrizo formation.
2. *Anona eolignitica* Berry, a perfect leaf from the eastern Gulf region, illustrating a common species of the Indio formation along the Nueces River in Zavala County.



FOSSIL PLANTS OF THE CARRIZO AND BIGFORD FORMATIONS OF THE WILCOX GROUP

1. *Sophora wilcoxiana* Berry, a leaflet from Carrizo Springs, Dimmit County.
2. *Mimosites variabilis* Berry, a leaflet from Concillos Creek, Webb County,
3. *Pterobalanus texanus* Berry, a fruit from Carrizo Springs, Dimmit County.
4. *Eugenia grenadensis* Berry, a leaf from a point 1½ miles south of La Pryor, Zavala County.
5. *Anacardites grevilleafolia* Berry, a leaflet from Concillos Creek, Webb County.
6. *Canna eocenica* Berry, fragment of a leaf from Concillos Creek, Webb County.

PLATE 38

MOLLUSCA OF THE WILCOX GROUP

1, 2. *Volutocorbis petrosa* subsp. *tuomeyi* (Conrad), topotype (U. S. Nat. Mus. No. 111904). 1, Rear view; 2, apertural view.

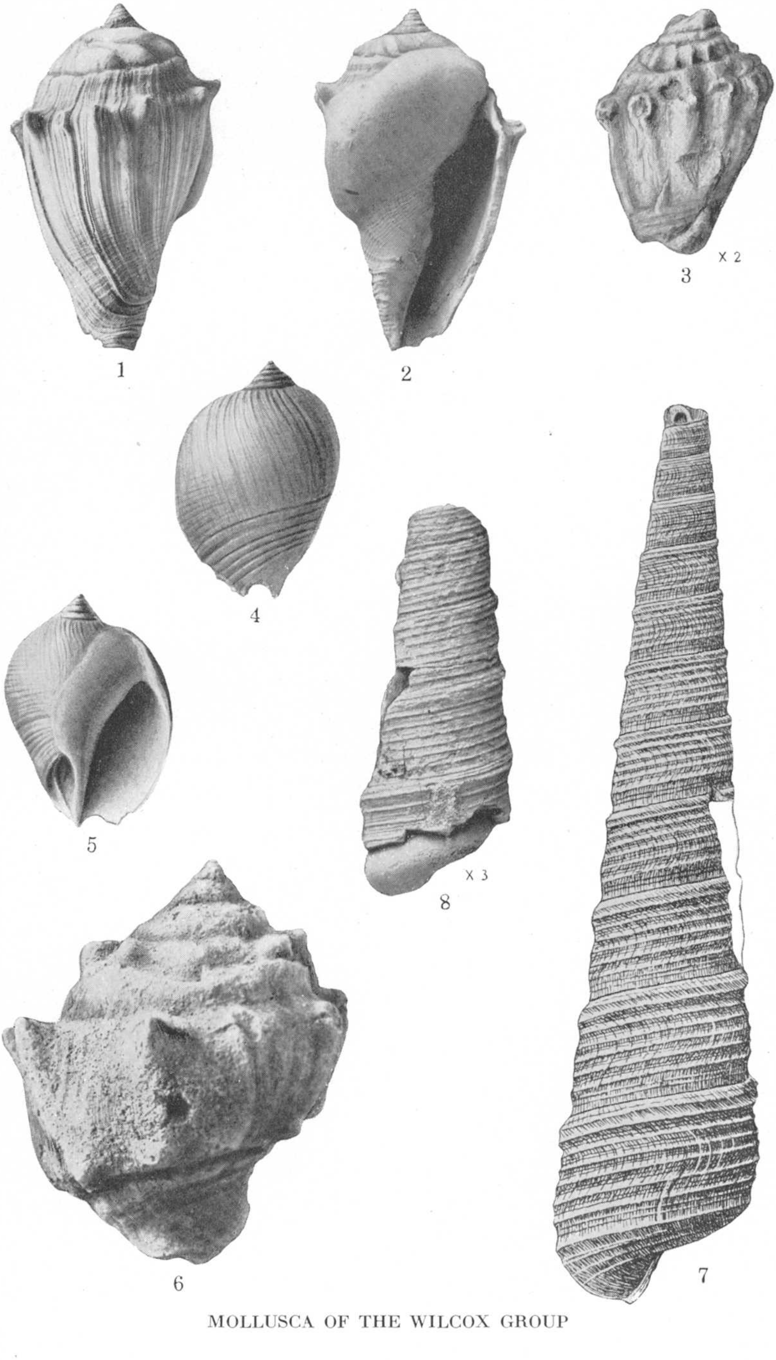
3. *Volutocorbis* sp. suggesting a dwarf form of *Volutocorbis petrosa* (Conrad) from the Wilcox 3 miles west of Altamira, Nuevo Leon, Mexico (U. S. Nat. Mus. No. 371781).

4, 5. *Pseudoliva vetusta* Conrad (common to the Wilcox, Claiborne, and Jackson), from Jackson of Montgomery, La. (U. S. Nat. Mus. No. 138392). 4, Rear view; 5, apertural view.

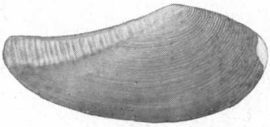
6. *Cornulina armigera* Conrad (common to the Wilcox and Claiborne), rear view of specimen from Cook Mountain of Chacon Arroyo, 3 miles east of Laredo, Tex. (U. S. Nat. Mus. No. 371789).

7. *Turritella humerosa* Conrad, rear view of specimen from Aquia formation of Maryland near type locality. (After Clark and Martin, 1901.)

8. *Turritella* cf. *T. humerosa* Conrad, from Indio formation, Maverick County, Tex. (U. S. Nat. Mus. No. 371779).



MOLLUSCA OF THE WILCOX GROUP



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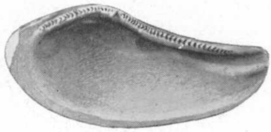

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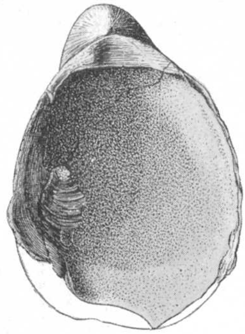

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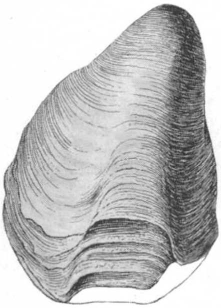

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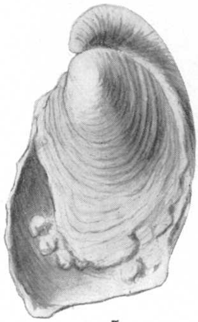

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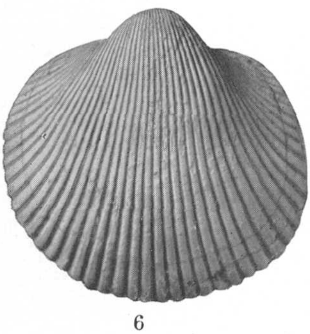

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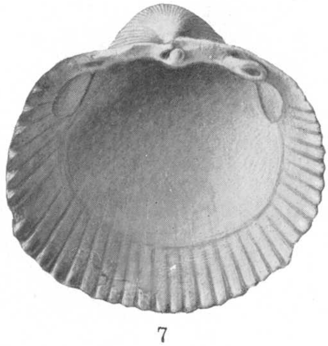


7

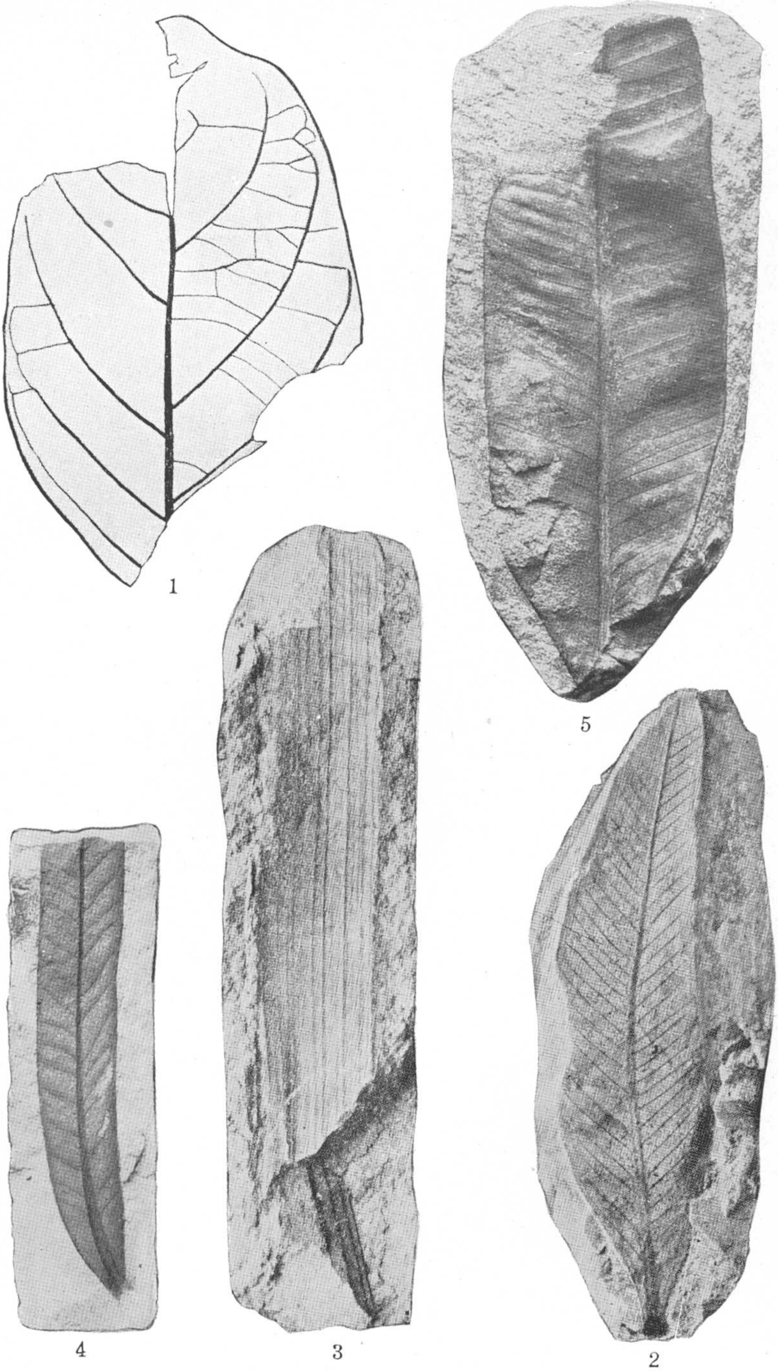
MOLLUSCA OF THE WILCOX GROUP

1, 2. *Leda elongatoidea* Aldrich, right valve. 1, Exterior; 2, interior.
3-5. *Ostrea thirsae* Gabb (after Harris, 1897). 3, Exterior of left valve; 4, interior of left valve; 5, double valves looking down on exterior of right valve.
6, 7. *Cardium tuomeyi* Aldrich, left valve of type (Johns Hopkins University). 6, Exterior; 7, interior.
8. *Cardium hatchetigbeense* Aldrich, exterior of left valve of cotype (Johns Hopkins University).

PLATE 40

FOSSIL PLANTS OF THE MOUNT SELMAN FORMATION

1. *Coccolobis claibornensis* Berry, a specimen from the Lisbon formation of Mississippi, illustrating a common species found at Palafox.
2. *Myrcia trowbridgi* Berry, a leaf from Palafox, Webb County.
3. A ray of the palm, *Geonomites claibornensis* Berry, one of the commonest fossils at Palafox, Webb County.
4. *Apocynophyllum grevilleafolium* Berry, a leaf from Palafox, Webb County.
5. *Ficus newtonensis* Berry, a broken leaf from Palafox, Webb County.



FOSSIL PLANTS OF THE MOUNT SELMAN FORMATION

PLATE 41

MOLLUSCA OF THE CLAIBORNE GROUP

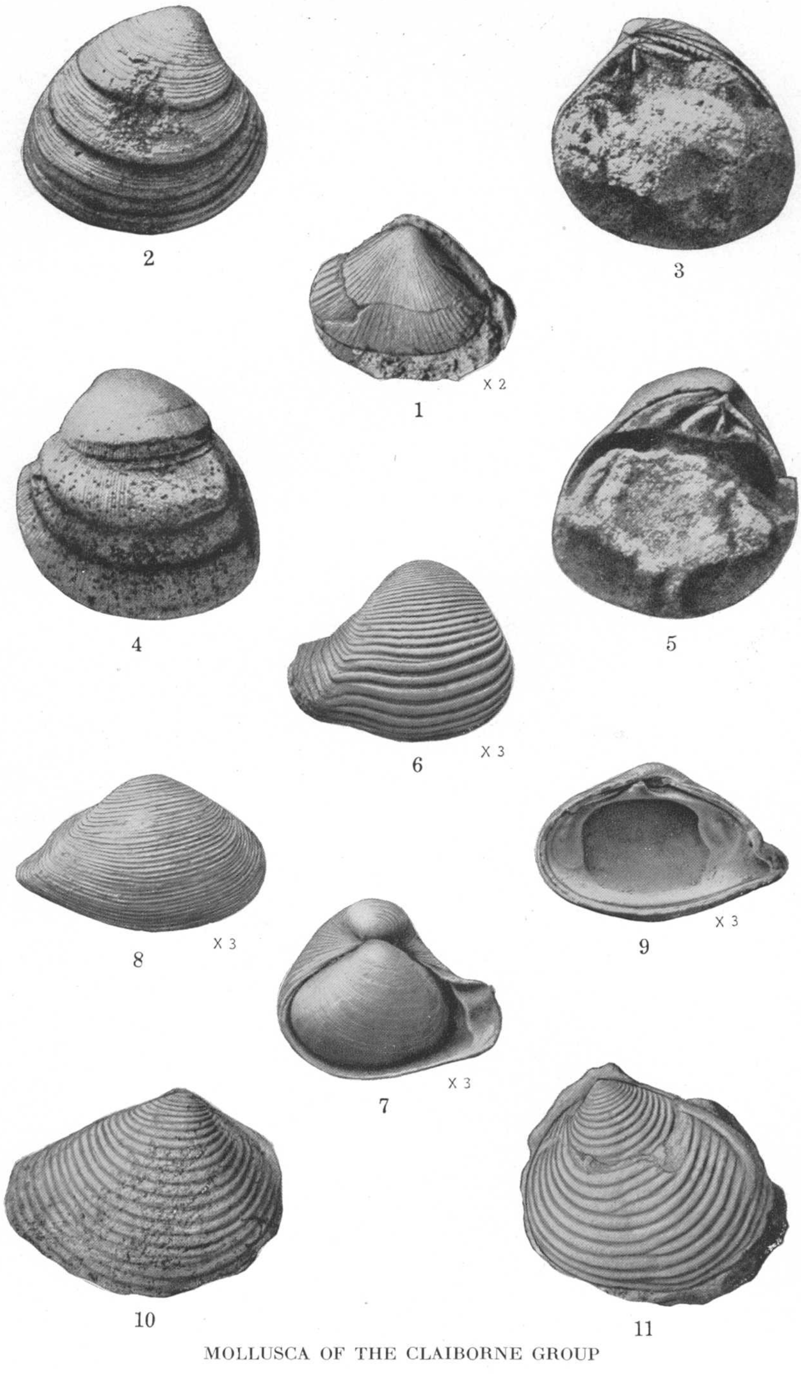
1. *Bornia zapataensis* Gardner, exterior of right valve of type (U. S. Nat. Mus. No. 369237).

2–5. *Callocardia astartoides* Gardner, type (U. S. Nat. Mus. No. 352272). 2, Exterior of right valve; 3, interior of right valve; 4, exterior of left valve; 5, interior of left valve.

6, 7. *Corbulasmithvillensis* Harris, topotype. 6, Exterior of right valve (U. S. Nat. Mus. No. 371790); 7, double valves looking down upon umbones and left valve (U. S. Nat. Mus. No. 371791).

8, 9. *Corbula deusseni* Gardner, right valve of type (U. S. Nat. Mus. No. 371791). 8, Exterior; 9, interior.

10, 11. *Pteropsis lapidosa* Conrad. 10, Exterior of right valve from Zapata County (U. S. Nat. Mus. No. 371184); 11, exterior of left valve from Webb County (U. S. Nat. Mus. No. 371783).



MOLLUSCA OF THE CLAIBORNE GROUP

PLATE 42

MOLLUSCA OF THE CLAIBORNE GROUP

1, 2. *Volutocorbis petrosa* (Conrad), from Jackson of Montgomery, La. (U. S. Nat. Mus. No. 147102). Introduced for comparison. 1, Rear view; 2, apertural view.

3. *Volutocorbis petrosa* (Conrad), rear view of specimen from Claiborne of Webb County (U. S. Nat. Mus. No. 371780).

4. *Lacinia alveata* Conrad, rear view of specimen from Claiborne of Arroyo Chacon, 3 miles east of Laredo (U. S. Nat. Mus. No. 371792).

5. *Cerithium webbi* Harris, rear view of specimen from point 1 mile northwest of Nye, Webb County (U. S. Nat. Mus. No. 371778).

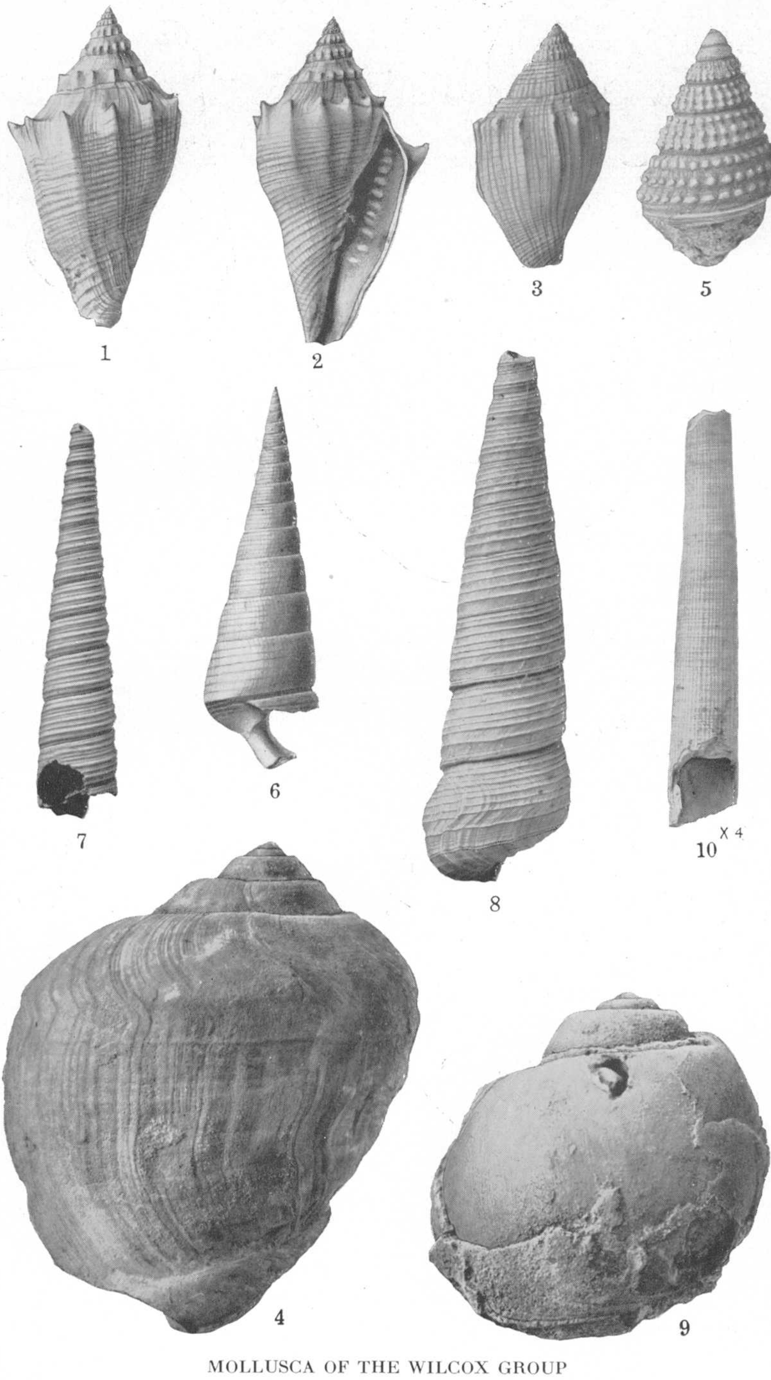
6. *Mesalia claibornensis* (Conrad), imperfect spire.

7. *Turritella nasuta* Gabb, imperfect spire.

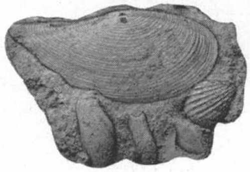
8. *Turritella nasuta houstonia* Harris, rear view.

9. *Natica dumblei* Heilprin, rear view of specimen from point 5 miles northeast of Laredo (U. S. Nat. Mus. No. 371794).

10. *Dentalium minutistriatum* Gabb, rear view of specimen from Smithville (U. S. Nat. Mus. No. 371793).



MOLLUSCA OF THE WILCOX GROUP



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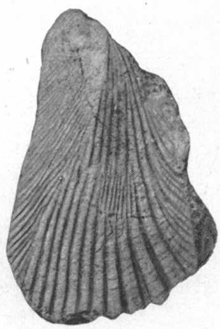

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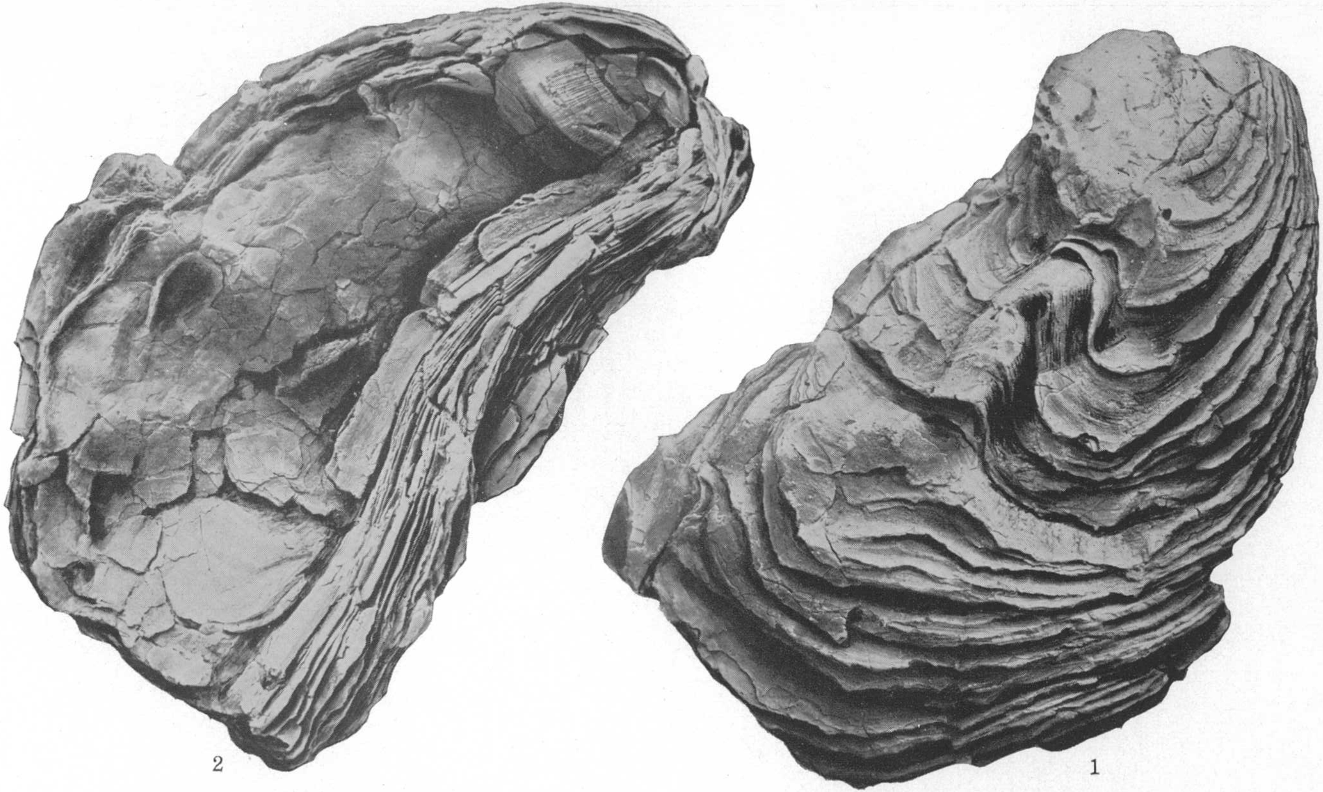
4

MOLLUSCA OF THE CLAIBORNE GROUP

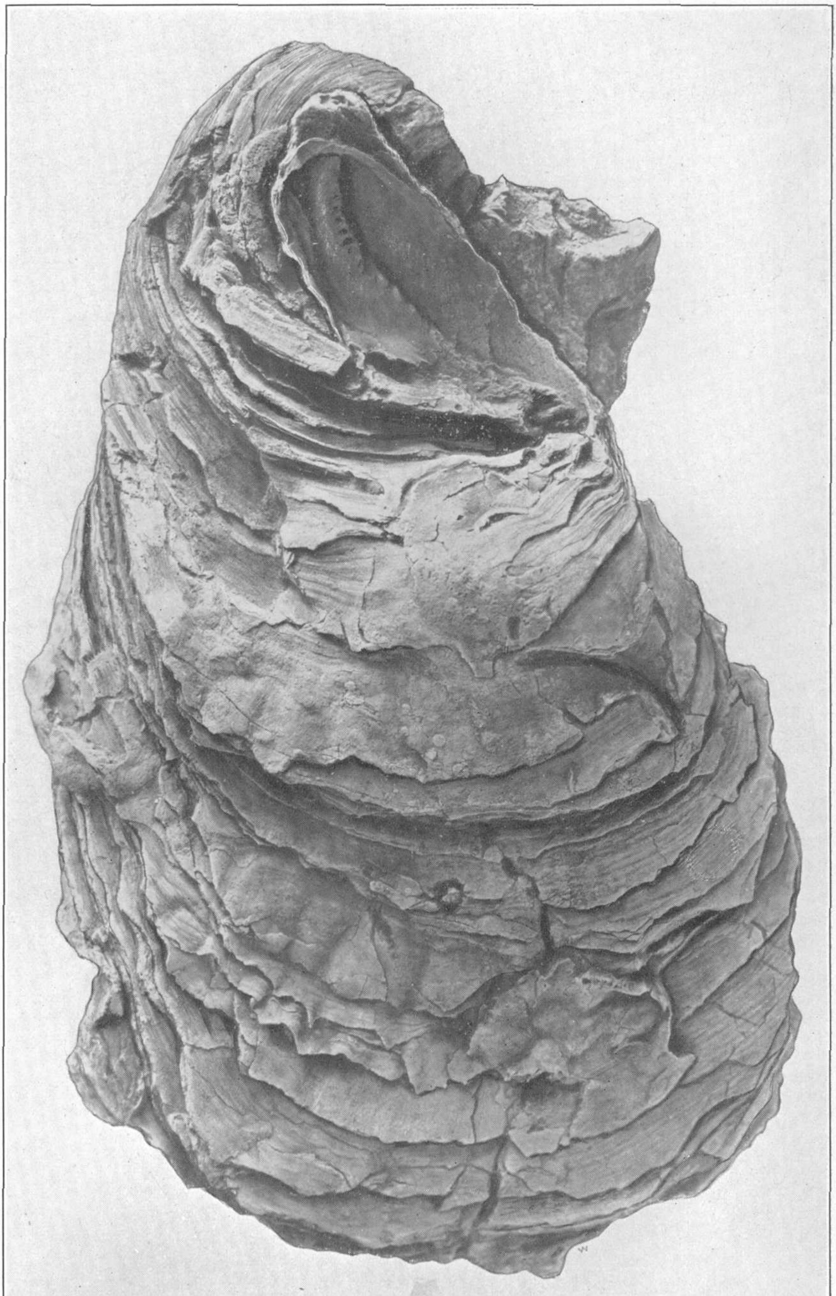
1. *Yoldia* cf. *Y. psammotea* Dall, from point 15 miles east of Laredo. Exterior of right valve (U. S. Nat. Mus. No. 371783).
2. *Anomia epippoides* Gabb, from point 10 miles northwest of Laredo (U. S. Nat. Mus. No. 371787).
3. *Modiolus texanus* Gabb, from point 4.8 miles southeast of Zapata (U. S. Nat. Mus. No. 371785).
4, 5. *Aturia alabamiensis* Morton, interior cast from point 3 miles east-northeast of Escobar ranch, Starr County (U. S. Nat. Mus. No. 371786). 4, Apertural view; 5, side view.



2 1

MOLLUSCA OF THE CLAIBORNE AND JACKSON GROUPS

Ostrea alabamiensis georgiana Conrad, left valve, from point 7 miles northeast of Laredo (U. S. Nat. Mus. No. 352264). 1. Exterior; 2, interior.



MOLLUSCA OF THE CLAIBORNE AND JACKSON GROUPS

Ostrea alabamiensis georgiana Conrad, exterior of right valve (U. S. Nat. Mus. No. 352263).

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